Handbook for Prospectors and Operators of Small Mines

BY

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Revised by

HARRY C. CHELLSON

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HANDBOOK FOR PROSPECTORS
AND OPERATORS OF SMALL MINES

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EDITOR'S INTRODUCTION

When the late Max W. von Bernewitz wrote his preface in 1938 for the 4th edition of his "Handbook for Prospectors and Operators of Small Mines," apparently he had considered his book completed. There was evidence, however, of a desire to keep adding more data, especially for the small-mine operator, and this may have kept him from believing his fourth edition ready for the publisher.

Unfortunately, the opportunity to consider the fourth edition ready for printing never came, as Mr. von Bernewitz died suddenly on May 18, 1940. His death was indeed a loss to the mining industry, but his service, here and abroad, to prospectors and miners will remain a permanent contribution to the industry.

About a year following his death, Mrs. von Bernewitz and the publisher requested me to undertake the editing of the book and bring any subject matter treated by the author up to date. My thirteen years' experience in prospecting, exploration, mine operation, and work in many other branches of the mining industry in the United States, Mexico, Central Asia, and Siberia, and the last seven years devoted to industrial journalism, supplies the background upon which I accepted the editing of the fourth edition.

My work has consisted mostly in supplementing the information contained in Parts I, II, III, and VI and a comprehensive addition of recent data to Parts IV and V, which discuss ore-dressing equipment and metal prices and ore-marketing, respectively. All this material is designed to aid the prospector and small mine operator in his war effort, as well as postwar mining.

I wish to acknowledge and thank A. H. Hubbell, associate editor and H. H. Wanders, market editor of *Engineering & Mining Journal* for the cordial assistance and cooperation they gave me in the preparation of certain parts of the book.

WASHINGTON, D.C.,
November, 1942.

HARRY C. CHELLSON,
Editor, Mining Congress Journal.

AUTHOR'S PREFACE TO THE FOURTH EDITION

Prospecting is the basis of the mineral industry, which is a basic industry in many countries, whether it is done to find new deposits at the surface or at depth. Prospecting is influenced more or less by economic conditions. The period 1929–1938 caused many prospectors to search for minerals, especially for gold and silver, all over the world. Unemployment during the two dull periods was an incentive for others to try their hand at prospecting, although they knew little of the methods.

The author's experience in mining and metallurgy covers 5 years in New Zealand and 12 years in Australia, part of 1 year in Netherlands Indies, 2 years in California, and general observations in Nevada, Colorado, Pennsylvania, the Appalachian Region, and Ontario and Quebec, during a period of 15 years. Journalistic experience and report reviewing were had with the *Mining and Scientific Press*, San Francisco; *The Mines Handbook* (now *The Mines Register*), New York City; *Mining and Metallurgy*, New York City; Federal Bureau of Mines, Pittsburgh and Washington; and for the *Mineral Industry*, New York City. In the whole period covered in the foregoing, four books, several booklets, and 200 articles were written on mining and metallurgical topics and published in several countries.

It should be understood that not all of the matter given in this book is original (no work of this character is or can be new), but the arrangement and the correlation of facts have not been previously presented in this style. Publications of the United States Geological Survey and Federal Bureau of Mines and State Geological Surveys and Bureaus of Mines, many of which are available free or at low price to the prospector, have been drawn upon freely, and it is hoped that this general acknowledgment will suffice. Notes suggested by articles that have appeared in *Engineering and Mining Journal, Mining and Scientific Press, Mining and Metallurgy, Mining Magazine*, and other journals have been included. Certain facts concerning foreign countries have been briefly abstracted from reports of their Mines Departments and Geological Surveys, also from mining journals published in Africa, Australia, Canada, and England. Thanks are due to several friends who suggested changes.

For the second edition, the first edition was revised and a chapter on geophysics added to give an idea of what the science and practice are, also the type of instruments employed.

For the third edition items in the previous editions were corrected, recent information on certain minerals added and new sections on maps and foreign mining laws, and the whole of Part III was re-arranged and expanded. The chapter on geophysics which appeared in the second edition, although fairly popular, was deleted because it treated of a science of deep search for specialists only; however, surface prospecting remains a fertile field for the prospector, and there is plenty of it to be done.

This fourth edition includes details of the United States Mining Law (previous editions had only brief items) and the new Philippine Mining Law. It also contains new tests; new items on minerals that are growing in importance; a new section on crystals; a new chapter on ore-dressing and treatment; and an entire new chapter on miscellaneous weights and measures, calculations, shipping ores and products, custom mills and smelters. charges, minerals and metal content, and prices for minerals, ores metals, and building materials over a long period.

M W. VON BERNEWITZ.

WASHINGTON, D.C.,
1938.

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HANDBOOK FOR PROSPECTORS
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PART I

CHAPTER I

AID TO PROSPECTORS

Writing in the sixteenth century, Agricola, a man much versed in mining and metallurgy, said that man could not do without the mining industry, and among many scenes shown in his *De Re Metallica* are prospectors with a windlass, working underground, and sorting, milling, and smelting ores. Amalgamation was practiced in those times in the Americas. Many methods in prospecting, mining, and ore treatment have been tried and improved since then, but the prospector is indispensable, especially if he has had some instruction in mineralogy, mining, and milling.

Grubstaking or Backing

Most ore deposits have been discovered by lone prospectors or by parties of prospectors who had sufficient funds for an expedition, but grubstaking or backing has been responsible for many discoveries. The basis of a grubstake is the lender's faith in and personal regard for the prospector. As a rule, a prospector receives from a storekeeper or others in a mining center an advance in cash and supplies on promise of a share in his discoveries, generally on a fifty-fifty basis. Grubstaking is common in the search for gold, but to be backed in a search for other minerals is more difficult, as there is less likelihood of rich finds; yet this should not be the practice, because most minerals have a market.

Grubstake contracts are agreements between two or more persons to locate claims on the public domain by their joint aid, labor, and expense—each person to acquire such an interest in the claims as the agreement specifies. In California such arrangements must be recorded, and *Bulletin* 106 (1939), free, should be obtained from the State Division of Mines.

Small syndicates also supply financial aid for the development of discoveries to the point where an exploration company can be approached for sale. In several countries are prospectors' associations which procure financial and legislative aid for prospectors. Many large mining companies employ experienced prospectors continually.

It has been customary for prospectors to set out alone on foot, with one or more animals carrying supplies. Frequently, two men constitute the party. Sometimes another man may be taken just to look after the camp and outfit and not participate in the field work. It is desirable that there be at least two in a prospecting party; three are better, but it is essential that they should be congenial mates. An ideal party would be headed by a trained geologist to direct field activities. He should decide the kind of metals to be sought, the region in which prospecting is to be done, and the time to be allotted to the work.

Government Aid

Government aid to prospecting in the United States, Canada, Australia, and other countries takes the form of departmental officials visiting new and old mining fields, making examinations, giving hints based on their knowledge of regional geology, and distributing geologic and other scientific reports free or at low price. In Australia, direct aid is extended in the form of cash, to be refunded, and public treatment plants. During 1934 the State of Western Australia was assisting 2000 men with supplies, as food, tools, explosives, transportation, and advice from visiting inspectors. In New Zealand 400 men were given relief in the form of a living wage. The United States Geological Survey has available many bulletins on districts and the economic minerals, and a number of excerpts and sketches therefrom will be found in this Handbook. Its topographic and geologic maps, which are easily available to all prospectors, cover many of the mining States and may be obtained at moderate cost either in Washington or at local stationers. Field parties should always carry such maps or reports describing the region that they propose to examine. This applies also to the publications of State Geological Surveys.

The Oregon State Department of Geology and Mineral Industries makes grubstake loans to prospectors under certain conditions. The sum is $50 a year per person.

Instruction

In the capitals of some States are mining bureaus that maintain collections of specimens of ores, as do State schools of mines. The mining departments of many Western States issue useful bulletins free and maintain a collection of specimens. Examination of these collections is of value to prospectors. In mining centers, free evening and part-time instruction in mineralogy, geology, and other subjects pertaining to mining can be made available through co-operation of Federal and State educational authorities, and the local Board of Education. Training in the fundamentals of mineralogy, geology, assaying, chemistry, and explosives will help any miner or prospector to become more efficient in his work.

Schools of mines and vocational schools in many Western States give prospectors' courses of 2 to 5 weeks free of charge. The instruction is thoroughly practical. The University of California has instituted a course of mineralogy by mail which teaches simple and practical methods for identifying minerals. The necessary apparatus, 100 specimens, and a textbook are provided.* In British Columbia, the Department of Mines has for sale, at 50 cents, sets of 50 common rocks. Ward's Natural Science Establishment, Rochester, New York, has, at reasonable prices, sets of rocks and minerals with accompanying booklets.

Most libraries in small towns file several of the weekly mining publications. Several of the large mining corporations encourage study and give night courses. Then there are the Y. M. C. A. and correspondence schools, which give instruction useful to miners at low cost. The Federal Bureau of Mines and the United States Geological Survey issue many reports and maps of practical

* This course was discontinued July 1, 1944.

value, at low charge, and the former promotes education in mining by means of motion pictures showing various phases of the mineral industry. These are also available free for showing at schools and other places throughout the country.

If procurable, the following regular publications are suggested for practical reading:

Engineering and Mining Journal, New York.
E. & M. J., Metal and Mineral Markets, New York.
Mining Congress Journal, Washington, D. C.
Minerals Yearbook, Federal Bureau of Mines, Washington, D. C.
The Mining Journal, Phoenix, Arizona.
Rocks and Minerals, Peekskill, New York.
Canadian Mining Journal, Gardendale, Quebec.
The Northern Miner, Toronto, Ontario.
The Mining Journal, London, England.
Mining Magazine, London, England.
Chemical Engineering and Mining Review, Melbourne, Australia.
South African Mining and Engineering Journal, Johannesburg, Transvaal.
The Mineral Survey, Mexico, D. F., Mexico.

We agree with E. D. Gardner of the Federal Bureau of Mines who says in its *Information Circular* 6843 (1935) that a majority of the metal mines in the United States have been discovered by qualified prospectors who were searching for valuable minerals at the time. Chance, however, always has played a large part in finding mineral deposits. Some of the discoveries of the past were made by men on other errands, as rounding up burros or hunting game or camping on an outcrop. Orebodies have been accidentally discovered in the making of cuts for roads, trails, or railways, also in excavating for mine structures. Burrowing animals and insects have brought ore to the surface. Important discoveries have been made by men who had no knowledge of rocks or minerals; on the other hand, many orebodies have been found by experienced prospectors, sometimes after hundreds of untrained men had already passed over the ground. Diligent and intelligent work is likely to be rewarded. Some prospectors make good discoveries; others never find anything; the proportion of the former is small. Only one of three or four hundred properties developed becomes a profitable mine. Most of the placer areas now being worked were found by early prospectors, who made considerable money. Many of the future discoveries will be of deposits without outcrop; and such mineralization requires much digging.

We disagree more or less, excepting his statements regarding petroleum, with K. C. Heald, staff geologist with the Gulf Oil Corporation, who, in the report *Technological Trends and National Policy* (National Resources Committee, Washington, D.C., 1937), argues that in the United States, at least, it is clear that the contribution of the old-time prospector, equipped with pick and burro, has now been largely made. By this, Heald means that until recently the search for new mineral deposits depended chiefly on the adventurous efforts of the individual prospector and that most of the world's known store of metal was first discovered by men trained in the school of adversity but lacking either scientific or technical guidance. In North America the golden age of surface prospecting followed the discovery of the yellow metal in California, and within the next half century a wave of exploration swept over the Western States and other lands. Except as new methods for locating concealed deposits may be developed, the influence of the factor of discovery is slowing down. Heald says this is true; yet if we consider the whole world, prospectors, sometimes aided by geologists and aerial photography, are still finding ore deposits, as in northwestern Canada, the Philippines, Africa, New Guinea, and Australia.

We admit the great importance and results of geophysical prospecting for petroleum and for iron ore, but these are special phases of mineralization. For petroleum, seismology is more extensively employed and more fruitful than any other method of geophysics. That the application of geophysical methods to the search for metals has encountered baffling obstacles of observation and interpretation is admitted by Heald. It has proved exceedingly difficult to find metalliferous ore deposits of any type when they are concealed at depths. For this reason, in the search for metal, geophysical methods will probably first be applied to enlarging the boundaries of known mineralized areas.

Most of the accessible parts of the earth have been at least casually inspected by the prospector; but important deposits not having prominent outcrops or exposures must await discovery in those regions where exploration is difficult and hazardous—areas that are cold or arid, areas that lack transportation facilities, areas of jungle or swamp, areas of the tropic zone, areas with unfriendly or savage people, and areas covered by vegetation, gravels, and ice. Such areas are of vast extent; some prospecting has revealed minerals, and more should be found.

CHAPTER II

TENTS, CLOTHING, WATER, FOOD, AND UTENSILS

Tents

In preparing his outfit the prospector should not forget the things that will make him comfortable but should avoid any unnecessary weight. Plenty of bedding is essential, especially in winter or early in spring. A light mattress adds much to comfort. The canvases used in covering packs should be spread on the ground, and the bed laid on that or on a good brush mattress of pine boughs. If the camp is more or less permanent, cheap comfortable folding camp-beds of wood and canvas or of steel with a spring are procurable in most towns. Good rest is essential to effective work, so a good bed is worth what it costs in effort.

The prospector should have a tent. Tents are of many designs, but the pyramid or wall shape is best liked. Wall tents are made in sizes ranging from 5 by 7 to 14 by 16 feet. The walls are 3 to 4 feet high, and the center 7½ to 9 feet. They weigh 24 to 76 pounds, according to the quality of the canvas. For two men, the 9- by 9- or 9- by 12-foot tent weighing 24 to 40 pounds is big enough, although one 7 by 8 or 8 by 10 feet is often used. For a party traveling light, the pyramid or miner's tent is the best. It requires only one pole and but few pegs. It sheds snow and rain better than other shapes shed them and may be set up quickly by one man. The 7- by 7- by 7- and 9½- by 9½- by 8½-foot miner's tent weighs 5 to 14 pounds. In the Lake Superior region the United States Geological Survey used the Van Hise model. Another good tent is the "pup" or A-shape. Its ridge is either a rope stretched between two trees or a pole supported by two forked sticks driven into the ground. In Canada the Ontario Department of Mines recommends a 7- by 9-foot wedge tent with wall, having a canvas sod cloth sewn in so that a tarpaulin floor can be laid down overlapping it, with a mosquito-proof front sewn in, and a heavy tarpaulin for the floor. The extra expense is warranted if much portaging is to be done. The style of tent most satisfactory is one with eyelets and short pieces of rope at the apex to fasten to an outside ridge-pole. Except where there are no trees, poles or pegs need not be carried but can be cut locally.

When shifting camp, tents can be used as the outer wrapping of bedding, clothes, and other supplies and are easily tied to a pack-saddle. Waterproof canvas may also be carried to keep things dry. It is advisable to bank the tent well to keep out the wind, and pegs should be driven in securely to prevent the tent's being blown down in a storm. Avoid a burned area or dead-tree area, and camp on points of lakes and rivers for the sake of the breeze. Whether in cool or in hot weather, a "fly" over a tent is an advantage. In interior Australia, "bush" sheds are often built over tents to keep away the sun.

A mosquito bar or net should be part of the equipment, also insecticides, including fly oil and oil of pine needles.

Clothing

Clothing should be of material that will stand hard wear. Woolen underclothing is the best for all-round use, and a sweater is also a good thing to have. Boots should have heavy soles and large hobnails, but not too many. A well-fitting pair of army boots or miner's high boots is comfortable, cheap, and durable. For working in wet shafts or tunnels, a pair of rubber boots should be taken, as leather will not stand continuous soaking. Thick socks are best for walking, and plenty should be carried.

For elevations up to 7000 feet it is well to remember that although the days may be warm, the nights become chilly and even cold, so that plenty of blankets are always required. This is so in the Sierras and in New Guinea. This applies to the desert in many instances, even after days that have been uncomfortably hot.

Water

Prospecting in arid regions or in deserts should be done in the latter part of winter and spring, as the heat in summer is intolerable and dangerous. In Australia the search continues most of the year, despite heat, flies, and precarious water supply.

The most vital consideration on a desert trip is water. In working in desert country the prospector should obtain all of the local information that he can. Knowledge of tanks, springs, trails, and such things frequently saves life. Sometimes the prospector must pack water considerable distances. At one camp in California water was carried on mules over 20 miles.

Always be sure about the water supply, and do not cut loose from one source until the next has been established. Most of the deaths from thirst in the desert are due to either ignorance or foolhardiness. Taking a chance does not pay, as the spring or the tank may not be where it was thought to be, or it may have dried up. Remember that if you make a day's journey to where you hope to find water, you not only use a day's supply in making the trip, but also if you do not find it you are a day away from your known supply. If there is any doubt, somebody should always go ahead and definitely locate the next source of supply.

These directions apply to reconnaissance work. If a prospector expects to camp any length of time at one place, he can arrange regular water packs from some spring or tank or build what road may be necessary and bring in a team with water barrels. Often it may be possible to develop a supply for camp use, because in many apparently dry regions water exists not far below the surface. A shallow well properly placed in a large wash may yield a reasonable supply.

Food

Circumstances govern the quantity and class of food taken on a prospecting trip. Time, the number in the party, distance from base, and the game or fish available are all factors in this calculation. To try to live off the land usually requires spending much time in hunting unless game is abundant, and this time is lost from prospecting. Whether to take a rifle and shotgun is a question. Fishing tackle is less cumbersome.

The staples on any trip are such things as "the two B's"—bacon and beans—tea, chocolate, or coffee, potatoes, flour, rice, dried fruits, raisins, with sugar, salt, and canned or dried milk—foods that will afford a maximum of nourishment with a minimum of weight and space. It is not feasible to carry fresh meat or butter and eggs. Condensed soups—that is, compressed, also bouillon cubes—are merely appetizers and do not contain enough nourishment for a hungry man. Neither do evaporated vegetables, though they give variety. Some vinegar may be carried as a prevention against scurvy, also lemons and onions; also canned tomatoes for their juice, a nutritious and popular American drink; and do not forget 12-ounce cans of fruit juices.

The food taken on exploring trips must provide a balanced ration; otherwise ill-health results. There must be some variety in the rations. Bacon is an excellent standby and keeps well in any climate. The fat from frying may be collected and used in bread or for cooking and as a substitute for butter.

ITEM	POUNDS PER MAN PER MONTH
Flour, cornmeal, hardtack, rice, grits, oatmeal, or similar foods, at least two-thirds of which should be flour prepared for self-rising	42
Clear mess pork, bacon, ham (say half pork)	27
Beans and split peas (two-thirds beans)	7
Evaporated fruits, mostly apple	4
Sugar	5
Butter	3
Canned milk	2
Cheese	2
Tea, coffee, and chocolate	2
Salt, pepper, mustard (two-thirds salt)	3
Baking powder, if self-rising flour is not used	1
Lime juice	2
	100

The quantity of food to be carried depends on the number in the party and the means of replenishing stock as it is used up. The United States Army garrison rations allow about 4 pounds of food per man-day, a liberal quantity. For men not undergoing great strain 2½ pounds per day is plenty, and for hard workers double this amount. Based on an average of these weights and allowing for unavoidable waste, the prospector can reckon on about 700 pounds of food to supply two men for 3 months, disregarding possible game. If game is plentiful, cut down on bacon and ham, but carry more salt and dried vegetables. This would apply to mountain or fairly hilly regions in the Western States.

A list of necessaries, based on actual field experience in a remote region, is shown on page 12.

During the examination of a prospect mine in Nevada, when most of the supplies were purchased at the nearest store, the cost of preparing 750 meals, equal to 250 man-days, was $120, or 50 cents a man per day.

Rations for United States Geological Survey parties were 3 pounds daily per man—a pound of meat and beans, a pound of flour, and a pound of other stuff.

For prospecting in Alaska the Cordova Chamber of Commerce recommended the following for one man for 8 months, consuming 3½ to 4 pounds a day:

Item	Weight, pounds	Item	Weight, pounds
Flour, meal, rice, etc.	370	Honey, syrup	24
Beans, peas, corn	80	Milk and cream (cases)	2
Potatoes and onions	55	Jams (cans)	6
Bacon, ham, salt pork	165	Evaporated fruits	100
Canned beef and other meat (cans)	27	Raisins	15
Lard, butter, cheese	76	Coffee (30 pounds), tea, chocolate	45
Sugar	110	Spices, baking powder, sauces	20
Evaporated eggs (cans)	8	Soaps (bars)	21
Tomatoes, cabbage and other vegetables (cans)	36	Candles (box)	1
Salt (iodized)	30	Matches (blocks)	10

In "Prospecting in Canada," published by the Dominion Geological Survey in 1930, the ration list given allows 3½ pounds per man-day. If food has to be carried for pack animals, the oats and hay per day are as follows: light and heavy horses, 10 to 12 pounds and 14 to 18 pounds; mules, 8 pounds and 12 pounds. Suitable outfits for Canada are listed.

The Department of Mines, Ontario, advises as follows:

> Usually, it is wise to take no more than one month's supplies, to save labor and time in portaging. In any case, if claims are staked they must be recorded within 15 to 30 days, and then fresh supplies may be procured.
>
> A selected list of provisions, ample to last two men for one month, might include the following and would furnish a varied diet. Canned goods are avoided as far as possible to cut down weight. Items and quantities may be altered to suit individual taste.

Item	Amount	Item	Amount
Flour or bread equivalent	45 pounds	Coffee or cocoa	2 pounds
Bacon	25 pounds	Baking powder	1 pound
Pork (long clear)	5 pounds	Dried apples	3 pounds
Butter (in tins)	8 pounds	Dried apricots	3 pounds
Beans	6 pounds	Dried peaches	3 pounds
Rice	6 pounds	Dried prunes	3 pounds
Raisins	2 pounds	Sugar	30 pounds
Cornmeal	4 pounds	Soup tablets	1 dozen
Rolled oats	8 pounds	Oxo cubes	1 dozen
Bag of salt	3½ pounds	Pot barley	1 pound
Pepper	1 can	Split peas	1 pound
Candles short	2 dozen	Desiccated potatoes	2 tins
Corn syrup	½ gallon or 10 pound tin	Evaporated cream, or equivalent of powdered milk	30 small cans
Tea	3 pounds		

> The weight would be approximately 200 pounds, and the cost, depending on locality, $25 to $30. Outfitters in the north will put these supplies in cotton bags of various sizes with tie strings attached —a necessary convenience for packing; paper bags are useless.

Utensils

In a cooking outfit there should be one or, better, two Dutch ovens, as they serve not only for baking but are useful for other purposes. Other utensils are frying-pan, coffee-pot, billy-can (in Australia for tea-making), sheath-knife, pail, knives, forks, spoons, and enamel-ware plates and cups. Ordinary aluminum ware is light, but it is too soft to stand hard usage; the cast metal is better. Copper utensils are available but rarely carried on these trips. Waterproof sacks may be used for packing many supplies.

Do not forget a water-tight match-holder and an ax with 27-inch handle, also a small belt ax. Always be careful where you light a fire and how you put it out.

CHAPTER III

METHODS OF TRANSPORTATION

The amount of money available and the character of the country to be explored necessarily govern transportation. Travel may be by foot, burro, camel, horse, llama, mule (either pack or in wagon), and by light automobile, motor-truck, or motorcycle. The airplane has been and is being utilized in northern Canada, Australia, and New Guinea and is regarded as a superior means of making quick trips into isolated regions, although the airplane has not been without trouble. And of course the canoe and dog-team should not be forgotten.

Walking with a pack on his back was the method of the old-timer and still is for men who are doing casual prospecting in addition to their regular work; many miners work in winter and prospect in the summer. Of course not much can be carried this way, and frequent trips must be made to the nearest town, yet considerable distances are covered with such a pack.

Animals

Pack animals should have care and attention, as they are susceptible to many different ailments and diseases. Their mouths, backs, and hoofs should be examined frequently. Loads should be adjusted when the animal faces downhill, not uphill. It is better to complete a day's march without a long rest during the period. Each animal should have its own saddle blanket.

Burros. The burro possesses sturdiness, endurance, and ability to find feed and exist on a small supply of water. This makes him peculiarly useful to the prospector (see Fig. 1). On the other hand, he has many traits that try his owner's patience. In arid regions, when the weather is cool, the feed is green, and there are occasional rains, burros get along with little water; in fact, when they are not working they drink practically none, and their average under those conditions probably is not in excess of 1½ gallons a day each. With warmer weather and the feed drier, the average will be nearer twice that amount. While in camp, do not fail

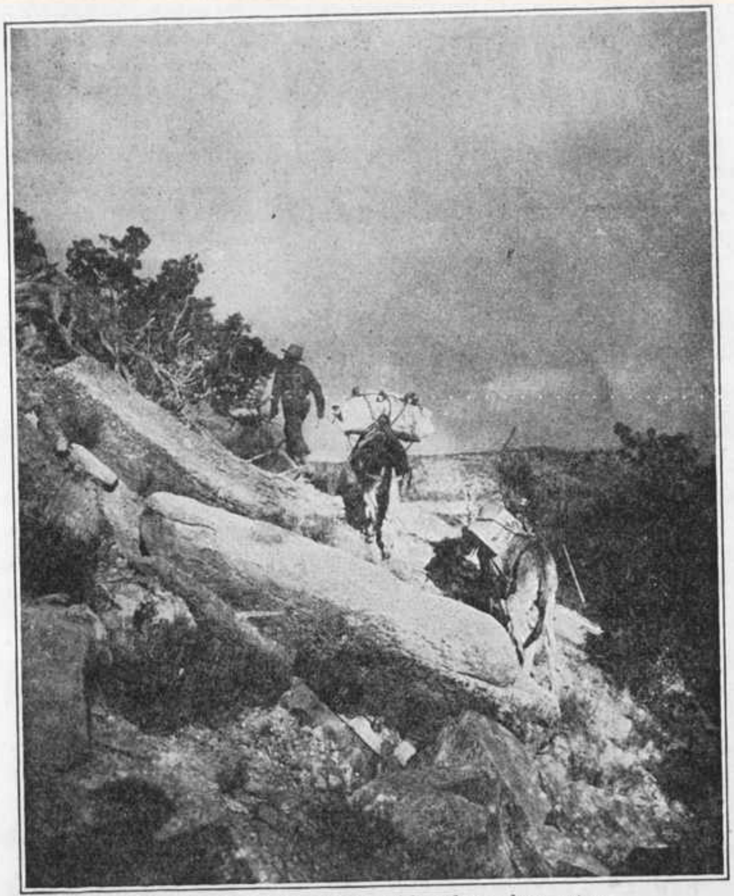


FIG. 1.—A prospector in arid and rough country.

to keep a watch over the burros. They should be turned loose, hobbled, and belled, but they are such travelers that they should be rounded up, or at least seen, every day. In hot weather, they can be depended upon to come into camp for water, but when the weather is cool and the feed green, they get along without it, and if they are allowed to roam there is no knowing where they will be when needed.

It is generally conceded that the average burro will carry 150 pounds and cover 15 miles a day regularly. Burros will travel on an average as far as a man cares to in a day, taking into consideration the additional work of packing, unpacking, and making camp. Under such conditions, 15 miles makes a day's work. For a large party it is important to have a good string of burros and a man who understands them. They are very serviceable in mountainous regions and are exceptionally sure-footed. In Colorado and Mexico, for instance, they are used in carrying supplies and sacked concentrates and ore.

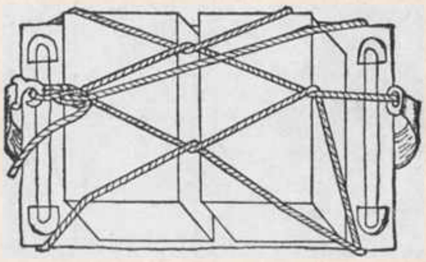


Fig. 2.—Single diamond hitch. Sling-ropes are used until the lash rope is secure. (*According to C. J. Post.*)

Each pack, except the water pack, should be covered with canvas, and all packs, water included, should be securely lashed. For this, the diamond hitch is the best. It is easy to throw, easy to release, and holds better than any other. The diamond hitch is a method of fastening a rope about a pack animal's load, in which the rope, secured by a cinch, crosses so as to leave a diamond-shaped space on top. Figure 2 shows a single diamond hitch tightened and tied. The double diamond hitch is more difficult to make. It is used when a riding or striding load is placed above the balanced load, especially if it be of an awkward shape, such as a keg. When it comes to packing it is best to have one man stand guard over the burros after they have been packed, as they will lie down if they get a chance. Once down they are hard to get up and are likely to shift their loads in doing so. The packs should fit properly and hang evenly. A pack-saddle should be fitted just as carefully as a riding saddle. After fitting, each saddle with its blanket should be labeled for its particular animal.

FIG. 3.—A string of loaded camels.

Camels. No camels are used in the United States, but in Australia, Central Asia, and even parts of Siberia, they are extensively employed in prospecting and carrying every kind of supply to distant camps and mining centers without railroad connection or good roads. Motor-trucks in some parts, however, have lessened the number of camels.

Although camels have been harnessed to wagons, supplies are mostly carried on their backs. A small saddle is strapped on, and the load, evenly balanced, is held in place by the diamond hitch. Camels will carry 500 to 900 pounds. In loading, the materials are lashed together on either side of the animal, which is in its sitting or crouching position, and tied across the saddle; the animal then picks up the load as it rises. With such a load a camel will travel 20 miles a day (see Fig. 3).

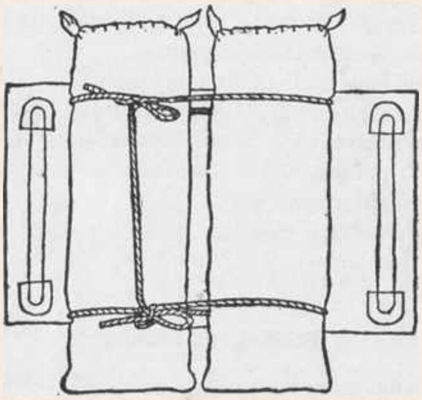


FIG. 4.—Double sling for long packs. (*According to C. J. Post.*)

Like the burro, camels live off the land, eating desert saltbush (similar to sagebrush), grass, and leaves of certain trees. They drink a great deal on starting a journey but little on the way and can exist for days without any water. At certain periods, the male becomes vicious and has a nasty bite. In camp, they should be hobbled and belled, although they are not such wanderers as the burro. The camel works well in sandy country but not on rough roads or soft wet soil.

Horses. Although they are employed to some extent, horses are not serviceable in dry country. They must have plenty of water and green or dry feed. Mountain horses are strong, sure-footed, and will follow a trail without needing much attention. They can carry 150 to 250 pounds and will cover up to 15 miles a day on steep trails at altitudes of up to 7000 feet. Horses should be well shod, as rough trails break the hoofs in a short time. These animals require regular attention to get good work out of them.

A handy way to load a horse is by saddle-bags. These just fit on the pack-saddle and hang down on either side and need no tying. Supplies are put in the bags, and a strap from one side to the other keeps them from falling out.

Mules. The mule is about the most useful animal under almost any condition. He has great endurance and will carry 200 to 400 pounds and travel 15 to 25 miles a day with such loads. The average is 250 pounds and 10 to 15 miles over hilly country. Mules work well in wagons also.

Llamas. Llamas are employed in South American countries, especially in the Andes. They are hardy and can carry 150 to 300 pounds.

Packing and Loading

Most men who have been out camping have some knowledge of packing, but if they have not, the local storekeeper or teamster will give instruction. The best size of rope to use is ⅜-to ½-inch manila, 30 to 50 feet long and wrapped at each end to prevent

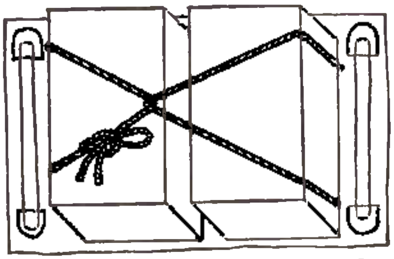


FIG. 5.—One-man cargo sling for case goods. In this method the sling-rope is used to hold the cases until the lash-rope is tied, then it is taken off. (*According to C. J. Post.*)

fraying. Sling ropes are for temporary use before the lash rope is finally fastened, especially if one man is loading an animal.

FIG. 6.—Loading dynamite. In loading two boxes or other articles it is important to bring the rope under both to prevent them from dropping out. (*Courtesy of George O. Argall, Jr.*)

FIG. 7.—Tying on a 3- by 12-inch board. Boards and small pieces may be nailed together. (*Courtesy of George O. Argall, Jr.*)

The hitch holds the load firmly to an animal. Figures 4 and 5 show two methods of securing packs.

There are other hitches, such as the Wiman one-man, the pole, cross-tree, squaw, lifting, saddle, and stirrup.

According to George O. Argall, Jr., in *The Mines Magazine*, Denver, for March, 1938, all the exploratory work in the Rocky Mountains was done by packing an animal. Mules and burros are used yet, but aerial trams and roads have lessened the need for them. Mules of 900 to 1100 pounds cost $50 to $125. They have amazing endurance and toughness for the hot desert and cold at high altitude. They will carry 250 pounds uphill and 450 pounds downhill. They must be fed grain, also hay or grass, preferably at night. Burros weigh 400 to 550 pounds. They are little use uphill but can carry 300 to 350 pounds downhill. Horses are seldom used; they need better food than mules and burros and are susceptible to injuries. A pack-saddle, blankets, and ropes for an animal cost $25 to $35. A packer needs experience because of the different materials, shapes, and sizes carried. There are different hitches for boxes, sacks, bales, lumber, lagging, and stulls, the end of the last dragging along the ground (see Figs. 6, 7, and 8).

Motor Vehicles

When it can be afforded, and there are passable roads, or even where the country is bare, a light motor-car of the station-wagon type or motor-truck is serviceable. Such a machine will carry two men and a lot of supplies, not forgetting extra containers for gasoline or petrol, oil, and water. Prospectors must not get too far from a "gas" supply, but gasoline is now procurable in many isolated places. The ordinary body may be left on the machine, or the back part fitted like a truck to permit carrying more supplies. Plenty of spares and chains for sandy country should be taken. Some prospectors have used their cars in driving a small crusher, sawmill, or other device.

Motor-vehicles cover the ground quickly; and if there is a rush to a new camp, the man in the machine soon outstrips those in other conveyances. When a more or less permanent camp has been established, a motor vehicle is useful in running to the nearest town for supplies. "Dude" prospectors in motor-cars have hauled a trailer.

The motor-cycle may be used in much the same manner as the automobile but is almost restricted to one man if the roads are bad. The side-car may carry another man, but this would leave little space for supplies. If a prospector is alone, and not too far from a town, he can make daily trips to the district being examined. Then he needs only the cycle itself.

FIG. 8.—Loading ore. Steel hangers may be used in place of ropes. (*Courtesy of George O. Argall, Jr.*)

Motor vehicles tend to a too rapid and impatient search for minerals, and many places are overlooked, not even looked over. Deposits are not discovered in that way.

Canoes

Canoes are frequently used and almost a necessity in parts of Canada, particularly Ontario, Manitoba, and Quebec, but men inexperienced in canoes should not use them. If two prospectors are on an extended trip and understand how to manipulate a canoe, they will find that a 16-foot boat with square stern, an outboard motor, and three paddles will be satisfactory. If there are many portages or long ones, a canoe without motor is best. Because of sudden storms, on large lakes it is safer to keep close in shore.

Airplanes

With regard to airplane travel, it has been suggested that an emergency kit should be taken in case of crash in cold regions. Of course, it might be impossible to get oneself and the equipment from a cracked-up ship. However, some rations, bear-paw snowshoes, first-aid essentials, blankets, sleeping bag, flashlight, and a few other items could be packed without too much difficulty.

CHAPTER IV

HEALTH AND FIRST AID

Health, it has been said, is man's credit at the bank of life. The prospector, in a temperate climate, can become run down if he does not take care of himself; in a cold climate, he needs plenty of food and clothing; in a tropical climate, he should take extra precautions. Overeating and lack of personal hygiene are general neglect of the body. The sanitary arrangements of a camp are important. Generally, drinking water is procurable from springs or streams, but in tropical regions it is likely to be darkened by vegetation, and in desert areas it may be brackish. All rubbish should be dumped at some distance from camp and burned each day to prevent decay of food scraps and that in empty cans, which always attracts flies, those carriers of disease.

In a tropical country like New Guinea, there is no cool season and rain is frequent. The goldfields are at an altitude of 2000 to 7000 feet, and in general the climate is healthful. But reasonable precautions should be taken in diet, exercise, and hygiene. Malaria exists up to 3500 feet, and white persons should sleep under a mosquito net and take a daily dose of 5 grains of quinine, according to medical experience. (This dosage is suitable for any tropical country.) If malaria is neglected, and men become run down, blackwater fever, which was at one time bad in West Africa, may follow. Warm days and cold nights are the rule at 6000 to 7000 feet, and natives are subject to pneumonia and dysentery. In Borneo, where the author spent some time at sea-level and in the jungle, he did not use a mosquito net or take quinine, although some malaria was prevalent. Doubtless some persons are more or less immune to tropical complaints.

Accident prevention is of prime importance, but a knowledge of how to render first aid for injury is important to everybody, especially to the prospector, because much of the time he is at a great distance from a doctor. When rescue-cars of the Federal Bureau of Mines are in any mining district, advantage should be taken of their visit to obtain free instruction in first aid. Its first-aid manual, obtainable free, describes standard practice in dressing wounds and other injuries, also in artificial respiration or resuscitation.

In northern Ontario are rescue stations at Kirkland Lake, Sudbury, and Timmins, where instruction may be given, also at Noranda, Quebec.

Before starting out on a prospecting trip, it is advisable to purchase a first-aid outfit consisting of triangular and roller bandages, gauze, adhesive tape, cotton lint, tourniquet, safety pins, mercurochrome, iodine, soap, ammonia, cold cream or coconut oil, boric acid, picric acid gauze, and tannic acid. All of these materials may be procured ready packed in a container at supply houses and drugstores, otherwise from a local storekeeper. The firms of J. D. Bullard Company, San Francisco, and Mine Safety Appliance Company, Pittsburgh, prepare compact first-aid and safety devices for small or large operations. The articles are not heavy occupy little space, and should be carried. Splints and the like can be made in the field from boards, branches, or bark. Leaves, grass, and moss make good padding. Picric acid gauze should be moistened before use. Strips of one's shirt or other clothing serve as outside bandages. Boric acid, as powder, is good for wounds, and, as liquid, for eyewash.

One of the dangers in prospecting, especially in rocky country and in warm weather, is that of snake-bite. In the western United States the rattlesnake gives warning of attack when in the open, but if in a rock-pile may strike without having previously been seen. In Australia, the black snake, tiger snake, and adder are venomous. If a person is bitten, he should keep his nerve. When working in a region where venomous snakes are abundant, one should at all times carry a snake-kit on one's person and not in the general first-aid kit. Each man should have one. The best outfit consists of a small wooden tube, about as thick as a pencil, fitted at each end with a screw-cap. Attached to one end is a sterilized blade, an inch in length, and in the hollow of the other end is some powdered permanganate of potash. This outfit costs about 30 cents. If one is bitten, a ligature should first be applied between the wound and the heart. The wound should then be cut with the blade; the blood sucked out as much as possible; and then the permanganate rubbed into the incision, followed by bandaging. The drinking of alcohol is detrimental; hot coffee or tea is better. Caustic or a hot iron or coal put in the wound is of good service. High boots or leggings serve as good protection for the legs, although British engineers prefer shorts.

Chromic acid, which burns the skin and flesh badly if concentrated, may be used with care, if diluted considerably with water, to allay the pain from bites or stings of insects and reptiles. When the wound is moistened with a little dilute chromic acid, the cure is said to be remarkably rapid.

In the Sierra Nevadas heavy snow begins to fall in October of each year, and by the end of December or in January at an elevation of 4000 to 7000 feet the ground is covered with 3 to 20 feet of snow in most regions. No prospecting is possible under such conditions, although a little development work can be done on prospects. Prospectors sometimes remain in their cabins all winter. In the fall they lay in a supply of wood and food to last at least 5 months. It is absolutely essential that men spending the winter in the mountains should be competent in the use of skis and snowshoes, so as to be able to go to towns in the lower altitudes when necessary. In the Sierras of California the ski is used almost exclusively.

To prevent the freezing of water in pipes, if such are laid from springs, a box, say, 6 inches square should be built around them, and the space filled with manure. This should be renewed each year if the camp is more or less permanent. As to frost-bite, mild cases are fairly common; but serious attacks require considerable care, particularly if they are complicated by other bodily troubles. Besides cold, wind velocity makes frost-bite worse. The humidity of the atmosphere has no effect; but if mittens and socks become wet, there is more chance of frost-bite, according to Leopold Brahdy, who studied 505 cases in New York among outdoor workers. Cold first causes a sensory (nervous system) paralysis; it is because of this that a person is unaware of the condition and exposure is continued, until the frost-bite progresses to the danger point. Prevention of frost-bite results from wearing adequate clothing—good quality underwear, outer clothes, socks, boots, gloves, and ear-laps on caps. Frost-bite of the ears may cause loss of time for a few days but seldom leaves any permanent effect. Most important is the prevention of frost-bite of the hands and feet. It is better to protect them than lose one or more fingers and toes or perhaps a large part of a hand or foot. If a person has been frost-bitten, the affected part should be warmed gradually with the hand, the armpit, or other part of the body. Colored glasses, which are cheap and comfortable, should be worn when one is in the midst of snow all the time.

Warning should be given not to enter old drifts, tunnels, or shafts until you are sure that the air is good or that there is no explosive gas present. Many lives have been lost by thoughtlessly entering such places. If, on walking in a drift or tunnel, a candle or acetylene lamp flame becomes low or goes out, it is time to back out of the workings because the oxygen content of the air is low. And before being lowered down a shaft, lower a candle or lamp to see what happens, because the air may be bad or explosive.

Safety first or accident prevention should always be a motto of the prospector—it pays to be careful and, if the need arises, to be able to attend to an injury to oneself or others.

CHAPTER V

LAWS PERTAINING TO MINING: UNITED STATES AND FOREIGN

UNITED STATES

A knowledge of Federal, State, and district laws and regulations is essential. Land offices have copies of the laws, and the General Land Office of the Department of the Interior at Washington, D.C., will supply them free or information on how to locate claims on the public domain.

Lodes and Veins

Circular 1278 of the General Land Office, 1935, which gives pertinent information on the location and purchase of mining claims, is here reprinted in full:

1. *Initiation of Rights to Mineral Land.* Rights to mineral lands, owned by the United States, are initiated by prospecting for minerals thereon, and, upon the discovery of mineral, by locating the lands upon which such discovery has been made. A location is made by staking the corners of the claim, posting notice of location thereon (see 10), and complying with the State laws, regarding the recording of the location in the county recorder's office, discovery work, and other regulations.

2. *State Mining Laws.* As supplemental to the United States mining laws there are State statutes relative to location, manner of recording of mining claims, and so forth, in the State, which should also be observed in the location of mining claims. Information as to State laws can be obtained locally or from State officials.

3. *Lands Subject to Location and Purchase.* Vacant public surveyed or unsurveyed lands are open to prospecting, and upon discovery of mineral, to location and purchase, as are also lands in national forests in the public-land States (forest regulations must be observed), lands entered or patented under the stock raising homestead law (title to minerals only can be acquired), lands entered under other agricultural

laws but not perfected, where prospecting can be done peaceably, and lands within the railroad grants for which patents have not issued.

4. *Status of Lands.* Information as to whether any particular tract of land is shown by the records to be vacant and open to prospecting may be obtained from the register of the land district in which the tract is situated. Since location notices of mining claims are filed in the office of the county recorder, ordinarily no information regarding unpatented mining claims is obtainable from the district land office or the General Land Office unless application for patent has been filed.

5. *Minerals Subject to Location.* Whatever is recognized as a mineral by the standard authorities, whether metallic or other substance, when found in public lands in quantity and quality sufficient to render the lands valuable on account thereof, is treated as coming within the purview of the mining laws. Deposits of coal, oil, gas, oil shale, sodium, phosphate, potash, and in Louisiana and New Mexico sulphur, belonging to the United States, can be acquired under the mineral leasing laws, and are not subject to location and purchase under the United States mining laws.

6. *Mining Locations—Areas.* Lode locations for minerals discovered in lode or vein formation may not exceed in length 1500 feet along the vein and in width 300 feet on each side of the middle of the vein, the end lines of the location to be parallel to each other. Placer locations, which include all minerals not occurring in vein or lode formation, may be for areas of not more than 20 acres for each locator, no claim to exceed 160 acres made by not less than eight locators. Placer locations must conform to the public surveys wherever practicable.

7. *Who May Make Locations.* Citizens of the United States, or those who have declared their intention to become such, including minors who have reached the age of discretion and corporations organized under the laws of any State. Agents may make locations for qualified locators.

8. *Number of Locations.* The United States mining laws do not limit the number of locations that can be made by an individual or association.

9. *Valid Locations—Discovery after Conveyance.* A location is not valid until an actual discovery of mineral is made within the limits thereof. A placer location of more than 20 acres, made by two or more locators and conveyed to a less number before discovery is made, is valid to the extent of 20 acres only for each owner at date of discovery.

10. *Locations to be Marked on Ground—Notice.* Except placer claims described by legal subdivision, all mining claims must be distinctly marked on the ground so that their boundaries may be readily traced, and all notices must contain the name or names of the locators, the date of location and such a description of the claim by reference to some natural object or permanent monument as will serve to identify the claim.

11. *Locations on Streams and Bodies of Water.* Beds of navigable waters are subject to the laws of the State in which they are situated and are not locatable under the United States mining laws. Title to the beds of meandered non-navigable streams is in the riparian owner. The beds of unmeandered, non-navigable streams are subject to location under the United States mining laws if they are unoccupied, as are also the beds of meandered non-navigable streams when the abutting upland is unappropriated.

12. *Maintenance—Annual Assessment Work—Adverse Claim—Jurisdiction.* The right of possession to a valid mining claim is maintained by the expenditure annually of at least $100 in labor or improvements of a mining nature on the claim, the first annual assessment period commencing at 12 o'clock noon on the first day of July succeeding the date of location. Failure to perform the assessment work for any year will subject the claim to re-location, unless work for the benefit of the claim is resumed before a re-location is made. The determination of the question of the right of possession between rival or adverse claimants to the same mineral land is committed exclusively to the court (see 18). However, failure to perform the annual assessment work on a mining claim in Alaska works a forfeiture of the claim, and resumption of work on the claim will not prevent re-location.

13. *Expenditures on Claim for Patent Purposes—Lode—Placer—Mill-site.* Five hundred dollars in labor or improvements of a mining nature, must be expended upon or for the benefit of each lode or placer claim, and compliance with the United States mining laws made otherwise, to entitle the claimant to prosecute patent proceedings therefor. Such expenditures must be completed prior to the expiration of the period during which notice of the patent proceedings is published. Patent expenditures on a mill-site are not required, but it must be shown that the mill-site is used or occupied for mining or milling purposes at the time an application for patent therefor is filed.

14. *Patent Not Necessary.* One may develop, mine, and dispose of mineral in a valid mining location without obtaining a patent, but possessory right must be maintained by the performance of annual

assessment work on the claim in order to prevent its re-location by another.

15. *Procedure to Obtain Patent to Mining Claims.* The owner or owners of a valid mining location, or group of locations, on which not less than $500 has been expended on or for the benefit of each claim, may institute patent proceedings therefor in the district land office. Information as to patent procedure can be obtained from the register of the local land office or from the General Land Office. In general, a survey must be applied for unless the claim is a placer claim located by legal subdivisions, the application for survey to be made to the public survey office in the State wherein the claim is situated. Applications for patent are filed in the district land office. A notice of the application is required to be posted on the land prior to filing the application and to be published by the register after the application is filed.

16. *Blank Forms.* No set form of location notices nor of the papers filed in patent proceedings for mining claims is required and no blank forms are furnished by the General Land Office, or by the district land offices, for use in mineral cases. Forms containing essentials are printed by local private parties or concerns. The registers of the local land offices can usually advise you where such forms may be obtained.

17. *Common Improvements.* An improvement, made upon one of a group of contiguous claims (cornering is not contiguity) owned in common, may be applied to such claims of the group, in existence at the time the improvement is made, shown to be benefited thereby.

18. *Adverse Claims.* An adverse claim may be filed during the period of publication of notice of an application for patent (or within 8 months after the expiration of the publication period in Alaska), by one claiming a possessory right under another mining location to all or some portion of the land applied for, and must show fully the nature, boundaries, and extent of the area in conflict, to be followed, within 30 days after filing (60 days in Alaska), by suit in a court of competent jurisdiction. If suit is filed, all proceedings on the application, except the filing of the affidavits of continuous posting and publication of the notice of the application, are stayed to await the outcome of the court proceedings.

19. *Co-owners.* A co-owner not named in the application for patent can not assert his rights by filing an adverse claim, a protest being proper to cause his alleged rights to be considered when the case is adjudicated. If a co-owner fails to do his proper proportion of annual

assessment work on a claim, or fails to contribute his proportion of the cost thereof, the co-owners who have caused the work to be done during any assessment period may, at the expiration of the assessment year, give such delinquent co-owner personal notice in writing, or notice by publication in a newspaper published nearest the claim for at least once a week for 90 days, and if at the expiration of 90 days after such notice in writing, or 180 days after the first newspaper publication, such delinquent should fail to contribute his proportion of the expense required, his interest in the claim becomes the property of his co-owners who have made the expenditure.

20. *Lode in Placer.* If a placer mining applicant fails to state that there is a known lode within the boundaries of the claim, it is taken as a conclusive declaration that he has no right of possession thereto. If no such vein or lode be known the placer patent will convey all valuable mineral and other deposits within the boundaries of the claim. A known lode not included in an application for patent to the claim may be applied for even after issuance of patent to the placer mining claim. Where a placer mining claimant makes application for a placer containing within its boundaries a lode claim owned by him the lode must be surveyed, the lode being paid for on the basis of $5 per acre and the remaining portions of the placer at the rate of $2.50 per acre.

21. *The United States Mining Laws Are Applicable to the Following States:* Arizona, Arkansas, California, Colorado, Florida, Idaho, Louisiana, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming; also to the Territory of Alaska.

22. *National Parks and Monuments.* With the exception of Mt. McKinley National Park in Alaska and Death Valley National Monument in California mining locations may not be made on lands in national parks and monuments after their establishment.

23. *Withdrawals.* Withdrawals usually bar location under the mining laws, but withdrawals made under the act of June 25, 1910, as amended by the act of August 24, 1912, permit locations of the withdrawn lands containing metalliferous minerals. Lands withdrawn for water-power purposes are not subject to location unless first restored under the provisions of Section 24 of the Federal Water Power Act.

24. *Minerals in Indian Lands.* In general, the mineral deposits in Indian reservations are subject to leasing and are under the administration of the Office of Indian Affairs.

25. *Mineral Land in Agricultural Entries—Protest—Contest.* Where lands known to be valuable for minerals are embraced in an agricultural filing, other than a stock raising homestead filing, a mineral claimant may initiate a contest thereagainst by filing a protest sworn to and in duplicate, in the local land office, alleging sufficient facts, which, if proven, will establish the mineral character of the land, and warrant cancellation of the agricultural filing. The protest must be corroborated by one or more witnesses having knowledge of the facts alleged. In the case of stock raising homestead entries, a mineral claimant, whose location antedates the homestead filing, must protest such filing in order to protect his title to the surface of his mining claim.

26. *Cost of Patent Proceedings for Mining Claims.* With the exception of the fixed charges, such as the fee for filing an application for patent, which is $10, the purchase price of lands in lode claims and millsites at $5 per acre, and $5 for each fractional part of an acre, and $2.50 per acre or fraction of an acre for placer lands, unless otherwise provided by law as to certain lands, no estimate can be furnished as to what it will cost to procure a patent. The cost of publication, survey, and abstract of title depends upon the services rendered and vary in each case.

Placers

The following items have been condensed from a report prepared in the General Land Office late in 1937:

1. **Definition.** Placers are defined as including all forms of deposits excepting veins of quartz or other rock in place.

2. **Lands Open for Location.** Lands subject to location are practically as given under paragraph 3 under Lodes.

3. **Private Lands.** If prospecting is to be done on privately owned lands, the prospector should determine whether or not title to the minerals passed with the patent for the land. If so, the United States mining laws are not applicable, and the prospector must obtain permission from the owner of the land to prospect thereon.

4. **Homestead Lands.** Lands entered or patented under the stock-raising homestead law are subject to prospecting and to location and patent, but the location and patent carry title to the

minerals only, title to the land itself remaining in the homesteader. A prospector is liable for all damages done to crops or other improvements. Only enough land to carry on mining operations is available.

5. Acreage to Be Staked. An individual locator can stake not more than 20 acres in a single claim, but several locators can join in making a single location embracing up to but not exceeding 160 acres, provided there is a co-locator for each 20 acres or fraction thereof. For example, two or more can locate 40 acres; three or more, 60 acres; four or more, 80 acres; and so on. But discovery must be made on each claim located. An amended location to take in additional land is permitted, but the acreage allowed must not be exceeded, and private rights of others must be respected.

6. Shape of Claims. All entries of mineral lands shall be as compact and regular in form as is reasonably practicable, not in long narrow strips or grossly irregular tracts.

7. Claim Boundaries.—When the extent of the placer deposit has been determined, the claim boundaries should be marked by setting up stakes or monuments at the corners if the land is unsurveyed. These are not required if the land is surveyed, although some States require the corners to be marked, whether the land is surveyed or not.

8. Re-locations. The fact that land has once been embraced in a placer-mining location does not prevent the making of a new location on the same land, provided the first location was never patented and has been abandoned or is in default as to assessment work.

9. Lodes and Veins. A placer location does not carry a right to any lodes or veins that may outcrop within its boundaries. If such deposits are present, a separate lode location should be made thereon. A lode claim within a placer is limited to 25 feet on either side of the lode at the surface. If a lode is not known to be present at the time of filing an application for patent of a placer claim, and a patent issues, such patent carries title to all minerals in the claim, including the lodes.

10. Assessment Work. The annual assessment work (the year in which a claim is located does not require it) shall consist of at least $100 in labor or in improvements on each claim. Where a number of contiguous claims or those with common boundaries comprise a group, the total assessment work for the group may be done on one claim, if this benefits or develops each claim. Failure to perform annual assessment work will subject the claim to re-location by others unless work is resumed before such relocation.

11. Selling or Leasing Claims. A valid placer claim may be sold or leased and passes by descent like any other real estate, even though unpatented. Minerals may be mined and sold from claims held under location the same as though the claims were patented. Patented and unpatented lode claims are subject to taxation by the State, as are buildings and their contents on the claims.

12. Timber Rights. Timber and stone on public lands may be used free by bona fide miners and prospectors for mining purposes but may not be sold. If the timber is to be taken from mining claims in national forests, it must be taken according to regulations issued by the United States Forest Service.

13. National Forests. Mineral lands in national forests in States where the Federal mining laws are not in effect are subject to disposal under special regulations of the United States Department of Agriculture.

14. Indian Reservations. In general, mineral deposits in Indian reservations are subject to disposal only under lease and are under the administration of the Office of Indian Affairs.

15. Patenting Claims. Valid placer claims or groups of claims on which not less than $500 has been expended for the benefit of each claim may be patented. If the claim is located by legal subdivisions, no mineral survey is necessary; otherwise it should be surveyed. The cost of a survey must be paid by the claim-owner. Before a patent will issue for a placer claim, the claimant is required to pay for the land at the rate of $2.50 an acre. Full information may be obtained from the Registrar of the district land office.

OTHER COUNTRIES

If a prospector desires to search for minerals in other countries, information regarding the mining laws, prospecting rights, permits, and payments may be obtained from the consuls representing those countries or direct from their Departments of Mines. The laws of several countries following have been abstracted by the author from *Information Circulars* published by the Federal Bureau of Mines.

There are two important factors to remember when prospecting in a country foreign to your own: Respect the other people's customs and laws, and do not become entangled in their politics; you may not approve of them, but you can not alter them.

Mining Laws of Canada

Briefs of the laws of four Provinces follow:

British Columbia. The holder of a free miner's certificate ($5 or £1 for 1 year) is entitled to all minerals within the claim, except extralateral ones. . . . The free miner is not entitled to hold more than one claim on the same vein or lode except by purchase, but he may hold a claim on any separate vein or lode. . . . The normal size of a claim is 1500 feet square. . . . Work worth $100 (£20) must be done each year to hold a claim, or, in lieu of work, this sum may be paid the Mining Recorder. As soon as assessment work to the extent of $500 (£100) has been recorded and a survey made, the owner of a mineral claim is entitled to a Crown grant upon paying a fee of $25 (£5) and giving notices required by the law. . . . In creek diggings, a claim is measured 250 feet along the stream and 500 feet from the center on both sides. . . . Discovery, if established to the satisfaction of the Gold Commissioner, permits larger claims to the discoverer; to one discoverer a claim may be 600 feet in length; to two discoverers, two claims totaling 1000 feet.

Ontario. A miner's license costing $5 (£1) is required to prospect for minerals upon Crown land or land in which the mining right is in the Crown or to stake out, record, or acquire any unpatented mining claim or area of land for a boring permit. A license is renewable at the same charge. . . . Claims must be registered with the recorder for the mining division in which they are situated within 15 days from the date of staking, one day additional being allowed for each additional 10 miles from the recorder's office. . . . Each application for a mining claim must be accompanied by a sketch or plan thereof. . . . A claim in a special mining division consists of 20 acres; outside these it consists of 40 acres. . . . A licensee may, in one year, stake out three claims for himself and three for each of two other persons, nine claims in all. . . . Two hundred days of work must be done within the 5 years following the date of recording of the claim; 30 days' work must be done within 3 months; and not less than 40 days' work in each of the following 4 years. . . . The recording of a mining claim entitles the licensee to seek a Crown patent; it also entitles him to two free-assay certificates and two additional certificates for each 40 days' work thereafter. One certificate gives the holder the right to an assay for gold, silver, copper, lead, zinc, or metallic iron; two certificates the right to an assay for nickel, cobalt, tin, or tungsten.

Quebec. A miner's certificate costing $10 (£2) may be delivered to any person applying therefor. It is valid from date of issuance until the end of the year (January 1, following). . . . On unsurveyed lands, the holder of a certificate may stake out one to five claims of 40 acres each (1320 by 1320 feet, north-south and east-west). In surveyed territory he may stake out one or two lots of 100 acres each (or half lots). If the lots are 120 acres, quarters may be staked. In either case, the claim must not exceed 200 acres. . . . The holder of a miner's certificate may stake out claims for other certificate holders, but he may not stake for others a total area exceeding 400 acres a year. . . . Discovery must be followed by active staking. . . . Claims in depth are bounded by vertical planes or lines.

Manitoba. A prospector may stake nine claims instead of three, and this costs $50 instead of $90. When claims are abandoned, the $10 fee is not charged but the Mining Recorder must be informed. The work as done may be disputed. Diamond-drilling charges are allowed as work.

Mining Laws of British Guiana

As far as actual enactments go, it appears that, except with respect to petroleum and bauxite, no discrimination is made against foreigners in British Guiana, South America. . . . A prospecting license ($5 or £1) entitles the holder personally or through an agent to prospect and locate claims on land in every mining district not previously occupied or reserved. A license is good for 12 months. . . . If a claim is located, the license entitles the holder to work the ground from the date of location until the application for a claim license can be published and the claim is either granted or refused. . . . A reward claim may be granted if the prospector discovers workable deposits 10 miles from existing working claims. No fees are payable by the holder of a reward claim, but he pays royalty as usual. . . . No ordinary gold, gem, or other mineral claim can exceed 800 by 1500 feet. . . . A claim license remains in force as long as the rent is regularly paid. It costs $5 to $19 (£1 to £3.8) per year for a license to mine gold or to mine gold and gems, $10 (£2) to mine for other minerals, and $14 (£3) to mine for gems. . . . Royalties are 50 cents (2 shillings) an ounce on gold, 4 cents (2 pence) on silver, 50 cents a carat for gems, and varying payments on other minerals.

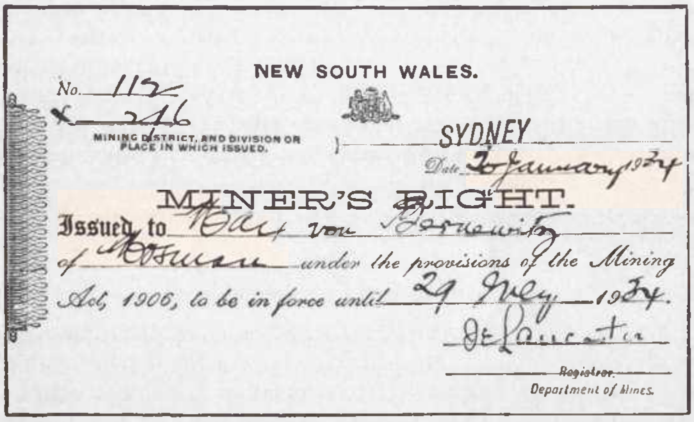
Mining Laws of Colombia

Foreigners in Colombia, South America, enjoy the same rights as are granted to Colombians by the laws of the nation to which the foreigner belongs, subject to stipulation in public treaties to the contrary. . . . Certain gold areas can not be "denounced"; neither can emeralds, petroleum, hydrocarbons, and salt. (Colombia is the world's greatest emerald producer.) . . . Prospecting itself gives no preferential right; this belongs to the first discoverer, who is obliged to give notice of discovery to the municipal chief of the district (or one of the districts) where the mine is situated and to make a formal denouncement of the mine within 90 days after the discovery is deemed to have been made. . . . The discoverer of a lode is entitled to an area not exceeding 240 by 1800 meters (792 by 5940 feet) or three *pertenencias* or claims each 240 by 600 meters (792 by 1980 feet). . . . For placers or alluvial claims, the area is either a square with a base of 3 kilometers (2220 acres) or a rectangle 2 by 5 kilometers

(2470 acres). . . . For sedimentary deposits, the area is a square with a base of 2 kilometers (990 acres). . . . Certain fees and taxes are payable for official inspections, denouncements, claims held, and certain minerals mined. . . . No labor may be imported to work a property. . . . Water-rights are permitted.

Mining Laws of Australia

As in Canada, where each Province has its mining law, so it is in Australia with each of the six States—New South Wales, Queensland, South Australia, Tasmania, Victoria, and Western Australia —also for the territories of Northern Australia and those of Papua and New Guinea. The laws of Western Australia and New Guinea are given here. The former gives an idea of most of the other State laws. A Miner's Right is required everywhere, and one for New South Wales is reproduced as Fig. 9.



NEW SOUTH WALES.

No. 112
£ 2/6

MINING DISTRICT, AND DIVISION OR PLACE IN WHICH ISSUED. } SYDNEY

Date 20 January 1934

MINER'S RIGHT.

Issued to Max von Bernewitz
of Mosman under the provisions of the Mining Act, 1906, to be in force until 29 May 1934.

Registrar.
Department of Mines.

FIG. 9.—Reproduction of Miner's Right of New South Wales, Australia.

Western Australia. In this State of nearly 1,000,000 square miles all minerals are primarily the property of the Crown, excepting those occurring in certain minor areas alienated with all mineral rights in the early days of the Colony, according to E. S. Simpson, Government Mineralogist.

A miner desiring to search for gold must provide himself with a Miner's Right. This costs 5 shillings or $1.25 and is renewable each year. A Miner's Right entitles the holder to apply for any area and authorizes him to appear in a Warden's Court (Registrar), one of which is held in every important mining center.

A Miner's Right entitles a man to take up and hold a miner's homestead lease, business, residential, tramway, market garden, machinery, quarrying, tailings (residues) or washing area, water-race (ditch and flume) or water-right, pipe-track, mineral claim, or dredging claim, at rental ranging from 6 pence (12 cents) to £4 ($19.40) an acre per year.

If promising ground is discovered, a prospecting area of 24 acres, if within a proclaimed goldfield, or 48 acres, if outside one, may be pegged (staked). On payment of 10 shillings ($2.50) registration fee a prospector has 12 months' protection, with the right to renewal for another 6 months. One man must be employed for every 12 acres held in the proclaimed goldfield, and one man for every 24 acres held outside. At the expiration of the 18 months, the holder must take up a lease of the whole or portion of his ground or abandon it.

A gold lease (claim) is 24 acres. The rental payable is 5 shillings ($1.25) an acre for the first year and £1 ($4.85) an acre for each succeeding year. A lease runs 21 years, but it may be renewed. The labor conditions are two men for the first 12 months and thereafter one man for every 6 acres, with a minimum of two men.

A coal prospecting area is up to 3000 acres with similar term and fees as in gold mining. Three men must be employed for every 1000 acres. A coal lease is 320 acres. The rental is 6 pence (12 cents) an acre per year. One man must be employed for every 60 acres. A royalty of 3 pence (6 cents) per ton of coal raised during the first 10 years, and 6 pence (12 cents) per ton thereafter, must also be paid.

For other minerals the prospecting area, term, fees, and conditions are as in gold mining. A lease is 48 acres at a rental of 5 shillings ($1.25) a year. Labor employed must be two men for the first 12 months and one man for every 6 acres thereafter. No less than two men can be employed.

Licenses to prospect for petroleum cost £5 ($24.25), and a bond deposited to ensure that work will be done.

If the labor conditions are not being fulfilled at any class of lease, any holder of a Miner's Right may apply for forfeiture. The case is heard in open court. An applicant for forfeiture, if successful, has pre-emptive or first right to the forfeited lease.

New Guinea. Mining in the Mandated Territory of New Guinea (northeastern part of the island) is controlled through the Commonwealth of Australia by provisions of "The Mining Ordinance 1928–1932" and the "Mining Regulations." The Territory is divided into a number of gold and/or mineral fields, which are under control of mining wardens or magistrates, according to H. Taylour and I. W. Morley of the Morobe goldfield.

A holder of a Miner's Right, which costs £1 ($4.85) a year, may take up (peg or stake) any number of claims, provided that they are worked by the prescribed number of men—one holder of a Miner's Right per claim, excepting dredging claims. If sufficient reason is advanced, a Warden may grant part or total exemption from the labor clause for periods up to 6 months. All claims excepting ordinary alluvial claims must be registered. Claims may be merged, mortgaged, sold, or tributed.

Claim areas are as follows:

Details of Claims in New Guinea

Class of Claim	Area
Ordinary alluvial	97.5 by 195 feet
River or creek	390 feet bank to bank not over 325 feet wide
Hydraulic	390 by 975 feet facing stream
Prospecting alluvial	Up to area of 10 ordinary alluvial claims, if a new discovery
Ordinary vein or lode	195 to 390 feet along strike
Extended	Up to area of 4 ordinary claims, if ground poor

No fees are payable on any of the foregoing tenements which are generally held by individual miners.

A dredging claim is limited to 500 acres and 6½ miles in length. Such claims must be surveyed, and an application fee of £5 ($24.25) paid. There is a rental of 6.25 shillings ($1.50) for each 2½ acres for the first 12 months, then double that thereafter. Machinery must be installed after 6 or 12 months, and one white man employed for every 125 acres. At least £3000 ($14,550) of machinery is required for each dredging claim. All machinery imported is subject to a duty of 10 per cent.

As to gold-mining leases, none shall be granted on a goldfield until 2 years after proclamation of the field; this protects the individual miner. A lease may be 50 acres. The application fee is £5 ($24.25) and an annual rental of £2.5 ($12) per 2½ acres. The Mining Warden may recommend part or total exemption from labor conditions, which are one white man for every 40 acres.

Leases for other minerals are granted on similar terms. Leases may be up to 250 acres with an annual rental of £1.25 ($6) per 2½ acres.

Areas may be acquired for machinery, stacking or treating residues, market gardens, businesses, and residences. Water-rights may be granted to holders of Miner's Rights for any purpose at a fee of £2 ($9.70) per 2 cusecs (1 cusec = 1000 cubic feet per second) for every water-right.

All gold won is subject to a royalty of 5 per cent of its realized value, exclusive of the silver content, which is high in New Guinea. All gold buyers within the Territory must be licensed and submit records.

Large areas may be taken up for prospecting for petroleum and coal, but licenses are required before doing this.

The employment of natives is regulated. They are generally engaged under the indenture system or recruited by the person who will employ them. A license has to be obtained to do this. New Guinea natives are tractable when under control and firmly and justly treated. They soon learn what is expected of them. Employers that illtreat them are liable to severe penalties. Natives are paid 4 to 10 shillings ($1 to $2.50) per month.

Mining Laws of British Africa

British Africa means those regions in Africa controlled by England. As a whole, they are relatively open to American mining operations; and by treaty, Americans have the same rights as British in the Mandate of Cameroon, Togoland, and East Africa. In the Gold Coast, Ashanti, Nyasaland, and Nigeria no aliens are granted the right to explore for or exploit mineral oils; in Rhodesia diamond mining (excepting alluvial) is a monopoly (not granted but acquired); and in Nigeria there is a discriminatory duty on the export of tin. In the remainder of British Africa, although exploring or mining is nowhere free, there is no apparent legislative or administrative discrimination against citizens of the United States. Americans, in common with South Africans and all other nationals, are practically prohibited from prospecting or digging for diamonds, because the Union Government is stabilizing the industry. The mining laws of the Union of South Africa have not been consolidated, and the laws passed by the Several Colonial (now Provincial) governments are still in force. Briefs of the laws follow:

Cape Province. No person, other than an owner, may prospect for **precious metals** unless he take out a license, but the only requirement of an applicant for a license to prospect on State or private land is that he be a person of legal age and of good character. The license is good for one year. The holder has the right to peg (stake) an exclusive prospecting area on all unoccupied State land and, with the owner's permission, to prospect on private land. . . . A prospector must report the discovery of any minerals to the Government. If he makes a discovery of precious minerals in workable quantities on either reef (vein or lode) or alluvial diggings, he is entitled to peg a larger number of claims. . . . Failure to work a claim leads to an increase in license fees and in 12 weeks to a proclamation of abandonment. . . . All holders of claims pay license fees or rent and royalties. . . . As to **base metals,** if these are found in workable quantities on State land, the prospector is entitled to a lease (claim) for one year with the right of further renewal. The rent is prescribed. There is no law dealing with base metals on private property whose title contains a reservation of minerals in favor of the State.

Gold Coast. The right to mine for minerals is mainly based on the grant or a concession from the native or natives having rights over the land or lands to which the concessions relate. The Government does not claim any prerogative right to minerals but controls prospecting and mining and helps operations by means of a system of licenses. . . . Prospecting may be started before any concession has been obtained, but a license must be procured. . . . A royalty on profits is levied by the Government.

Kenya. In this progressive Colony a prospecting license, good for a year, authorizes the search for minerals other than oil, the pegging of claims, and the acquisition of protection areas—one marked off by the prospector, where he has the exclusive right to prospect. A license-holder obtains the right to developmental work by pegging and registering a claim, any number of which may be held by the same person. . . . The dimensions are established. The minimum work to be done on a claim is also prescribed. . . . No mineral may be disposed of without a lease for which claim-holder has certain preferential rights.

Southern Rhodesia. The right of searching and mining for, and disposing of all minerals, including oil, is vested in the Southern Rhodesian government. . . . Rights can be acquired to all minerals except precious stones and building stone. . . . A prospector's license entitles him to peg off one block of 10 gold claims, one block of 30 base-metal claims, one alluvial claim (exclusive of gems), one coal location, and one petroleum or natural-gas location. . . . The holder of a registered block of claims may mine everything within his area and also the extralateral right of such portions of his discovered vein as descend outside the limits of the vertical block—as in the western United States, the law of the apex. . . . Work must be done to hold a claim, and royalties range from 2 to 7½ per cent.

Transvaal. State land is not open to prospecting until the Minister of Mines declares it to be. . . . There is no expressed discrimination in the law against citizens of the United States. . . . Prospecting is not free. . . . Unless the prospector is the owner of the land, a prospecting permit is required. . . . Discovery of mineral must be reported to the Mining Commissioner, who may give the prospector a notice to peg out a claim. . . . Except on leased land, no royalty is payable on gold, but it is on base metals.

Mining Laws of Mexico

The mining laws of the United States of Mexico became effective in October, 1930, but in recent years there have been proposals to amend the laws. With certain restrictions of lands, minerals, and rights a prospecting concession will cover 9 *pertenencias* within a square of 300 by 300 meters (990 by 990 feet). . . . The application for concessions has to be presented to the Mining Agency for the Municipality in which the respective claim is located. A copy of the application must be posted on the bulletin board of the Agency and published in the *Bulletin of Mining Concessions.* If the applicant is a foreigner, he must deliver a certificate from the Department of Foreign Relations. . . . Of the three classes of concessions covered by the Mining Law of interest to the prospector are the "prospecting concessions, which authorize and cover the works for the purpose of discovering mineral deposits that may be susceptible of exploitation," to quote the section of the Law. . . . The unit of concession is the "mining *pertenencia*," which is a solid of indefinite depth, limited on the surface of the land by the four vertical planes or lines corresponding to a horizontal square of 100 meters (330 feet) on each side. A mining claim is the single *pertenencia* or the united contiguous *pertenencias*, even though adjoining at only one point, covered by a single concession title.

Mining Laws Recently Enacted

Uganda, in Africa, and Manchukuo, in Asia, have in force mining laws which were enacted during 1935. The new Philippines law (still of interest for the record) follows:

PHILIPPINES

The Mining Act of the Philippines was passed late in 1936, and abstracts of some of the provisions are as follows: The Act is administered by the new Bureau of Mines, Manila, which was created in 1936.

Prospectors may prospect for themselves or for other persons, associations, corporations, or other entities qualified to locate claims and to acquire leases of mineral lands under the provisions of the Act. Patents are not granted, but those in force are respected. Temporary permits to mine minerals before a lease is granted, subject to royalties, are allowed.

Prospecting may be carried on within public lands and private land, in accordance with the provisions of the Act:

Before entering *private lands*, the prospector shall first apply in writing for written permission of the private owner, claimant or holder thereof; and in case of refusal by such owner or other to grant such permission or in case of disagreement as to compensation for prospecting, the amount of compensation shall be fixed with the Director of the Bureau of Mines or, failing this, by the Court in the province in which are the lands in dispute.

No prospecting shall be allowed (1) in a mineral reserve that has been proclaimed closed to mining locations; (2) in lands covered by patented mining claims; (3) in lands in which minerals have been discovered prior to the effective date of the Act and are claimed by the discoverer or his successors in interest; (4) in lands that have been located for mining leases by other prospectors under the provisions of the Act; (5) near or under certain public and private works.

The *right to locate* a mining claim shall in all cases be based upon the discovery of mineral therein.

The *finding of mineral or minerals* in place, whether assaying high or low, loose or fragmentary, or in other forms shall constitute a valid discovery for the location of lode or placer claims.

In case of *conflicting locations*, priority of discovery, followed by continuous occupation and prospecting of the land, shall determine the right to lease the claims, subject to any question as to the validity of the location and record of the claim and subject to the holder's having complied with the law.

Immediately upon the *discovery of mineral* or as soon as possible thereafter, but not more than 30 days after the date of the said discovery, the discoverer or locator may locate a mining claim in accordance with the provisions of the Act, covering the land where the mineral has been discovered. If no such location is made within this period, the right to locate a mining claim covering such land shall be deemed to have been waived.

Within 60 days after completion of the acts of location of a mining claim, the locator shall *record* it with the mining recorder of the province or district within which the claim is situated. A claim that shall not have been recorded within the prescribed period shall be deemed to have been abandoned.

The *maximum areas* that may be acquired as a mining claim are as follows:

Maximum Areas for Mining Claims
(1 hectare = 2½ acres)

Mineral group	Conditions and area	
	Individuals	Associations
1. Metals or metalliferous ores.	Lodes, 9 hectares Placers, 8 hectares	Lodes 9 hectares Placers, 64 hectares
2. Precious stones	Lodes or placers, 4 hectares	Lodes or placers 4 hectares
3. Fuels	Licenses, concessions, or leases for 25 years, renewable for similar period	
4. Salines and mineral waters.	4 hectares for any qualified locator or applicant	
5. Building stones, clay, fertilizers, or other nonmetals.	Lodes, 8 hectares	Lodes, 64 hectares
	Placers, 9 hectares for any class of locator	

Locators are entitled to all minerals within vertical boundary lines downward and not outside thereof.

Lode claims shall be as nearly of rectangular form as possible, measuring not more than 300 meters (984 feet) in length by 300 meters in breadth.

Sections 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, and 50 of the Act detail how claims are staked and lined, and a number of forms are provided for the approximate measurements, sketches, and notice of location.

There shall be *paid* to the provincial treasurer or to the mining recorder a fee of 3 Philippine pesos (₱3 = $1.50) for each original or amended declaration of location of a mining claim, for each affidavit accompanying such declaration, and for each power of attorney, document, or instrument in writing regarding or affecting the mining claims.

Conflicts and disputes arising out of mining locations may be submitted to the Director of the Bureau of Mines for decision. Such decision may be appealed to the Secretary of Agriculture and Commerce within 90 days from the date of its entry or eventually to the courts.

The Director of the Bureau of Mines may designate competent mineral or deputy mineral land surveys to survey mining claims for any necessary purpose.

Any person authorized to locate a mining claim, having claimed and located a piece of land for mining purposes, who has complied with the terms of the Act, may file with the Director of Mines an *application for a mining lease* thereon. In the case of an application to lease a mining claim located on private lands, the same shall be accompanied by a written authority of the owner of the land or a decision of the court if the owner refuses.

Application for a lease on a mining claim shall be filed within 2 years from date of recording the claim. (In June, 1938, this was extended to 4 years.)

All applications for mining lease shall be addressed to the Director of Mines, shall be sworn to, and shall give all details of the applicant and how the property is to be worked—partnership or other. The Director of Mines will publish the application once a week for three consecutive weeks.

The *maximum areas* that may be leased to a person or any association are as shown on page 51.

Rental on all mineral lands of the first, second, fourth, and fifth groups shall be ₱1 (50 cents U.S.) per hectare or fraction thereof.

Royalty on these four groups shall be 1½ per cent of the actual market value of the gross output thereof. Gold lode mines have an upward scale of royalty depending on their production, com-

MAXIMUM AREAS FOR MINING LEASES

Mineral group	Conditions and area	
	Individuals	Associations
1. Metals or metalliferous ores.	Lodes, 450 hectares, not exceeding 250 claims in the Philippines	
	Placers, 400 hectares	Placers, 3200 hectares
2. Precious stones.....	40 hectares	320 hectares
4. Salines and mineral waters.............	24 hectares	192 hectares
5. Buildingstones, clay, fertilizers, and other non-metals.	Lodes, 450 hectares, not exceeding 250 claims in the Philippines	
	Placers, 400 hectares	Placers, 3200 hectares

mencing at 1½ per cent and rising to 5½ per cent; but 15 and 25 per cent of the royalty may be deducted if the ore averages less than ₱10 ($5) and ₱7 ($3.50) per ton. Gold placers may deduct 35 per cent of the royalty payable.

Taxes cover all buildings and other improvements built in the land leased but not apparatus, machines, and other necessary mining and milling equipment.

Any person or association holding a lease shall perform each year while the lease is in force not less than ₱200 ($100) worth of *labor or of improvements* on each mining claim of the first and fifth group and ₱100 ($50) on each claim of the second and fourth group. But work may be concentrated on or in any one of the said groups. That this work is done must be sworn to.

A *bona fide* holder of a mining claim or group of contiguous claims shall have the *free right to cut trees or timber* within such claim or claims for use in the development or operation thereof. This cutting must be done in accordance with the regulations of the Bureau of Forestry.

There shall be allowed a *free water-right or rights*, provided other rights are not impaired. But the Government reserves the right to regulate water-rights.

Rights of way for any purpose are allowed, but arrangements must be made with the owners of other property to cross it.

Salting mineral deposits to mislead other persons and permitting *sludge or tailings* to become a nuisance are punishable by imprisonment or fines.

PART II

CHAPTER VI

MINERALOGY

Definitions and Characteristics

A mineral is a natural substance with a definite chemical composition and usually a definite crystal structure. Most minerals are solids and are of inorganic origin, which means that they are not products of life. A rock may consist entirely of one mineral, but most rocks consist of several. The purpose of the study of mineralogy is to recognize the various minerals either alone or in rocks. The principal object of the prospector's study is to develop the ability to recognize the common and industrially valuable minerals at sight or by making a few simple tests.

The principal characteristics of minerals are:

1. Hardness.
2. Color.
3. Streak, or the color of its fine powder when scratched with a knife. The streak is usually obtained by rubbing the mineral on a piece of unglazed porcelain. This streak often varies widely from the color of the mineral itself, such as chromite and coal, and when it is not white it is useful in making a determination.
4. Tenacity, or brittleness, malleability, elasticity.
5. Fracture, or the nature of surface obtained by breaking, whether rough and irregular, smooth, plain.
6. Specific gravity, or its weight as compared with that of an equal volume of water.
7. Luster, or the character of reflected light.
8. Crystal form.
9. Cleavage.

Minor characteristics, which are sometimes helpful in determination, are taste, odor, and feel.

Hardness of Minerals. An easy means of identifying minerals is to test their hardness. Minerals that look alike may vary considerably in hardness. To determine the comparative hardness of two minerals try to scratch no. 1 with no. 2; then try to scratch no. 2 with no. 1. If each mineral shows scratches, they are of the same hardness; if no. 1 scratches no. 2 but no. 2 does not scratch no. 1, then no. 1 is harder. One must distinguish between a scratch and a cut and the dust of abrasion. Some sandstones may be cut with a knife, hardness 5½, yet quartz, from which this rock is formed, is harder than the knife. The knife does not scratch any of the individual grains but just scrapes them off. A knife will cut the metals aluminum, copper, gold, lead, magnesium, silver, and zinc.

To determine how hard a mineral is, its hardness may be compared with that of some other mineral. A scale of hardness has been devised and consists of 10 minerals, arranged in the order of their hardness from 1 to 10, thus:

1. Talc (softest, if pure).
2. Gypsum.
3. Calcite.
4. Fluorite.
5. Apatite.
6. Feldspar.
7. Quartz.
8. Topaz.
9. Corundum.
10. Diamond (hardest).

All of them are well known, and each except the last is a common mineral.

In making determinations, a set of these minerals may not always be at hand with which to compare a specimen, so the table following shows other minerals and objects that can be used. A good file, hardness 6½, may be used to test the hardness of some rocks.

In a hardness test, the mineral or metal that does not scratch slides over the standard test piece or other mineral; but when it scratches, it grips.

PART II

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10. Diamond (hardest).

All of them are well known, and each except the last is a common mineral.

In making determinations, a set of these minerals may not always be at hand with which to compare a specimen, so the table following shows other minerals and objects that can be used. A good file, hardness 6½, may be used to test the hardness of some rocks.

In a hardness test, the mineral or metal that does not scratch slides over the standard test piece or other mineral; but when it scratches, it grips.

In estimating specific gravity one has to be careful, as impure mixtures are usually lighter than pure minerals and a porous rock weighs less than the same rock in compact form. One must also be careful that the color does not mislead, for a dark mineral is expected to be heavier than a light-colored mineral, because heavy light-colored minerals are not common, whereas dark minerals, except coal, are usually heavy.

Streak. The color shown when the freshly broken surface of a rock is scratched with a knife or when the mineral is rubbed on unglazed porcelain is useful in identification. As each mineral is described later, its characteristic streak is given, such as brown for chromite and coal, red for cinnabar, and pale green for malachite. A streak plate or white pocket hone can be bought for this purpose.

[illegible] 8.55

Common minerals of little value when found in small quantities are sometimes mistaken for valuable ones; this results in waste of time and money; hence, the prospector should be sure of his ground before doing much development. He should always make a few of the simple tests described to confirm his identification by sight, and if still in doubt he should have the material examined by more experienced persons. Under the headings of Gold, Copper, Tungsten, and others are given instances of other minerals mistaken for them.

Crystallography

Since the prospector will come across many crystals in his examinations, a knowledge of this condition of minerals is more or less useful. The subject is not easy of explanation in simple terms.

Crystallography deals with the natural forms, bounded by plane surfaces, that minerals assume when changing from a liquid or gaseous state to that of a solid and with the physical properties relating to such forms.

What is known as "rock crystal" is transparent quartz. It may be found clear and flawless with faces almost as perfect as a cut gem. It may also be found with inclusions of various colors and form, making the crystal more or less attractive and valuable.

These impurities, as they may be termed, were enclosed while the quartz was crystallizing from solution.

There are six systems of crystallization: the isometric, tetragonal, hexagonal, orthorhombic, monoclinic, and triclinic; but there is no need for defining them here.

Fig. 10*a*.—Beryl (emerald) from North Carolina.

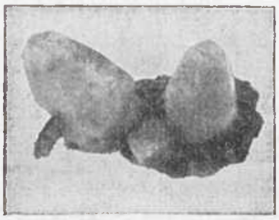


Fig. 10*b*—Calcite from Mexico.

Fig. 10*c*.—Cassiterite from Alaska.

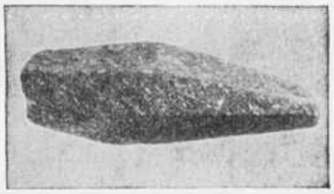


Fig. 10*d* —Corundum from Transvaal.

Fig. 10*e* —Galena from Missouri.

A rock is crystalline when it pertains to the nature of a crystal having regular molecular structure. A crystalline rock is one composed of closely fitting crystals that have formed in a rock substance, like granite, as contrasted with a rock made up of volcanic glass. Minerals without crystal form are termed "amorphous"—amorphous graphite, for example.

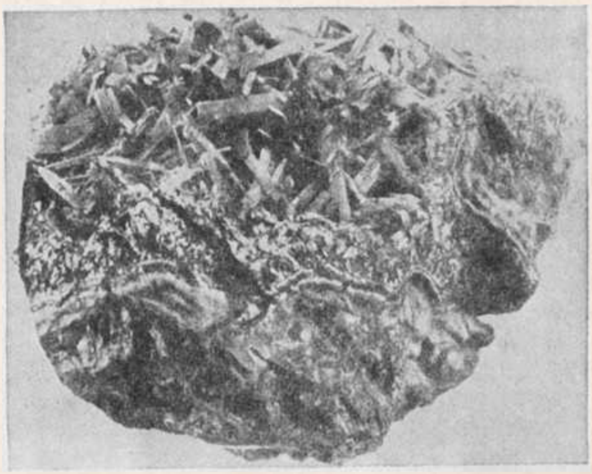


FIG. 10*f*.—Crystals of pyrolusite projecting into a vug in high-grade manganiferous iron ore in south Australia. Twice natural size. (*From A. B. Edwards, Proc. A.I.M.M.*, 1936.)

FIG. 10*g*.—Pyrite from Elba Italy.

FIG. 10*h*.—Quartz from Arkansas.

Discoursing on crystallography in London early in 1937, at a meeting of the Royal Institution, Sir William Bragg said the following in part regarding the varieties of Nature's structures:

There is a further simplicity in the regularity of arrangement of the atoms and molecules in all substances, or at least in an effort to achieve regularity. It is naturally most in evidence in the solid body. When the solid forms from the melt, or assembles out of solution, or grows from deposited vapour, the atoms and molecules of which it [the solid] is made settle themselves in orderly array. [This means changes taking place in the earth.] The process is often sensitive to disturbance of the surrounding conditions, but if it is allowed to go on as it begins, it ends in the production of a visible crystal.

FIG. 10*i*—Stibnite from Nevada.

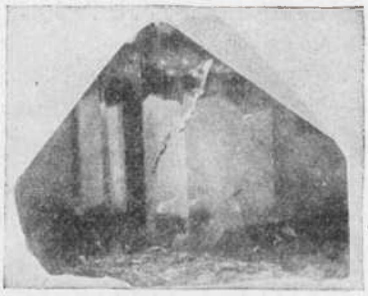


FIG. 10*j*.—Topaz from Burma.

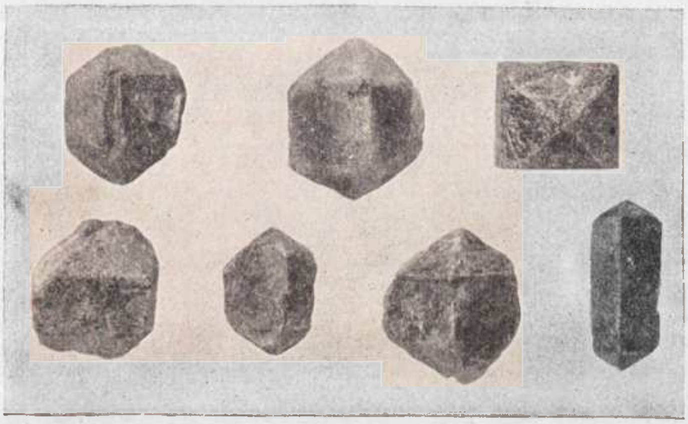


FIG. 10*k*.—Zircon crystals from North Carolina pegmatite. (*Courtesy of Foote Mineral Company, Philadelphia.*)

This explains why perfect crystals are not common.

Figures 10*a* to 10*k*, inclusive, show a few of the common mineral crystals. It has been said that such knowledge is not helpful to prospectors and miners, but others have a different opinion. Except two of these, all the pictures were supplied by the Department of Mineralogy, National Museum, Washington, D. C.

CHAPTER VII

ELEMENTARY GEOLOGY

Classification of Rocks

In geology the term "rock" is used to signify any material that constitutes a portion of the earth, whether hard or soft. Hardness is a variable condition, as is toughness.

All rocks are divided into two general classes—stratified and unstratified. The former are sedimentary rocks, which were originally laid down in the form of sediment under water, while the unstratified have been more or less completely fused or molten and are of igneous origin. Stratified rocks are characterized by the fact that they consist of sheet-like masses or layers, called strata. Shale, sandstone, and limestone are familiar examples of sedimentary rocks. A large portion of the surface of the earth is covered with rocks of this character, which proves that practically every portion has at some time been covered with water. They were originally formed in a nearly horizontal position, and when strata are found inclined or folded, it means that they have been subjected to earth movements of some kind, since their original formation. Sedimentaries have a specific gravity of 2.52 to 2.80 and weigh 133 to 171 pounds per cubic foot.

Unstratified or igneous rocks have consolidated from a molten or semi-molten condition and have originally been a portion of the great mass that goes to make up the interior of the earth. It has been estimated that not more than one-tenth of the land surface of the earth is composed of rocks of this class. These rocks are classified in a general way by their mode of occurrence and may be divided into two primary groups—namely, the deep-seated rocks, such as granite, and eruptive or volcanic rocks, such as rhyolite. Those of the first group occur in great masses and sometimes make up entire mountain ranges, while those of the second are of lesser extent and ordinarily occur in one of the following forms: (1) as inclined sheets, filling fissures which have occurred in the surrounding rock; these sheets are known as dikes; (2) as horizontal sheets, which have been forced between the strata of sedimentary rocks; and (3) outpoured on the land surface, as from an active volcano.

An intrusion is a mass of molten igneous rock that has forced its way into or between other rocks. Intrusive rocks are very favorable for promoting the formation of ores, especially when in contact with other igneous rocks and stratified rocks. Igneous dikes are a frequent yet not at all an invariable accompaniment of ore deposits. Basic dikes particularly, such as diabase, basalt, and lamprophyre (rock of porphyritic texture), frequently occur in connection with deposits.

The deep-seated rocks have cooled and solidified in great masses at great depths; and where they are found on the surface, they have been exposed by erosion. The andesites, basalts, dacites, and granites have a specific gravity of 2.49 to 2.96 and weigh 155 to 187 pounds per cubic foot.

Another class of rocks is the result of alteration of one or both of the two great classes already mentioned—namely, the metamorphic rocks. They are often formed as a result of pressure, heat, and other forces, resulting from the intrusion of a volcanic rock through an area of sedimentary formation. The most important of the metamorphic rocks are gneiss, schist, slate, serpentine, quartzite, and marble. These have a specific gravity of 2.55 to 2.88 and weigh 156 to 179 pounds per cubic foot.

Description of Ore Deposits

All rocks, especially those found in mountain regions, are seamed and broken in every direction. All such seams and scars, of whatever kind and by whatever process formed, are commonly called "veins." True veins, from the miner's viewpoint, however, are accumulations, mostly in fissures, of certain mineral substances, usually in a more concentrated form than exist in the neighboring rocks. The accumulation of this material has in all cases taken place after the formation of the fissure and by extremely slow process. As the vein is a filling of a previously existing fissure, the distinction between the vein and the wall-rock is often well marked. With few exceptions metallic ores occur in veins, although some metals, particularly iron, occur in the form of beds laid down by a process similar to the formation of sedimentary rocks. The contents of a metalliferous vein are the ore itself and the gangue or vein-stuff. The most common gangue mineral is quartz. A large proportion of the vein is ordinarily vein-stuff; the ore exists in comparatively small quantities, sometimes in the form of a thin central sheet, sometimes in bunches or pockets or grains, irregularly scattered through the vein-stuff, and often extends for some distance into the wall-rock.

The chemical formations in which metals exist are various. Sometimes they occur as the native metal but more commonly in the form of some chemical compound or mineral. This subject is taken up in detail under the head of Mineralogy of Ores.

Mineral veins are seldom found outcropping on the surface in the condition described. They undergo various changes through erosion and the influence of other agencies, which render their surface appearance quite different from that of the same vein at depth. These changes depend partly upon the metallic content of the ore and partly upon the nature of the gangue material. A knowledge of these conditions is of the utmost importance to the prospector, but familiarity with various field conditions is also essential in this regard.

Faults

The prospector and miner frequently find that a vein has been moved from its regular course by an earth movement, termed faulting. A fault is a break or dislocation in the continuous strata or masses of rock attended by a movement on one side or the other of the break or crack, so that what were once parts of the rock or vein are now separated. This action mostly takes place in the stratified rocks, whose beds are forced out of their original horizontal position into various folds. The amount or distance of the movement may be a few inches or many feet—one instance of a copper vein in California was 1100 feet. There are a number of different types of faults, some of them complex, but Fig. 11*a*, *b*, and *c* illustrates the common fault.

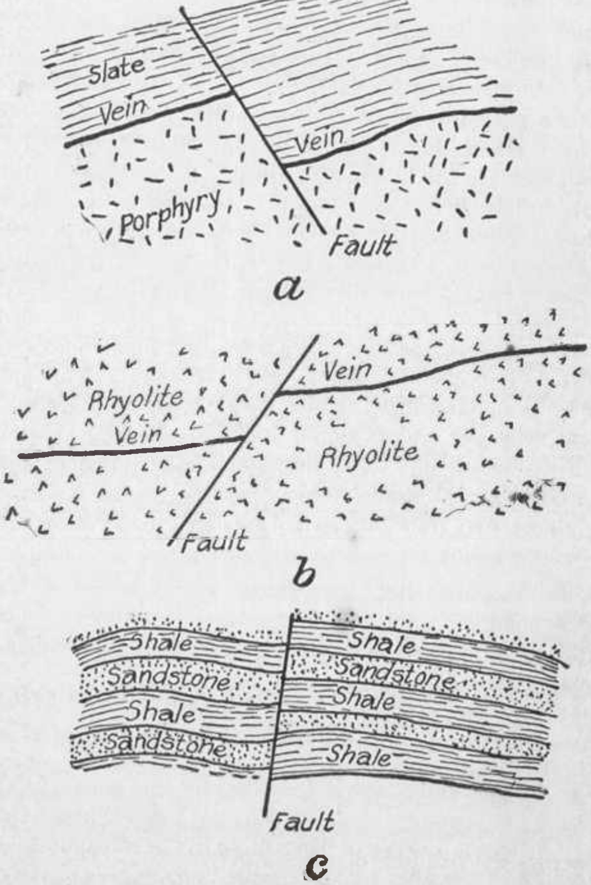


Fig. 11.—Types of common faults.

All of the stratified rocks were originally laid down in a flat or horizontal position but have since become tilted in two directions, the result of earth disturbances. The inclination of these rocks from the horizontal is their dip or underlay—in other words, the slope downward from the surface. The other direction is the strike or pitch of the rock. These statements apply also to veins, and the subject is best illustrated by Fig. 12.

Ores are often formed on or near faults because these afforded the easiest circulating channels for mineralized waters. Veins are frequently faulted, and the throw is anything from a few inches to hundreds of feet. If a vein is faulted, the fault should be followed or, if not clear, the amount of movement may be determined to some extent by a study of the surfaces of the rocks up to the point of faulting.

FIG. 12.—Illustrating the terms dip and strike. *(According to Spurr.)*

Certain minerals are usually associated with rocks of a certain character. Mineral-bearing lodes may be expected to be more persistent in some formations than in others. This point may be of assistance after a prospect has been partly developed and an attempt is being made to bring it to the attention of capital. Note should also be taken showing whether or not there are any traces of recent volcanic action or whether the vein runs parallel to or across the bedding of the country rock. These data have a more or less important bearing on the question of whether or not one may expect to find a vein extensively faulted and broken.

CHAPTER VIII

GEOLOGY IN PROSPECTING

Some knowledge of geology, and still more of mineralogy, is valuable to the prospector. Without it a man is handicapped nowadays, but observations throughout the world show that many prospectors and miners do recognize the value of scientific study and deduction. Geology is of practical value, notwithstanding argument to the contrary. There are many instances of valuable discoveries resulting from geologic deductions. Most of the large metal and oil companies employ geologists—in fact, find them almost indispensable

Many mountains and hills are literally peppered with barren tunnels driven to cut the downward extension of outcropping veins, whereas a careful study of the outcrops would have shown that they would not persist at depth, an instance of the practical value of geology.

It is frequently said that Government geological departments make their reports too late—that is, they are delayed too long to be of practical use. According to the late F. L. Ransome, of the United States Geological Survey, in the study of geologic conditions both new and developed districts should be covered, but the first can not be if the second is neglected. The opened ground gives far better opportunities for the study of rocks at depth and on the surface than one in which work has hardly begun. The characteristics of formations are thus better visible, such as changes from original ore, through a zone of enrichment, to the oxidized material on the surface, or conversely. The probable changes at approximate depths may be predicted. Faults can not be studied from surface exposures alone. Rarely can the rock structure in any district be said to be completely understood. Geologists with experience in deep mines are of aid in new districts. Even in developed areas active prospecting is being done more or less. A prompt outline of the general geology of a new district will prevent a waste of effort in unwise prospecting.

Ore Deposits Developed by Scientific Prospecting

Specific instances of scientific prospecting that revealed great orebodies are those of the United Eastern gold mine and Miami and United Verde Extension copper mines in Arizona, the copper mine at Chuquicamata in Chile, the zinc-lead deposits of Oklahoma, the uncovering of many silver veins at Cobalt, Ontario, and several rich lodes in Western Australia. In the last-named country a method known as "loaming" was responsible for uncovering a lode at the Hampton Celebration, which resulted in the discovery of others and started a boom. The search for copper ore at Jerome, Arizona, and for silver ore at Divide, Nevada, was done only by systematic prospecting, following geologic deduction. No other method could apply in such formations. The same may be said regarding iron and copper in the Lake Superior region and oil in all parts of the world.

Another specific instance of scientific search, in which no ordinary prospector had a hand, was the finding of ore on the Suan Concession in Korea. A mass of granite extrudes through sedimentary rocks, chiefly schist and limestone. The periphery (extremes) of the contact is 25 miles long by 6 miles wide. It was measured and plotted. Ore occurrences were associated with dikes of aplite (a quartzose type of granite) and not with the later dikes of basic rock, such as basalt and dolerite. The granitic intrusion had faulted the limestone; this created channels for the circulation of mineral-bearing solutions, which were stimulated into chemical activity by the heat emanating from the aplite dikes. The schist contains no ore, and limestone only where the contact is crossed by faults. The ore deposits near the contact carry copper and gold; those farther away, lead and zinc. Several geologists were employed to guide the prospecting operations, which consisted in the first instance of systematic panning, both of the lodes in the native workings and of the detritus in the creeks. If the signs were favorable—that is, if gold, ore minerals, or contact minerals were detected—then holes were sunk 300 feet apart to bedrock, to be followed by intermediate holes, accompanied always by detailed recording and mapping. Then special areas were selected for closer examination, prospect holes and trenches being dug and everything panned carefully. The average area covered by one white man in an intensive campaign of panning was about 4 square miles in 6 months. His assistants were natives. Prospecting was devoted to the following: (1) leached, oxidized, rusty-looking, and copper-stained outcrops; (2) placers at or below the contact; (3) old workings; (4) contact minerals, such as tourmaline, diopside (a calcium-magnesium mineral), and garnet; (5) faulted or sheared zones in the rock adjacent to the contact; and (6) differentiation in the magma (source of igneous rocks) as shown by the presence at the contact of small bodies of igneous rock related to the granite.

Other examples of good results following intelligent prospecting are the Rouyn district of Quebec (copper and gold), Great Bear Lake district of northwestern Canada near the Arctic Circle (silver and radium in pitchblende), Transvaal (platinum), and New Guinea (gold and silver).

In 1934 the Rogers-Gentry gold mine at the edge of Antelope Valley in Los Angeles County, California, was found by an experienced prospector on an old patented homestead several miles from the nearest producing mine. The initial discovery at this mine was an iron-stained, decomposed, siliceous limestone outcrop, with no vein structure evident at the surface, near a small, barren quartz outcrop and a water seep. Another discovery, the Silver Queen gold mine, in the same general region and near Mojave, California, was found by an experienced miner on an open fraction 400 by 1400 feet in size between two old properties which were thought to have been worked out years ago. The discovery was made as the result of finding a single piece of float unlike any ore in the region. The vein did not outcrop; the discovery point was under 6 feet of cover.

During 1939 hematite ore was found at Steep Rock Lake, Atikokon, Ontario, 35 miles west of Lake Superior and 5 miles from rail. In 1897 a Dominion surveyor, C. B. Dawson, said that iron might be present, and in 1930 J. G. Cross, an experienced and scientific prospector, visited the area after reading Dawson's report. He found massive boulders of high-grade hematite on the south shore but none at the north, so decided that ore must be below lake bottom. Drilling and development up to late 1941 has blocked out many millions of tons of good-grade iron ore on the property of Steep Rock Iron Mines, Ltd., that comprises 7,500 acres. The ore, principally hematite, has a low silica content.

CHAPTER IX

OCCURRENCE OF ORES

It is important to know how and in what kind of rocks the different metals occur. For instance, tin, tungsten, and molybdenum are almost always found either in or near coarsely crystalline igneous rocks; on the other hand, platinum, chromium, and nickel are usually in or near close-grained igneous rocks. It should be clearly understood what is meant by a metal's being found in or near a certain kind of rock. Generally speaking, ores were not formed at the time that the surrounding rock was but were introduced later by molten rock which hardened or crystallized to form the different grades of igneous rocks, such as granite, pegmatite, gabbro, and other similar rocks. The ores themselves may be carried from the molten rock by escaping steam and fluids through cracks and crevices into the surrounding rock. Ore may thus be carried long distances from the molten rock, but ordinarily the distance is not much more than a half-mile or a mile. Tin, tungsten, and molybdenum and some other metals are usually brought in by granite or pegmatite, and so when those metals are found the rocks usually are also; but it does not follow that whenever granite and pegmatite are found the metals will be there too. Many ore deposits are related to granular rocks—that is, in rocks in or near intruding granite. The areas of earlier rocks containing deposits were probably caught up by granitic intrusions and formed islands and roof pendants in the granite, according to W. H. Emmons.

When it is remembered that certain metals are brought in by certain rocks it is easy to understand why some metals and minerals are found together. Such minerals as tourmaline and beryl also exist in granites, and so they are also often found with tin and tungsten.

In some districts are distinct areas containing lodes which yield different metals. For instance, in the vicinity of Randsburg, Kern County, California, are three distinct areas yielding gold, silver, and tungsten (scheelite). No two are found in the same area, and their respective total production is almost the same. The gold is in schist or quartz-monzonite in veins along faults or fractures; the silver is in veins of bluish-gray silica cutting schist along faults and fractures; the tungsten is in quartz veins in quartz-monzonite.

A knowledge of mineral associations assists greatly in determining minerals. For example, if the rock is identified as serpentine and if a heavy, black, metallic mineral is found with it, the prospector will think of chromite and magnetite and will be almost sure that the mineral is not wolframite or tantalite. The two former are commonly found in serpentine, but the others are not. Serpentine is a silicate of magnesia. It is a soft, greasy, fibrous rock of olive-green to black color and when once seen is readily remembered.

In general, it may be said that in a district which does contain metals the prospector is rather likely to find ores in limestone beds adjacent to the igneous rock that brought in the ores, because the chemical action of limestone is such that it may be said to extract the metals from the ore-carrying solutions which escaped from the molten rock from which the ores originally came.

The rock-forming minerals include carbonates, chlorides, oxides, phosphates, sulphates, sulphides, and silicates. The most important are the silicates, oxides, and carbonates. Under the first two come the igneous rocks, consisting of quartz, feldspars, pyroxenes, such as calcium and magnesium; amphiboles, such as hornblende; micas and other minerals, such as magnetite and zircon. Under the carbonates come the sedimentary rocks, such as fragments of quartz and feldspars; calcite, dolomite, kaolinite, and limonite; also the metamorphic rocks, such as quartz, feldspars, muscovite, hornblende, garnet, calcite, serpentine, and talc. The silica content of igneous rocks varies from 40 to 80 per cent.

Brief definitions of the terms oxide, carbonate, and sulphide may be given at this point. An **oxide** is a compound of oxygen with another element or elements. So the oxide of an ore deposit is that portion in which the minerals have been subjected to the action of surface waters containing oxygen and carbon dioxide (carbonic acid gas). For instance, cuprite is an oxide of copper. A **carbonate** is a salt formed by the union of carbon dioxide with a base. Malachite is a copper carbonate and exists at or near the surface. A **sulphide** is a compound of sulphur with some metal, such as bornite, a sulphide of copper. When sulphides are acted upon by oxygen and surface waters they become oxides.

Formation of Ores

Ores are formed in several ways, the most important of which are as follows:

1. Deep in the earth are masses of molten rock, and because the pressure is great and these masses are so hot, they gradually "eat" their way toward the surface of the earth. Some of them reach the surface, and volcanoes are formed, but more of them cool and harden before they reach the outside. Because of this pressure and heat the solid rocks around these molten masses crack, and the cracks are filled with some of the molten rock, which results in dikes and sills. When the molten rock hardens we have what is termed an igneous rock. There are many kinds of such rocks—granite, gabbro, pegmatite, porphyry, basalt, and rhyolite, for example. Igneous ore deposits are found in two different forms. In some molten rocks one mineral separates from the others and forms a band of this mineral in the rock. An example is the nickel ore at Sudbury, Ontario. Here the igenous rock is a gabbro (a lime-soda feldspar); the pyrrhotite, chalcopyrite, and pentlandite collected in bands or masses near the bottom or sides of the gabbro mass, and so formed the ores.

The other kind of ore deposit in an igneous rock is a pegmatite. In any molten mass of rock there is a great deal of water. When a molten rock cools, the outer part first congeals or becomes solid, while the inside is still molten. All the water that was in the part first cooled passes over into the part still liquid. Certain metals like tin, tungsten, and molybdenum apparently stay with the water, so that the first part to harden would not have any of these minerals, but the last part would. The last part to cool is very different from the remainder of the rock because of the presence of the water and the metal, and so it is given a special name, pegmatite. Such rocks are often found in cracks or veins into which pressure has forced them.

Pegmatites may exist as irregular masses, as locally regular tabular dikes, or lens-shaped. They may cut the older rocks around margins of granitic intrusions, or they may cut the parent granitic body, or part of the granite mass may be locally pegmatitic. Pegmatites occur irregularly at the surface and to a 2000-foot depth in the sillimanite gneiss at Broken Hill, New South Wales, Australia. They vary greatly in texture and grain size. Molten rock is their origin. In Canada, according to H. V. Ellsworth of the Dominion Geological Survey, the rare-element minerals have most often been most abundant in the segregated type of pegmatite—potash, feldspar, microline, and quartz. The minerals are uranium, thorium, tantalum, columbium, zirconium, hafnium, beryllium, lithium, rubidium, and caesium. The pegmatites of South Dakota, according to Frank Hess and Barnabas Bryan, Jr., contain amblygonite, the fluophosphate of lithium and aluminium, beryl, columbite, mica, tin, and gold.

2. The molten rock-masses usually contain large quantities of water and steam. These may soak out into the solid rock next to the cooling melted rock and will then change the nature of the solid rock. Sometimes the water and steam are barren of valuable ores while at other times the hot waters, soaking in, bring ores of gold, silver, copper, tungsten, or other metals. Some of the ores at Philipsburg, Montana, and at Bishop, California, are of this type. It should be noticed that this kind of ore deposit is more often found in a limestone than in any other kind of rock, because the waters soaking in have a much greater chemical action on limestone than on other kinds of rock. These deposits contain heavy gangue minerals, such as amphibole, corundum, epidote, olivine, garnet, hematite, ilmenite, magnetite, and pyrite; and the rock is usually dense and tough. The orebodies are usually

irregular in shape and are only a few hundred feet from the igneous rock.

3. As already stated, when a mass of molten rock is cooling, large quantities of liquids and gases are given off. Some of these soak into the rock as explained, but more follow cracks and crevices, sometimes for 2 or 3 miles, and deposit mineral matter along these cracks; thus is formed the ordinary vein. If the crack is a simple opening it is called a fissure vein, but sometimes there are thousands of small cracks, and the vein is very uneven and irregular. The waters forming these veins are hot and are under pressure, so that sometimes they soak into the walls of the cracks and the ore may be wider than the actual vein crack. Veins formed as here described often have quartz, calcite, varite, fluorite, or pyrite in the gangue. There are some deposits that belong in this class but do not correspond to the average man's idea of veins. The porphyry or disseminated copper ores may be mentioned; these ores were formed as follows: A molten mass of rock matter forced its way up near the surface, when it started cooling. The top cooled first and formed a granitic rock, sometimes called porphyry, but deeper the rock was still hot. From the deeper parts steam and water were trying to escape. Some movement of the earth, or the pressure from beneath, shattered the cooled upper part and filled it with countless tiny cracks, into which the water from the hot parts below came and left in the upper, cold, cracked part small amounts of ore minerals. These orebodies sometimes extend a mile or two in each direction and are usually low grade but do not exist to a great depth—that is, below 1000 feet.

4. Veins are also formed by cold water, which soaks in from the surface. This water dissolves minerals in one place, and when it comes to a different kind of rock or to large cracks, the minerals are deposited. The lead ores of Wisconsin were formed in this way. Some of the changes discussed under Surface Changes later on might be mentioned here as veins formed by ordinary ground water.

5. Placers are formed from other deposits. As water for centuries washes over a gold vein on a mountainside it is worn away, and the gold is carried down by some stream. As gold is heavier than ordinary sand it will be dropped in any little hollow

in the stream bed, together with more or less sand and gravel. Thus a placer is formed. Placers may be rich or poor, large or small. Any heavy mineral that does not weather or powder easily may be found in placers. The valuable minerals so found are chromite, cassiterite (tin), monazite, platinum, gold, and some gems. The gangue minerals in placers are usually quartz, garnet, hematite, magnetite, rutile, zircon, apatite.

6. Some ores are formed by deposition in oceans or lakes, similarly to shales, sandstones, or limestones. By far the most important example of this is the iron ore of Minnesota, the copper ore of Michigan, and possibly the gold ore of the Rand in South Africa.

7. Several of the foregoing processes may have contributed to the making of ore. For example, an ore may be formed as described under paragraph 2. Later the rock may be cracked and veins form as shown under paragraph 3, and then rain water may soak in from the surface, dissolve some of the ore, and carry it down into the rock and make the deeper parts richer. This is known as secondary enrichment. By this is meant the enrichment of a vein or an orebody by minerals of later origin, often derived from the oxidation of decomposed overlying ore-masses—in other words, nature's process of making high-grade out of low-grade ores. This condition should be considered in the development of prospects.

Alteration of Ores

Secondary Enrichment. A deposit that is porous or permeable and has impervious walls represents ideal conditions for enrichment. If the walls in general are shattered and porous, the enriching solutions may be dissipated and scattered. Climatic conditions and topography are factors directly responsible for or against enrichment. Study of the physical features of a district is important. When the surface permits the accumulation of water near veins enrichment may be expected. One of the best books on this subject is *Bulletin* 625 of the United States Geological Survey, written by W. H. Emmons in 1917, who in a later paper stresses the importance of lode deposits related to granular rocks.

Evidences of secondary enrichment should be carefully studied because the greater part of all ore produced comes from enrichments of primary orebodies. Indications may be summarized as under:

Favorable Evidence. 1. Residual indications of a good primary mineralization, together with a porous or brecciated (fragmental) structure or the presence of post-mineral fractures (fractures after mineralization).

2. Absence of sulphides and presence of limonite, quartz, and kaolin or kaolinite alteration of the rock.

3. Arid climate with a moderate rainfall favors enrichment, especially disseminated chalcocite deposits.

4. Certain structural features, such as zones of fracture, intersections of veins, contacts of certain rocks.

5. Moderate altitudes.

6. Considerable relief and deep ground-water level.

7. Rapid erosion, where the primary metals are easily soluble.

Unfavorable Evidence. 1. Presence of pyrite or any sulphide except galena.

2. Cold climate; all chemical reactions are retarded by cold.

3. Evidence of glaciation; this indicates a cold climate at least at some period, and this action may have sliced off the upper portion of the mineralized region. This has happened in many places. [Read United States Geological Survey *Professional Paper* 160 (1930) for glaciation.]

4. Contact deposits with little pyrite, as the minerals are usually very resistant to erosion.

5. Evidence that deposits are surficial, such as evidence of organic origin.

6. High altitudes; where erosion is rapid and temperature low.

7. Base leveled country or region of low relief, where the water circulation is sluggish.

8. Hard, compact, impervious deposit, in which solutions can not circulate freely.

9. Too rapid erosion or too slow erosion. In the first case the minerals are removed more rapidly than they can be leached;

and in the second, fresh minerals are not presented fast enough to the action of the weathering agents.

Effect of Change of Enclosing Rock on Veins. All forms of vein deposits are to some extent affected in size, shape, and richness by the character of the fissure and by passing from one type of enclosing rock into another. The vein is likely to widen in an easily shattered material, pinch in a tough rock, and split into small stringers in brittle or soft rock, with the mineral so disseminated that the deposit becomes worthless; or the fissure may be replaced by a flexure (folding), and the deposit be entirely lost. Also, the type of deposit may be entirely altered—for instance, when a vein system passes from an area of granitic rocks or rocks of similar physical characteristics to an area of schists it often changes from a system with few open fissures to one with many small, tight fractures. Though fissure filling would be the predominating process of ore deposition in the former, replacement would take place in the latter. For these reasons no vein or orebody is permanent, as is often incorrectly said, but it may persist—that is, maintain its characteristics more or less to the point where the foregoing factors render it unworkable.

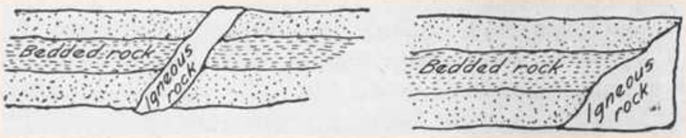


Fig. 13.—Relation of igneous rocks to sedimentary rocks.

In almost all systems of ore formation igneous rocks had a part to play. It is necessary therefore to know how to recognize an igneous rock, and a few suggestions are given that may assist in such identification: (1) Igneous rocks frequently cut across the bedding of other rocks as shown in Fig. 13; (2) the rock next to an igneous rock often shows the effect of having been heated; coal is always charred or coked; (3) igneous rocks nearly always contain feldspar; (4) igneous rocks never have fossils—that is, remains of life, such as shells or plants—and (5) they show no bedding planes and are generally hard.

Surface Changes. The surface changes that affect ores are important. Most minerals will change when left to the action of weather; thus pyrite changes slowly to limonite, and chalcopyrite changes to limonite and malachite. Sometimes the valuable minerals are entirely dissolved at the surface, and the rock is left barren. This is particularly true of copper ores, though usually some traces of copper will be left at the surface. Below are listed some of the weathering changes of most common occurrence, and of greatest interest:

Feldspar changes to clay.

Olivine and hornblende change to serpentine or chlorite rocks.

Impure limestone may dissolve and leave clay.

Pyrite changes to hematite and limonite.

Copper-sulphide minerals change to malachite, azurite, cuprite, or metallic copper or may be dissolved entirely; some copper minerals have limonite.

Silver minerals change to horn silver (cerargyrite) or dissolve.

Lead minerals change to cerussite or anglesite.

Rhodochrosite and rhodonite change to psilomelane or pyrolusite (manganese minerals).

Calcite dissolves.

Gold may dissolve if manganese is in the rock.

Quartz, fluorite, apatite, barite, and tourmaline are not likely to change.

In discussing each mineral in Part III, weathering effects will be described more completely.

Wall-rocks and Mineralization

Many lodes are the result of part deposition in previous fissures and are partly replacements of wall-rocks. In the Central City district of Colorado the association of minerals formed by replacement in the walls of filled fissures is in general different from that deposited in the fissure itself, in spite of the fact that both mineral associations were obviously formed almost at the same time and under the same general conditions of pressure and temperature. One of the most striking exemplifications of these contrasts is the scarcity or entire absence of galena and sphalerite in the walls of many fissure fillings in which these minerals are very abundant; in such walls pyrite is the dominating sulphide. Carbonates may be present in a filled fissure but absent from its walls. Conversely, sericite, the commonest alteration product in the walls, is never found in the fissure fillings.

The influence of wall-rocks in many cases has a great bearing on vein fillings. Where the vein cuts different kinds of rock the replacement is usually selective. This may indicate a replacement of the rock as a mass, as in limestone, a replacement of fragments, as in a conglomerate, or replacement of certain constituent minerals, such as ferro-magnesian minerals, in basic rocks. This mineralogical effect is not easily studied in a district without a developed mine or, better, several developed mines.

CHAPTER X

OUTCROPS

An outcrop is the surface exposure of an orebody. Outcrops vary in size and appearance. Some are great masses of heavily mineralized siliceous rock standing boldly above the surface; others form no striking topographic features; while others are small and obscure but may be rich. The large gold mines of the Mother Lode of California had no prominent quartz outcrops, although the Lode has. There are practically no outcrops at Cripple Creek, Colorado, or at Kalgoorlie, Western Australia. The zinc-lead deposits of Oklahoma show no surface indications. Outcrops in the Baguio district of the Philippines are not strong; many veins do not outcrop and are found underground. Some veins are mantled by a heavy gossan of iron and manganese oxides—black and ragged. Others are large masses of white quartz but worthless. Some are stained with copper yet contain no ore shoots. A little copper may stain a lot of quartz, so may manganese, iron, and mercury. Outcrops distinguished by extensive iron mineralization are often indicative of large masses of sulphide ore at depth. Many notable copper mines have a large outcrop of iron oxide or gossan, formerly worked for iron, gold, or silver. According to one observer, in the vicinity of copper deposits there is twice as much quartz in the ore-bearing ground as in the ground containing no ore. Two important features of outcrops are color and degree of silicification. Silver and lead-silver deposits are often discovered by opening outcrops of siliceous manganese dioxide, which is prominent at Broken Hill, Australia.

Outcrops could be studied in a quantitative (bulk) way by mapping them under the heads of texture of rock (physical characteristics); distance apart of fractures; kaolinization (degree of decomposition to clay); silicification (amount of quartz); distance apart of quartz in veinlets; limonite (iron oxide) in kaolin, in veinlets, and as disseminations; sericitization (micaceous schist); and copper stain in kaolin and in veinlets.

Different outcrops of veins, deposits, or impregnations are generally found to have a distinct bearing on one another. The intersection of two water-courses is undoubtedly the cause of a large proportion of ore-shoots. This may be the intersection of any combination of channels that offer free circulation to mineralizing waters. As this is true, the study of the physical structure or texture of the rocks is of paramount importance in determining the opportunity that they afford for ore deposition through the circulation of water. The richest portion of an ore-shoot in strong veins is likely to be at the intersection of fractures or small veins or where the fracture is complex, such as crushed zones or zones of brecciation.

Relation of Outcrops to Lodes

The nature of lodes is often indicated by their outcrops, as shown by the following:

1. Siliceous ores in limestone or other soluble rocks outcrop conspicuously as a rule.
2. As the pyrite increases, the outcrop is less conspicuous, and when highly pyritic it is usually a depression with gossan.
3. Siliceous deposits in igneous rocks usually outcrop above the surface but very irregularly.
4. As the pyrite increases, the outcrop may be in a depression or it may have no effect on the topography, except in scattered places.
5. Siliceous deposits in quartzites weather at about the same rate as the rock and may affect the topography only in scattered places.
6. Pyrite-rich deposits in quartzite erode more rapidly, and outcrop is usually a depression.

There is nothing that the prospector desires so much as the ability to judge what minerals are present beneath the surface of an outcrop. Such determinations cannot always be made, even by a trained geologist, but a fairly accurate estimate may be made by anyone who has an understanding of the changes that occur in minerals through the action of weather as briefly outlined. The changes in depth, as indicated by outcrops, depend upon several factors. The maximum amount of most resistant material tends to remain longest at the surface and as far as possible to monopolize the outcrop. Therefore, if a deposit varies greatly in width down the dip and is eroded more rapidly than the country rock, in a majority of cases the width will increase in depth; and if the lode is resistant and the rock is more easily eroded, the width is more likely to decrease in depth. Veins that are wide and long in the direction of the strike are likely to continue in depth.

Minerals in Outcrops

Minerals found at outcrops are of two types:

A. Residual minerals, which are insoluble and are left after the migration of the more soluble ones. They are quartz, gold, platinum, cassiterite, rutile, zircon, and some gems. Less common are galena and enargite and sometimes magnetite and specularite.

B. Secondary minerals, formed by oxidation and hydration, are most of the oxides, sulphates, carbonates, silicates, phosphates, and chlorides; and native gold, silver, and copper. Iron oxide, usually as limonite, is found on a majority of outcrops, because pyrite is an important constituent of nearly all primary gold, silver, and copper ores. The study of gossan formations is therefore very important. They may be classified as follows:

1. Pseudo-gossan (false gossan), which is of no economic significance, and which may originate either by the oxidation of ferro-dolomite, siderite, or complex silicates or by the oxidation of very minute, disseminated crystals of pyrite.

2. True gossan, which may be of great importance in determining the type of deposit and the ores likely to be found beneath the surface. There are several features of gossan formations which should be considered, such as

a. Position with respect to zones of fracture.

b. Size and shape of the formation; the shape may indicate the extent and shape of the lode, while its size will indicate the amount of leached ground represented.

c. Porosity; if the gossan is porous and brecciated (fragmental), mineralizing solutions have a better chance to circulate. In some districts a soft, porous gossan seems to indicate the presence of copper in the ore.

d. Casts and pseudo-morphs (a crystal or apparent crystal having the outward form proper to another species of mineral) may show what minerals were present before erosion took place.

e. Association with certain rocks; when with igneous rocks or metamorphic schists, it is probable that the gossan is derived from pyrite with little or no copper.

f. Siliceous character; if low in silica (less than 10 per cent), it is probable that the gossan was derived from iron carbonate; if silica is high, it was derived from sulphides.

g. Association with certain minerals:

(1) With gold and silver; it is probable that these minerals will be found in depth associated with sulphides.

(2) With manganese oxides; the zone of enrichment for gold is probably deeper. If in excess of 1 per cent, the gossan is probably of carbonate origin.

(3) With barite.

(4) Oxidized copper minerals; indicates action of copper-bearing solutions.

(5) With alunite; indicates presence of gold.

(6) With hematite; in arid regions the gossan from pyrite is often represented by massive limonite, while chalcopyrite in the original ore is represented by patches of bright red hematite.

Overburden

Overburden is a feature closely related to outcrops, as alluvium, slide rock, frozen muck (as in Alaska), conglomerate, and other débris frequently hide the outcrops from view. If ore is found beneath such overlying material, it is more or less by chance, although if float ore has been properly traced and trenches cut, ore-bodies may thus be uncovered; yet in some instances only drilling to 50 or 100 feet will reveal the possibilities.

If veins are suspected in any area but have no surface indications, it is well to observe whether burrowing animals, such as ants, gophers, and squirrels, have scraped out pieces of ore from their holes. This material, whether ore or just soil, should be panned or assayed. Such débris has resulted in the discovery of ore. Scrapings from a rabbit burrow in Western Australia resulted in finding rich gold ore in 1933.

In Mexico and Central and South America, as well as in Asia and Africa, ancient workings should never be passed without examination. It is said that every antigua (old working) is not a bonanza, as the ancients were good miners. Some of these old mines have been carefully examined by geologists and later developed and made into substantial producers by modern equipment.

Indications of Mineralization

In some regions what are termed indicative plants grow in the soil that contains certain minerals. The shrubs are local varieties rather than distinct species, and their color is affected by absorption of the particular metallic ingredient in the soil. These plants are considered to be of little practical value to prospectors, who usually will identify the mineral itself in the soil before they have noticed the indicative growth.

When prospecting it is worth while studying every physical phase of the surface; do not pass anything with the thought that it could not be of any value. Always examine arid regions, contacts, colored or stained rocks, clays, eruptive areas, faults, dikes, schistose rocks, dry lakes, hot springs, oily films, oozing of tarry matter from rocks, incrustations, manganese and iron on outcrops, black sands, heavy minerals in panning, outcrops near water catchments and lakes, receding glaciers, and such.

While no general rule can be made regarding the association of certain rocks and certain minerals, the following may be suggestive in prospecting:

ASSOCIATION OF ROCKS AND MINERALS

COUNTRY ROCK	MINERALS LIKELY TO BE FOUND
Chert	Iron, manganese
Conglomerate (metal in cementing material)	Copper (as in Michigan), gold (as in South Africa), silver (as in Ontario), diamonds (as in South Africa)

Association of Rocks and Minerals (*Continued*)

Country Rock	Minerals Likely to Be Found
Diorite	Gold
Eruptives (andesite, basalt, dacite, latite, rhyolite, trachyte—massive or as cemented fragments)	Copper, fluorspar, gold, nickel, iron, silver
Gneiss	See Schist.
Granite (including pegmatites, porphyry)	Antimony, bismuth, copper, diamond, feldspar, garnet, gold, lead, mica, molybdenum, tantalum, tin, topaz, tourmaline, tungsten, zircon
Jasper	Copper, manganese
Limestone	Antimony, arsenic, barite, calcite, copper, cobalt, emerald, flint pebbles, garnet, gold, lead, manganese, opal, quicksilver, sulphur, tin, zinc (with lead)
Quartzite	Copper, gold, iron, lead, manganese, yellow ocher, zinc (with lead)
Sandstone (and shale)	Antimony, barite, carnotite, coal, copper, manganese, mercury, oil-shale, petroleum (oil), rock salt, silver, turquoise, vanadium
Schist (and gneiss)	Cobalt, copper, corundum, cryolite, gold, graphite, lead-silver-zinc, mica, monazite, mercury, nickel, pyrite, quartz, silver, talc, tin, tantalum
Serpentine	Asbestos, chromite, diamond, magnesite, mercury, nickel, platinum, pyrite, talc
Slate	Antimony, arsenic, coal, gold, lead, pyrite, zinc (with lead)

Prospectors and others should remember (1) that the grade of ore in a vein does not increase as depth is gained—that is, after the enriched zone is passed—(2) that all vein outcrops do not, or did not, contain valuable minerals and that if they did, the minerals are not always attacked by surface waters and leached out; (3) that the size of an outcrop has nothing to do with the size of a vein at depth, nor do veins always widen below their outcrops; (4) that the presence of certain plants is not a very reliable indication of the existence of ore; (5) that veins do not always contain ore shoots; (6) that ore shoots are not always found where conditions seem favorable, nor should ore be found in one district similar to another.

As regards the statement that the surface of many regions "has not been scratched," C. W. Henderson, who wrote "Mining in Colorado" (*Professional Paper* 138 of the United States Geological Survey, published in 1926), says of Colorado that this "is a statement not borne out by facts," which are, to quote part of his conclusions:

> The surface has been well scratched and even intensively perforated with holes ranging from 10 to 3000 feet in depth, and with tunnels as much as 5 miles in length. Much of this "scratching" was misdirected . . . Colorado has been a large producer of metals, and to the end of 1923 the total value of gold, silver, copper, lead, and zinc amounted to $1,531,000,000 ($1,819,648,576 to end of 1940).

As to outcrops, Mr. Henderson has this to say:

> It is well to attempt to visualize the outcrops of the deposits before ore was discovered. In Gilpin County, except in places of bold outcrop, the surface in the creeks was covered with swampy soil upon which grew aspen trees, and on the hillsides was a growth of brush and even luxuriant evergreen forests. Leadville was in general heavily forested at the time of discovery of the silver-lead ores in 1877. Nearly all that timber was soon removed to make charcoal for the furnaces or for mine timbers.
>
> Is it to be presumed that outcrops have been overlooked? No doubt some have been overlooked, but most of the easily found outcrops have been discovered.
>
> The new silver-lead-zinc orebodies found in 1923 and 1924 on Mt. McClellan, 3 miles west of Silver Plume, and 4 miles north of the

Belmont lode, which was discovered in 1864, were found by tunnels 1600 to 3000 feet in length. The outcrops are either completely hidden by brush and forests or are inconspicuous and uninviting. Some of the best veins of the San Juan region did not reach the surface. The Leadville blue limestone, so productive at Leadville, lies under morainal wash in Park County. A combination of intensive geologic examination and the energy of the informed prospector may find new surface ore bodies. For the present the old districts should be the starting points. Prospectors should have the unfavorable localities eliminated by competent geologists.

In 1899 the tungsten deposits near Nederland, Boulder County, were recognized and opened. In 1918 the enormous deposit of molybdenite near Climax, which had been known for many years, began to be worked. The ore averages less than 1 per cent molybdenum sulphide. So far Colorado has found no "porphyry copper" deposits such as those in Utah, Arizona, Nevada, and New Mexico, where the copper averages between 1 and 2 per cent. In fact, Utah has found only one such deposit so far; New Mexico two, with one only profitable to date; Nevada one; and Arizona five. Will the granite outcrops of Colorado disclose such deposits?

On the other hand, take Western Australia as an example: This is almost entirely a gold-producing state, and the potential gold-bearing areas cover at least 300,000 square miles, about a third of the state's total. After yielding £190,000,000 ($900,000,000) and after many mines had been shut down and mining towns deserted and the end of all was thought near, an abnormal price for gold revived prospecting, development, and mining, with the result that many of the supposedly worked-out mines were found to contain large tonnages of pay-ore and the industry is again flourishing. The prospector, therefore, should keep abreast of the times by reading and by conversing with men who understand the trend in economics, such as the price of metals and commodities and wage-scales.

CHAPTER XI

PROSPECTING

Where to Search

Generally speaking, volcanic areas are most favorable for ore deposition. Almost invariably lode deposits of gold and silver are found in areal (surface) association with intrusive igneous rocks. Faults and fractures are developed, and conditions necessary to ore deposition are present. The intersection of veins is a surface feature of importance also. As each district has its peculiar rock and metal association and surface characteristics it also has its peculiar type of topography, governed by natural distribution, relative hardness, nature of faulting, folding, and other conditions. A much-faulted region is likely to be marked by steplike outlines. Low, rounded hills are often the results of complex faulting with at least two systems of intersecting faults. If such hills are of notably different outline from the general relief of a region, mineralized areas may be associated with such a feature.

In the disintegration of the rocks of desert areas, physical agencies play a more active part than chemical agencies. And, attention has been directed to the lack of moisture such as spread by rainfall and in the air, a principal chemical reagent in the alteration of rock. An important feature in disintegration, however, is the action of heat and cold and erosion by torrential streams and wind. As is well known, there is a considerable difference in temperature between day and night in deserts. Because of the light soil cover, or the entire lack thereof, the rocks are more directly affected by temperature fluctuations than they would be if heavily mantled with soil and protected by forest growth. The net result of these physical forces in arid regions is the accumulation of the fine and coarse rock in alluvial aprons. This material assumes a more or less compact mass or conglomerate, frequently cemented if the original rock carried carbonate of lime.

Although prospecting in the desert is simplified by the lack of vegetation and overburden, work has been limited by physical difficulties and the knowledge of how to overcome them.

Surface Indications

Having decided upon some area for investigation, the first step in prospecting is to seek for signs and follow them as far as they go. Thus the seeker after ore looks for "float," the bits of mineral or vein-matter that have been broken by frost or other agencies of erosion from an outcrop, that part of a lode which protrudes above the surface; or perhaps he follows traces of insolu-

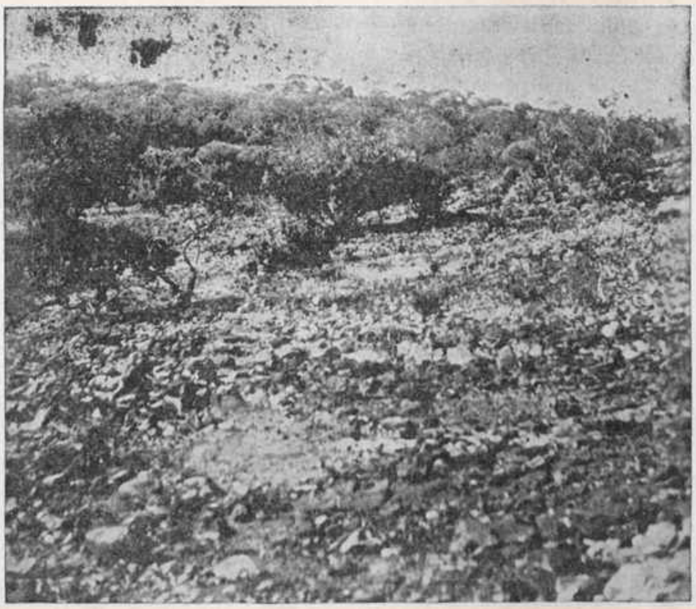


FIG. 14.—Float.

ble metals, such as gold, or insoluble minerals, such as tinstone (cassiterite), chromite, molybdenite, or scheelite, among the products of erosion, either in the wash of the creek or in the soil on the hillside. He hunts for these fragments first in the gullies and valleys to which the rain, the rivulet, and the river are likely to have brought them. He follows them upstream as far as they continue; then he traces their migration up the adjoining hill-slope until at least he can find no more, a circumstance which indicates that he has gone beyond their source. As he looks about he may find the outcrop from which they came; if not, he digs and makes a trench across the line of movement of these promising pieces of mineral or rock. This is termed "costeaning."

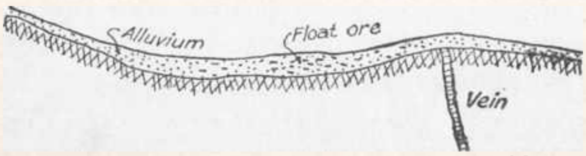


FIG. 15.—Outcrop of vein covered by alluvium and traced by panning or loaming.

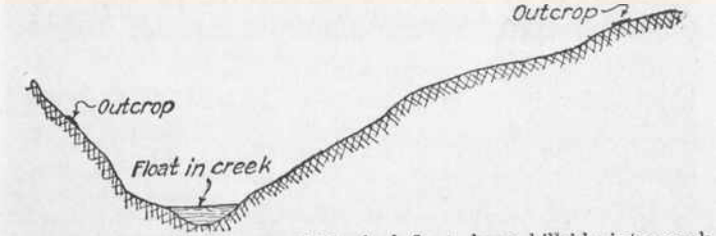


FIG. 16.—Exposed outcrops which shed float down hillside into creek.

Float does not migrate in arid regions (Fig. 14) to the extent that it does in a country in which the mountainsides are traversed by numerous streams and rivulets, which may assist in carrying a piece a long distance from the point where it was broken. Consequently, outcrops may be sought generally within a reasonable distance of float, and topography forms a fairly reliable guide as to the relative positions of the two. Float gold that is rough indicates a nearby origin. Figures 15 and 16 show how float and veins may be traced.

After discovering a mineral deposit, it should be traced as far as possible on the surface to ascertain whether it is a true vein or not. Little difficulty will attend this work when the vein-matter is harder than the country rock. The principal point to be noted in that case is the character of the ore in different portions of the lode, so that the most promising place may be selected on which to begin the work of sinking a shaft or driving a tunnel. When the gangue-matter of the vein is soft and has been weathered to the level of the ground or has been covered by earthy material, as is the case in many mining districts of the world, exploration becomes more difficult. It is often advisable to dig narrow trenches at regular intervals across the ground where the vein is supposed to lie, as shown in Figs. 17 and 18. These trenches should be sunk until the rock is found unbroken and continued until the walls of the lode has been developed.

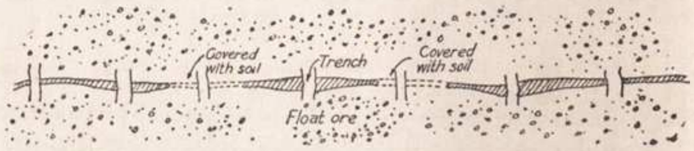


FIG. 17.—Plan of outcrop, showing trenching across for sampling.

FIG. 18.—Side view of outcrop, with trenches.

Under favorable conditions another plan may be adopted, which, however, is usually more costly and in many cases is not advisable. This method is to strip the vein in the direction of its length from the point where the original discovery was made. This is done by pick and shovel or by animal or truck and scraper or by tractor with scraper attached (bulldozer). The advantage resulting from this work is obviously the more complete knowledge that may be gained regarding the character and richness of the vein at every point. Whether the outcrop be persistent or otherwise, the dip of the vein (its inclination to the horizon) should be taken into account. Information in this regard is of the utmost importance in estimating the cost of all future development. Figure 19 shows a quartz vein that has been stripped. It averaged $2 per ton, and no shoots were found.

The surficial indications of ore are as varied as the minerals that comprise such deposits. The seeker after gold and silver looks for outcrop of quartz, because quartz is usually, but by no means always, the matrix of the precious metals. If the quartz is iron-stained, it is a good sign because minerals containing iron, notably pyrite and chalcopyrite, are commonly associated with gold and silver. Iron in an oxidized form is a characteristic indication of the outcrops of most veins and lodes, so much so that a gossan is regarded as a likely cap for ores of both the precious and the base metals. The iron may be present as a definite mineral, such as hematite or the hydrous oxide limonite, but usually it is a mixture of oxides and is distinguishable chiefly by its reddish-brown stain.

FIG. 19.—How a quartz vein in Maryland was stripped.

There are other favorable signs which should be followed, such as white chalky-appearing igneous rock, especially granite or porphyry, pyrite in a vein (not pyrite in clay or coal beds), a quartz vein with limonite in it, and milky or cloudy quartz veins.

The Ontario Department of Mines offers these suggestions in prospecting:

> Where contacts or fissures in the rock outcrops are observed, removing the moss or shoveling off the overburden (trenching) may be necessary to expose fractures or veins.
>
> Every vein of quartz should be closely scrutinized. In many cases boulders of float quartz are observed. These floats should be carefully examined and, if possible, traced to their place of origin, which may be a few feet or many yards from the final resting place. Occasionally, small fragments of quartz are seen in the roots of upturned trees and such occurrences should hold the prospector's attention closely. As a matter of fact, it was such a clue which led to the discovery of the Kenty mine in Swayze Township. Panning should be resorted to, and a closer search made by trenching to bedrock, if this is possible; more serious work, such as drilling and blasting, may be undertaken if any evidence of gold is found by panning.
>
> The secret of success is curiosity, close observation, and steady hard work. The prospector crosses and re-crosses any favorable area and takes samples from all out-of-the ordinary occurrences. For those not accustomed to the bush, running out a preliminary blazed line or two a few miles from the camp is a precaution which may save time and often considerable mental worry. It is advisable to stay close to favorable formation. If the rocks are of an encouraging type, it is better to prospect patiently there than to keep traveling, forever looking for a better country. Every prospector should be his own authority—that is, he should not depend too much on written reports and books. Reports descriptive of one area will not apply to another.

Prospecting by Drilling

Drilling is a reliable method of prospecting for ore or gravel whose existence is suspected, of searching for new orebodies whose position may be inferred, and of exploring known deposits to determine their value and extent preparatory to developing them. To carry on prospecting successfully it is necessary to know as much as possible of surface indications and geologic conditions, so that the drill-holes can be placed properly and the results correctly interpreted. It has been said that applied geology, audacity, and pure luck have led to discoveries.

Drilling may be done by several methods, such as by hand and power, but the latter method will not be discussed here. A hand auger or hand drill has been used to some extent in prospecting for coal and clays where they exist near the surface. Holes have been drilled as deep as 80 feet, by this method, using an auger for soft ground and a churn-drill for hard. Two men can do the work of drilling the shallower holes, but for the deeper holes three men are required, and a frame from 15 to 20 feet high is needed. The cost of hand drilling is low and depends upon the cost of labor. After a depth of about 50 feet is reached the cost increases rapidly.

A mining man of considerable experience in Montana and in New Zealand, and a friend of the author, believes that mountain chains may be in the future, as they have been in the past, great sources of minerals. He referred particularly to the Rocky Mountains, which run from British Columbia through Montana, Wyoming, and Colorado and into New Mexico. The Cascades of the Pacific Northwest, the Sierra Nevada and Coast Range of California, and the chains in Idaho, Nevada, and Arizona have also been productive and promise much more—likewise, the Sierra Madre of Mexico and the Andes of South America. In the mountainous parts of Europe—Spain, for instance—are extensive mineral deposits, also in the Urals. Of course, large areas of the world's mountains have been prospected; but much remains to be done, especially in parts difficult to reach. Although some mountain chains have been great producers of minerals, others have not revealed much, so there are exceptions to this argument.

Foothill country—that which leads to mountains, hilly country of medium altitude, and flat or rolling country—has been a prolific producer of metallic and non-metallic minerals. This applies to many parts of the world. In such areas may be placer or alluvial deposits, resulting from water action or from wind action and arid conditions—California, several Western States, and parts of Africa, Australia, Central Asia, and Siberia, for example.

CHAPTER XII

WHAT MINERALS TO LOOK FOR AND WHERE

The following list shows the principal industrial minerals existing in the United States for which search should be made:

Metallic

- Aluminum
- Antimony
- Arsenic
- Chromium
- Cobalt
- Copper
- Gold
- Iron
- Lead
- Manganese
- Mercury (quicksilver)
- Molybdenum
- Nickel
- Platinum (and associated metals)
- Radium
- Silver
- Tantalum
- Tin
- Titanium
- Tungsten
- Uranium
- Vanadium
- Zinc

Non-metallic

- Asbestos
- Asphalt
- Barite
- Bauxite
- Building stone (basalt, granite, marble, limestone, sandstone)
- Borax
- Clays (kaolin, fullers earth, bentanite, fireclay)
- Coal
- Diatomite
- Feldspar
- Fluorspar
- Garnet
- Glass sand
- Graphite
- Gypsum
- Kyanite
- Magnesite
- Mica
- Monazite (thorium and cerium)
- Nitrates
- Oil-shale
- Pebbles (grinding)
- Petroleum
- Phosphate rock
- Potash
- Precious stones
- Pumice
- Pyrite
- Quartz (silica)
- Salt
- Sand and gravel
- Spodumene.
- Sulphur
- Talc
- Tripoli
- Zirconium

The United States has an exportable surplus of many of these metals and minerals; but it produces only a fraction of its needs of antimony, asbestos, cobalt, graphite, manganese, mica, monazite, nickel, nitrates, precious stones, tin, and vanadium. More of several of these could be produced, especially in time of emergency.

There is a constant demand for the minerals of the alloy group—beryllium, chromium, manganese, molybdenum, tantalum, titanium, tungsten, uranium, vanadium, and zirconium.

As a guide to prospectors, it might be said that the United States may be divided into three irregular divisions—namely, the Western, Central, and Eastern. Although the whole country contains more or less of the various minerals, each of these three divisions abounds in certain rocks which contain large quantities of certain ores. By the West is meant the Pacific Coast States, embracing Arizona, California, Colorado, Idaho, Montana, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming. The Central States include Arkansas, Illinois, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Missouri, Oklahoma, Tennessee, Texas, and Wisconsin. The Eastern States comprise Alabama, Connecticut, Florida, Georgia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North and South Carolina, Pennsylvania, Rhode Island, Vermont, Virginia, and West Virginia. A table may be arranged as shown on page 96.

The Western division might be termed metallic; the Eastern, non-metallic; and the Central, more or less of both.

Many parts of the United States remain but half explored, such as northeastern California, southeastern Oregon, northern Nevada, southern and central Idaho, much of Alaska, besides large areas in other Western States. In Canada there is plenty of scope: Labrador, much of British Columbia, Ontario, Quebec, the Hudson Bay region, and Manitoba. An immense and most attractive territory remains to be explored—the region of ancient rocks in which the iron and copper of Lake Superior, the nickel-copper deposits of Sudbury, the silver veins of Cobalt, and the gold lodes of Porcupine and Kirkland Lake have been found already. This region extends into Arctic Canada and is,

Minerals Found in Three Divisions of the United States

Western States	Central States	Eastern States
....	....	Asbestos
....	Abrasives (corundum, etc.)	Abrasives
....	Aluminum (bauxite)	Aluminum
Antimony		
Asbestos		
Barite (small)	Barite	Barite
Borax		
Building stones	Building stones	Building stones
Chromite	....	Chromite (small)
Clay	Clay	Clay
Coal (small)	Coal	Coal
Copper	Copper	Copper
Diatomite		
Fluorspar	Fluorspar	
Fuller's earth	Fuller's earth	Fuller's earth
Gems	Gems	Gems
Gold	....	Gold (small)
Graphite	Graphite	Graphite
Gypsum	Gypsum	Gypsum
Iron	Iron	Iron
Lead	Lead	Lead
Limestone	Limestone	Limestone
Magnesite		
Manganese	Manganese (with iron)	Manganese
Mercury	Mercury	
....	....	Mica
Molybdenite		
....	....	Monazite
....	....	Ocher
Oil (petroleum)	Oil	Oil
Oil-shale	Oil-shale	
Phosphate rock	....	Phosphate rock
Potash		
Pyrite	....	Pyrite
Salt (lakes)	Salt (rock)	Salt (rock)
....	Silica	Silica
....	....	Slate
Silver		
Strontium		
Sulphur (small)	Sulphur	
Talc	....	Talc
Tin (small)	....	Tin (small)
Titanium	....	Titanium
Tungsten		
Uranium		
Vanadium		
Vermiculite	....	Vermiculite
Zinc	Zinc	Zinc

except for Australia, probably the largest and most promising territory for prospecting to be found anywhere. It is open to English-speaking peoples, as the Canadian Government allows the same right of location to Americans as to its own citizens. The extension of the railway to Hudson Bay and the greater use of the airplane over this vast wilderness are giving the prospector access to this part of the North American continent, which, unlike many unexplored or partly explored regions. is free from the miasmas and other drawbacks of the tropics. Mexico, as a field for American and Canadian enterprise, is intensely attractive. The Mexican Government has expressed itself hospitably toward Canadian and American mining exploitation, provided such exploitation is consistant with the labor laws and mining regulations of the Republic of Mexico. There are also enormous areas awaiting the prospector in South and Central America, Cuba, the Philippines, and Siberia. But in all of the regions mentioned the work must be undertaken by scientifically equipped parties.

Alaska is a territory of great mineral possibilities, yet it is far distant from the United States, the seasons are short, and expenses of getting there and of prospecting are high. With the railroad from Anchorage and Seward to Fairbanks, right through the middle of the Territory, prospecting should be done more easily and with less risk than formerly.

One of the objectives of future prospecting will be the "lost placers"—namely, the undiscovered detritus (sediments) of erosion from known lodes. For example, the Homestake lode enriched the Potsdam conglomerate of the Black Hills, and the erosion of the gold veins in the foothills of the Sierra Nevada made the famous placers of the Yuba and American rivers. It has been suggested that the débris derived from the glaciation of the gold-bearing rocks of northern Ontario will be embedded under the clay that extends to James Bay. A similar question arises concerning the veins that enriched known alluvial deposits. Where are those that contributed to the placers of the Klondike and its tributaries, or were they entirely removed in order to form the gold-bearing gravel of Bonanza, Eldorado, and other famous creeks? Untold mineral wealth must lie buried under the ice and moss of the North, not to mention the glacial drift. Many great veins and lodes must be hidden from sight under the cement of the desert and the lava of the bad lands. It will be the business of the scientific prospector to pierce the blanket laid over this ore, and he will exert his best skill in selecting the most likely places for exploring by means of the drill or geophysics. Besides these chances there are the orebodies that have been lost by poor observation and bad mining. Many an orebody has remained undiscovered for lack of a crosscut through a supposed vein-wall or by following the wrong geologic trail underground.

Many mines and mining areas are held idle by estates or heirs, railroads, and land-grant syndicates, who will neither work them nor sell on reasonable terms nor even allow prospecting to be done. The holding of claims simply by annual assessment work ties up large areas which should be properly exploited.

Observations of the author in Australia and Ontario and Quebec lead him to believe that prospecting in Canada with its abundance of water, timber, fish, game, and rock outcrops is probably easier, despite its dense growth, than, say, prospecting in mountainous and arid parts of the western United States and other countries. Anyhow, the possibilities appear to be greater in this region; in fact they are. Perhaps a close competitor may be Western Australia, which is dry and largely tree-covered, has conspicuous outcrops, and has considerable chances of further discovery. Both in Canada and in Central Australia are flies to bother the prospector and engineer.

The Ontario department of Mines has this to say regarding prospecting in that Province.

> Briefly, the most favorable prospecting areas in Ontario lie within the older pre-Cambrian rocks in belts of greenstone (Keewatin) and sediments (Timiskaming) which have been intruded by more recent and younger igneous rocks, such as granites or porphyries. It is in the vicinity of the contacts of the intrusive rocks with the greenstones or sediments that suitable conditions for mineral deposits occur, the simplest explanation for this being that the intrusive mass penetrates and fractures the overlying or adjacent rocks, thus creating cracks,

fissures, or shattered zones, into which gangue minerals from the intrusives find their way. These minerals may be quartz, calcite, and barite and may carry with them enough valuable minerals to create what is termed an ore deposit.

Greenstone formations and the accompanying sediments have been fairly well mapped by Ontario geologists. A glance at any good geological or mining-claim map will indicate these areas. Commencing in northwestern Quebec, there is a belt or zone running to the west through Kirkland Lake and Matachewan to the Swayze area north of Ridout on the main line of the Canadian Pacific Railway, on which many mines have already been found. There is also a zone paralleling this area to the north, extending from Lightning River through Munro township to Porcupine. Favorable areas are known to occur to the west along the height of land on both sides of the Canadian National Railway and along the Canadian Pacific Railway, right across the Province and into Manitoba. Many deposits, no doubt, remain undiscovered owing to the heavy overburden of soil. The percentage of exposed rock is small, and the detailed geology of many areas remains unknown. It is a fact that where porphyry has been discovered intruding the greenstone, indications of gold are often found; and where conditions are right, as at Kirkland Lake, wonderful gold mines have been developed.

CHAPTER XIII

SAMPLING AND ASSAYING

Ability to sample correctly is important for the prospector. Incorrect sampling has led to much disappointment, also mistrust of public assayers and custom plants to which prospectors have sent samples for assay or large quantities for treatment. The fault lies in selecting a few pieces of good-looking ore which are more likely to yield good returns, but when a large quantity of this same ore is mined and sampled the resultant assay shows a value that is frequently only a fraction of that shown by the first. One, two, or three pieces of ore do not make a sample, but 2 pounds or more per foot of vein do. The soft portions of veins are usually richer than the harder ones, therefore, because they are easy to pick there is a tendency to take more of them; but no more soft material should be cut than hard ore.

General Rules

Some of the essential principles of correct sampling of a prospect are as follows:

1. Small samples should be taken at regular intervals across the entire width of the vein or deposit.
2. The samples should include impurities present in the vein in the same proportion as they will be present in the material mined.
3. Bands or veinlets that can be mined separately should be sampled separately, also nodules in manganese and other deposits.
4. All samples should be carefully numbered as taken, and their position marked on a sketch.
5. Accurate measurements of the width of vein and the width represented by each sample should be taken and recorded with the position of the sample. If a vein dips, the width should be measured at right angles to the dip.

6. Several complete samples from the entire width of the vein should be taken at intervals throughout the length of the deposit.

7. Samples of ore picked from the surface of the ground are rarely of any value in showing the true character of the deposit. The vein should be exposed throughout the entire width by means of a shaft, tunnel, trench, or pit.

8. Care should be exercised to prevent material that does not belong in the sample from getting into it; otherwise the sample becomes salted—unintentionally, of course.

9. Sampling must be carefully and cleanly done. The result of an ore shipment or the future of a mine depends upon attention to the details.

Only by following these essential principles can even an approximate idea of the value and extent of the deposit be obtained. This work should be done before an engineer is called upon to examine and place a value upon a property.

The tools required are a gad, pick, moil, hand hammer (the head of an ordinary pick or a sampling pick serves as a hammer), pestle and mortar, fine sieve (with practice the fingers can judge the requisite fineness), and pan.

Ore Veins, Dumps, Tailings, and Coal Beds

If a vein is being sampled underground, the intervals between samples should not be more than 10 feet, preferably 5 feet. On an exposed outcrop the intervals may be 10 to 20 feet. Before cutting a sample, clear off all weathered or soft material from the vein and thus leave the unaltered and fresh rock exposed. A cut should be 2 to 3 inches wide and 1 inch deep. If fairly soft, a sampling pick should suffice; but if hard, a moil and single-jack hammer are needed. Any clean box or piece of cloth may be used to catch the sample. To reach high places a rough scaffolding may be built.

If a dump ore is to be sampled, either the grab or pit methods may be used. In the former, pieces of rock are picked up here and there, also knocked off larger lumps; at the same time it is better that some system should be observed, such as taking these samples in regular lines and from fresh surfaces. In the pit method, round holes are dug as deep as possible, and either the material excavated is sampled on the surface or pieces are taken from the sides of the pits. Care should be exercised in doing this, as the sides might cave; therefore some timbering may be required.

If tailing or other fine material is to be sampled, a 1- or 1½-inch pipe is driven down into it, and the cores recovered are mixed together and quartered down.

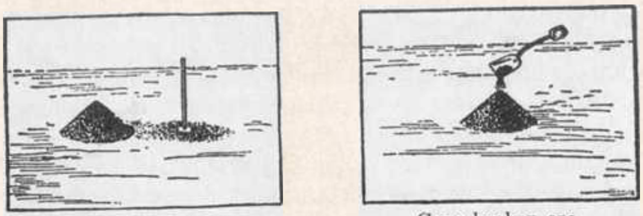
In sampling coal, the face of the bed should be cleaned of all loose coal, dirt, and dust to a depth at which clean hard coal is reached and a width that will warrant keeping any foreign substances out of the sample. Then a width of 12 inches should be squared or faced from top to bottom in the center from which the sample should be taken. Take 6 pounds for each foot of thickness —that is, if the bed is 3, 4, 5, or 6 feet thick, take 18, 24, 30, or 36 pounds of coal. Partings of ⅜ inch or more should be excluded from the sample. The sample should be crushed to pass ½-inch sieve. The operations of cutting and preparing the sample and filling into a can or pack should be done underground.

If it is desired to sample beyond the walls of a vein, drill dry several feet and save the cuttings. These will be fine enough for cutting down to a pound or two for panning or assay.

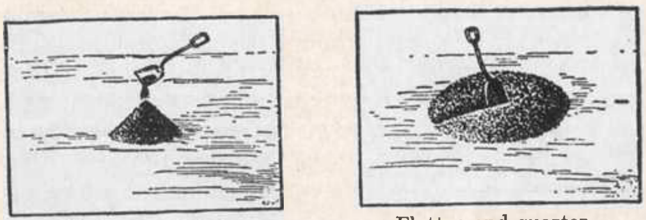
Preparing Samples for Evaluation

Generally, in prospecting, one sample is taken at a time. For every kind of ore the further manipulation of the sample is the same. If the sample weighs about 5 pounds, it is first crushed to ½-inch size. This may be done with a pestle and mortar of the regular kind or one made from a mercury bottle with the top cut off, using a pestle made of a piece of drill-steel somewhat spread at the bottom end. The mercury flask should be thoroughly cleaned by heating and grinding in it some valueless rock, such as white quartz.

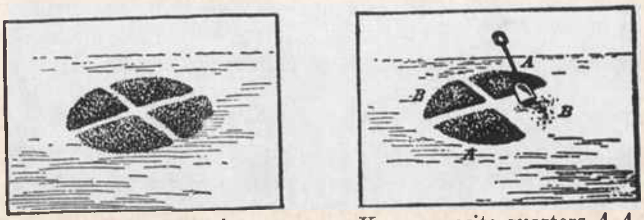
The ½-inch ore is mixed on a clean floor, steel sheet, rubberized cloth, or heavy canvas. It is then made into a cone, flattened, and quartered. Two opposite quarters are rejected, while the two remaining are crushed further to, say, ⅛-inch size. This material is again mixed, coned, flattened, and quartered. Finally, a sample weighing 1 pound remains. This should be crushed to the size of fine sand.



Break lumps of ore. Cone broken ore.



Mix by new cone. Flatten and quarter.



Sample quartered. Keep opposite quarters *A,A.*

FIG. 20.—Steps in reducing size of a sample of ore. This may start with 50 or 100 pounds of mine-run ore and be broken to 1-inch size, then to ½-inch, then to ⅛-inch, and finally to powder. Each time the quarters *B, B* are rejected and *A, A* are re-crushed and re-sampled. (*Adapted from Technical Paper* 133 *of the Federal Bureau of Mines.*)

Whatever the character of the ore, the prospector will probably wish to pan it. If the rock is any but gold-bearing, unless he has testing apparatus with him, he should cut the sample to ½ pound and send it to an assayer. If it carries gold, panning is the best method for getting a quick and fairly close estimate of the value. When 1 pound of ore crushed to 30 mesh or finer is panned, the quantity per ton is easily calculated, but of course this requires practice. By panning, some prospectors and millmen can estimate close to assays the gold, mercury, and tin content of those ores.

When a number of samples are taken across varying widths of vein and give different assay returns, the mistake is frequently made in dividing the number of samples into the total of the assays. For instance, if we take five samples across 12, 18, 24, 6, and 20 inches of vein, and these assay 18, 10, 13, 24, and 7 pennyweight (dwt.) per ton, the average is not 5 into 72 or 14.4 dwt., but it is 12 by 18, 18 by 10, 24 by 13, 6 by 24, and 20 by 7 or 992 inch-dwt., which, divided by 80 inches, the total of the widths, gives an average of 12.4 dwt. per ton. The same system may be used with pounds of copper, lead, or zinc or units of the alloy metals—chromite, tungsten, molybdenite, and others.

Occasionally, in sampling, the pan or assay may give rich ore. This sample may have included a high-grade spot which will upset the average series of samples, so the place should be re-sampled, also the ore between this point and the next sample, to determine whether or not it is all rich. Generally, it is safer not to include a rich assay but rather to give the sample the average of the adjoining samples or discard the high value. Of course, if the whole orebody is rich, all high assays should be taken into account; but if the vein is of medium grade, discard any extraordinarily high assays.

In 1922 the author of this Handbook was co-author of a bibliography on sampling containing 1000 references, and he is frequently reminded of the importance of proper sampling.

Samples may be carried in any clean container or tight cloth, but for mailing they should be put in cotton sampling bags. These are of duck, tightly woven and strong. The 7- by 9-inch size is handy and holds several pounds. It is tied with tape or with good twine. This bag costs around 10 cents and less if a number are purchased. Special 3½- by 6-inch envelopes of heavy Kraft paper with gummed flaps for fine material and metal fasteners for coarse ore cost 40 cents and $1.25 per hundred, respectively.

As shown in Fig. 21, a crushing-grinding-sieving outfit may consist of a cut-down mercury bottle (thoroughly cleaned by heating and grinding some barren rock), a length of drill-steel, and a piece of screen tacked on to four boards, with a pan to hold the fine material. With such equipment any ore may be sampled, crushed, and panned.

Although sieves are not indispensable when crushing samples for panning (the fingers are a good judge of fineness), several sizes should be carried if not too burdensome, say 10, 20, 60, and 100 mesh. These may be purchased nested of full or half height or telescoped, either set with top and bottom pans. Sieves cost $2 each up to 70 mesh and $2.50 for 100 mesh; tops and pans $1 each.

FIG. 21.—A simple and workable sampling outfit—a short mercury flask for mortar, drill-steel for pestle, sieve tacked to a frame, and pan.

Phantom Gold

It is in order here to refer to the claim fairly often made by prospectors and others that fire assays do not extract the gold from certain ores and minerals and they "know" that their samples contain more gold than the assays found. Men in the field and others have argued about this with the author when he was with the *Mining and Scientific Press* and with the Federal

Bureau of Mines. They were told personally and by letter to forget such ideas and rely on their pans or on assays of well-taken samples. Many engineers have had similar arguments put to them. Yet the idea maintains its hold on some prospectors and promoters. If assays do not reveal all the gold in ores, then the methods must be faulty, which is not the case with fire assaying properly conducted. The point to remember is that custom mills and smelters pay only what the assays give. If they and umpire assayers agree within the tolerable limits, payment follows on that basis and no argument will change the result.

If a prospector or miner has spare cash, it is better for him to have an assay or identification made of an unknown rock rather than to guess at it and believe that he actually has valuable ore in large quantity, which is frequently done.

Where, How, and Cost of Getting Rocks Identified, Assayed, and Tested

In most district mining centers there are reliable assayers who make tests at reasonable charge. Also, in the large cities of mining States are several well-known firms. Prospectors might be able to arrange with the assayers at large mines and smelters to assay an occasional sample free or at a low charge. But for this purpose the sample should be from a real ore deposit and properly taken, not selected. Schools of Mines as at Tucson, Arizona; Golden, Colorado; Moscow, Idaho; Houghton, Michigan; Reno, Nevada; Socorro, New Mexico; Pullman and Seattle, Washington; and Salt Lake City, Utah, make assays and in most cases charge for the work. In any event, a prospector or other person should first make inquiries of his own State officials regarding tests, names of assay offices, and other information; the Federal Bureau of Mines should not be asked until such sources are exhausted or when certain publications are desired.

Following is the work done by certain Governmental bureaus in the United States and in other countries:

United States. Most State Bureaus of Mines, Geological Surveys, and Schools of Mines make identification of rocks and assays. The former is generally free if the sample originates within a particular State; but all assays are charged for.

The Federal Bureau of Mines does not make any individual tests. (It has for distribution a list of assayers, analysts, and ore testers, with charges.) The United States Geological Survey makes free identifications but no assays or analyses; this applies also to the National Museum. These three organizations are in Washington, D.C.

The United States Bureau of the Mint makes assays of copper, gold, lead, silver, and zinc ores at its Assay Offices in Seattle, Washington, and in New Orleans, Louisiana; it also makes assays of platinum, palladium, and iridium (metals only) at its Assay Office in New York City. For each metal determined in ore or in bullion, there is a separate charge, as follows for ores: gold, \$1; silver, \$1; lead, \$1.50; copper, \$2; zinc, \$2. Payment should accompany the sample and should be in cash or as money order, only.

California. The State Division of Mines, San Francisco, receives rocks and minerals from deposits within the State for free identification and qualitative analysis (test to determine what mineral, not how much). A half-pound sample in lump form is desirable, with a letter stating where it is from, what tests are required, and why.

Alaska. An Act of the Territorial Legislature in 1937 established three assay offices in Alaska, at College, near Fairbanks; at Ketchikan; and at Nome. Assays and analyses are made free for residents of Alaska, but non-residents are charged a fee for such work.

Canada. In Ottawa, Canada, the Mines and Geology Branch, Department of Mines and Resources, maintains laboratories for free ore-dressing and treatment tests of Canadian ores, non-metallic minerals, and fuels. Chemical analyses and physical tests are charged for.

All the Provincial Departments of Mines (Alberta, in Edmonton; British Columbia, in Vancouver; Manitoba, in Winnipeg; Nova Scotia, in Halifax; Ontario, in Toronto; and Quebec, in Quebec) make identifications, assays, and analyses. Most of them make certain free assays and analyses for prospectors who have provincial licenses.

Mexico. In Mexico, the central laboratory (Laboratorio-Central, Venezuela 3, Mexico, D. F.) undertakes research for private and official investigations in mining, metallurgy, and petroleum. Assays and analyses and amalgamation, concentration, roasting, and cyanidation tests are made. Free tests are made for individuals if they are for creating new processes or for developing natural resources. Assay charges are 1 to 5 pesos; and for tests on gold-silver ore, 40 pesos for amalgamation, 60 pesos for concentration, 50 pesos each for cyanidation and flotation, and 100 to 150 pesos for a complete investigation. Assay samples should weigh ½ pound; and test samples, 100 pounds.

Australia. In Australia, the Commonwealth Government is providing funds for the free testing of ores from the several States at the Schools of Mines at Kalgoorlie, Western Australia; Adelaide, South Australia; and the University of Melbourne, Melbourne, Victoria. Results are published once a year. Assays are made free for prospectors.

New Zealand. The Schools of Mines, which are under the Department of Mines, make free assays for prospectors. The School at Thames has a small treatment plant for small parcels of ore, and a charge is made for such work.

South Africa. During 1934 a Minerals Research Laboratory was organized by the Union Department of Mines, in conjunction with the University of the Witwatersrand, Johannesburg. The staff and equipment is suitable for assaying, analyzing, and ore-testing. The results of experiments on ores are published in the *Annual Report* of the Department.

Great Britain. The Imperial Chemical Industries, Ltd. (known as I.C.I.), makers of sodium cyanide, whose industrial interests cover the British Empire, has a complete ore-testing station at Billingham-on-Tees, England. It provides facilities for ore-testing and ore research for all mining companies and consulting metallurgists. No expense is incurred by a client other than the cost of freight on the ore samples, which should not be less than 200 pounds for small tests and 2 tons for large tests. Results are not made public.

During 1936, the I.C.I. issued free a 62-page booklet, "Gold Extraction: Notes on Cyanidation for the Small Operator." This should be procured from the firm at Millbank, London, S.W.1, England. It includes milling operations, concentration, and cyanidation.

Charges for Assays

Reliable assayers and analysts, of whom there are many throughout the United States, have the following range of charges for results that can be depended upon:

Metal	Charge	Metal	Charge
Aluminum	$3.00	Molybdenum	$2.50–$5.00
Antimony	$2.50–$4.00	Nickel	3.50– 5.00
Arsenic	3.00– 4.00	Phosphorus	3.00– 5.00
Barium	3.00– 4.00	Platinum	5.00
Bismuth	3.00– 4.00	Platinum group, with	
Cadmium	4.00– 5.00	gold and silver	15.00
Chromium	2.50– 4.00	Selenium	5.00
Cobalt	3.50– 5.00	Silver	1.00– 1.50
Copper	1.00– 1.50	Sulphur	1.00– 3.00
Gold	1.00– 2.00	Tellurium	5.00
Gold and silver	1.50– 2.00	Tin	2.50– 5.00
Insoluble (silica)	1.00– 3.00	Titanium	5.00
Iridium	5.00	Tungsten	3.00– 5.00
Iron	1.00– 2.00	Uranium	4.50– 5.00
Lead	1.00– 1.50	Water:	
Lime	1.00– 3.00	Acidity or alkalinity	5.00
Magnesium	2.00– 3.00	Complete	10.00–25.00
Manganese	1.50– 3.00	Vanadium	3.00– 5.00
Mercury	2.50– 5.00	Zinc	1.00– 2.00

Mineral identification costs up to $3 for a blowpipe test and $5 for a chemical test. A qualitative (elements present) analysis costs about $10; and a quantitative (amount) analysis, $20. Charges are reduced if several assays are made.

Spectrographic qualitative analysis of ores is a method to determine what metals are present in an ore. A complete analysis is made for $6 per sample by the John Herman Laboratory, 771 San Julian St., Los Angeles, California. For a special investigation into the platinum group the fee is $10.

CHAPTER XIV

FIELD TESTS AND MEASUREMENTS

The Blowpipe

The blowpipe is an extremely useful and reliable guide for the identification of minerals. With it several different tests can be made, but the most important is the bead test, which depends upon the coloration of borax or a salt of phosphorus, previously attached to a platinum wire and dipped in the fine ore to be tested, in a flame blown by a blowpipe. Some of the requisite articles of a blowpipe outfit are shown in Fig. 22, and the list following needed for a complete equipment. In place of the torch lamp as shown, a large candle will do. Any hard charcoal suffices, but it should be free from cracks. A plate of rough porcelain might be used for getting the streak of minerals, rather than a knife-blade.

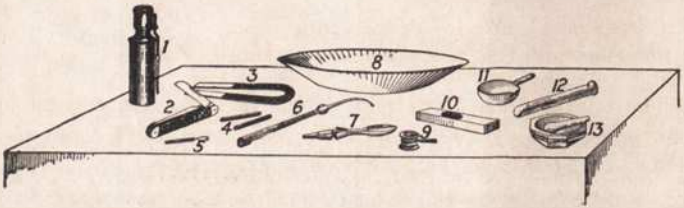


FIG. 22.—A blowpipe outfit. (1) Torch for blowpipe; (2) knife; (3) magnet; (4) glass tubes for platinum loop (5); (6) blowpipe; (7) forceps; (8) pan; (9) lens; (10) charcoal for blowpipe; (11) porcelain dish; (12) test-tube; (13) agate mortar for grinding small pieces of rock.

CHEMICALS AND APPARATUS FOR BLOWPIPE TESTS

1 ounce borax (powdered).
2 ounces sodium carbonate (powdered) or baking soda.
¼ ounce salt of phosphorus (powdered).

6 pieces each of sheet tin and zinc.
2 ounces hydrochloric (muriatic) acid (concentrated).
2 ounces nitric acid (concentrated).
2 ounces sulphuric acid (oil of vitriol).
4 ounces denatured alcohol (if an alcohol lamp is used).
4 ounces concentrated ammonia.
Small agate mortar and pestle.
Horn for panning.
File—three-cornered—small.
Hammer—small.
Anvil—block of steel—1½ by 1½ by 1½ inches.
Color screen—Merwin or Flint's.
Small glass beakers—to hold several ounces of liquid.
2-inch glass funnel.
1 package 4-inch filter-papers.
1 ounce potassium bisulphate.
¼ ounce oxalic acid.
2 ounces mercury (quicksilver).
1 ounce cobalt nitrate solution (10 per cent).
Some bismuth flux, potassium nitrate, and tin chloride.

The study of the flame of a candle or lamp is necessary for blowpipe work. Close observation will reveal three zones in a flame, as shown in Fig. 23. They are respectively yellow, blue, and black, from outside to interior. Only the middle and outer zones are used by the blowpipe.

Fig. 23.—Zones of a flame.

In blowpipe work it is important that the blast be continuous and uniform, although this may seem difficult at first. The blast is not produced by the lungs but results from a bellows-like action of the distended cheeks. During the operation air is inhaled only through the nose and is exhaled largely through the mouth and the blowpipe. This requires practice but comes naturally later.

Place the candle or lamp so that the longer dimension of the wick is from right to left and set its right-hand edge upon a pencil or some other low support so that it will tip somewhat to the left. Insert the tip of the blowpipe about ⅛ inch within and just above the right-hand side of the wick and blow steadily parallel to the wick, directing the flame to the left and producing a clear blue flame about an inch long. If all the flame can not be thus diverted to the left, or if there are yellow streaks in it, trim or lower the wick. If the whole flame is inclined to be yellow, move the tip of the blowpipe a trifle to the left. If it is impossible to produce a flame approaching the length mentioned above, the opening in the end of the blowpipe is too small; and if a very long, hissing flame is produced, this opening is too large. To be able to succeed in blowing a steady flame, the hand must rest upon some support. (See Fig. 24 for general arrangement.)

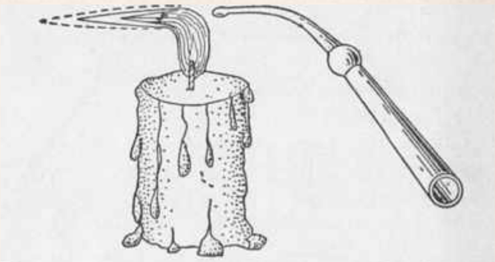


FIG. 24.—Flame turned to normal position for test.

In analytical operations it is sometimes desirable to oxidize substances to be tested, and at other times the aim is to reduce them to the metallic condition; either result can be more or less readily obtained with the blowpipe.

A flame produced in the manner described is called an oxidizing flame, but the action of all portions of such a flame is not oxidizing. The blue cone contains considerable carbon monoxide and is feebly reducing in its action, but just outside the blue cone at the tip of the flame is an extremely hot but nearly colorless zone, which is strongly oxidizing because of the free oxygen present there, and anything held in this cone about a quarter of an inch from the tip of the blue flame will be in the most favorable position for oxidation.

The oxidizing is hotter than the reducing flame, and its hottest part is just outside the blue zone. In testing by means of the borax bead, substances should always be heated there.

To produce the reducing flame, hold the tip of the blowpipe about 1/16 inch above and to the right of the wick, and a long, yellow flame containing much unconsumed carbon will be produced. The strongest reducing action will take place at the tip of and within the yellow cone of this zone.

The procedure for the color test is first to grind some of the rock to a fine powder in the agate mortar. (All sulphide ores must be roasted on charcoal before testing. Some powder is put on the charcoal and heated lightly with the flame until all sulphur fume disappears.) Then the platinum loop is heated in the flame and dipped into the borax or salt of phosphorus several times until a bead twice or three times the size of a pin head is formed. This is heated and dipped into the powder. Too much ore spoils a test, as it makes the bead too dark. Then, holding the blowpipe with the right hand and the wire with bead in the left, the flame is directed against it as in Fig. 25.

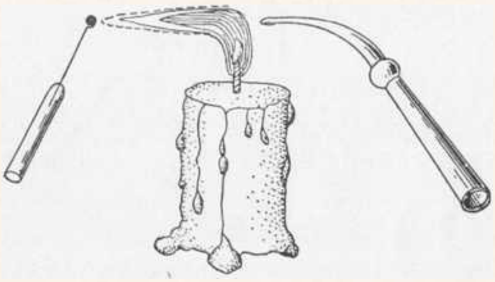


FIG. 25.—A blowpipe test.

The mineral fuses or melts in the bead and imparts its characteristic color, as shown in the table following.

Chromium and vanadium reactions are sometimes confused, but the yellow of the latter is a distinguishing feature.

The borax or phosphorus beads must be discarded after each test, which may be done by breaking them off the wire by gentle tapping when cool or by shaking when in molten condition.

COLOR OF FUSED MINERAL IN BORAX OR PHOSPHORUS BEAD

Mineral	Borax				Phosphorus salt			
	Oxidizing		Reducing		Oxidizing		Reducing	
	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold
Chrome	Green	Green	Green	Green	Green	Green		
Cobalt	Deep blue	Deep blue	Deep blue	Deep blue	Deep blue	Deep blue	Deep blue	Deep blue
Copper	Green	Blue	....	Red				
Iron	Red to yellow	Amber	....	Green				
Manganese	Opaque	Reddish	....	Colorless				
Molybdenum	....	....	....	....	....	Colorless	....	Pale green
Nickel	Violet	Red-brown	....	Gray				
Niter:								
Sodium	Green flame							
Potassium	Yellow flame							
Tungsten	....	....	....	....	....	Colorless	....	Blue
Uranium	....	....	....	....	Yellow	Yellowish green	Yellowish green	Green
Vanadium	....	Light yellow	....	Green	....	Yellowish	Dirty green	Fine green

Some minerals impart a coloration to the flame produced by the blowpipe, such as a bluish green to greenish from copper; red from calcium, lithium, and strontium, in the presence of sodium; yellowish green from molybdenite; and green and yellow from potassium and sodium nitrates. Many flame tests are uncertain, especially with impure minerals.

Metallic minerals are best tested by fusing with soda. For this purpose some of the fine ore is mixed with soda, placed in a depression or hollow in the charcoal block, and the flame turned on to it, as in Fig. 26.

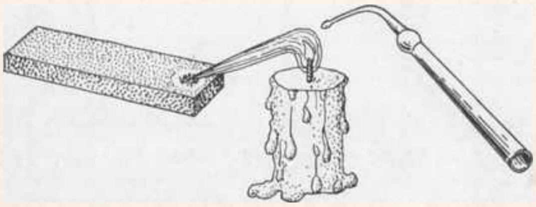


FIG. 26.—Ground rock mixed with soda and fused on charcoal.

The test is not applicable to all metallic minerals, so an inconclusive result does not mean that metal is absent. When the metal appears as a bead in the charcoal, sometimes with an incrustation around it, the test is finished. Hammering shows whether the metal is malleable or not. With aluminum (in cryolite), fumes of fluorine are given off, and metal remains as a crust, giving blue when heated with cobalt solution; bismuth leaves a white bead and yellow coating; copper, a red bead; gold, yellow; iron, dark-colored; lead, white, with yellow coating; manganese, reddish color; molybdenum, white crystals; molybdate, lead globules and yellow coating; silver, white bead; zinc, no metal but the white oxide.

Minerals may be held in the flame with forceps to determine whether they contain sulphur or arsenic, and to give a flame-test, as in Fig. 27.

The glass tubes shown in Fig. 22 are for heating certain minerals to determine whether they contain water, arsenic, carbon, sulphur, change of color, mercury, and other properties.

Some minerals, such as cobalt compounds, iron and nickel, become magnetic after heating on charcoal.

All minerals that contain sulphur should be roasted before being subjected to blowpipe test. As some ores contain both arsenic and sulphur, and as each gives off fumes, a good test for sulphur in the presence of arsenic is to grind fine the mineral under investigation, mix it with soda, and melt in the loop of the platinum wire. When cold, crush the bead on a clean silver coin, and moisten with a drop of water. If sulphur is present, the coin will be stained brown. Usually, however, the presence of sulphur can be detected by the sulphur smell given off when heated before the blowpipe. If it is desired to pan such ore, grind it and roast it carefully over a fire, stirring meanwhile.

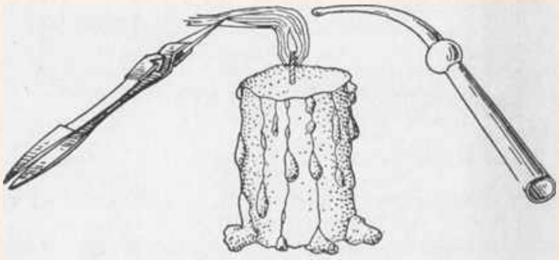


FIG. 27.—Holding mineral with forceps.

Arsenic, antimony, and lead spoil the platinum wire, so bead tests should not be made.

Field Chemical Tests

Apart from those tests described under the blowpipe, reliable assays may be made of copper, gold, lead, and silver ores by field chemical outfits. These weigh about 20 pounds and cost $60 from The Braun Corporation, Los Angeles, California. Such outfits include a book of instructions, enough chemicals for 150 assays, a pulp-scales and button balance, and test-tubes. The ores must be finely ground, for which a small pestle and mortar is provided. **Copper** is determined by dissolving the ore in nitric acid, and adding ammonia. This gives a blue coloration, which is examined through a copper gage. **Gold** is dissolved by aqua regia (3 parts muriatic and 1 part nitric acid), and precipitated from the liquor by mercury. The mercury is dissolved, leaving a pure bead or button of gold, which is weighed on the button balance. **Lead** is reduced to a sponge, which is re-dissolved and precipitated, again reduced to sponge, then pressed, dried and weighed. In assaying silver ore, the gold solvent and the silver solvent are combined, and the silver is precipitated on zinc. It is re-dissolved and the quantity determined by the amount of a standard solution required to precipitate the silver.

RESPONSE OF CERTAIN METALS TO GAS FLAME AND ACID[1]

Name	Specific gravity	Effect of oxy-gas flame	Effect of nitric acid	Effect of hydrochloric acid	Melting point, degrees C.
Aluminum	2.70	Ignites; white oxide	Slowly soluble; colorless solution	Quickly soluble	658
Chromium	6.92	Ignites; dark oxide	Insoluble	Soluble if hot	1505
Copper	8.93	Melts; dark oxides	Green solution	Insoluble	1083
Brass	.....	Melts; darkens; may ignite	Green solution	Insoluble	
Gold (fine)	19.32	Melts cleanly	Insoluble	Insoluble	1065
Gold (ordinary)	.....	Melts; darkens	Insoluble	Insoluble	
Iron (steel)	7.85	Ignites; sparkles; dark oxides	Insoluble until scratched	Soluble; brown solution	1505
Lead	11.34	Melts, then ignites	Soluble in warm, dilute acid	Insoluble but slowly soluble in hot acid	327
Mercury	13.6	Boils; evaporates	Colorless solution	Insoluble	
Nickel	8.6	Blackens	Green solution	Slowly soluble	1452
Nickel silver	.....	Blackens	Green solution	Slowly soluble	
Palladium	12.16	Melts; swells	Brown solution	Insoluble	1542
Platinum	21.37	Melts cleanly	Insoluble	Insoluble	1750
Silver	10.50	Melts; spits	Colorless solution	Insoluble; but in hot acid slowly changed to the chloride	961
Tin	4.31	Burns to dark oxides	Insoluble; but converted to gelatinous solid	Slowly soluble; but quickly if hot	232
Zinc	4.1	Ignites to white oxide	Colorless solution	Colorless solution	419

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[1] From C. M. Hoke, "Testing Precious Metals," Jeweler's Technical Advice Company, New York.

In 1935 The Jewelers Technical Advice Company, New York, published at low price Miss C. M. Hoke's "Testing Precious Metals." It is a practical and well-written booklet of 60 pages, mostly on gold, silver, palladium, and platinum. What constitutes green, red, yellow, and white golds; coins; silver alloys; and miscellaneous alloys; and how to test them by means of a flame and acids; also, tests for nickel, platinum, and stainless steel are told in simple language. The equipment required and where to get it are listed. Karat and specific gravity are explained.

Measuring Instruments

To be well equipped, a prospector or party should carry a good compass, a 100-foot tape, pocket aneroid, pocket lens, and thermometer. All instrument dealers in cities and some storekeepers in mining towns carry all or some of them in stock or can procure them on request.

Compass. Experienced prospectors, explorers, and hunters have the natural gift of orientation or direction, yet a compass should be carried. Even prospectors become lost in woods or bush and in arid parts. There is a varied selection of compasses, from the case style to the Brunton transit. A watch size (say, 2 inches across), brass, hinged-case compass, jeweled center with throw-off needle, as shown in Fig. 28, costs about $1.25 (5 shillings) and should be sufficient. The Suverkrop transit, developed by Lew Suverkrop, Bakersfield, California, is one of the latest models of pocketable transit, indicating vertical and horizontal angles with an accuracy of 5 minutes of arc.

Tape. A 2- or 3-foot rule is useful, but a 100-foot cloth or steel tape is necessary for accurate measurements. These cost about $5 to $10 (20 to 40 shillings).

With care, using a good compass and steel tape, a prospector or engineer can get a fair approximation of his underground workings and can make fair connections between winzes and raises, determine where to start other workings underground and on the surface, and lay out a surface plan. The author has done this.

Aneroid. The aneroid barometer (Fig. 29), watch-size, costing $9 or 36 shillings, shows altitude and atmospheric pressure. On the scale the inner figures represent inches of pressure, and the outer figures mean feet of altitude. Approximately every 1000 feet in height climbed is equivalent to ½ pound pressure less. For instance, the author was for some time at 6000 feet in the Sierras of California where the pressure was 12 pounds per square inch, whereas the sea-level pressure is 15 pounds, nearly. By reading an aneroid at regular intervals a rough topographic map may be sketched of the country traversed. Also, the elevation of the outcrop of a vein may be plotted, and the depth of a shaft may be determined.

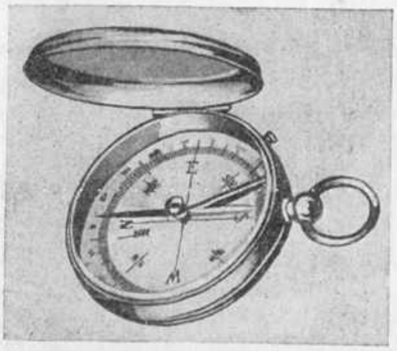


FIG. 28.—A handy and reliable compass, as described.

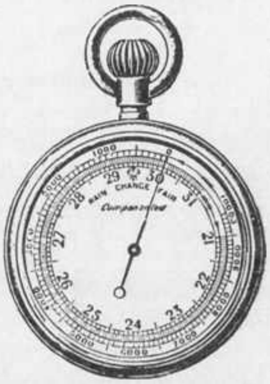


FIG. 29.—A pocket aneroid, as described.

Lens. A good lens is extremely useful in identifying rocks, minerals, and metals and is generally carried by prospectors. One handy style is a small lens and compass combined, the former folding under the latter when not in use; it costs 50 cents or 2 shillings. Other styles, with one, two, or three folding lenses, cost 60 cents to $2 or 30 pence to 8 shillings.

Thermometer. Rugged yet accurate thermometers cost little (60 to 90 cents or 30 to 45 pence), occupy little space in a kit, and will be found useful.

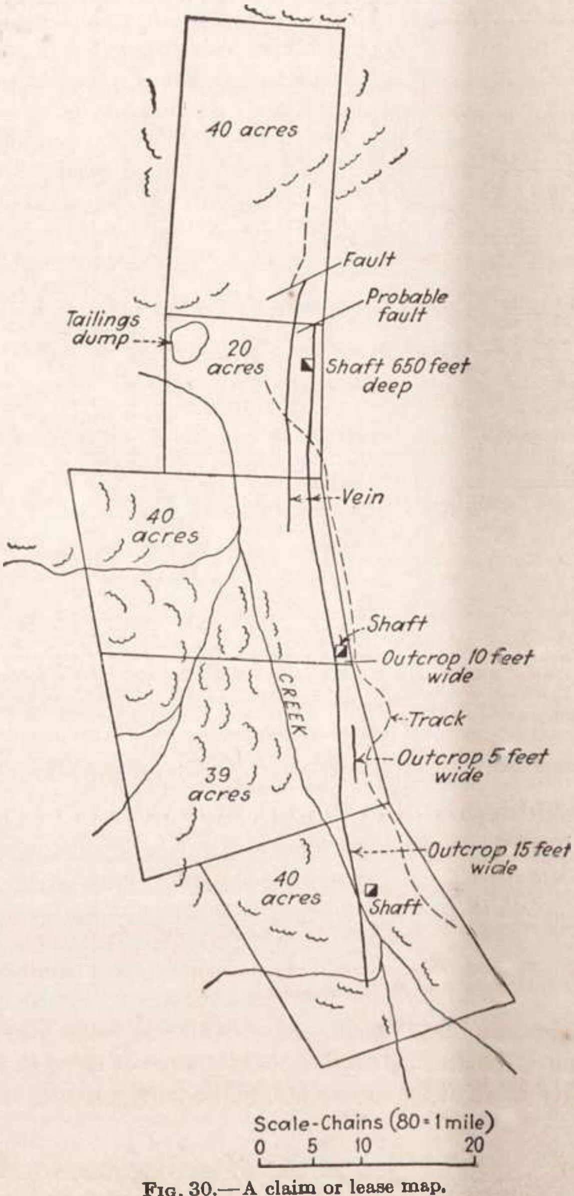


FIG. 30.—A claim or lease map.

Maps

Every metal prospector or miner should be able to sketch and understand simple property, mine, and geologic maps. Many coal miners can "read" a mine map. As a rule, maps consist of a plan and a longitudinal section. The former may be explained as looking down at the surface or into the mine workings as if the

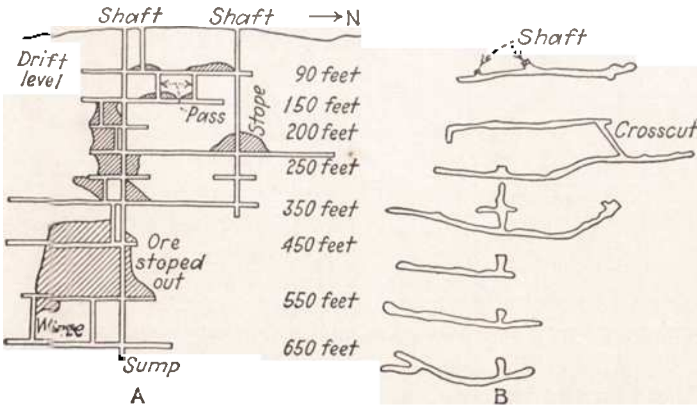


FIG. 31.—Compass survey of a silver mine. *A*, longitudinal section; *B*, plan.

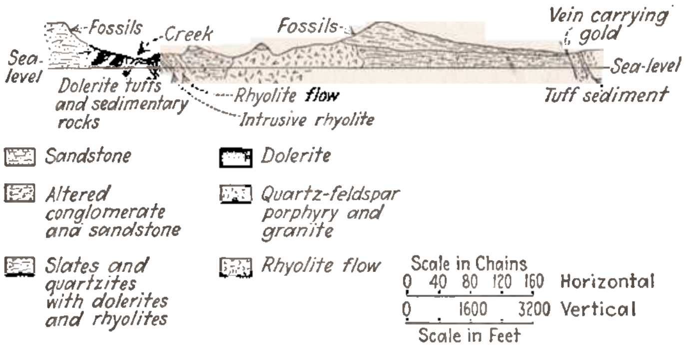


FIG. 32.—Geology across the Yalwal goldfield, New South Wales, Australia.

FIG. 33.—A topographic map. The interval or height between each line is 50 feet.

country were removed from the surface downward. A section may be defined as looking at the mine workings or across country as if the rock in front were removed from one side. Figures 30 to 33 are self-explanatory and are simple maps. The claim or lease map shows the important surface features—areas, outcrops, hills, creek, shafts, and track. The compass survey of a small mine reveals the levels and where ore has been stoped out. The geological cross section explains how the various rocks lie in relation to a gold vein. The topographic map shows lines of equal altitude ranging from 2400 down to 1600 feet, with forest, swamp, and creeks. Maps are a great help, cost little, and occupy small space. State and Federal departments sell them at low price, and Government travel bureaus, also railway and steamer companies, give useful maps to anyone interested. For a man in a foreign country or traveling, an atlas is useful and may be purchased for as low as 50 cents or 2 shillings or, a better one, for $2.50 or 10 shillings. Maps tell a person where he is and where he is bound.

Pocket Microscope. Two useful pocket microscopes are available for the field: The vest-pocket size costs $1.50, magnifies 20 times, and has an adjustable focus. The coat-pocket size costs $4.75 and is adjustable to magnify 40, 50, or 60 times or any magnification within this range. It is 5 inches long and nearly ¾ inch in diameter. A small mirror near the objective aids in illuminating the object under observation. A removable cap protects this mirror and objective when the instrument is not in use. The Fisher Scientific Company, Pittsburgh, sells these pocket microscopes.

Portable Ultra-violet Light. Of interest to the prospector looking for fluorescent mineral is the portable ultra-violet light made by the Ultra Violet Products, Inc., Los Angeles, California. Their type lamp no. 120 is for prospecting and mining and is capable of detecting scheelite and other fluorescent minerals at a distance of 10 feet or more under normally dark conditions.

Fluorescence of Minerals

When the ultra-violet light or ray is directed on to certain minerals, they glow or display a fluorescence of colors. The better known minerals that do this are calcite (calcium carbonate), fluorite (calcium fluoride), scheelite (tungstate of lime), sphalerite (zinc sulphide), and willemite with franklinite (zinc silicate with zinc, iron, and manganese). The purer the minerals the greater is their fluorescence. Advantage is taken of this property to tell the approximate grade of these ores in a mine or in a concentrating plant.

It is not very likely that a prospector would carry an outfit to detect fluorescent minerals, but an argon mixed-gas lamp-bulb, which fits into any electric-light socket, costs 60 cents, or a case of 10 specimens with a lamp cost $3.25 to $4.25 from Ward's Natural Science Establishment, Inc., Rochester, New York. The lamp may be fitted to a portable holder or battery to permit moving around underground or in a mill.

As the ultra-violet light is somewhat severe on the eyes, care should be taken in this regard.

Following is a list of makers and dealers in laboratory, mine, and mill supplies. Prices are approximately similar, so it is merely a question of dealing with the firm nearest the claim or mine being worked.

Braun Corporation, Los Angeles, California.
Braun-Knecht-Heimann Company, San Francisco, California.
*Burrell Technical Supply Company, Pittsburgh, Pennsylvania.
Cave & Company, Vancouver, British Columbia, Canada.
*Central Scientific Company, Chicago, Illinois.
Denver Equipment Company, Denver, Colorado.
Denver Fire Clay Company, Denver, Colorado.
Eimer and Amend, New York City.
Elliotts & Australian Drug Proprietary, Sydney, New South Wales, Australia.
*Fisher Scientific Company, Pittsburgh, Pennsylvania.
Macdonald, Adams & Company, Johannesburg, Transvaal.
Mine & Smelter Supply Company, Denver, Colorado.
Sargent & Company, Chicago, Illinois.
*Arthur H. Thomas Company, Philadelphia, Pennsylvania.

(The firms starred (*) are mainly chemical supply houses and do not stock many of the items carried by the others.)

CHAPTER XV

DEVELOPING AND EQUIPPING A PROSPECT

Opening a Vein

When an ore-shoot has been found it should be followed. Crosscut tunnels are not advisable in the early stages of development unless conditions are unusual. Either shafts (vertical or inclined) or adits, where possible, offer the best means for exploration. A good cross-tunnel side offers a temptation that often leads to foolish expenditure of money. Often the amount thus spent would have been enough to explore several prospects or to prove a good property to considerable depth. As a general rule, long crosscut tunnels should not be driven unless the ore is rather well proved to the depth that will be obtained by the tunnel. Where the topography (surface) is favorable, tunnels are of course the cheapest method of development and should be driven in at frequent intervals. However, the country is often such that shafts must be put down, and they should follow the vein as long as the property is in the prospect class. Drifts, as with tunnels, should be driven at frequent intervals. It is advisable to do the underground work in the cheapest and quickest way possible, in the early stages of development, even if some of the work will not be available for future use. The prospector prefers an adit to a shaft, as the adit drains itself if water is encountered.

Prospecting Shafts

Shafts may be round or rectangular; the former may be 5 feet in diameter to a depth of 30 feet, and the latter 4 by 6 or 8, 5 by 9, or 6 by 8 feet inside timbers, to 100 feet in depth. To a depth of about 8 feet, rock and ore can be shoveled to the surface, but after that a windlass must be used. To make a high dump, if the ground is level, it is best to timber with round logs to a height of 6 to 10 feet above the shaft, as in Fig. 34. Rock is then dumped all around and built higher if desirable. The dump depends entirely upon the topography of the country near by. A windlass is built on top as shown in Fig. 35. One or two men can work it, two especially when depth is attained. Not including the value of his time, which the prospector seldom considers, shaft-sinking by hand and windlass costs $8 to $16 a foot for a shaft 4 by 6 feet and $21 for one 5 by 9 feet. These costs may be increased by any extraordinary conditions of rock, timber, or water.

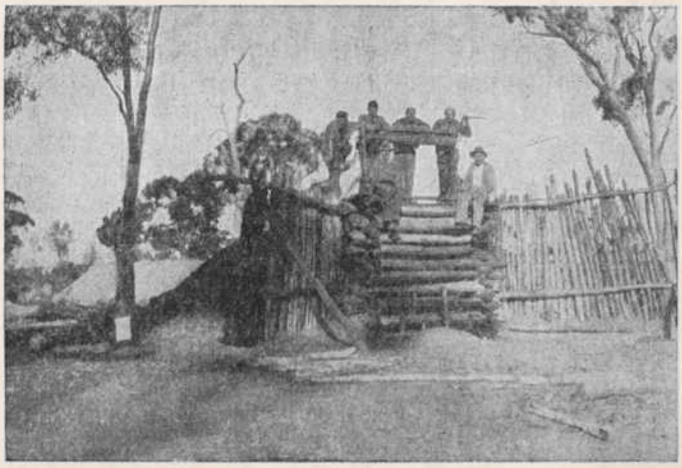


FIG. 34.—How they build up sets above a prospect shaft in Western Australia. The pole fence or stockade is for ore.

A $\frac{3}{4}$- to 1-inch hemp or $\frac{3}{8}$-inch steel rope is strong enough for shallow shafts.

In *Engineering and Mining Journal* for March, 1935, Charles Labbe tells of the deepening of a prospect shaft, 5 by 7½ feet, from 50 to 251 feet for $3000, or $15 a foot, in desert country, California. A windlass had carried it down to 50 feet on a quartz vein which lay in beds of schist, quartzite, and shales, with sills of intrusive quartz dipping 30 degrees. A 25-foot head-frame consisting of two braced uprights, platform, and ladder to wheel

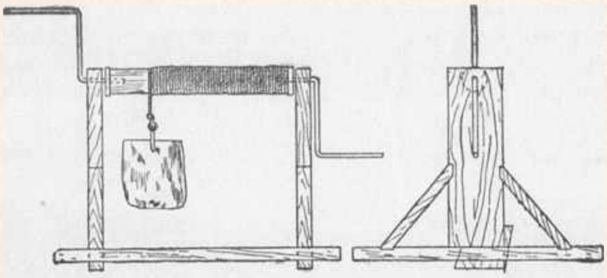


Fig. 35.—Hand windlass for prospecting.

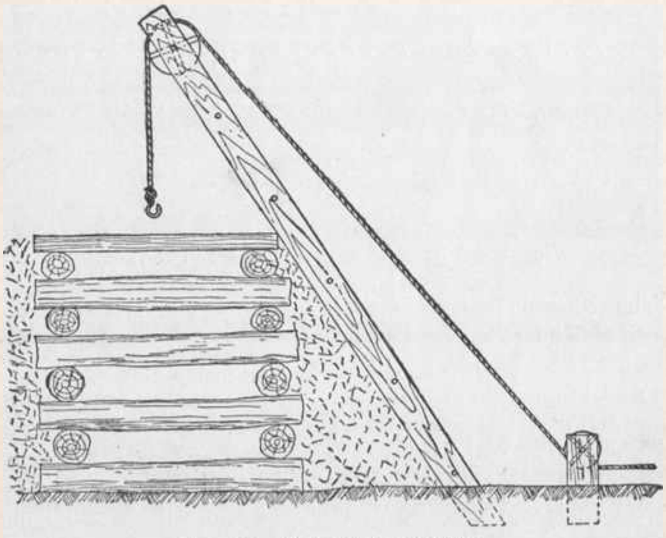


Fig. 36.—A simple horse whip.

cost $165. The other equipment consisted of a hoist and compressor driven by tractor engines, small jackhammers, and a bucket dumper. Dynamite was used. Timbering was simple because the ground stood well. The job took 98 days, two men working in the shaft and two on top. Labor cost $11 a foot.

E. D. Gardner and C. H. Johnson of the Federal Bureau of Mines report $14.35 a foot for sinking a 7- by 10-foot shaft from 65 to 104 feet in Arizona and $15.50 for a 6- by 8-foot shaft from 150 to 316 feet in Oregon. Both shafts were vertical, and gasoline hoists and air-drills were used in sinking.

Buckets are generally of rawhide, light sheet iron, or half barrels holding 150 to 300 pounds of rock.

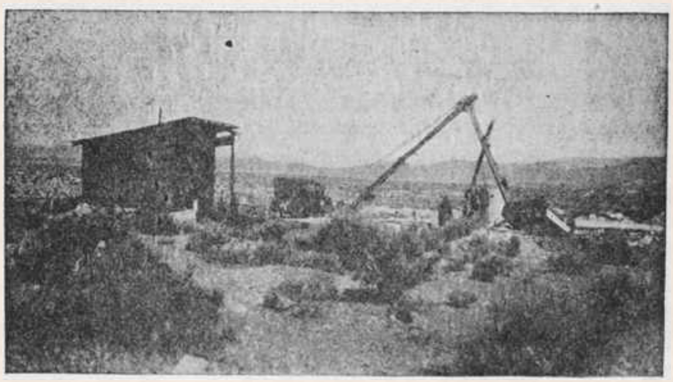


FIG. 37.—A horse whip at a prospect in Nevada.

The economic limit of hoisting by hand is 100 feet, although a depth of 350 feet has been sunk by windlass. Two men can haul about 4 tons a day from 100 feet. After the 100-foot point is reached it is advisable to put up a horse whip. The simplest type, and serviceable, is that used in Australia. It may be put together and erected quickly. Figure 36 is a sketch of this simple whip, and Fig. 37 is a photograph of one in Nevada. The pole is made up of two pieces of 2- by 9-inch board, with 2-inch dividers between, and is bolted together. If boards are not available, a straight pole, with the top sawed out to admit the sheave-wheel, is just as good. A horse whip of this type will hoist a large quantity of rock. Shaft-sinking with a whip may cost $16 per foot for a 4- by 5-foot section.

Another type of horse-driven machine is a whim. It is fairly expensive and takes some time to erect, as the drum must be bolted down and some sort of head-frame put up. What is known as the Davis hoisting whim is a good machine. The size 1, for one horse, has a capacity of 800 pounds lifted at the rate of 75 feet per minute. It is a durable horse-power hoist, with safety brake. The drum is driven by a friction clutch, and the operations of hoisting, dumping, and lowering can be performed with the horse in constant motion. It is readily knocked down for mule-back transportation and costs $100 or, with complete head-frame, $50 extra. A complete prospector's outfit, including horse whip with head-frame and bolt, ventilating fan and jack, 300 feet of light air-pipe, wire rope with safety hook attached, two size 6 ore buckets, mine gong and cord, bucket car, ore car or truck, 100 feet of track, and blacksmith outfit, weighing approximately 6000 pounds, may be obtained new for under $1000 or £200.

The heaviest work at the shaft collar is dumping the buckets, although there is considerable knack in handling them. Where a small head-frame has been erected and a heavy steel bucket is used, a self-dumping arrangement is easily fixed by attaching a chain, with hook at one end and bolted at the other end to the ring at the bottom of the bucket of the head-frame. When the bucket has been hoisted to the shaft collar, the hook is put in the ring; then the horse is backed, or the engine is reversed. This allows the chain to take the weight, and the bucket empties on the dump or into a chute.

Buckets are handled in drifts by means of a flat car running on rails.

After the extent of an ore deposit has been roughly determined, it may be found more economical to sink a second shaft. Its size should be considered first, and then its most convenient position. It is a great advantage to have two shafts. For one thing it is difficult to ventilate the mine properly without two openings. Another benefit comes from using one for hoisting ore and the other for hoisting and lowering men and handling timber and supplies. From a safety consideration two shafts are desirable, as in case of accident to one the men have the other for escape.

Head-frames

Figure 38 shows a head-frame good for sinking a two-compartment shaft to a depth of 500 feet. Many designs could be submitted, but this type has been found satisfactory in operation and economical in erection.

Where the use of skips or the hoisting of mine-cars or cage is contemplated, it is better to sink shafts with a 4½- by 5-foot hoisting compartment. A 5- by 9-foot shaft would provide a 4½-foot square compartment and 4- by 4½-foot manway (Fig. 39).

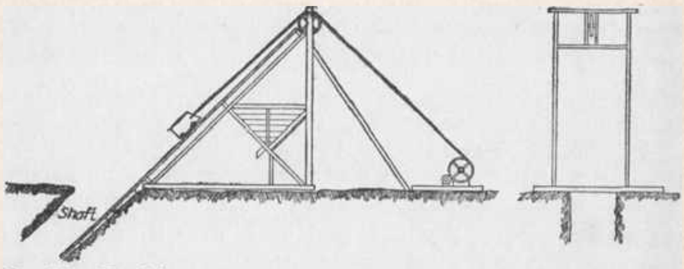


FIG. 38.—Head-frame over a small incline shaft, with skip and ore bin.

There are numbers of reputable manufacturers and dealers in used equipment throughout the country, especially in mining regions; and as a hoist is the first requisite for a mine opened by shaft, there are many compact and self-contained oil engines of all sizes. Some of them use kerosene, which is a cheap fuel. Second-hand ore cars and skips are always obtainable. In buying such used machinery, see that cracks or holes have not been filled with lead or other material and then painted over.

If guides are used to steady the buckets in shafts, a cross-head is needed. There are several types of these in use. They are free on the hoisting ropes but are liable to stick in the shaft, which results in accidents, so they should be watched.

A platform should be placed at least every 30 feet in the manway compartment. This is a safety precaution; if a round breaks on the ladder or a man loses his balance, he will not fall more than

30 feet. The ladder should be staggered at each landing station so that it will be necessary for the man to step off one ladder at the landing and walk over to the next one. The timbering between the manway compartment and the hoisting compartment usually takes up about 6 inches of space. It is a good plan to line the interior of the hoisting compartment with boards so that there will be no projections upon which men or material being lowered or hoisted may be caught.

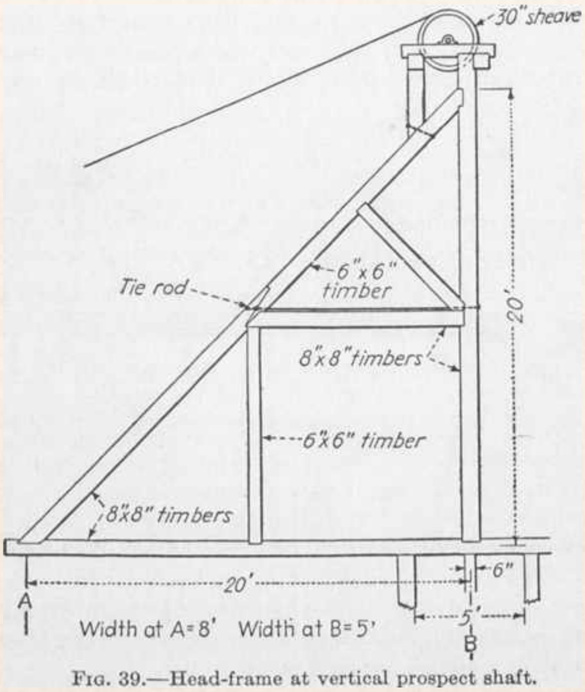


Fig. 39.—Head-frame at vertical prospect shaft.

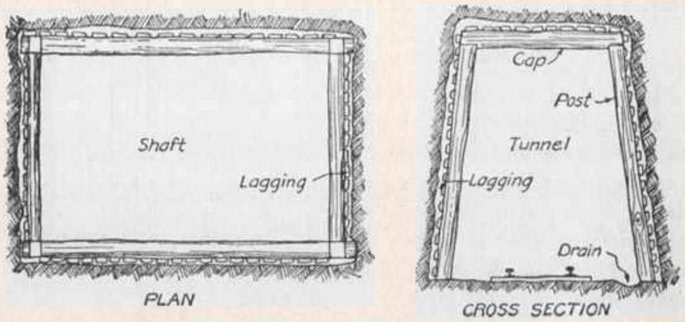
If the hoisting compartment is carefully boarded, the shaft is ventilated, as the movement of the bucket or cage as it is lowered and raised tends to create a draft. The air sucked down through the manway escapes through the hoisting compartment. If there is no seal between the hoisting and manway compartment, there is no way to create a circulation of air.

Drifts and Tunnels

Although many prospecting drifts and tunnels are mere gopher holes, the minimum size, if any orebody of value is being followed, is 3½ by 6 feet in the clear. It is rarely necessary to drive one larger than 5 by 7 feet in the clear; but when a large amount of work is to be done, it is better to make it this size. It is unnecessary to have the back higher than 7 feet; a high back is dangerous, and sounding of the ground is more difficult. All drifts and tunnels should be run on a grade so that the drainage will be toward the shaft or portal. Where there is little water, a grade of 1 foot in 400 feet is ample, but with a large flow, 1 foot in 100 feet. It is easy to push an empty car against such a grade and to control a full car coming out.

Timbering

Some ground stands without timbering; other rock requires close timbering. Where timber is plentiful, logs from small trees make good sets for shafts and caps and posts for tunnels. The bark should be peeled off before using. The simplest form of roof support is a horizontal piece set at each end in hitches in the walls. When the sides of the tunnel are of poor holding ground, posts are used with a cap; and if the floor is soft, a sill



PLAN

CROSS SECTION

FIG. 40.—Timbering in a shaft and tunnel or drift.

piece is put under the posts and forms a four-piece set. The lining of shafts and tunnels behind the sets is done by driving lagging or spiling. This is about 1½ to 2 by 6 to 9 inches and 5 feet long and is split from logs cut from large trees, or else it may consist of small round logs. Wedges are driven behind the lagging to keep it tight against the sets. Shafts frequently require nothing more than the square set, although for safety, in preventing rock that slabs off the sides from falling down the shafts, lagging is advisable. Drifts often need only lagging above the cap-piece. If ground is likely to swell, it is best not to put the lagging too close together; leave plenty of space for such ground to crowd between the lagging. Figure 40 shows shaft and tunnel timbering.

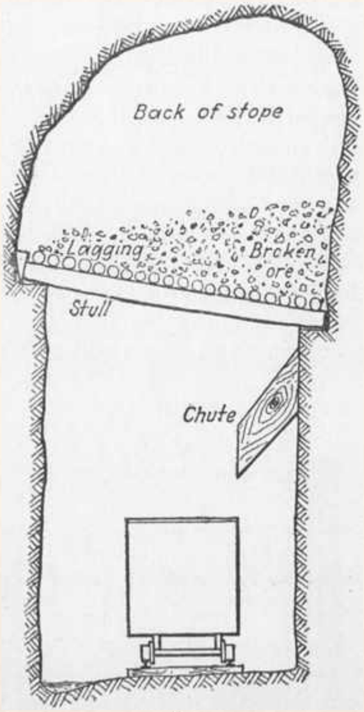


FIG. 41.—Stoping above stull timbering.

Stoping

In starting a stope in good standing ground the simplest satisfactory method of timbering is with stulls, as in Fig. 41. Hitches are cut in the walls of the drift, and the timber slipped in and wedged from the top end. Round or flat lagging is laid across two stulls, and the breaking of ore is begun. Stulls or pillars of rock may be put in or left as stoping moves upward. When a stope has advanced the length of several sets, chutes must be built at intervals of, say, 30 feet, so as to pass the broken ore down to the car on the level below. Chutes may be constructed of rough timber, with a door consisting of 2- by 9-inch plank and sliding in place between two slots.

This type of work may be considered as open stoping. If the open space is filled with waste as the breaking of ore proceeds upward, this is termed cut-and-fill stoping. When only enough ore is drawn through the chutes to allow for the swell of the broken ore (half as much more as ore in place), and the remainder is drawn later, this is shrinkage stoping.

Ventilation of Shafts and Tunnels

A shaft or tunnel without another outlet to the surface may be considered a dead-end. Little air circulates. Consequently it becomes hot, humid, and more or less foul, and this condition renders little work possible. Some method of ventilation usually becomes necessary by the time that a shaft is 50 feet deep or a tunnel is 100 feet long. The first contrivance used at prospects is a windsail or a canvas tube up to 10 inches in diameter, with a wide bell-shaped top attached to something at the top of the shaft or mouth of the tunnel and moved around as the wind shifts. This device will carry a large volume of air to the bottom or face.

It might be said here that in hot weather, especially in arid regions, it is advisable to erect some sort of cover or shelter above a shaft. This may be done quickly by putting four posts into the dump around the shaft, at a little distance from it, and laying a few poles across, on which is laid brush or old canvas.

When the workings get too deep or too long for such methods of ventilation, recourse must be had to a fan or furnace. If water power is available, a fan may be used. Old water pipes and air-pipes are nearly always procurable in many districts, also fans and water wheels (Pelton type). Fans operate as either blowers or exhaust, but the latter is preferable. They are placed near the portal of the tunnel. The air-pipe is fixed near the roof and should discharge as near the face as possible. The whole plant is light and easily moved.

A similar air-pipe may be used for furnace ventilation. An ordinary vertical sheet-iron wood stove will do as a furnace. The air-pipe is connected to a housing about the stove something like a pipeless furnace. When a fire is lighted, air is drawn from the workings—in other words, this is an exhaust system. Stoves should never be set in the workings.

Falling water may also be used to blow air into tunnels and shafts. The water is allowed to drop into the open end of, say, a 6-inch pipe which stands on end in a tub or tank. A foot or two above water-level in the tank a *T*-piece is fitted to the down-pipe. The entrained air from the top of the pipe can not escape at the bottom where the water escapes so flows through the outlet at the *T*. This arrangement also may serve for blowing a forge fire.

If compressed air is available, the Venturi system is effective. A little air is blown into a bell-mouthed pipe lying on the floor or attached to the roof. This air draws in a considerable volume of free air and carries it to the face. Also, a little air allowed to escape from valves along the air-pipe helps ventilation.

Water

Generally, in sinking a shaft, water must be hoisted regularly after water-level has been reached. Most shallow shafts can be sunk without the aid of a pump. The miners working in the bottom of a shaft dig a small sump into which the water drains. As soon as it fills, the water is bailed out with a bucket, emptied into the hoisting bucket, and hoisted to the surface. In this way a considerable seepage may be successfully handled.

Drilling

Until a prospect warrants it, all drilling of holes is done by hand. For single-hand work a hammer weighing from 3 to 4 pounds is generally used; whereas in double-hand work, where one man holds the drill and another strikes it, a 7- to 8-pound sledge is required. A depth of about 4 feet is the economic limit for hand work. The starter drill is about 18 inches long, the set of steel increasing by foot lengths as depth is gained. Skill is required to sharpen and temper steel.

Where and how to place drill-holes is discussed later on. If bituminous coal or lignite is being developed, an auger is used.

It is somewhat similar to the ordinary brace and bit. The auger is usually 5 feet long and has a peculiar-shaped cutting edge (as if the auger were cut off square, then split and each half bent outward) which can be kept sharp by filing. It is screwed into the brace, which is worked with both hands while it is being held against the miner's body (see Fig. 42).

Three types of drilling machines are commonly used in mines. The first of these are high-speed hammer-drills using hollow steel, through which a jet of water is fed to the bottom of the hole to wash out the cut, also to prevent any dust from rising, which in certain kinds of rock is injurious to the lungs. These drills are also universally used for driving tunnels and drifts and have almost entirely superseded the old piston type. Small air hammer-drills held in the hands of the operator are used for sinking. These drills are self-rotating and can be used with or without a water-jet. This type drill is also frequently used for driving in soft ground, but when used for this purpose it should preferably be mounted on a column or cross-bar. The third type of machine is the stoping drill, which is usually non-rotating and has to be rotated by hand. It is held against the face by air pressure in the air-fed cylinder. The placement of drill-holes for most effective results can be learned by experience only. In Fig. 43

FIG. 42.—A drill or auger for coal.

holes marked 1 are cut holes or lifters; 2 are relief holes; and 3 are trimming holes. More or less are used, according to the character of the rock.

The cut holes and nearer relief holes are usually drilled first. In the sketch (Fig. 44) of a tunnel face, holes 1, 2, and 3 are fired first,

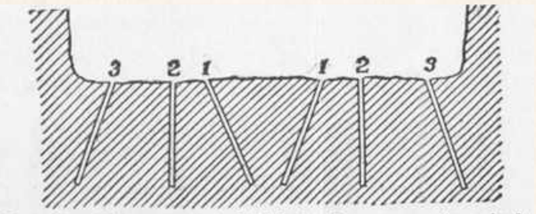
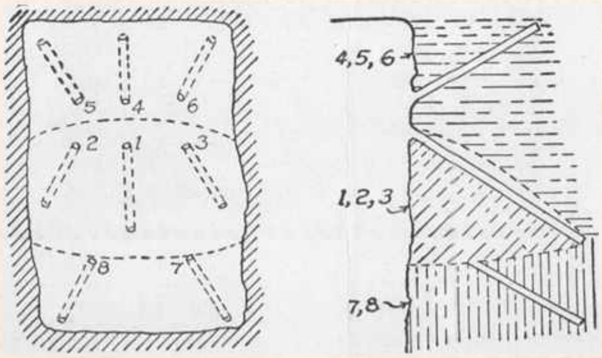


Fig. 43.—Placement of drill holes in prospecting shaft.



PLAN SECTION

Fig. 44.—Face of tunnel drilled for blasting. The shaded areas show what each set of holes breaks.

then 4, 5, and 6, followed by 7 and 8. The holes 4, 5, and 6 are known as uppers. If the ground is fairly soft, fewer holes will do the work.

Detachable bits, which screw onto or into drill steel, are suitable for drilling many types of rock and less steel is needed.

Use of Explosives

Due regard for safety and effectiveness requires that the prospector have a knowledge of explosives. Carelessness and overloading may be wasteful of life or limb as well as of explosives. The apparent contempt with which explosives are sometimes handled is foolhardiness.

Dynamite. Dynamite of various grades and strengths is made into cartridges of several sizes which are sold in wooden cases and in cartons that hold 50 pounds. Common dynamite consists chiefly of a mixture of nitroglycerin and some absorbent, such as wood pulp or sawdust, and an oxidizing material, such as sodium or ammonium nitrate. A tough paper encloses the cartridge. Ordinary dynamite of different grades will freeze, but the specially prepared low-freezing dynamites may be used at fairly low temperatures without freezing. When heated to about 200°F. dynamite explodes as the result of a sharp shock or blow. Dynamite also explodes as the result of a shock or blow at ordinary temperatures, but the violence of the shock or blow required to explode it becomes less as the temperature increases. When dynamite is heated to 350 or 400°F., it explodes from heat alone. Liquid nitroglycerin, as used in shooting oil wells, is very sensitive to shock. Nitroglycerin is readily taken into the body

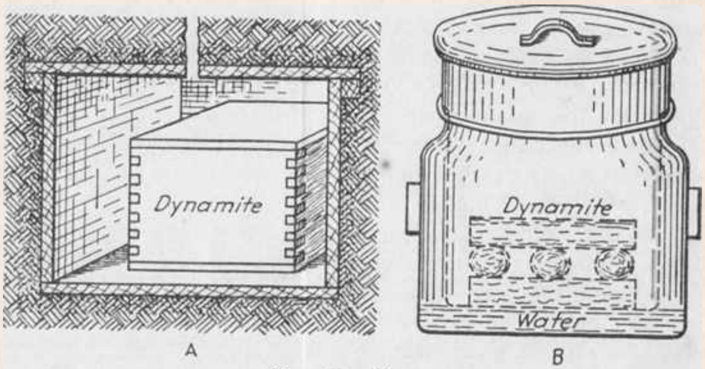


FIG. 45.—Thawers.

through the pores of the skin. It makes the heart beat faster and usually causes headache in persons not accustomed to it.

If dynamite freezes, it should be thawed carefully at a temperature not higher than 100°F., or about body heat, or half as hot as boiling water. In Fig. 45*A* is shown how a thawer may be made in camp for a case or a few pounds of dynamite. The door end has been cut off to show the interior. The opening at the top is for ventilation. For a few sticks of dynamite a double-boiler cooking utensil will serve. The warm water surrounds the covered pot in which is placed the explosive (Fig. 45*B*).

Detonators, Fuse, and Stemming. The accessories required in blasting rock are caps or detonators, fuse, cap crimpers, dynamite, tamping rod, and stemming material. Detonators are small (up to 2¼ inches long and ¼ inch in diameter) copper cylinders, closed at one end, and contain a charge of a highly explosive mercury or other fulminate, set off by the spit or sparks from the fuse when this is inserted at the open end. The cap is squeezed onto the fuse by means of a crimper, somewhat similar to a pair of pliers. Caps are sold in boxes of 100. Some detonators are made of aluminum, and another detonating material is lead azide.

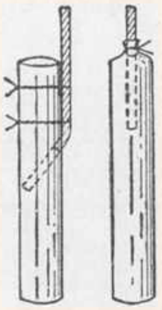


FIG. 46.—Two ways of arranging primer and cartridge.

The primer, as the cap and the attached fuse are called, is next put into the dynamite cartridge. A no. 6 cap is commonly used, but a no. 8 should be used for gelatine dynamites. A hole is made in the dynamite with the handle of the crimper or a piece of wood about the size of a pencil. The primer is then inserted, and a cord tied around the cartridge and the fuse. If the hole to be blasted is wet, put some soap or tallow around where the fuse enters the cartridge. The explosive, but not the primer, should be forced firmly to the bottom of the hole. Figure 46 shows a simple method of preparing the cartridge.

The amount of explosive and the length of fuse depend upon the depth of the hole drilled, the toughness of the rock, and the distance that a man has to go after lighting the fuse. As a general rule, allow, 1 minute for each 2 feet of fuse. Some of the dynamite is put into the hole, then the primer cartridge, and next more sticks of dynamite. Use care in forcing it firmly to the bottom of the hole with a wooden tamping rod, made of a straight sapling from a tree or from a shovel or broom handle. Loam, sand, or clay, called stemming, is then dropped in the hole and tamped or pressed down until it is filled to the top. In a coal mine never use coal dust as stemming, because it may start an explosion.

Figure 47 shows a charge before tamping.

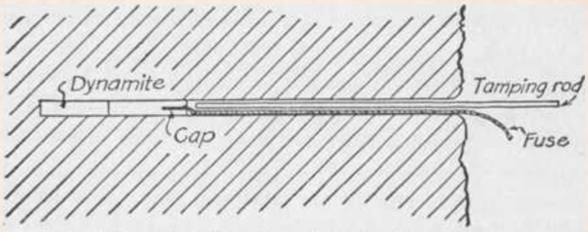


FIG. 47.—Charging a hole for blasting.

To prevent débris or rich ore from flying, if the work is being done in the open, the top of the hole should be covered with logs or other available material. Logs and tree stumps can be split in the same manner as rock, but much less explosive is required.

There are three methods of dislodging or breaking a boulder—namely, blockholing, snakeholing, and mudcapping or bulldozing. The first consists of drilling a hole, slightly deeper than halfway into the rock, so that the center of the charge is at the center of the rock, and giving it a small charge, say half a stick of dynamite. The second method is that of punching a hole under but immediately against the bottom of the boulder and loading it. This will cause the rock either to roll out or to break up. Mudcapping is used underground as well as on the surface to break up large pieces of rock and ore. The dynamite is removed from its container and packed in a compact conical heap on the rock. After inserting the cap and fuse, cover the whole with several inches of sticky mud, and fire. No hole is bored. Never put gravel or stones on the mud, for some one may be hit with the flying débris.*

Safety Notes. Some of the "don'ts" in the use of explosives are: Don't crimp a cap with the teeth; don't open a box of caps or dynamite with a hammer, nail, or hatchet; don't store caps and dynamite near one another; don't smoke or carry open lights while carrying explosives; don't use frozen dynamite; don't load a chambered or sprung hole until it has cooled; don't go near a misfire for 3 hours or attempt to remove the stemming or charge of any misfire—drill another hole near it and explode that.

The use and misuse of explosives are responsible for many deaths in mines in all countries. The most dangerous gas in fumes of explosives is carbon monoxide, which frequently becomes concentrated in the air at newly blasted faces; so care must be exercised after blasting, and ventilation attended to. Gelatine and ammonia dynamites produce less asphyxial gas than other classes of dynamites.

Explosives can generally be obtained from or through local stores or by writing the following makers: United States: Apache Powder Company, Benson, Arizona; Columbia Powder Company, Tacoma, Washington; E. I. du Pont de Nemours & Company, Inc., Wilmington, Delaware; Giant Powder Company, Giant, California; Hercules Powder Company, Wilmington, Delaware; Atlas Powder Company, Wilmington, Delaware; Illinois Powder Manufacturing Company, St. Louis, Missouri; The National Fuse & Powder Company, Denver, distributor for Rocky Mountain region; Trojan Powder Company, Allentown, Pennsylvania. Canada: Explosives Division, Canadian Industries, Ltd., British Columbia, Manitoba, Ontario, Quebec. Australia and New Zealand: Nobel (Australasia) Proprietary, Ltd., agents in principal

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* "Blasting," an extremely useful pocketbook, bound in artificial leather, fully illustrated with practical drawings, may be obtained without cost by writing to the E. I. du Pont de Nemours & Co., Inc., Wilmington, Delaware. The company's comprehensive 1942 edition "Blasters' Handbook" has 340 pages and is available for $1.00.

towns and for Fiji and New Guinea. Africa: African Explosives & Industries, Ltd., Johannesburg, Transvaal.

Small lots of dynamite cost 16 to 20 cents (8 to 10 pence) per pound, depending on freight charges.

Handling Broken Rock

In starting drifts driven from the bottom of shafts or in tunnels it is customary to convey broken rock and ore in wheelbarrows to the shaft or tunnel. A useful conveyance in tunnels is a warehouse truck. A bucket or sacks of ore may be stacked on this and pulled with ease. Of course, the floor must be fairly smooth and dry for this method. Such a truck may be constructed on the job. Light metal barrows fitted with wheels having rubber tires are available and suitable. They are used on many construction jobs.

When drifts are long enough, rails are laid. In ordinary prospect work it is seldom necessary to use a rail heavier than 12 pounds per yard, as this is a convenient size. For temporary track 8-pound rail is heavy enough; and where the work is heavy, 16-pound rail is used. Ties or sleepers should be laid at least every 3 feet, sometimes every 2 feet.

Piping

Considerable pipe is used about a mine. There is the pipe for supplying air to the drills. For a mine using 10 drills a maximum size of 2-inch pipe gives service. On the different levels, where the lead is not too long, 1-inch pipe may be used. The delivery pipe to the drills may be 1 inch. A 1-inch pipe is a good size for two drills and may serve to feed three machines; but where the pipe is too small, the friction is increased. The ordinary small drills, such as the stoper and jackhammer, consume 65 to 75 cubic feet of free air per minute, while the larger drills consume 100 to 125 cubic feet.

Bending Rails

The prospector is generally short of funds and is compelled to economize in every way on equipment. To bend a rail he often uses it as a "pry" between two trees or rocks. The best way to bend rails is with a jim-crow—a piece of iron of U-shape, with a large set-screw which works in the center of the U and presses against the rail and so bends it. Where the rail is light, some think that this method is slow, but by using a jim-crow a more even curve can be obtained and a much better track made. Sometimes, if a jim-crow is not obtainable, the rail is placed between two timbers or trees and bent with a screw-jack. In laying curved track always pack up the outer rail with ballast or blocks higher than the inner rail.

Cars

Probably the best mine-car for shafts or tunnels is the standard car with rotary dump. The size generally used is of 16 cubic-foot or 1600-pound capacity. There are several improvements on cars of this kind which make them more tractable, such as roller bearings for the axles and the automatic dumping attachment which opens the gate. Figure 48 is an outline of such a truck made by a Denver firm.

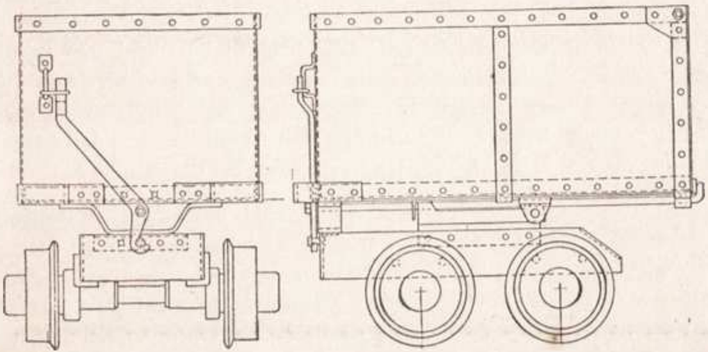


Fig. 48.—End and side views of an end-dumping truck of 1600-pound capacity.

Lighting Underground

Candles and carbide lamps are generally used for lighting in prospect shafts and tunnels; a better light can be obtained from the latter. The cap-lamp size gives good light for 2 hours or more without re-filling and gives a head-on light equal to four to six candles. The carbide is cheap enough and easily procured. Dry calcium carbide is odorless, but on exposure to the air it emits an odor. Always store carbide in airtight cans. Carbide is 62½ per cent calcium and 37½ per cent carbon. When water is added, acetylene gas is generated. It can form an explosive mixture with air or oxygen. Never test for a leak in a large generator with a light; use soapy water, which bubbles.

Certain precautions must be observed with carbide lamps; some accidents happen, although several hundred thousand lamps are used in the coal and metal mines of the world. Only flame safety or electric cap-lamps should be used in coal mines, because although gas may never have been detected in a mine nobody knows when it may be released and accumulate. Thousands of miners have been killed by explosions caused by open lights igniting gas, and many other fires started by open lights igniting flammable materials. In recent years the electric cap-lamp has been more commonly used in the larger metal mines.

Prospecting for New Orebodies in a Mine

Further exploration should be carried on by (1) following stringers of ore; (2) following fractures and contacts with intrusives; (3) following the general trend of previously worked orebodies; and (4) following any indications brought out by a careful study of conditions, such as specially indicative minerals, galena, for example.

Methods of exploration may be by (1) driving shafts, drifts, crosscuts, raises, and winzes or extending present workings and (2) putting in machined-drill holes on the surface, at the face of drifts and crosscuts, at the bottom of shafts and winzes, and in the tops of raises.

Detailed and frequent sampling and mapping of assays are essential as exploration goes forward.

SELLING A PROSPECT

C. W. Wright of the Federal Bureau of Mines offers prospectors and miners some advice on the selling of a prospect, as follows in part:

Many promising prospects are idle because their owners do not have proper reports to present the merits of their properties to potential investors and thus obtain capital for development. It must be mentioned, however, that owners generally are extremely optimistic as to the value of their undeveloped properties, and mining engineers representing buyers are usually conservative and refuse to accept the owners' statements without corroborating evidence. The result is that many good ore deposits remain undeveloped. The owner should realize the risk taken by capital in investing in mining property and not be too exacting in his terms; the engineer in turn should not refuse to accept some uncertainties if the prospect is a promising one and the facts are available in proper report form. The risks can usually be divided between the owner and the investor by a long-term option to give the investor time to explore the property, provided that he agree to spend certain sums or do certain things in development; or by selling the property on a royalty basis with a minimum guarantee, preferably arranging for small payments during the first few years and larger payments later.

If the owner has his mine on the market and it is to be examined by an engineer, it is advisable to have the property in presentable shape—the ladders in repair, drifts cleared, decayed timbers removed, machinery cleaned, broken windows in buildings replaced, and the rails, scrap iron, and other material piled up neatly. This, of course, will not affect the value of the property, but it will aid in giving the examining engineer a more favorable impression and may influence his decision. To assist the engineer, the owner should have copies of the recorded documents showing ownership of property and timber and water rights, maps of mining claims, and plans of the mine workings available for inspection. If the owner makes a report on his property as outlined, such information will be contained in it. The average engineer is just as anxious to give a mine or prospect the benefit of a doubt as the owner is to have him do so, and he welcomes reporting on a mine or prospect that has real merit.

If a claim-owner wishes to interest an investor in his property, he might prepare a report of his own to give an idea of its possibilities. Start the report with a short summary giving the name of the property, its location and ownership, size and type of the deposit, characteristics of the ore and adjacent country rock, the average grade of ore, production if any, the amount of development work, the tonnage blocked out, and briefly describing labor, water, and timber supplies and transportation facilities. Terms for an option and a short statement setting forth the investment possibilities of the property should also be included. This summary will give the reader a general idea of the major features of the report which follows and will assist him in grasping its details.

What to Do with Ore

A prospect may yield ore rich enough to be sent direct to a smelter and thus return a profit for continuing the work. If not all the ore is rich enough for shipment, hand picking, described in chapter 19, may yield a rich portion which can be so shipped. This may be supplemented by a little hand-jig mechanically to concentrate ore from 2 inches down to ½ or ¼ inch, and, to go a step farther, a shaking table may be installed to dress fines below ¼ inch. Further expansion of ore treatment may lead to the installation of some type of small plant, placed as near as practicable to shaft, slope, or tunnel, yet not too close in case of fire. Brief descriptions of suitable equipment and its operation will also be found in chapter 19.

If ores other than copper, gold, lead, silver, and zinc are found, and the prospector is sure from assays or analyses that he has something, he should write the Bureau of Mines or the United States Geological Survey within his own State or the Federal Bureau for the names of buyers and dealers of such ores.

CHAPTER XVI

MARKETS AND PRICES

To be able to sell ore is as important as to find it, and the prospector must keep in touch with the markets, either through correspondence or by reading his local paper or some mining journal which gives weekly quotations for ores and metals. It should be remembered that freight charges and the nearness of a mine to rail and markets are often the deciding factors in its profitable operation. An ore containing a certain quantity of mineral may be mined at a profit in one part of the country but not in another, simply because of transportation costs. Other minerals in an ore make a difference in its value through extra payments or penalties. When gold and silver are by-products of copper, lead, and zinc ores, they are paid for, but zinc in copper or lead ores above a certain percentage is penalized so much per ton. Likewise, silica is penalized in most smelting ores.

It is well to remember that nearly all metals and ores, even gold, have daily changes in prices, and although some do not change much from day to day they may vary enough in the course of a year to make the difference between profit and loss.

The unit system of buying and selling ores has come into general use and is puzzling to those who are unfamiliar with it. Dealers in ores must have some basis of calculating prices, so the desired content of a metal to be used by certain industries is fixed. All quotations for this ore are on this basis, and the price of any ore produced by a miner is the assay in percentage of metal multiplied by the quotation. This is the unit system, used mostly for the alloy and non-metallic ores. A unit is 1/100 or 1 per cent. If a short ton of 2000 pounds is in force, the unit is 20 pounds, and if the long ton of 2240 pounds, the unit is 22.4 pounds. As an example: Chromite is sold on a basis of 40 per cent chromic oxide (and under 8 per cent silica), so if the quotation or price is 35 cents per unit, the ore is worth $14 per ton; but if it contains 30 per cent, the value is $10.50; and again if 48 per cent, the miner receives $16.70 per ton. It is incorrect to suppose that because a unit is 20 pounds, and there are 100 units in a ton, therefore the price of each unit should be multiplied by 100. This is not so, as the price is based on a fixed metal content, and there are only 40 units in a ton of 40 per cent ore and 30 in a ton of 30 per cent ore. The following list shows the base-metal content on which prices are calculated in the unit system:

ORE	FIXED BASE, PER CENT
Antimony	50 metal
Barite	88–94 barium
Chromite	40 chromic oxide
Fluorspar	85 calcium fluoride
Iron	55 metal
Magnesite	90 magnesium carbonate
Manganese	40 metal
Molybdenite	85 sulphide
Monazite	6 thorium oxide
Phosphate rock	66–77 tricalcic phosphate
Pyrite	40 sulphur
Tantalum	60 tantalic acid
Tin	60–70 tin oxide
Titanium	52–95 ilmenite or rutile
Tungsten	60 tungstic acid
Vanadium	18 vanadic oxide

The amount of silica and other impurities affects the prices of these and many other ores, which are bought under other conditions.

Copper ore is settled for by smelters at the number of pounds of metal contained, as shown by assay, less the loss in treatment, multiplied by the current price. If an ore assays 10 per cent copper, or 200 pounds, and the smelter recovers 95 per cent, and the market price is 10 cents (5 pence or £47 per long ton) per pound, settlement is for 190 pounds, multiplied by 10 cents or

5 pence, less costs, and penalties, if any, and plus bonus, if any, also gold and silver.

Lead ores are sold on a similar basis or, as in the Tri-State region of Kansas, Missouri, and Oklahoma, on a basis of 80 per cent metal content. Zinc in that district is based on 60 per cent metal. Molybdenite is sold at so much a pound for ore or concentrate carrying 85 per cent sulphide. Mercury is sold at so much per flask of 76 pounds.

Wherever a prospector or miner may be, he should watch quotations in the papers published in any mining district or those from the important cities that are financially interested in prospecting, development, and production.

PART III

MINERALS: THEIR OCCURRENCE, DESCRIPTION, DETECTION, AND USE

In this part of the handbook are brief notes on the occurrence, description, detection, and use of the metallic and non-metallic minerals, arranged alphabetically under the two heads.

CHAPTER XVII

A. METALLIC MINERALS

ALUMINUM

Aluminum is a bluish, silver-white, malleable, light, and ductile metal that never occurs in native form. The crude ore bauxite is used as an abrasive (grinding material) and for making chemicals and heat-resisting bricks, cement, filtrants, and the pure metal. The abrasives and silicate minerals are described under Corundum and Gems.

Occurrence

Alumina is an important constituent of such minerals as clay, feldspar, and mica. The ore from which aluminum is obtained is called bauxite. Both it and the metal weigh about 160 pounds per cubic foot. It is found as a surface deposit and is formed when clay weathers under certain conditions. Generally bauxite is the result of the decomposition of aluminous rocks and appears as a residual product. It is probably also produced by the action of sulphuric acid, derived from weathering pyrite, upon such rocks as shales. Clay or kaolin is the most important associate of bauxite deposits.

The principal deposits of the world are in Arkansas; Alabama; Georgia; Baux, France; and British Guiana, South America.

Bauxite is composed of small, round concretions which vary in size from 1/10 to 1 inch or more in diameter. The color is from white or light gray to brick red, depending upon the amount of iron present. The ore contains variable quantities of iron and silica, but these two should not exceed 10 or 12 per cent. In Alabama the bauxite deposits are only in the belts containing iron ore (limonite) which are bounded by areas of dolomite (limestone with chert nodules). Figure 49*a* shows bauxite deposits in Georgia, and Fig. 49*b* those in British Guiana.

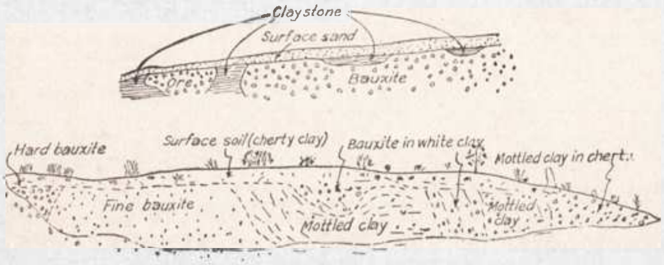


FIG. 49*A*.—Bauxite deposits in Georgia.

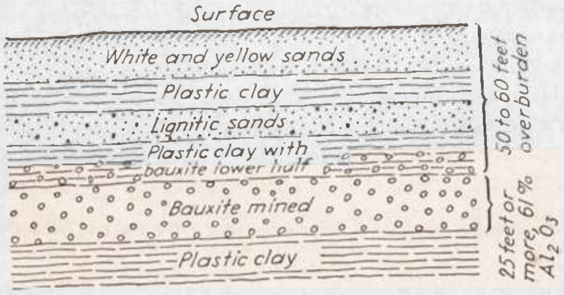


FIG. 49*B*.—Occurrence of bauxite in British Guiana. (*J. S. Luck.*)

Bauxite is an aluminum oxide or a hydrous compound of alumina, iron oxide, and silica. It is white, yellow, brown, or red and almost always has "eyes" or peculiar red or brown spots.

It is soft, the hardness being 1 to 3, and of light weight, its specific gravity being 2.55. It can not be melted in a blowpipe flame. It is earthy, somewhat resembling clay—in fact, it is often mixed with clay, when it is impossible to tell by appearance whether or not the material is rich enough to be an ore. A chemical analysis is necessary to determine its value.

Good bauxite granulates, crumbles, or falls to powder when rubbed between the fingers; clay does not—it becomes plastic. Bauxite is either granular or plastic according to the proportion of alumina or silica present. If a small quantity of dry bauxite is ground in a mortar and sticks to the bottom and side, it is good ore. Dry clay will not stick to a mortar. Good bauxite will not scratch glass, but clay will. High-grade bauxite will not grit the teeth when bitten or chewed.

Silica, the chief impurity in bauxite, should be less than 8 per cent. The ore should carry more than 55 per cent alumina, which equals 30 per cent of the metal aluminum.

Most of the bauxite deposits in the United States are controlled by one large company manufacturing aluminum. Products range in size from a bottle cap to parts of an 800-foot bridge. Aluminum is a keen competitor of copper and of some steel.

Four silicates of alumina that have become of industrial importance recently are andalusite, kyanite, sillimanite, and dumortierite. These minerals are mainly used in the manufacture of spark-plugs and refractories. They have the same chemical composition but differ in physical properties. They occur in pegmatites and schists in California, Nevada, South Dakota, North Carolina, and Virginia. There are several colors; the luster is vitreous; hardness, 6 to 7.5; and specific gravity, 3.1 to 3.7.

ANTIMONY

There are deposits of antimony in the United States, but at the prices usually prevailing they cannot be worked in competition with the metal that comes from China. There is little encouragement for prospecting for antimony under normal economic conditions. Most of the American production is a by-product from lead smelters.

Antimony rarely occurs in native condition. Its common mineral is stibnite, the sulphide, which contains 71 per cent metal. Antimony somewhat resembles arsenic and bismuth. All three are brittle, but the hardness of bismuth is lower than the other two, and its specific gravity is half as much again. Before the blowpipe, on charcoal, the three act somewhat alike. Antimony and arsenic frequently occur together in gold ores, making the recovery of gold difficult.

Stibnite is a soft, lead-gray, fibrous mineral, with a bladed (needle-like) structure. In the natural state it is used in safety matches and percussion caps, fireworks, and rubber goods. It is the chief source from which the metal antimony is made, itself used in bearing and type metals. Its streak is lead-gray; hardness, 2; and specific gravity, 4.6. Stibnite weighs 280 pounds per cubic foot; and the metal, 416 pounds. The former melts easily, even in the flame of a match if a thin splinter of mineral is used. When melted on charcoal by the blowpipe a heavy white smoke is given off but no odor. Stibnite is dissolved by hydrochloric acid.

Occurrence of Antimony Minerals

Stibnite. Stibnite is found in quartz veins in various rocks, usually limestone, and in veins in granite and schists. In Alaska antimony lodes are more or less closely allied with igneous intrusive rocks. Arsenic often accompanies antimony; so do gold, cinnabar, galena, and sphalerite; limestone is the most likely indicator. Near Bernice, Nevada, antimony occurs in quartz veins in slate, overlain by granite. There is no igneous rock in the slate, and there is limestone near by. Figure 50*a*, *b*, *c*, shows types of antimony deposits.

Jamesonite. The mineral jamesonite belongs to the antimony group and carries 30 per cent antimony and 59 per cent lead, but it does not commonly occur in large quantities.

Bindheimite. Bindheimite, as found in the Arabia district of Nevada, is an antimonate of lead and silver. It is yellowish brown, with a brilliant pitchy luster. It contains a little sulphide and from 15 to 80 ounces of silver per ton. Bindheimite also occurs with the silver ore at Candelaria, Nevada.

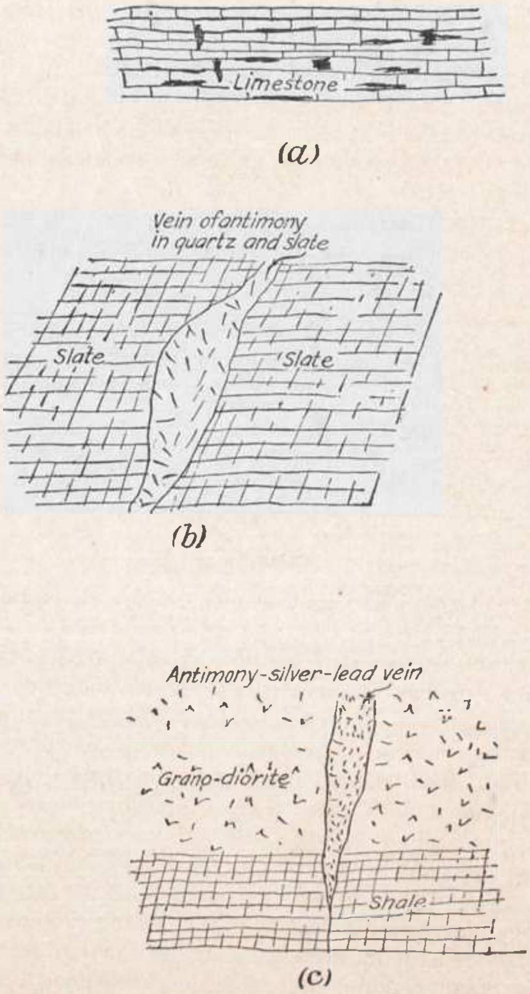


FIG. 50.—Three types of antimony deposits. (*a*) As in China; (*b*) as in the Coeur d'Alene, Idaho; (*c*) as near Arabia, Nevada.

Kermesite. Kermesite or red antimony is a cherry-red mineral that results from the part oxidation of stibnite. The only place where it occurs in considerable amounts is in Italy.

Valentinite. Valentinite is the tri-oxide of antimony. It is usually white or gray. It has a hardness of 2.5 to 3 and a specific gravity of 5.57 and gives the antimony reactions before the blowpipe.

There are three antimony-silver minerals found in silver ores, but they are not a source of antimony. They are as follows:

Antimony-silver Minerals

Mineral	Color	Streak	Luster	Hardness	Specific gravity
Polybasite....	Iron-black	Iron-black	Metallic	2–3	6
Pyrargyrite...	Gray-black	Purplish-red	Metallic	2.5	5.8
Stephanite...	Iron-black	Iron-black	Metallic	2–2.5	6.2

ARSENIC

Although arsenic is a metallic element, it is rarely found as such. The common forms are the sulphide arsenopyrite or mispickel, which contains 46 per cent metallic arsenic; orpiment, the tri-sulphide, with 61 per cent arsenic; and realgar, the mono-sulphide, with 70 per cent arsenic. The metal is brittle, with a tin-white to steel-gray color and metallic luster. Arsenic as the oxide is in great demand each year for insecticides and drugs.

Arsenopyrite supplies most of the world's arsenic and is recovered mostly at smelters. Arsenic frequently accompanies Montana antimony and gold in deposits in limestone; but arsenopyrite usually occurs with ordinary pyrite in quartz veins and, like galena, is a fairly good indication of the possible presence of gold. The Hedley Mascot in British Columbia; the Jardine in occurrences in South Dakota, and Ontario; the Wiluna, Lancefield, and Transvaal mines in Western Australia; and the Morro Velho, Brazil, are examples of gold mines whose ores contain arsenic. The mineral also occurs with cobalt and nickel arsenides. It is gray-white, with a hardness of 5.5 or 6 and a specific gravity of 6. A cubic foot weighs 390 pounds.

Tests

If broken, there are usually some flat, mirror-like faces in arsenopyrite. It can be melted in a blowpipe flame and gives off a dense white smoke which smells first of sulphur and then of garlic. Even when struck with a hammer, arsenopyrite emits this odor. Although antimony gives off a similar white fume, it has no odor.

Orpiment is yellow; realgar is orange-colored; and the streak of each is like its color. Their hardness is 1.5. The specific gravity of realgar is 2.6; and of orpiment, 3.4. They melt easily and give a dense white smoke which smells like arsenic (garlic).

Orpiment and realgar look like limonite and hematite, from which they may be distinguished by the garlic odor which the two former give when heated.

If heated in a closed tube, arsenical minerals give a yellow ring and, nearer the ore being treated, a ring of dark, silvery arsenic so dense that it gives a mirror effect.

The arsenic deposit at Brinton, Virginia, consists of a gray mica quartz-schist impregnated with arsenopyrite, adjacent to faults along which aplite (finely crystalline mica-granite) or pegmatite has been intruded and later crushed to schist. The shoots are from 2 to 8 inches thick, but the main lenses are 30 feet long and 8 feet thick.

BAUXITE

See Aluminum

BERYLLIUM

Beryl is the ore of beryllium which, like aluminum and magnesium, is a light and hard metal and of probable future similar use. It is found in pegmatite veins, in clay slate, and in mica schist. Until recent years only the gems emerald and aquamarine have been sought, but there is a growing market for the ore. As a rule beryl is of some shade of green. It is about as heavy as quartz, but its hardness is 7.5 to 8. It may occur as columnar or granular pieces. It is found in 15 States but mainly in South Dakota, North Carolina, New York, and the New England region, where it is saved in working feldspar and mica. In Transvaal, beryl occurs as clusters or nests in pegmatites cutting red granite and gneiss. Crystal aggregates vary in weight from a few pounds to several tons. The metal beryllium and many alloys, particularly with copper, are on the market and have many uses in tools which are hard and possibly sparkless, in electrical parts, and in chemical industries.

BISMUTH

Bismuth is a metal somewhat like antimony. It occurs as bismuthinite and is mostly obtained as by-product from refining lead, copper, and molybdenum ores. Its hardness is 2 to 2.5 and specific gravity, 9.8, giving 600 pounds per cubic foot. It melts easily, the reason for its demand for alloys, but does not give a dense smoke as do arsenic and antimony. It is brittle when cold but malleable when heated. The principal use of bismuth is in easily fusible alloys, such as for sprinkler systems and safety plugs for boilers, but it has other uses, as in medicinal salts.

Occurrence

Bismuthinite, the principal mineral, is the sulphide, a light-gray mineral with a light-gray streak. Its hardness is 2 and specific gravity, 6.5 or 400 pounds per cubic foot. It occurs in veins in gneiss and other crystalline rocks, with copper, lead, silver, and zinc. An important Australian occurrence is with molybdenite. In Bolivia, bismuth is found with tin, tungsten, and silver. It gives a test for bismuth as directed later. It melts easily. Bismuthinite somewhat resembles stibnite and jamesonite (antimony minerals), from which it may be most easily distinguished by a test for bismuth.

Tests

A test for any bismuth mineral is as follows: Grind a small quantity very fine; then add an equal amount of potassium iodide crystals and sulphur; and grind together. Put a little on charcoal and bead with the tip of a blowpipe flame. A yellow coating fringed with bright red forms if bismuth is present. Bismuth also dissolves in nitric acid; and if water is added, a white precipitate is thrown down.

Bismuth oxide, known as bismuth ocher, evidently misled same millmen in Transvaal during 1933. Some concentrates, reputed to be high in gold, were found on panning to leave a long, yellow band or tail. On drying and examining it under a glass the tail was found not to be gold. Further tests proved the tail to be bismuth oxide which, after exposure, turns blackish. Therefore all is not gold that is yellow and does not shine similarly from all angles.

CADMIUM

Cadmium is a metal of growing importance, generally found in zinc ores, from which it is saved as a by-product. It is seldom, if ever, that an ore is mined for this metal alone. A large quantity is recovered at American, Canadian, European, and Australian metal-refining works. It is used in alloys and for plating.

Greenockite is the only mineral of cadmium, a sulphide. It is yellowish to reddish, powdery, or in small crystals and occurs as crusts in zinc ores. Its hardness is 3.5 and specific gravity, 5. Like sphalerite, when hydrochloric acid is poured on the powdered form, an odor of rotten eggs is given off. The color and association of the mineral serve to distinguish it from any other material.

CALCIUM

This silver-white metal, which never appears in the native state, is of the same group as barium and strontium and occurs as marketable ores as calcium carbonate (limestone), calcium fluoride (fluorspar), and calcium sulphate (gypsum); therefore, see these under their respective heads.

There is a growing demand for calcium, which is used in aluminum and aluminum-magnesium alloys, also beryllium oxides are reduced to form a beryllium-iron alloy with calcium or calcium agents. Calcium is also employed in the purification of scrap aluminum.

CERIUM

See Monazite under Rare-earth Metals

CHROMIUM

Chromium as a metal is made in the electric furnace. The industrial mineral is chromite or chromic oxide, which is used in certain tough and stainless steels, in refractory brick for furnaces, in dyeing, tanning, paint, and electroplating. High-grade ore is required for steel-making; lower grade is suitable for refractories.

Occurrence

Chromite occurs almost invariably in dark-colored, coarse-grained igneous rocks or in the deposits resulting from the weathering of such rocks. The most common of these is serpentine, which is the product of weathering of peridotite, a dark, granular igneous rock usually associated with magnetite. The magnetite is often so intimately intermixed that the chromite is too low grade to mine. Nickel is sometimes found in the same rock, or at least in the same region; so is platinum. Weathered serpentine, constituting part of river or beach sands, carries chromite and platinum, although in small quantities. There are concentrations in spots. Chromite seldom shows weathering effects.

Deposits of chromite may occur in masses of a ton or less as a pocket in serpentine, as 50 tons in irregular lenses or a regular vein, or as several hundred or even a thousand tons in a well-defined vein—that is, as far as American deposits are concerned. In addition, there is the disseminated or scattered type where the grains or particles of chromite are distributed through a mass of serpentine. Such ore must be concentrated before being marketed. The foreign deposits are of great extent. Chromite in the United States is mainly restricted to California, Oregon, and Montana where there are great belts of serpentine. Float ore is the usual means of tracing deposits, yet some outcrops do not shed float and are discovered by careful search in the serpentine. Figure 51 shows types of chromite deposits. In New Caledonia the ore occurs as pockets and fragments in serpentine and accumulates

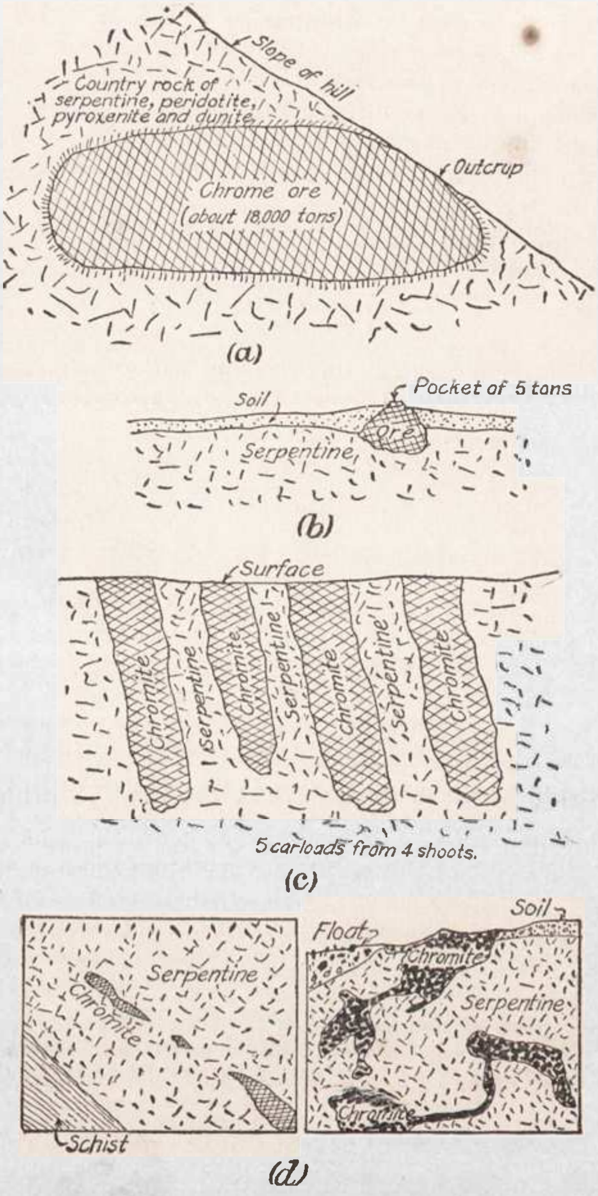


FIG. 51 (*a*, *b*, *c*, *d*).—Four types of chromite deposits.

on or near the surface from weathering of the rock, which is on the crests of mountain ridges. Rhodesia has extensive deposits of chromite, as have Transvaal, Turkey, and the Philippines, the last having deposits occurring in large masses.

Dunite, an iron-magnesium rock, sometimes exists at or near chromite deposits and may be mistaken for the mineral, but the test for chrome will clear any doubt.

In California, chromite and magnesite are found in adjacent districts; so are chromite and cinnabar.

Chrome Minerals

Although several minerals contain chromium, only one is ever used as an ore—namely, chromite. It is iron chromite with the formula $FeCr_2O_4$. The mineral when pure contains 46 per cent of the metal. It is iron-black to brown-black, and its streak is dark brown. Its hardness is 5.5 and specific gravity, 4.6. A cubic foot of it weighs 270 pounds. It can be melted in a blowpipe flame. It is sometimes magnetic. Heating will always make chromite magnetic. The chemical test given later will prove chromite.

Chromite is easily confused with magnetite, ilmenite, hematite, and franklinite, but none of these contains chromium.

Tests

Make a bead of salt of phosphorus in a loop of platinum wire; put in the salt a little powder of the mineral to be tested, and melt the bead in the tip of the blowpipe flame. If the bead is green, chromium is present.

This test is satisfactory after one has become accustomed to making it, but many persons have difficulty in getting good results, especially if too much mineral is used. The following test is more certain but takes more time: Grind a little of the mineral with five times as much sodium carbonate and twice as much sodium nitrate. Make several beads of this powder on a platinum wire. Grind the beads to powder and dissolve in water. Let the part that will not dissolve settle for 10 or 15 minutes and pour off the clear solution, stirring it well, and keep on adding acid till all bubbling stops. Add a few drops of lead acetate solution. If a bright-yellow cloud appears, chromium is present. This end reaction must not be confused with the pale-yellow color of vanadium; the blowpipe test distinguishes the two.

Marketing

The grade and the value of chromium ores depend upon their use. As a source of ferro-chromium the ore or concentrate should contain 50 per cent chromic oxide or more; as a refractory, to be used in lining furnaces, the grade may be as low as 20 per cent, although 25 per cent ore is better. Generally speaking, anything over 35 per cent is salable. The silica content should be less than 8 per cent; otherwise the ore may be rejected or penalized. The base on which prices are calculated is 40 per cent or 40 units: if 60 cents a unit is offered, the price per ton is $24.

COBALT

Cobalt is a nickel-white metal with a specific gravity of 8.6, weighs 530 pounds per cubic foot, and occurs with nickel, iron, arsenic, sulphur, and silver—always with either arsenic or sulphur. It does not occur in native form but commonly as the arsenide or sulphide. Cobalt compounds are in demand for special steels, plating, and coloring. Cobalt is largely a by-product of nickel ores, of the silver ores of Ontario, and of the copper ores of the Congo and Rhodesia.

Occurrence

Little cobalt ore has been found in the United States. One of the two deposits of note is in Idaho in a fine-grained, gray-black quartzite, with some dark-green schist; in Missouri in lead and nickel ores; and in Nevada as an oxide in basic dikes. The most important deposits were in Ontario, where the rich silver veins were in calcite, itself in a conglomerate. There, on the surface, the cobalt veins are traced by the peach-blossom color of cobalt bloom (the arsenate of cobalt), which occurs as an incrustation.

Minerals and Tests

A satisfactory test for cobalt is as follows: Melt some borax in the loop of a clean platinum wire, sprinkle on it a little of the finely powdered mineral, and melt it, using the tip of the blowpipe flame. When it has melted, let it cool and watch the color of the bead—if it is black, too much powder was used, so do this over again; if it is blue, it is cobalt or copper. But there is this difference between copper and cobalt: While it is cooling, just after the red heat leaves it will be green for a short time and then turn blue when it is cold, if it is copper alone; but it will be blue and stay blue if any cobalt is present or if cobalt and copper are both contained. This test is easy after a little practice.

Cobaltite, smaltite, and linnaeite are the commercial cobalt minerals; erythrite, chloanthite, and stainierite are less important.

Cobaltite. This mineral contains cobalt, arsenic, and sulphur and sometimes a little nickel. It contains 35 per cent cobalt. Its color is steel-gray, sometimes with a pink tint. The streak is black. It is so hard (hardness 6) that only a good knife will scratch it. Like most metal-like minerals it is heavy and has a specific gravity of 6, which is equivalent to 380 pounds per cubic foot. It will melt easily on charcoal in the blowpipe flame and will give off white smoke owing to the arsenic that it contains; this smoke smells like garlic and will make one's nose itch because it has sulphur in it. It may be tested for cobalt as described above. If finely powdered cobalt is warmed in dilute nitric acid, the acid becomes rose-red.

Cobaltite looks much like arsenopyrite, which gives the smoke and smell of arsenic but will not give the test for cobalt.

Smaltite. Smaltite, the valuable silver ore of Cobalt, Ontario, looks like cobaltite but if pure will not give the sulphur test. It is an arsenide of cobalt and contains 28 per cent of the metal. Smaltite and chloanthite contain cobalt, nickel, and arsenic; the former has more cobalt than nickel, and the latter more nickel than cobalt. Only a chemist can tell the two apart. Each has a tin-white or steel-gray color, with a pinkish tinge. Either mineral can be barely scratched with a good knife. Each is heavy, melts easily, and gives a white smoke and a garlic smell because of the arsenic.

Both smaltite and cobaltite may be altered to erythrite, the arsenate, at the outcrop of a vein.

Linnaeite. Linnaeite is a sulphide of cobalt and nickel. It is steel-gray and rather hard (hardness 5.5). It gives a test for cobalt. Its specific gravity is 4.9. If the powder is boiled in dilute nitric acid, the acid will become red. It melts easily but does not give a white smoke or the odor of garlic, but the odor of burning sulphur can be detected. It looks something like cobaltite, smaltite, and arsenopyrite but can be easily distinguished from them because they all give the white smoke and garlic smell when melted on charcoal whereas linnaeite does not.

It should be remembered that in testing such minerals for cobalt the arsenic and sulphur should be roasted off first, also that all cobalt compounds become magnetic when heated on charcoal before the reducing flame.

Stainierite. This is a hydrated oxide of iron, alumina, and cobalt, found at Goodsprings, Nevada. A process for concentrating the ore has been worked out by the Federal Bureau of Mines. It averages 2 per cent cobalt.

COLUMBIUM AND TANTALUM

Columbium and tantalum are metals of increasing value. They closely resemble each other chemically, but tantalum is twice as heavy as columbium and is very hard.

Occurrence

Columbium and tantalum are almost always found in either granites or pegmatites or in sands and gravels near these rocks. Other minerals frequently associated with columbium and tantalum minerals are cassiterite, wolframite, tourmaline, beryl, spodumene, topaz, fluorite, quartz, feldspar, mica, and minerals containing the rare-earth metals. Columbium and tantalum are always present together; neither occurs alone. In South Dakota, deposits of tin, tungsten, and tantalum are closely connected, both geographically and in origin.

Rocks containing minerals of these metals are found in several States and countries, but the deposits in Rhodesia and Western Australia are the richest and are the source of most of the tantalum used. The metal occurs there as stibio-tantalite (antimony and tantalum). There are some moderate-size deposits in the Black Hills of South Dakota, but the tantalum minerals found there were almost entirely bought by collectors.

Some tantalum was used to make filaments for electric lamps, but it has been displaced by tungsten. Both columbium and tantalum give steel desirable properties, and some have been used for that purpose. Tantalum carbide is used as a cutting tool.

Tests

There is no satisfactory or easy test for columbium and tantalum. One test can be made as follows: Powder a small piece of the mineral and with it grind ten times as much borax. Moisten with a few drops of water. Melt some on the loop of a platinum wire with the blowpipe flame and keep it melted for at least a half minute. Cool, break off the bead from the wire, and grind in a mortar. Repeat this operation several times until the amount is as large as a pea, all ground fine. Boil it in a third of a test-tube full of hydrochloric acid for several minutes. Add some metallic tin (not pieces of tin cans, but pure tin bought for the purpose) and boil. If either columbium or tungsten is present, the liquor will turn blue. If tungsten is present with columbium, the liquid will stay blue after water is added; but if columbium is alone, it will not. If both are present, testing will be difficult. Titanium also gives a color something like the blue obtained with columbium or tungsten, but it is more reddish. It is generally easier to recognize the minerals by their properties than by this test.

Minerals

The three most important minerals are columbite, tantalite, and samarskite.

Columbite. Columbite and tantalite are much alike, and only the trained mineralogist or chemist can tell them apart. Both contain iron, manganese, columbium, and tantalum. They are iron-black in color, but their streak is dark red-brown. They are so hard that they can not be scratched with a knife, unless it contains unusually hard steel. The hardness of columbite is 5.4 to 7; and of tantalite, 5.3 to 7.3. A piece of quartz will scratch them. They are much heavier than most minerals, the actual specific gravity of each being 7, nearly two and one-half times as heavy as quartz. If they are broken, they will show many flat faces. The hottest blowpipe can barely melt the corners of a thin splinter of either mineral.

Tantalite. Tantalite is rare. The pure mineral contains 70 per cent metal, but the percentage in actual minerals is lower.

Minerals like columbite and tantalite are chromite, franklinite, wolframite, ferberite, specularite, magnetite, ilmenite, tourmaline, and sometimes cassiterite. Wolframite and ferberite are much easier to melt in the blowpipe flame. Both minerals will give a blue color to acid when tested as directed above, but the color will stay after adding a little water if the mineral is wolframite or ferberite. Specularite never gives the blue color. Magnetite and ilmenite are both magnetic; if they are ground up, a magnet will pick up some of the powder. The streak of both tourmaline and cassiterite is almost white.

Samarskite. Samarskite contains the rare-earth metals and columbium and tantalum. This mineral is described under the Rare Earths.

COPPER

Copper is a common metal of reddish color, ductile, malleable, tenacious, and one of the best conductors of heat and electricity. It is a heavy metal and has a specific gravity of nearly 9. A cubic foot weighs 550 pounds, which is 60 pounds more than steel. It is in great demand throughout the world. Few high-grade deposits are now being worked, and apparently but few remain to be discovered. Most of the copper now comes from extremely low-grade orebodies; therefore the prospector will do well to direct his search toward looking for large low-grade deposits rather than small high-grade ones. Additional incentive to the search for copper is the gold and silver and sometimes the nickel that often occur in copper ores. Workable deposits of copper are found in more than 30 States and Territories.

Occurrence

In looking for copper veins both float ore and stained rocks are indications. It should be remembered that a little copper will color an extensive area; so although the stain indicates something, it may not mean much of value. Iron gossans, the leached outcrops of copper veins, should be carefully tested.

Copper ores exist in many different rocks—in igneous rocks of almost any kind, such as granite; in metamorphic rocks, such as schists; in sedimentary rocks, such as shale; in conglomerates; in contact zones with limestone. Some of the largest copper orebodies have been formed by a combination of several processes. The so-called porphyry or disseminated ores, such as in Arizona, Nevada, New Mexico, and Utah, are formed as follows: A large mass of molten rock (usually of the granite family) works its way up toward the surface. The upper portion of it hardens and cracks in doing so. The liquids (steam and metal-bearing solution) fill the cracks and make a lean copper ore deposit; then surface or rain water soaks in and dissolves the copper from the surface and carries it back in solution to greater depths. When the solution gets to a place where conditions are such that the water can not keep the copper in solution, it is left or deposited there. That copper added to the metal already present makes a richer ore.

All of the "porphyry" or disseminated copper deposits are in semi-arid regions, at altitudes of around 5000 feet above sea-level but where snow falls in the winter. Excepting in Utah, the surface near these orebodies is more or less rolling or consists of low hills. The orebodies are chiefly parts of large masses of mineralized monzonite-porphyry. They lie directly beneath surface products of complete weathering and grade downward into material of appearance similar to the ore but too low in copper for profitable mining. The capping may contain 0.2 per cent copper; the ore, 2 per cent; and the underlying rock, 0.6 per cent.

The weathered porphyry is more porous than the unaltered rock, and at Ely, Nevada, the former is yellow, red, or brown, against the gray of the unweathered material. The overburden is 20 to 200 feet thick. This rock and the ore are easily identified. At Santa Rita, New Mexico, and at Miami, Arizona, the ore is a creamy-yellow color, bleached and dead looking.

To the western miner, porphyry means an eruptive rock—whether occurring in sheets, masses, or dikes—which is distinguished from granite by its finer grain and from limestone and quartzite by its fracture.

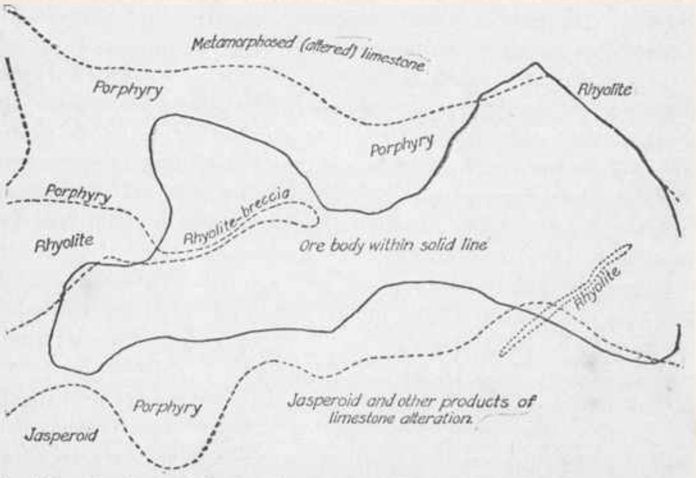


FIG. 52.—Geology of the porphyry copper deposit at Ely, Nevada, about 5000 ft. in length. (*According to the United States Geological Survey.*)

Chalcocite is the important mineral in these porphyry deposits. It is scattered or disseminated through the rock-mass. Fig. 52 shows the general occurrence at Ely, Nevada.

The enclosing and adjacent rocks to the monzonite-porphyry deposits are jasperoid (silicified limestone), rhyolite, shale, and limestone at Ely, Nevada; quartzite at Bingham, Utah; schist, granite-porphyry, and conglomerate at Miami, Arizona; schist and granite-porphyry at Ray, Arizona; and limestone, sandstone, and shales at Santa Rita, New Mexico. Large deposits of rich copper ore have been opened in limestone near the intruding porphyry at Ely. Prospectors and others interested should read A. B. Parsons' "The Porphyry Coppers," published in 1933. The skill and persistence of the prospectors and the money that they made are splendid tributes to them.

According to W. H. Weed, copper-bearing conglomerates or gravels and other deposits carrying chrysocolla, copper pitch, and other oxidized copper minerals, which occur near disseminated or porphyry copper deposits, are purely superficial in type. They have often led to costly and ill-advised deep exploratory work which failed to find the source of the ore. Although a few deposits are profitably worked, most of them are unpayable. They show close connection with pyritic deposits whose weathering has furnished the copper-bearing waters cementing the gravel or metallizing the related impregnation deposits quite different in manner of occurrence but of similar genesis.

Certain surface features in arid and semi-arid regions indicate the presence of copper ores caused by enrichment, according to the late F. L. Ransome when he was with the United States Geological Survey. Given the fundamental association of a granitic rock—usually a granite-porphyry—intrusive into rocks favorable for scattering pyrite and subsequent enrichment, the most obvious suggestion of the existence of ore is likely to be a general rustiness of the rock outcrops, due to the presence of limonite or other iron oxides left behind in the oxidation of the pyrite. Experience has proved that an intense redness is not a very favorable sign. On the typical surface above one of these orebodies the prevailing color is brown or yellow, on a rock that has itself been bleached nearly white. In searching for the existence of ore under the oxidized surface, the prospector should watch for quartz stringers in this material. If the quartz shows cavities, recognizable as having once been filled with pyrite, the probability of the presence of an orebody is increased. Copper minerals may not show everywhere, but green stains are worth studying.

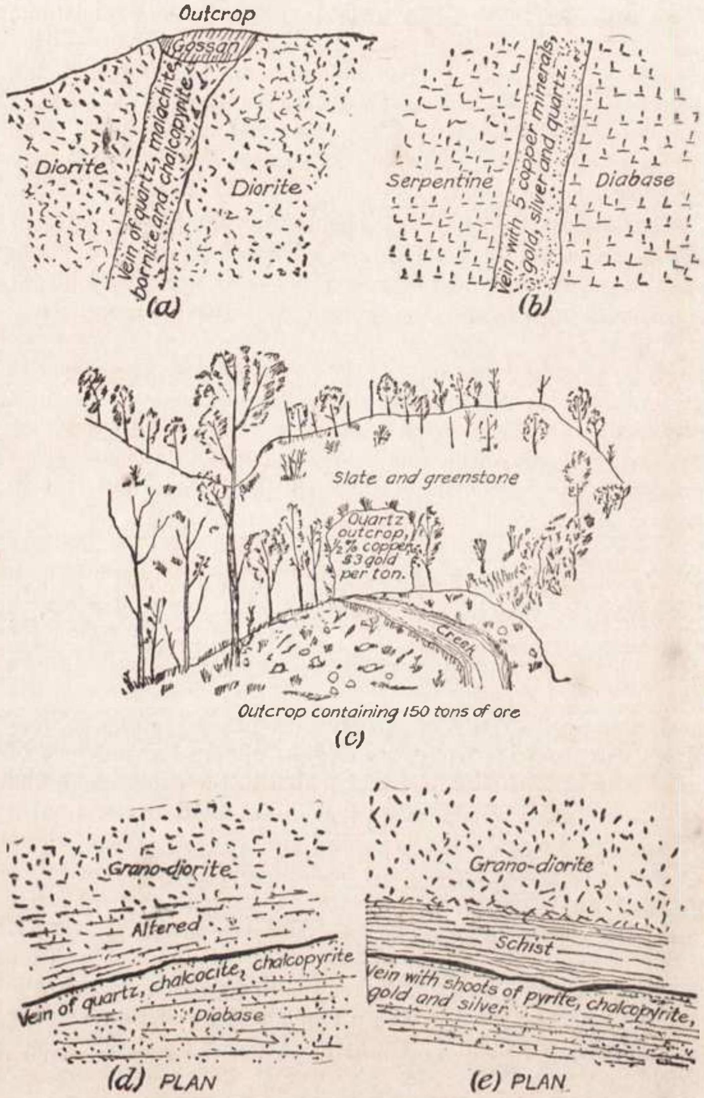


Fig. 53 (*a* to *e*).—Types of copper deposits.

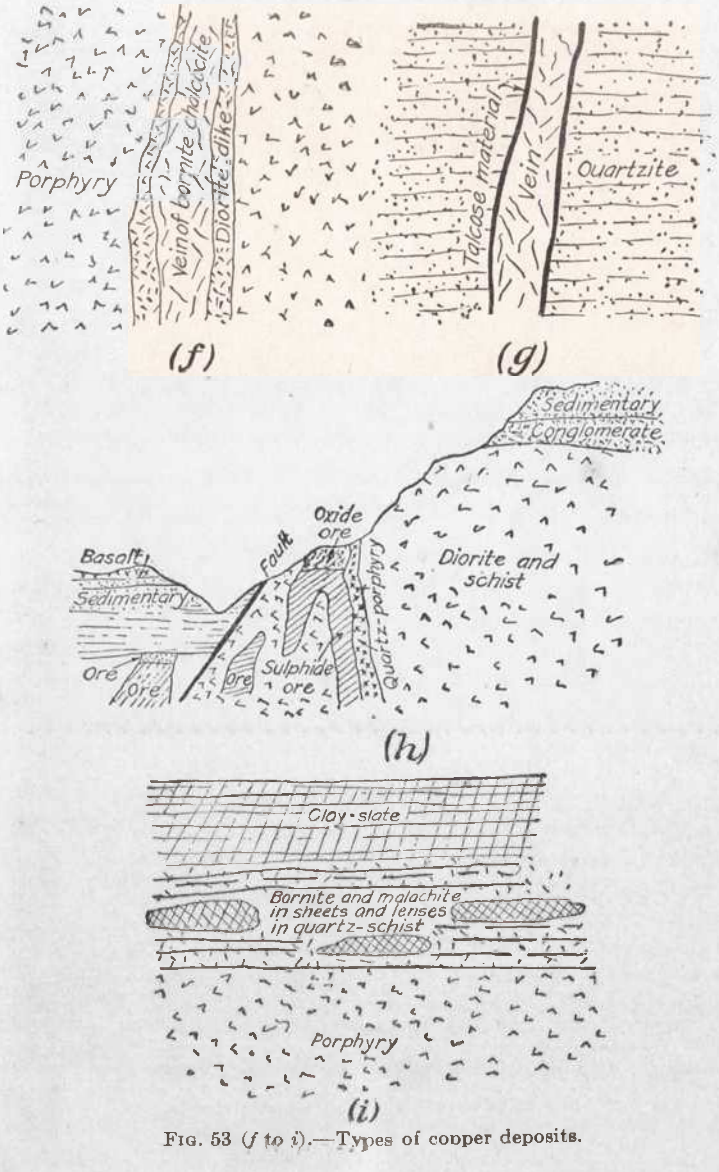


FIG. 53 (*f* to *i*).—Types of copper deposits.

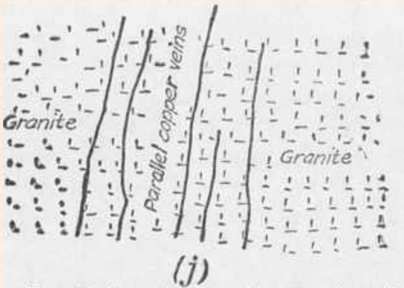


FIG. 53 (*j*).—A type of copper deposit.

The red beds of southwestern United States, especially in New Mexico and Texas, consist of chalcocite scattered through sandstone and nodules in shale. The deposits are not exactly red, being light brown to gray. Production has not been and is not important.

The famous orebodies of the Kennecott mine (now exhausted), Alaska, consisted of chalcocite and its oxidation products, malachite and azurite, in a gangue of gray limestone and dolomite. Some cavellite and enargite were seen.

Figures 53*a* to *j* give an idea of the conditions under which copper ores may be found.

The copper belt of Northern Rhodesia, which has been rapidly developed within the last several years and has three of the world's greatest producers and several others of importance, is considered to be one of the best examples of large-scale scientific prospecting for metals in a region previously unknown geologically. Alan M. Bateman, in his chapter in Volume 2 of "Copper Resources of the World," published in Washington, D.C., in 1935, wrote that this copper district lies in a country 70 miles long and has emerged within a few years from a bush-covered African wilderness to a region of industrial activity. An expedition of 1895, headed by George Gray from England, found indications of historic mining and smelting for copper as malachite and chrysocolla. He staked an area that later became productive. (Belgian Congo was worked many years before the Rhodesian field.) In 1902 an English prospector named Collier located two orebodies, but not much was done until after 1926. Now it is estimated that the four big mines contain 600 million tons of ore assaying 3½ to 4⅔ per cent copper. This ore persists to depth, and costs are low. The outcrops are normally poor and not easy to follow. The region is one of sedimentary rocks, with schists and granite intrusives. Ore in three mines is associated with a syncline. Most of the ore consists of chalcocite, bornite, and chalcopyrite in a gangue of the enclosing rock.

Tests for Copper

1. By means of a pair of forceps hold a sharp-pointed splinter of the mineral in the blue flame of an alcohol or gas lamp. Copper will color the flame a vivid green. The test sometimes works more easily if the mineral is moistened with nitric acid. This green coloration is not at all like the paler green given by boron, phosphates, and barium; but if one is not familiar with these colors, he had better get a sample of copper ore and one of barite and see the difference in the color given to the flame.

To make another flame-test, dip the wick of a lighted candle in some of the pulverized copper ore, both before moistening the ore with the acid and afterward. The same results as mentioned above will be noticed. This test is much used by the miners in copper mines to make a rough assay of copper ore; the degree of the flame coloration depends upon the grade of the volatile compounds of copper present in the ore.

2. Powder the mineral fine. Boil in nitric acid and use about as much mineral as a pea in a spoonful or two of acid. Wait until the acid is cool and then add ammonia slowly, stirring the acid with a glass rod or iron (not copper) wire. Add ammonia until a heavy-brown material, which is iron hydroxide, has formed in the solution. Let it stand until the brown settles out. If the liquid above is blue, there is either copper or nickel in the mineral-Then make the distinguishing test as given under Nickel.

If a piece of metallic iron, steel, zinc, or aluminum is immersed and left for a sort time in the dilute copper solution before the ammonia is added, it will soon become coated with a film of copper.

This is termed "cement copper." The metal dipped must be clean.

3. Some crushed ore may be put into a vessel containing dilute sulphuric acid and stirred. The acid will turn blue; and if the clear liquid is poured into another container and a scrap of iron added, the copper will be deposited on the iron. This test is good only for carbonate ore.

4. If some of the pulverized copper mineral, thoroughly mixed with at least twice the volume of a powdered flux (sodium carbonate alone or mixed with a little borax), is intensely heated on charcoal in the reducing (yellow) flame of the blowpipe, an irregular spongy mass of metallic copper will be produced.

5. Borax and sodium meta-phosphate (salt of phosphorus) beads are blue in the oxidizing flame and opaque red in the reducing flame. In the presence of iron the oxidizing-flame bead is green or bluish green.

Precautions in testing. Sulphides of copper must be roasted by gently heating the powdered mineral spread out on charcoal before they are used in the bead tests.

In making the third flame-test, platinum wire may be used, although a piece of iron wire or nail inserted in a stick or cork is used sometimes. The wire is dipped into ore moistened with hydrochloric acid, which gives a bluish-green color in the flame. After each flame-test the wire should be well cleaned of all adhering mineral so that when it is used again this mineral will not interfere with the next test. Never dip the wire into the acid bottle to wet it with the acid, because if this is done the acid in the bottle will dissolve any mineral which may be on the wire and the acid will be made useless for making further flame-tests, as it has become "salted." When used with reducible copper compounds the copper alloys with the platinum and makes the alloyed piece of wire worthless for making other copper flame-tests, so in these instances platinum should not be used.

Copper Minerals

There are more than a hundred copper minerals, but a prospector need be able to recognize only about ten. If he finds any other, he can tell that it is a copper ore by the tests given above. Most copper ores carry three or four and sometimes more minerals of copper. The minerals described are native copper, chalcocite, covellite, cuprite, malachite, azurite, bornite, chalcopyrite, tetrahedrite, and chrysocolla. Brief descriptions follow, starting with the outcrop and working downward:

Native Copper. Native copper is almost pure metal. It is copper-red with a copper-red streak; it is, however, frequently tarnished on the outside to a bronze-green color. It is soft (hardness not quite 3) and may be cut with a knife. A scratch made with a knife is bright and shiny. No other copper-red mineral both gives a test for copper and has such a shiny scratch. Cuprite is a red copper mineral, but a scratch is not shiny, and it is harder than copper. Both melt easily in a blowpipe flame and dissolve rapidly in hot nitric acid.

Native copper may be a product of weathering of other copper minerals and as such is usually an unimportant part of the ore and is found only near the surface. Most copper veins show a little native metal. (Copper weathers slowly to malachite, the carbonate.) The metal also occurs as specks or masses of many tons weight in basalt and associated conglomerate, as in Michigan. Sandstone and shale form part of the beds. Apart from the rich mass copper the average metal content is about 20 pounds per ton or 1 per cent. Such deposits persist to great length and depth. Native copper deposits are found in many countries and places, but Michigan and Bolivia are the only places where it occurs in workable quantities.

Chrysocolla. Chrysocolla is a copper silicate and when pure contains 36 per cent metal. It has a dull-blue or blue-green color, with an almost white streak. Its hardness varies from 2 to 4; its specific gravity is 2.3, so it is much lighter than any other copper mineral, a cubic foot weighing 130 pounds. It usually sticks to the lips. It breaks up—almost explodes—in a blowpipe flame and turns black but will not melt. Chrysocolla is slowly soluble in sulphuric acid.

Chrysocolla looks like malachite, with which it is generally found. Malachite bubbles in hydrochloric acid, but chrysocolla does not; the former releases carbon dioxide. It also looks like garnierite—a nickel mineral—but garnierite has no copper in it. Turquoise, a rare copper mineral and much harder (hardness 6), is also similar to chrysocolla. Chrysocolla does not weather easily.

Azurite. Azurite is like malachite in every way except that its color is azure blue and its streak pale blue. The specific gravity is 3.6 and weight, 220 pounds per cubic foot. It contains 55 per cent metal. It is not so common as malachite. It is the only blue mineral that both gives a test for copper and bubbles in hydrochloric acid, as it is a carbonate.

Malachite. Malachite is a carbonate of copper and contains 57 per cent metal. It is of bright emerald-green color. Its hardness is 4 and specific gravity, 4. In a blowpipe flame it flies to pieces and then melts. It may be tested for copper. It bubbles up if put in hydrochloric acid. (Care must be used in this test to get a piece of pure mineral, as several white minerals do the same thing.) Malachite resembles some of the rare copper minerals from which it is distinguished by its bubbling in acid. It also looks somewhat like garnierite, a nickel mineral.

Malachite occurs only as an alteration of other copper minerals, sometimes as a green stain in a rock. It has the distinctive green color so often ascribed to copper and is one of the best surface indications of the metal.

When found in large pieces free from flaws malachite finds a ready sale to jewelers and makers of ornaments.

Brochantite. Until the enormous copper deposit at Chuquicamata in Chile was developed, brochantite was little known. It is a sulphate of copper and contains 56 per cent metal. Its color is emerald-green, and it gives a somewhat paler streak. The hardness is up to 4 and specific gravity, 4. A cubic foot weighs 240 pounds. This ore is essentially a surface mineral.

Cuprite. Cuprite is an oxide of copper, carries 89 per cent of metal, and is an important source of copper. Its color is a shade of red, usually carmine, and its streak is a shiny red-brown. It is brittle. Its hardness is about 3.7 and specific gravity, 6. A cubic foot weighs 370 pounds. Cuprite blackens and melts in a blowpipe flame. It may be tested for copper as already described.

Cuprite looks something like cinnabar (mercury), proustite (silver), and hematite (iron), but none of these contains copper. It also resembles native copper, but cuprite is brittle.

Cuprite is formed only by the weathering of other copper minerals and so is found only near the surface where such alteration took place. It weathers slowly to native copper, malachite, or azurite.

Chalcocite. Chalcocite is a sulphide of copper containing 80 per cent metal. It is dark lead-gray but is often colored black or green on the surface. Its streak is gray. Like native copper, when chalcocite is scratched with a knife a shiny mark is left, hence the name of copper glance. It is soft, as its hardness is only 3. The specific gravity is 5.8 and weight, 350 pounds per cubic foot. It melts easily in a blowpipe flame and may be tested for copper as previously described.

Chalcocite looks somewhat like argentite (silver) and hessite and petzite (tellurides of silver and of silver and gold), but none of these contains copper. It also resembles tetrahedrite (copper), but this gives a test for arsenic or antimony.

Chalcocite is found in veins. It is also formed in any kind of copper deposit where rain water soaks in and dissolves the copper at the surface of the ground and re-deposits it deeper. The valuable mineral in the porphyry deposits is chalcocite. The presence of chalcocite frequently means that the ore is leaner at greater depths. None of the disseminated or porphyry orebodies persists to any great depth—say below 1000 feet, more often several hundred feet shallower.

Chalcocite weathers to cuprite, copper, malachite, azurite, and other less common copper minerals. It tarnishes readily.

Covellite. Covellite is also a copper sulphide, with 66 per cent metal, but is an unimportant mineral. It is dark indigo-blue in color and has a black streak. It turns purple when moistened with water. Its hardness is 2.5 and specific gravity, 4.51. It melts and burns in a blowpipe flame.

A little covellite is frequently found with other copper minerals. It is easily distinguished from similar looking minerals in that it turns blue when moistened.

Bornite. Bornite is sometimes called horseflesh ore, peacock ore, purple ore, or variegated ore. Bornite is a sulphide of copper and iron and contains 55 per cent metal. When just broken its color is a dark red-brown, the color of horseflesh, but the surface is usually weathered to blue or purple. Its streak is dark gray. Its hardness is 3.3 and specific gravity, 5. It can be melted in a blowpipe flame and gives the test for copper mentioned before. This mineral weighs more than 300 pounds per cubic foot.

Bornite resembles copper, niccolite (nickel), and pyrrhotite (iron sulphide). Bornite is brittle and has a black streak; copper is not brittle and has a red streak. Niccolite will not give a green color to a flame; neither will pyrrhotite.

Bornite is usually found where surface waters have soaked into the ground and dissolved the copper at the surface and deposited it deeper down. It is almost always found with other copper minerals and weathers to cuprite, native copper, malachite, azurite, or limonite (iron).

Chalcopyrite. Chalcopyrite, sometimes called copper pyrite, is a sulphide of copper and iron. It has a brass-yellow color; its streak is greenish black; it is brittle; the hardness is about 4 and specific gravity, 4.2. It can be melted to a magnetic mass in a blowpipe flame. It gives the tests for copper of which it contains 36 per cent. A cubic foot weighs 250 pounds.

Chalcopyrite and pyrite look much alike, but the latter has a paler color and does not give a test for copper. Chalcopyrite can be scratched with a knife rather easily, but pyrite can not. Chalcopyrite is sometimes mistaken for gold, but gold can be cut with a knife.

Chalcopyrite may be found in igneous rocks, in veins, or in rocks near igneous rocks. It is the most common of all copper minerals and is the mineral from which nearly all the other copper minerals are usually formed either directly or indirectly—the Michigan copper deposits probably are the biggest exception to this statement. Chalcopyrite is frequently found with pyrite and often has a little gold in it, as at Noranda, Quebec, where pyrrhotite is also abundant.

Tetrahedrite and Tennantite. Tetrahedrite is a copper-antimony sulphide, and tennantite is a copper-arsenic sulphide; the former carries 52 per cent metal, and the latter 48 per cent. In nature we find neither one nor the other but something in between the two. They are steel-gray with a gray or brown-gray streak. Their hardness is about 4 (sometimes only 3); their specific gravity, 4.5; and weight ranges from 270 to 320 pounds per cubic foot. They melt in a blowpipe flame. On charcoal they give a dense white smoke and sometimes an odor of garlic. They also give the tests for copper. Both look something like chalcocite, but this does not give the white smoke. Arsenopyrite is lighter gray and has no copper. Both minerals frequently carry silver, tetrahedrite, particularly, in the Sunshine mine, Idaho.

Green iron-bearing minerals, such as chlorite (a green mica), epidote (a calcium-aluminum silicate, with some iron), actinolite (a calcium-iron-magnesium silicate), and others are often mistaken for ores of copper. These valueless minerals may be distinguished from the ores of copper by the flame-test. Powdered copper minerals, without hydrochloric acid, color a flame a bright emerald-green, but with the acid the flame color is a greenish blue.

Water from Copper Mines. If the water from a copper prospect carries copper, the metal may be saved by running the water through a trough, launder, or sluice-box in which is placed any scrap iron or detinned tin cans from which the grease and paper have been burned off. The copper precipitates or is deposited upon the iron and eventually falls to the bottom of the trough as a sludge or slime. For ease in cleaning up, the bottom may consist of a wooden grating or have holes drilled through, and the precipitate is washed to one end. This is then dried and shipped to a smelter. It may contain up to 70 per cent metal. Several copper deposits have been leached by running water through them and recovering the copper as explained. One waste dump yielded 20 pounds of copper per 1000 gallons of water. One pound of copper requires 1½ pounds of iron and the cost may be 2 to 4 cents per pound of copper recovered.

GOLD

Gold is probably the first objective of the prospector. There are many attractions and possibilities of fortune in its search. There is always a market for gold, especially in recent years when prices have been high. Nine-tenths of the world's gold output is obtained from gold ores; the remainder is a by-product of base-metal ores. The metal is frequently associated with silver, and both may be extracted by the same process at the same time. In placer deposits, platinum in small quantities often accompanies the gold, although in Colombia, South America, the proportions are 75 per cent platinum and 25 per cent gold. Gold is found all over the world but not always in workable quantities. It occurs in more than 30 States and Territories of the United States. Transvaal is the world's greatest producer, then Canada, United States, Russia, Australia, Mexico.

Properties

Gold is an element and exists in a metallic condition, except when as a telluride. Gold in pyrite is mechanically not chemically mixed. Gold crystallizes in the isometric form, but crystals are rarely found. One of the distinguishing features of gold is its color—a pale to deep yellow—which is the same from every angle; no other mineral possesses this characteristic. Where scratched, or melted and cooled, it is always yellow. When hammered, gold will flatten; other yellow minerals break. Its hardness and specific gravity, depending upon impurities, are 2.5 to 3.0 and 15.6 to 19.2 respectively. A cubic foot of cast gold weighs 1200 pounds; a cubic inch, about 10 ounces. Gold is not soluble in nitric or hydrochloric acid, but a mixture of 3 parts of the latter and 1 part of the former, which makes aqua regia, dissolves the metal readily. If the metal is very fine, potassium or sodium cyanide will also dissolve it easily.

The natural alloys of gold—namely, amalgam, bismuth-gold, and electrum (gold plus silver)—are rare and of little importance.

Tellurides of Gold

The natural compounds—tellurides—are important if found in large quantities, as at Cripple Creek, Colorado; Goldfield, Nevada; Kalgoorlie, Western Australia; Kirkland Lake, Ontario; and Transylvania, Rumania. The tellurides are:

Altaite. This telluride of lead carries more or less gold, as at Kirkland Lake.

Calaverite. This contains 40 per cent gold, 3 per cent silver, and 57 per cent tellurium but varies in composition. Its hardness is 2 to 3; its specific gravity, 9; it is of pale bronze-yellow and has a yellowish-gray streak. It is the most important of the tellurides.

Sylvanite. This is also a telluride of gold and silver, with 24 per cent gold and 13 per cent silver. The color is steel-gray to brass-yellow, hardness 1.5 to 2, and specific gravity 8. If the mineral is melted with soda under the blowpipe flame, a bead of gold will be reduced.

Petzite. This is a telluride of silver and gold; the proportion of the former metal is more than double the latter. It is twice as hard as sylvanite and a little heavier. Petzite is steel-gray to black, is brittle, and has an iron-black streak. In most physical features it resembles hessite.

Hessite. This is the telluride of silver, which contains up to 63 per cent silver. This may be reduced to metal with soda on charcoal.

Tests for Tellurides. If telluride is suspected in a gold ore, grind a little of the mineral, place in a test-tube, and add some strong sulphuric acid. If tellurium is present, a reddish-violet color will show. When cool (this reaction causes heat) carefully add water, when the color will disappear and a grayish-black sediment of tellurium will be thrown down in the tube.

If some powdered telluride is heated in an open tube, tellurium passes up the tube as a white smoke, but most of this condenses near the heated part as a white powder or sublimate. On being heated this sublimate volatilizes and fuses into yellow globules when hot and is white or colorless on cooling.

Minerals Mistaken for Gold

Certain common and often valueless minerals are frequently mistaken for gold; probably the most frequent error is that of pyrite, pyrrhotite, chalcopyrite, or mica. In order that the precious minerals may be distinguished from the others a brief description of some of these common minerals and their properties is given:

Pyrite is a sulphide of iron, brass-yellow in color, with a metallic appearance, and occurs either as distinct cubical crystals or in massive crystalline forms. It is slightly harder than steel and thus can not be scratched with a knife. When finely powdered it has a greenish-black color. It may be distinguished from gold or silver in that the latter are both soft and easily cut with a knife. Pyrite, of course, often contains gold rendering its extraction difficult.

Pyrrhotite is also a sulphide of iron but is usually found in massive form. It is of a bronze color and metallic luster, though when finely powdered it is grayish black. It differs from pyrite and chalcopyrite in that it is feebly magnetic and also that chalcopyrite can be scratched with a knife. Unlike gold it crumbles into a powder under the knife, while gold cuts more like lead. Pyrrhotite at Alaska Juneau, Homestake, Morro Velho, and Noranda contains gold and is troublesome to treat.

Chalcopyrite is a sulphide of iron and copper combined and contains, when pure, nearly 35 per cent copper. It is a golden-yellow mineral with a metallic appearance and is usually found in massive form. It is slightly softer than pyrrhotite and may be easily scratched with a knife. In fine powder its color is greenish-black, which distinguishes it from gold, whose bright-yellow color is not changed by cutting. Chalcopyrite is valueless in small quantities, but when scattered more or less uniformly through a large body of rock it may become an important ore of copper.

These three minerals are brittle and emit sulphur when heated.

Occurrence of Gold

In the chapter entitled "Prospecting" the preliminary search for gold is discussed, so the following notes will cover other features of this metal:

Gold is found either in placer deposits or in veins or lodes. Placers are the result of shattered and eroded veins in the mountains.

The following examples of gold occurrences may be suggestive in prospecting:

Quartz in dacite.

Quartz in schist.

Quartz in breccia and granite.

Quartz in schist near granite and gneiss.

Quartz in slate near its contact with diorite.

Quartz in slate or at the contact between slate and diorite.

Porphyry dikes.

Granite in gneiss.

Shale and quartz-porphyry.

Quartzite in a region of granite or diabase.

Faults or fractures and stockworks in schist or quartz-monzonite.

Areas near contacts of granite and diorite.

Areas along contacts of granite and felsite.

Calcite as a replacement in slate (pocket deposit).

Gravels lying on schist, slate, or decomposed volcanic matter.

Feldspar-porphyry and quartz-porphyry intrusions in or near belts of conglomerate, slate, and greywacke.

Primary hematite.

Stringers of feldspar and adularia with little silica in shale.

Barite.

Placer or Alluvial Deposits

Some regions have a little gold scattered over a wide area. This makes few large profitable operations possible; it is generally left to the small operator to work such an area. The southern Appalachian region of the United States is an example. In 136 years the States of Alabama, Georgia, South Carolina, Tennessee, North Carolina, Virginia, and Maryland have produced 52 million dollars of gold but little in recent years. This is not equal to the output of either the Portland mines of Cripple Creek, Colorado, or the Empire and North Star mines of Grass Valley, California. A large part of this gold was recovered by placer operations. The gold in the veins is spotty. Shoots are short, although the veins persist.

Alluvial gold varies in quantity according to climate and topography, the goldfields of Western Australia and of New

Guinea being extremes. The former, mainly flat, have had and have now no regular flowing streams; the latter, mountainous, have many of them. Much of the so-called alluvial gold of Western Australia is not in stream beds, some of it is in "deep leads" to depths of 100 feet or more, but most of it represents the concentration of the surficial portions of rock by removal of the light stuff by rain and wind.

Some countries—the Netherlands Indies, Southern Rhodesia, and Transvaal, for example—have yielded little alluvial gold; other countries—for example, Belgian Congo, British Guiana, and Siberia—have yielded mostly alluvial gold; others—Canada, New Zealand, New Guinea, and the United States, for example—have yielded large quantities of both alluvial and lode gold; and still others—the Gold Coast, Korea, Queensland, Tasmania, and Western Australia, for example—have yielded one-one hundredth to one-fifth as much alluvial gold as lode gold. Bendigo, Australia, has yielded 16 million ounces of gold, 4 million being alluvial. Geologic changes are responsible for these variations.

In his book "Gold Deposits of the World," W. H. Emmons believes that, where gold lodes are exposed, it is reasonable to expect placers and that, where these have been found, a search for the source of their gold is warranted. In panning, a line up a slope may be found above which gold is absent. Trenching may then disclose a lode. Not all lodes have associated placers because the gold has been dissolved and carried deeper or concentrated in gravels or floated or blown away entirely. In some regions of placers no workable veins are present, having been eroded.

With regard to the formation of placers, streams carry the boulders, cobbles, and fine gravel with the released gold down to the valleys, where it settles and sometimes partly solidifies. The gravel and the gold are deposited along and in the beds of streams. In other places gravel deposited in rivers was covered with lava (basalt), and later, as the result of upheaval of various earth movements, these rivers were raised to higher levels. This is called drift-gravel, and such deposits in California have yielded large quantities of gold. The pay-streak is difficult to find, and continuous sampling is the only guide. A later river system cut through some of these buried channels and concentrated the gold in the new beds, as in the Sierras of California. This is shown in Figs. 54 and 55.

Placer deposits sometimes have a false bedrock, but this is difficult to determine. At Bulolo, New Guinea, two dredges had worked about 21 months and dug 8 million cubic yards of gravel from a clay bottom at a depth of 22 feet, when drilling revealed pay gravel to a depth of 75 feet or 53 feet below the false bottom. The upper stratum had yielded 14 pence or 28 cents per cubic yard, and the lower stratum carried 10 pence or 20 cents. From this it may be inferred that if any alluvial ground has a clay bottom, it might be worth while testing beneath it. In northern Pershing County, Nevada, a false clay bedrock was found, but the best gold content was in the gravel 8 to 36 inches above it.

The conditions under which gold-placer deposits occur and are worked in the United States vary from the frozen gravels of Alaska to the mostly year-round workable placers of California, the more or less arid areas of Arizona and Nevada, the valleys in Montana, and the mountain districts of Idaho and Colorado. For any condition, except where there is a lack of water, similar methods of prospecting and equipment will more or less apply. In this Handbook it is impossible to cover everything, so we recommend the following publications for further reading:

1. "Placer-mining Methods and Costs in Alaska," by Norman L. Wimmler, *Bulletin* 259, Federal Bureau of Mines, 1927, 236 pages, Superintendent of Documents, U. S. Government Printing Office, Washington, D.C. This report describes in detail, with illustrations, the prospecting methods practiced, sinking shafts and drill-holes, water, dams, thawing, and stripping, scraping, sluicing, elevators, dredges, sluices, riffles, undercurrents, screens, the clean-up, and selling gold.
2. "Elementary Placer Mining in California and Notes on the Milling of Gold Ores," by C. McK. Laizure, in *California Journal of Mines and Geology*, April-July, 1934, 169 pages, State Division of Mines, Ferry Building, San Francisco, California. With this publication at hand, the prospector can try a couple of hundred machines and processes, none of which has been tested or approved

by the State Division of Mines, although some have been observed in operation by representatives of the State. A considerable number of these contrivances have passed out of the picture. But full instructions, with pictures, cover the standard equipment—the pan, the batea, the rocker, the long-tom, and sluicing over riffles of various designs. A shaded map shows the placer-mining areas of California. The section on the milling of gold ores is full of practical advice on hand sorting, amalgamation, concentration on tables and by flotation, and cyanidation. Two axioms are given: Do not consider building any mill, unless (1) enough pay ore has been developed and (2) it has been properly tested for a suitable process.

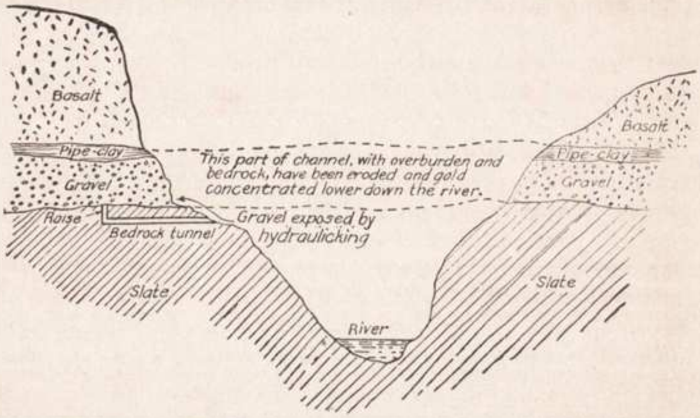


FIG. 54.—A gold-bearing drift-gravel channel in the Sierras.

3. "Placer Mining in Nevada," by William O. Vanderburg, *Bulletin* 4, University of Nevada, Reno, 1936, 180 pages. There are placers in 14 counties of Nevada, and 65 illustrations show what the country looks like and how prospectors and companies work. A few pages cover the geology in simple language. The importance of and procedure in sampling is discussed. Then follow 26 pages on the use of the pan and batea, rocker, long-tom, sluice, dry-washers, wet-washers, and the disintegrator. These machines are drawn to scale as well as photographed.

Alluvial gold is generally easy to save, but that of New Guinea has revealed new problems in recovery. There the bullion ranges from 80 to 90 per cent gold and 20 to 10 per cent silver to 35 to 40 per cent gold and 65 to 60 per cent silver. On the basis of 1000 parts for fine gold, the bullion assays from 939 to 522 parts or, on a value basis, 79 to 44 shillings ($18.96 to $10.56) an ounce. This high silver content results in low specific gravity, and the gold is not so easily caught. A 50:50 gold-silver bullion would have a specific gravity of 8, against 17 for average alluvial gold. Plenty of riffles are necessary. Some of the gold recovered by prospectors and dredges is not easily amalgamated with mercury. Grinding and acid treatment render it amalgamable.

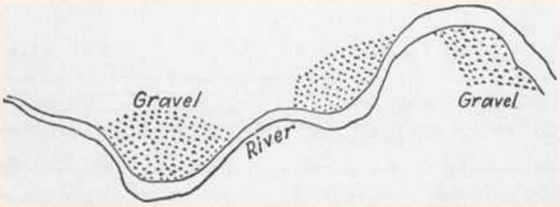


FIG. 55.—Formation of placer deposits. The river has carried the gravel from an eroded channel, originally covered with lava. Such placers have yielded much gold.

Lodes or Veins

The occurrence of gold in the great goldfields of the world may be summarized as follows:

The lodes of the Juneau belt, southeastern Alaska, lie either in a zone of slate and greenstone or in intrusive masses of diorite. East of the former is a zone of schists. The Juneau belt resembles the Mother Lode of California in that the stringer lodes or veins contained occur in slates and schists. The veins are of quartz, with a little pyrite and galena. The quartz outcrops carry little gold.

At Cripple Creek, Colorado, the veins are in breccia (a fragmental volcanic rock) and granite. Dikes of basalt and phonolite (an uncommon porphyritic rock) run through the breccia and granite. Completion of the Carlton Tunnel in 1941 disclosed veins below the deepest mine in the Cripple Creek district.

Rocks of the Goldfield district of Nevada are andesite, alaskite (a granite rock), rhyolite, dacite, latite, and basalt. There are many outcrops in andesite, dacite, and latite. These outcrops are craggy and of silicified volcanic rock; few of them have been productive. The veins are mostly in the dacite, at or near its contact with the latite. The silver district of Tonopah is only 25 miles from Goldfield. Ores of the former carry a little gold, but those of the latter contain a fair quantity of silver, although each is what might be termed a straight ore of each metal.

The "reefs" of the Rand in South Africa are composed of a conglomerate of quartz pebbles, pyrite, and sand, lying in quartzite. The gold is in the cementing material, not in the pebbles themselves. Mining is now below 8000 feet vertical.

In the Porcupine district, Ontario, are quartz lodes in schist, with dikes cutting the lodes. At Ramore, the most common rock is greenstone, and the few outcrops made prospecting difficult.

The Kolar field of India has a persistent vein in schist, which lies in granite. The mines are now 8000 feet deep.

At Bendigo, Australia, the "saddle reefs" are anticlines in quartzite. They live to below 4000 feet and are related to granitic intrusions.

In Western Australia gold is not confined to any particular rock, although it is common in areas of the oldest changed and basic igneous rocks near their contact with granite. Sometimes the gold is in veins traversing granite, but these do not persist, as proved by the Cosmopolitan mine years ago.

The area including what is known as the "Golden Mile" of Kalgoorlie, Western Australia, which has produced £115,000,000 ($445,000,000) of gold, may be described as a series of sediments interbedded with fine-grained greenstones which were originally basalts. These sediments and basalts collected in depressed areas of granite and gneiss. The nearest granite is 20 miles west of Kalgoorlie, and there may be seen contacts between granite and greenstone. The lodes occur in quartz-dolerite greenstone and have been developed to 3600 feet. There is little or no difference between country and ore, and only careful sampling and drilling into the walls reveal how far to go. At the surface the lodes are in a cemented material consisting of lime, iron, and silica. Some alluvial gold has been recovered but at a distance from the lodes. With the lode gold are pyrite and tellurides. The formations at Wiluna, 350 miles northwest of Kalgoorlie, are rather similar to those of the latter. Most of the gold comes from shattered zones in calc-schist adjoining crust zones with a persistent shear or fault line. The gold is associated with iron pyrite and arsenical pyrite, 3½ per cent of each.

Gold deposits of New Guinea occur mainly in the changed complex of the high mountains, which parallel the length of the island, and are associated with intrusive granite, porphyry, and diorite. The beds of the streams flowing from the ranges are littered with products of denudation—schist, phyllite (a foliated rock of sedimentary origin, with composition between slate and mica-schist), slate, gneiss, indurated (hardened) sedimentaries, granite, diorite, gabbro (crystalline igneous rock), and dark, fine-grained basic intrusive rocks; and some volcanic agglomerates, andesite, rhyolite, and basalt. The gold gravels, which occur at 2000 to 6000 feet altitude, of the streams have been enriched by denudation of the quartz and manganese veins and veinlets occurring in the higher portions of Mount Kaindi. The richness of Edie Creek gravels is probably due to a re-concentration of the gold formerly in old glacial streams. The method of prospecting consists of starting at the mouth of a river system, working upstream, and testing the banks and bed with a dish or pan.

Vein material in New Guinea is often exposed by systematic trenching from the point where the gravels, when traced upstream, cease to carry gold. The surface soil over Edie Creek plateau is covered by a thick layer of moss and humus, which adds to the difficulty of prospecting. The known veins contain considerable quartz. The country rock over the greater part of this area is a soft mudrock, a changed schist or slate, and much of it has been tested by means of an iron bar driven down. The quartz, if present, can be felt by the bar; and if not, the conclusion is that probably there are no veins. If quartz is found, pits, trenches, and small tunnels are driven. Landslips also expose veins.

Near the surface the vein of the Day Dawn (New Guinea) Company is much weathered and is an iron-stained friable quartz, with a little manganese, in slate. At depth the quartz is harder and heavily mineralized with pyrite. The gold is free, but the pyrite carries a little of it.

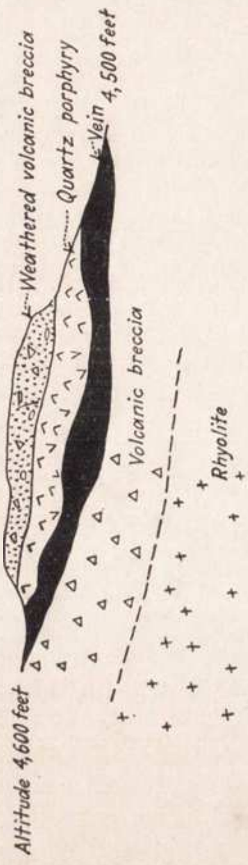


Fig. 56.—Ore conditions at Golden Ridges, New Guinea, according to the company geologist.

The Edie Creek veins of the New Guinea Goldfields Company are of sugary to hard iron-stained quartz, with considerable manganese, some calcite, lying in changed slate or schist, partly intruded by weathered porphyry. The ore contains gold and silver. The Golden Ridges vein of this company consists mainly of manganese, quartz, clayey decomposed porphyry, and volcanic breccia (Fig. 56). The overburden is removed by sluicing, and the orebody by scrapers. The gold is intimately associated with the manganese.

A gold-silver lode of importance is that of the Martha mine, Waihi, New Zealand. The ore consists mainly of quartz and calcite and occurred in tuff at the surface, rhyolite lower down, and latterly in andesite. To 1934, the upper levels yielded 4 million tons; the eighth level, 1 million tons; and the thirteenth or bottom level, about 50,000 tons. The total is 8 million tons. The pinching out is pronounced. The metals occurred with pyrite and a little galena.

True veins appear in which the quartz is irregularly distributed, the gold continuing along the fracture plane independently of the quartz, which is not the only vein material. Veins are either of quartz in mica-schist, with some schist enclosed in places, also with some pyrite and galena, or of crushed and decomposed ferruginous schist with some quartz, as in Maryland and Virginia.

Gold occurs in quartz veins, interstratified in thin slate beds between bands of quartzite. The veins are near the tops of anticlines or domes, sometimes folding over, as in Nova Scotia.

Gold is found in quartz and mineralized schist veins in greenstone, as at Porcupine. Distribution of the quartz is irregular and in places carries blocks and strips of schist. The vein frequently occurs as lenses of quartz separated by schist.

Gold is also present in mineralized porphyry with some quartz occurring as masses or as stringers, also some calcite, as at Kirkland Lake.

Silver and gold (27:1) and some lead in veins of part quartz occupy fracture zones cutting andesitic tuffs and agglomerates intruded by dikes, sills, and irregular masses of granodiorite porphyry, as at Premier, British Columbia.

In the Tennant Creek field, Central Australia, the orebodies consist of primary hematite surrounded by gold-bearing talcose schist as a narrow band. As the lodes resist weathering, outcrops are common. The ore averages 1 ounce per ton. Bismuth carbonate, which interferes with amalgamation, is an indicator. There are some malachite and chalcopyrite.

SUMMARY

It will be seen therefore, that gold may be found in almost any rock, and Fig. 57*a* to *o* of actual deposits gives a clearer understanding of some of the foregoing occurrences.

Limestone is not a likely rock in which to find gold, yet the lodes at Manhattan, Nevada, and of the Hedley Mascot mine in British Columbia have been good producers. At the former place one deposit is a replacement of limestone by quartz, pyrite, and arsenopyrite; another has deposits in the limestone. The Hedley mine has ore at the contact of dikes and gabbro in altered limestone. Characteristics of gold deposits in limestone are faulting and the presence of much arsenopyrite.

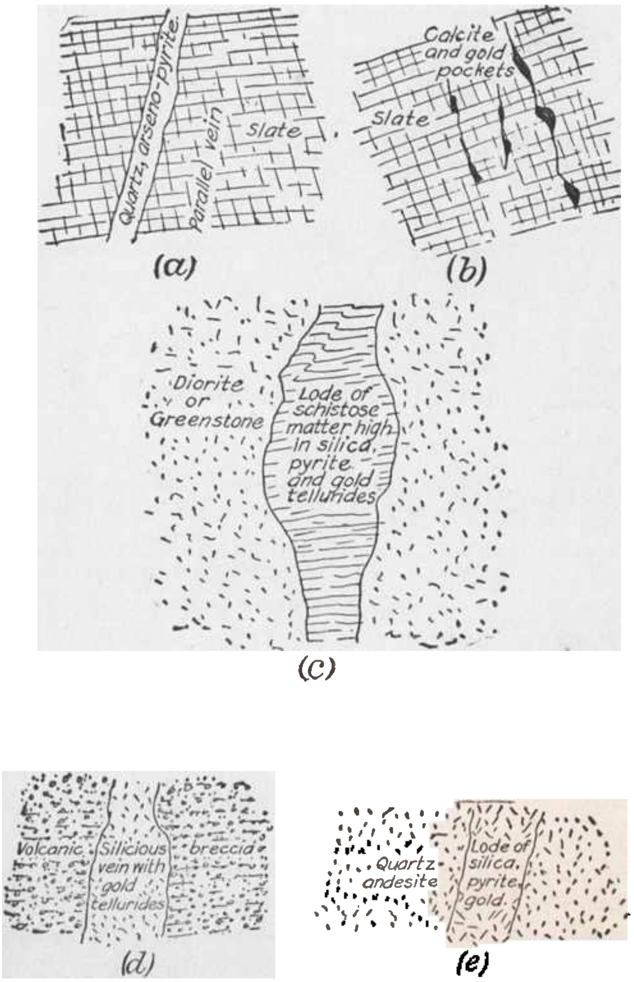
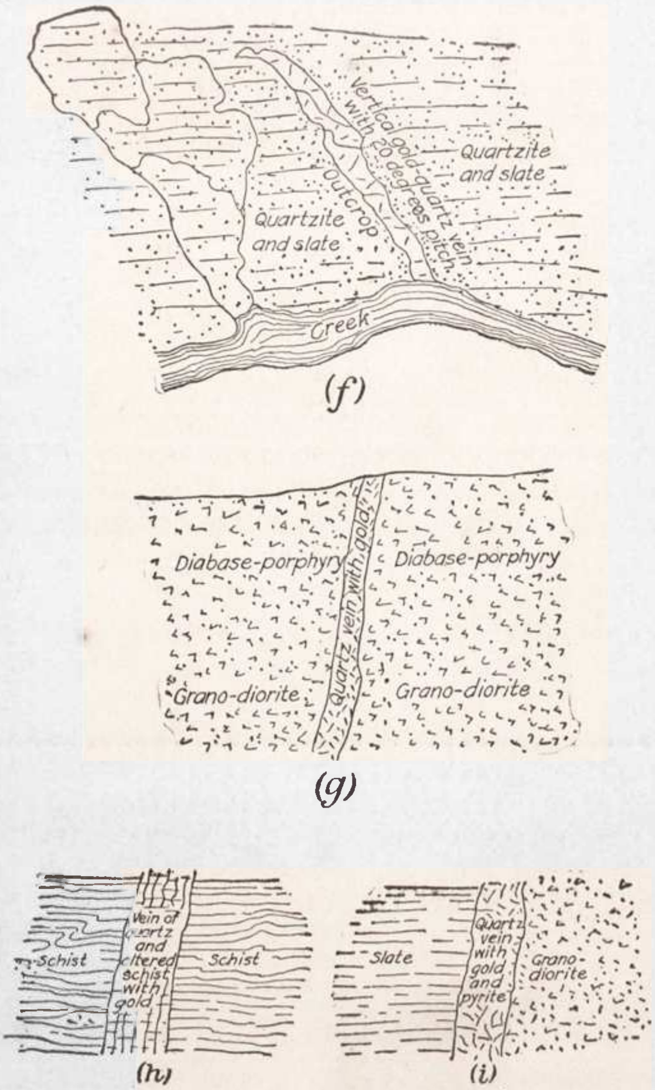


FIG. 57 (*a* to *e*).—Types of gold deposits.



(f) (g) (h) (i)

FIG. 57 (f to i).—Types of gold deposits.

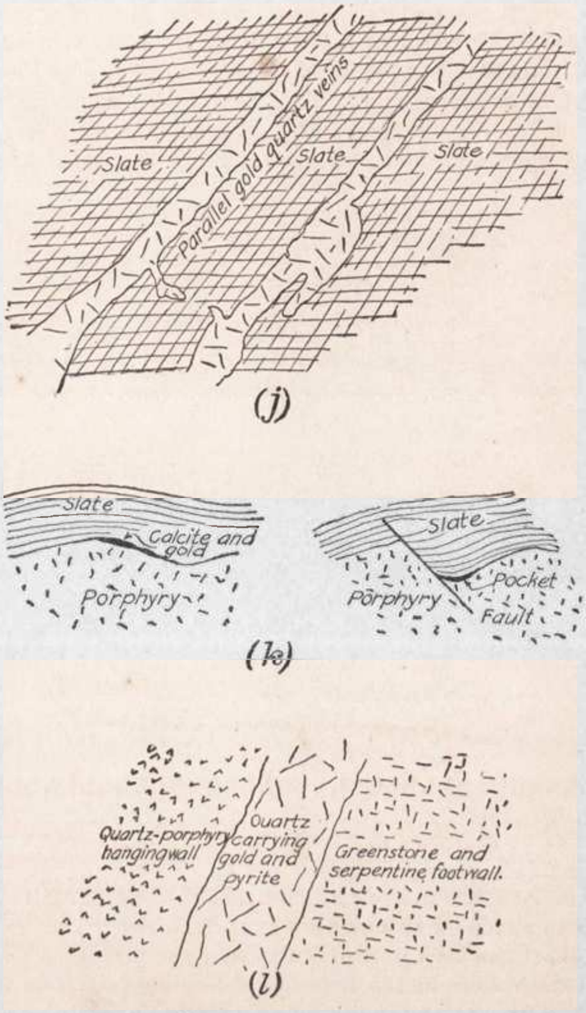


FIG. 57 (*j* to *l*).—Types of gold deposits.

While most prospectors have not the time, money, or patience to bother with veins that are low grade at or near the surface, it is often profitable to follow an ore shoot to a depth of 50 or 100 feet before stopping work. Take the Grass Valley district of California as an instance: There the outcrops of veins were inconspicuous and were not traceable for any great distance on the surface, but rich ore was opened at 150 feet, and the veins have been mined for thousands of feet. It is also advisable when a rich shoot has been worked out to continue through what may be a barren zone in the hope of finding another good shoot. Also, if there are any indications that other orebodies may be present, put in crosscuts to prospect for parallel veins. One never knows what may be beyond the point of the pick or the bit of a

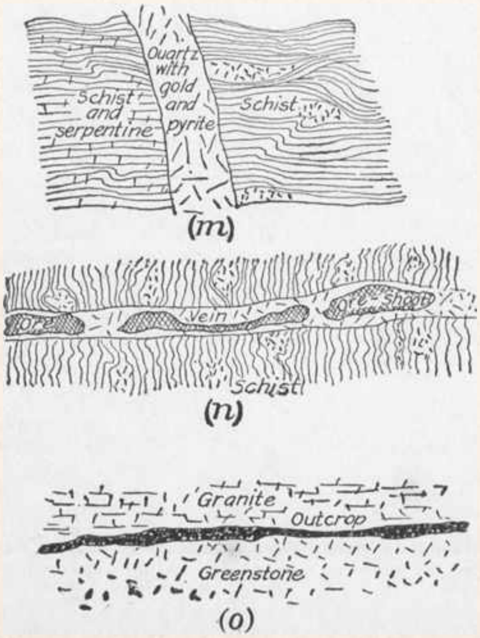
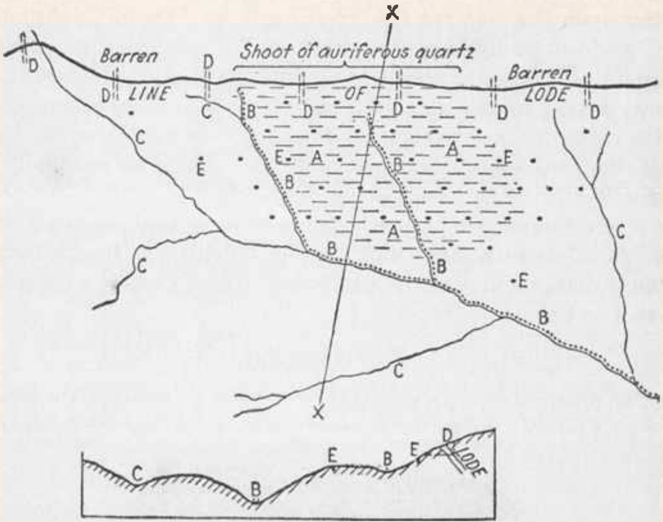


FIG. 57 (*m* to *o*).—Types of gold deposits.

drill, and such dead work has many times revealed ore and given a mine a new lease of life.

TRACING GOLD

After one has arrived in a likely district for gold, the thing is to search for "float" gold or gold-bearing ore.



Section X-X

FIG. 58.—Diagram showing method of locating and testing a lode by following gold in creeks, by loaming and by trenching, as described.

Figure 58 is so easily understood that it is reproduced from the *Mining Review* for the half-year ending December, 31, 1930, issued by the Department of Mines of South Australia. Reading from the sketch: *A* is the area containing gold in soil; *B* are creeks containing alluvial gold, shown by dots; *C* are creeks not containing alluvial gold; *D* are trenches cut at regular intervals across the cap of the lode, to determine its course and to find where payable ore occurs by systematic sampling; and *E* are test pits in the loam, sunk to provide samples for panning.

Once the vein is found, it is necessary to determine its course or strike, and a series of trenches should then be cut across the outcrop every few feet to obtain samples. The samples should be tested systematically by crushing the stone and then washing the sample in a dish. The skillful prospector does not require many assays. He can obtain a good idea of the value of the ore by this procedure. He should make a sketch plan of his workings and enter upon the plan the results of his tests. The distribution of the gold will rarely prove to be even. The richer portions are the outcrop of shoots of ore, and these are the places at which to begin shaft-sinking for deeper work. It is unwise to make assumptions with regard to the unexplored portion of a newly discovered lode, and the prospector should always follow the gold as closely as possible during the initial stages of mining.

Where sampling pits or shafts are sunk in gold-bearing gravel the round type is preferable to the rectangular, as the former stands better and may be put down in bad ground. They are 3 to 4 feet in diameter.

Use of the Pan

The prospector's pan is almost invaluable, not only in the search for gold but for concentrating other ores which have been crushed fine for blowpipe or other tests. The work is generally done in water, but in arid regions dry-blowing, which is described later, may be resorted to. Black iron or steel pans cost 60 cents to $1.

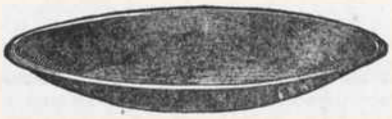


FIG. 59.—A pan or dish. (*Courtesy of Eimer and Amend.*)

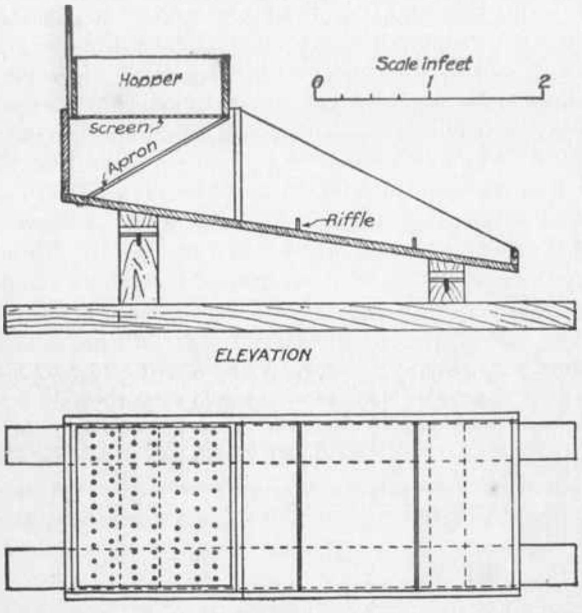
A pan, as shown in Fig. 59, is 9, 12, or 16 inches in diameter and 2 to 3 inches deep, with the sides sloping at an angle of 45 degrees. The Australian pan has a shallow fluting partly around the inside for finishing off a washing; also the rim is re-inforced to give a better grip and stiffness. It is filled about half full of the gravel to be tested; but if crushed ore is used, take a pound or two, from which fairly close estimates of the gold content may be obtained. The pan is held in both hands, and stooping down by a stream one fills it with water and the light material is washed out; the heavier stuff and large pebbles are left behind. While the pan is under water, the larger washed pebbles are taken out by hand and discarded. The pan is then shaken, in a way difficult to describe, until all of the valueless material has been washed out and only gold and black sand remain. The discarding of waste should be done carefully and slowly toward the end of the process. Finally the gold remains in the bottom of the pan for examination and calculation. Panning is an art and requires considerable practice. The method of dipping it in water, the peculiar circular, concentric, or oscillating motion, depressing the edge to discharge waste, and the final collection of the gold require skill.

In South America and in Netherlands Indies two similar pans or dishes are used—the *batea* and the *dulong*. Both are about 15 inches in diameter and slope to the center, where the gold is caught. The author has seen Chinese girls in Borneo panning gravel with great skill using a *dulong*. A batea is obtainable from the Denver Equipment Company.

Use of the Rocker and Long-tom

When pay-gravel has been discovered and water is available, a rocker or a long-tom may be constructed on the job, and considerable gravel washed and the gold saved. Figures 60 and 61 are self-explanatory. The screen in both machines may be made of any flat iron with ½-inch holes punched through. In the long-tom the large stones are forked or shoveled out as another man feeds in the gravel, and so the operation is continuous; in the rocker the hopper must be emptied after the fine material from a few shovelfuls is washed through the screen. The apron under the rocker screen consists of a light frame on which canvas, blanket, or corduroy is tacked.

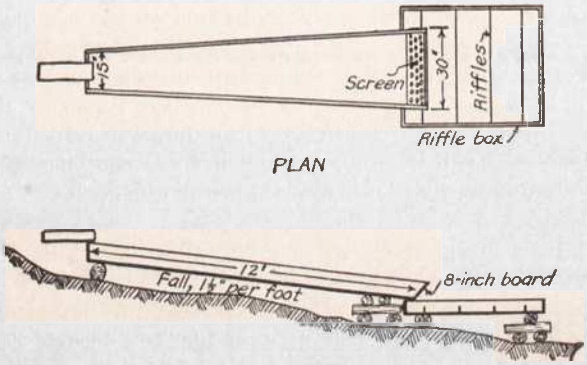
Improved saving of fine gold may be made by laying on the bottom of a sluice such materials as blanket, burlap, canvas, carpet, coco matting, corduroy, cowhide with the hair on, moss, and sponge rubber, held in place by cleats or wire in some form.



ELEVATION

PLAN

FIG. 60.—A rocker.



PLAN

ELEVATION

FIG. 61.—A long-tom.

Indicator Minerals. As the prospector moves from one gold district to another, he may notice the recurrence of certain minerals. In alluvial or placer areas are more or less black sands, prominent near the surface or coming to light in sluices and other gold-saving equipment. Their presence does not necessarily indicate gold or platinum; yet in general, where there is placer gold, there may be black sands, or conversely.

Another indicator is pyrite. This mineral is common almost from the outcrops of veins. It may or may not carry gold, but fine pyrite in quartz often does, especially at depths; likewise arsenopyrite.

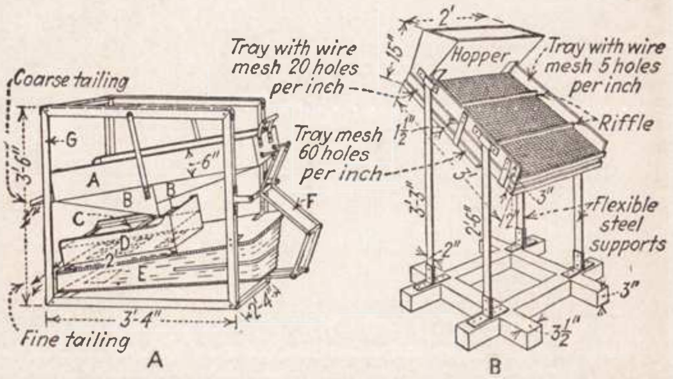


FIG. 62.—Two types of Australian gold-savers for waterless country. *A*, dryblower; *B*, dry shaker, as explained.

Galena is a third indicator. We have noted or learned of it in Alaska, California, Ontario, Maryland, Australia, New Zealand, and India. The bluish mineral is unmistakable; and gold with it is good-looking.

A lead-bismuth mineral is an indicator in the Quartzburg district of Idaho. The gold is intimately associated with it, yet free.

The Australian method of dry-blowing is quite applicable to United States desert conditions—in fact the dry-washing machines used at Quartzite, Arizona, and Manhattan, Nevada, are somewhat similar in operation. Figure 62 *A* and *B* shows two types of dry machines, as described by the South Australian Department of Mines. The first is built within an angle-iron frame. *A* is a shaking screen; *B* is metal chutes delivering on to *C* which is a removable porous tray with riffles and bottom of burlap or toweling backed by metal gauze; *D* is the wind-box; and *E* is bellows with clack valves opening into *D* and with trap below to facilitate removal of dust; *F* is gearing which operates the bellows while the shaking screen is pushed to and fro. Figure 63 shows a machine being worked.

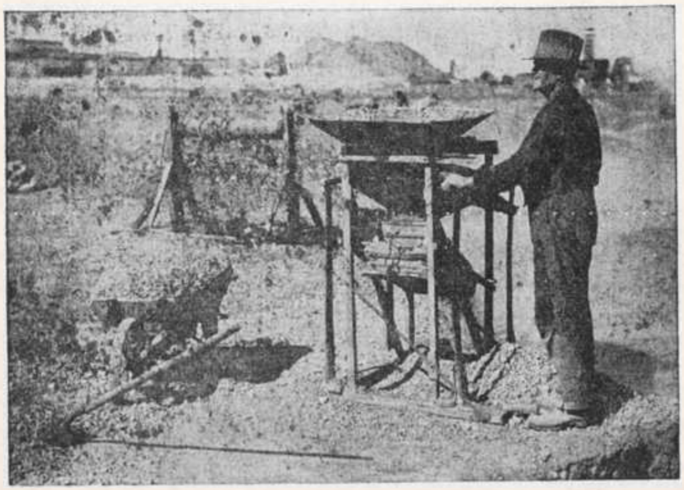


Fig. 63.—A dryblower machine and a dryblower working it near Kalgoorlie, Western Australia.

The American machine comprises a wooden framework to which are attached a coarse screen, hopper, crank and gear, riffle-board, and bellows. The gravel passes a ¼-inch screen to the hopper, from which it goes to an inclined riffle-board which also has a screen with wood riffles at right angles to its length. Air from the bellows keeps the fine material in motion. Under the riffle-board and over the air chamber is a muslin cloth. The riffles on the riffle-board hold the heavy particles such as gold, which drop through the screen on to the cloth, after which they are panned dry by allowing the wind to carry away the dust and fine sand as the material is dropped, say, 6 feet from one pan to another.

During 1932 the Denver Equipment Company designed and patented a mechanical gold pan. A ¾- to 1½-horsepower gasoline engine, through a ball-bearing eccentric, works a compact and superimposed set of trays 24 inches in diameter consisting of feed hopper, coarse screen, fine screen, an amalgamating pan, and two pans covered with matting. Operation is continuous, and the machine will wash 1 to 1½ cubic yards in 10 hours, using only 1 gallon of gasoline. The outfit, ready for transport, costs $160.

IRIDIUM

See Platinum and Platinum-group Metals

IRON

With the exception of aluminum, iron is the most widely distributed of all metals. It constitutes more than 5 per cent of the earth's crust, while other industrially useful metals such as copper, zinc, lead, and others combined amount to less than 1 per cent. Nearly every rock contains at least a little iron, but to be workable it must contain large amounts of it; and unless the other substances present are useful in smelting, an ore that contains less than 40 per cent iron will not be salable. Cast iron has a specific gravity of around 7 and weighs 450 pounds per cubic foot. Iron ores are not usually sought by the prospector, because they sell for a low price. Iron is the cheapest of all the metals, the ore having a price of only $1.50 to $3 a ton for 52 per cent iron at the mines. Transportation facilities must be available, because low-priced ores cannot stand high transportation costs. However, if the prospector can discover large deposits of iron ores which meet these conditions, they are likely to be a source of much profit.

Tests for Iron

It must be remembered that almost any mineral will give a test for iron. Just because a rock contains iron does not mean that it is an ore of iron or even one of the iron minerals listed later.

Grind a small quantity of rock very fine and boil in hydrochloric acid for a few seconds. Add a drop or two of strong nitric acid, then add diluted ammonia. If a yellow-brown substance forms in the liquid, there is iron in the rock.

A much more sensitive test is to boil the material in concentrated hydrochloric acid for a minute or two, add one or two drops of strong nitric acid, cool, and add a little water. A drop of sulphocyanate will give a deep-red color if iron is present.

If iron minerals are heated in the inner part of the blowpipe flame, the residue will generally be magnetic—that is, it may be picked up by a magnet.

Magnetic Characteristics of Iron Ores

All iron ores are magnetic when tested by sufficiently delicate means. Ordinary magnetite (the magnetic oxide) is the only iron mineral that causes conspicuous disturbances of the magnetic needle (say, in the compass). Nearly all Lake Superior iron ores contain varying quantities of magnetite and so are more or less magnetic. It must be remembered that strong magnetic disturbance does not necessarily mean iron ore and that ore does not necessarily cause such disturbance. For example, certain schists and basalts of the Lake Superior region are magnetic. The instruments used in prospecting iron formations are the dip needle, the dial compass, and the magnetometer.

Iron Minerals

There are only four industrially important minerals of iron, although several hundred minerals contain iron. These four are magnetite, hematite, limonite, and siderite. Hematite is the most common industrial iron ore, after which come limonite or brown ore, magnetite, and siderite.

Hematite. Hematite is also an oxide of iron and contains 70 per cent metal. Its appearance is varied, and each different kind has a name. It is sometimes an earthy brown or red-brown powder, when it may be called red ocher or red iron ore. This is the type of material found on the Mesabi range in Minnesota.

Hematite also occurs as a heavy, rather hard, blue-black mineral, when it is called blue hematite. Such material is found on the Vermilion range in Minnesota and the Marquette range in Michigan. A pure shiny black variety occurs in crystals, some of which are large and plate-like, and some small and flaky like fine-grained mica or graphite.

Except the earthy form, which is very soft, the hardness is about that of good steel, 5.5 to 6.5. Its color is red, brown, blue, or black. Its streak, whatever its color may be, is always red or red-brown. It is not magnetic, and it cannot be melted in the blowpipe flame. It is a noticeably heavy mineral, and its specific gravity is 4.8 to 5.3. A cubic foot weighs up to 330 pounds. Hematite may be tested for iron by any of the chemical tests described.

The earthy form of hematite can seldom be mistaken for any mineral except cinnabar, a mercury mineral, or cuprite, a copper mineral. A little earthy hematite may color a lot of clay or sandstone, which must not be confused with the pure hematite. Specular hematite (the black, shiny variety) is frequently confused with magnetite, ilmenite, wolframite, limonite, and other black minerals. Hematite is never magnetic, which will serve to distinguish it from magnetite. It will not give a test for titanium and so may be distinguished from ilmenite; moreover, the streak of ilmenite is black. Specular hematite may be distinguished from limonite by the streak—hematite is red, and limonite is yellow. Fine-grained, flaky, specular hematite is often confused with molybdenite or graphite, from which it may be known by its red-brown streak. Wolframite has a dark-brown streak and sometimes looks much like specular hematite. It may be distinguished by a test for tungsten.

The industrially important hematite deposits are almost always sedimentary beds, of which the Lake Superior iron ores are the best example. Such hematite is of either the earthy or the blue variety. Its chief impurities are quartz and kaolin. Frequently a large amount of limonite is also an iron ore. Specular hematite occurs in sedimentary rocks near a contact with igneous rock, also in veins and in schists.

In the Birmingham district, Alabama, the red and brown ores are hematite and are important. The former averages 36 per cent iron and is high in lime; the other ore assays 45 per cent iron and is rather high in silica.

Hematite weathers very slowly, except the earthy variety, which is easily worn away by the action of rain or streams.

Hematite is the most abundant of all the iron ores. Besides being used as an iron ore pure hematite is used in paints, especially the ordinary barn red, which is an extremely good preservative for wood or metal.

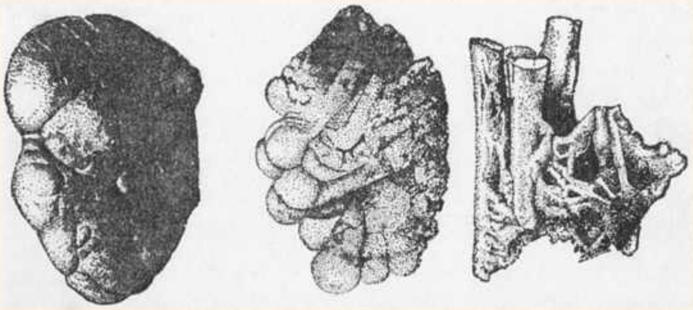


FIG. 64.—Typical shapes assumed by limonite ores.

Limonite. Limonite is an oxide of iron containing water—chemically combined—and 65 per cent metal. It grades from a soft, yellow, earthy material to a compact, hard material, varying from brown to shiny black. The specific gravity of the hard material is 3.8 and hardness, 5 to 6. A cubic foot of it will weigh about 230 pounds. The soft form is often called ocher or yellow ocher. It soils the fingers readily. A small quantity of this material will color a large amount of rock, which must not be confused with the pure limonite. The compact variety has about the hardness of a good knife. Its streak is always yellow; no other common mineral has this streak. It is rather heavy. It sometimes takes on fantastic shapes, such as the so-called pipe ores, kidney ores, or mammillary ores, shown in Fig. 64.

Thin splinters will melt in a blowpipe flame if the test is skilfully made; and after they are melted, they are magnetic.

Mineralogists will distinguish between goethite, turgite, and limonite, but they are all closely similar and of practically the same composition; hence it is needless to distinguish between them.

Limonite is formed in many ways. The valuable iron-ore deposits are usually of sedimentary origin, although they are frequently made richer by other processes, such as the dissolving out of quartz and other valueless minerals associated with the limonite. Limonite is also a common product of the weathering of pyrite and other sulphides. As limonite is a product of weathering, one should not expect it to weather further. Limonite is so soft, however, that it is easily worn away.

Like hematite, limonite is also used in paints, to which it gives a yellow color.

Magnetite. Magnetite is an oxide of iron and yields 72 per cent metal. It is a shiny, metallic, black, hard mineral. It cannot be scratched with a good knife, as its hardness is 6. Its specific gravity is 5.2, and a cubic foot of it weighs over 300 pounds. Magnetite is magnetic, which means that its powder may be lifted by a magnet. Some magnetite is a natural magnet—that is, it will attract iron filings—it is then known as "lodestone." The streak of magnetite is black, and the mineral can not be melted in a blowpipe flame. It will give any of the tests for iron enumerated before. It will be completely dissolved in hot, strong hydrochloric acid, if powdered and left in long enough.

Magnetite weathers extremely slowly, if at all. Massive magnetite is the highest grade of iron ore.

The minerals most frequently confused with magnetite are franklinite, chromite, ilmenite, wolframite, and tantalite. Franklinite gives a test for manganese and zinc. It is magnetic. although not so strongly so. Chromite may be distinguished by a test for chromium. Magnetite and chromite often occur together. Ilmenite is closely similar to magnetite and can be distinguished only by its weaker magnetism or by a test for titanium. Ilmenite and magnetite are frequently found mixed together. Wolframite and tantalite are distinguished from magnetite as described under their own heads.

Magnetite is commonly found in igneous rocks, especially those of dark color. It sometimes occurs in these rocks as bands large enough to be mined. Frequently associated with magnetite in igneous rocks are ilmenite, chromite, olivine, and feldspars. Magnetite is also found in veins but is seldom of importance as such. It also occurs in sedimentary rocks near the contact with an igneous rock such as the deposit at Cornwall, Pennsylvania. In New Jersey are 18 parallel lines of magnetite lenses yielding 30 to 60 per cent ore, which is concentrated by magnetic means. Near Colville, Washington, is high-grade ore.

The so-called black sands of the coast and rivers of the Pacific are composed largely of magnetite. It is doubtful if such sands will be a source of iron, as they contain too much titanium. In New Zealand there are many miles of black sands on the west coast of the North Island, but beyond considerable experimentation nothing has ever been done with them on a large scale. In Argentina there are also beach deposits of black sands.

There are good possibilities of increasing the use of magnetite as an industrial mineral rather than as a source of iron; therefore deposits of good ore should be sought.

Siderite. Siderite is an iron carbonate—that is, a chemical compound of iron, carbon, and oxygen. It contains 48 per cent metal. Its color is either brown or gray, and its streak is white or pale brown. It breaks with smooth faces which are very shiny. It is harder than calcite but is easily scratched with a knife, its hardness being 3.7. It is heavier than most light-colored minerals; and although its specific gravity is 3.8, it would not be classed as very heavy; siderite weighs approximately the same as limonite. When heated in a blowpipe flame it breaks into small pieces and sometimes throws them off with considerable force; it blackens and becomes magnetic. It can hardly be melted in a blowpipe flame.

Siderite may be tested for iron by any of the methods given above. When put in hot concentrated hydrochloric acid it will make the acid boil or bubble.

Siderite is easily confused with sphalerite (zinc), dolomite (lime), smithsonite (zinc), and hübnerite (tungsten). It may be distinguished from sphalerite by warming some of the powder in hydrochloric acid; if an evil-smelling gas is given off, it is sphalerite. Dolomite, smithsonite, and siderite may be identified by putting some of the powder in hot, dilute hydrochloric acid; if it is dolomite or smithsonite, the acid will bubble vigorously; while if it is siderite, there will be no such action.

Siderite is found in sedimentary deposits and in veins. Little is mined in America, although considerable quantities are extracted in other countries. In many of the siderite deposits there is enough lime to make the ore self-fluxing—that is, limestone does not have to be added when the ore is smelted. Siderite is also frequently found as nodules in clay-beds.

Siderite weathers rather easily to limonite or hematite.

As most siderite contains only small quantities of phosphorus and sulphur, it is in demand as an iron ore. Siderite has several other names, such as "spathic iron ore," "brown-spar," or "clay ironstone." In Europe it is improved in grade by magnetic separation.

Iron-ore Deposits

Pyrite, an iron sulphide, is a source of iron from cinder or residue after the sulphur has been driven off in the manufacture of sulphuric acid.

Hematite deposits are the most important source of iron ore in the United States. In the Lake Superior region, which produces about 90 per cent of the total iron-ore production, the ores occur as concentrations in rocks of Archean or Algonkian age and represent alterations of chemically deposited sediments such as cherty iron carbonates, which are usually interbedded with slate and quartzite. Figure 65 shows the general way in which iron ore occurs in the shallow deposits of Minnesota. The deeper deposits found in Michigan and Wisconsin vary widely in form and dip steeply as a rule, as shown in Fig. 66.

The Clinton iron ore, so called because it occurs nearly everywhere in rocks belonging to the Clinton stage of the Silurian, is a fossil or oölitic (like fish eggs) ore which is rather low grade but can be smelted because it contains lime (self-fluxing). It is mined principally in Alabama and Tennessee.

Limonite ores (see Fig. 67) can be smelted for iron where there is a local market for them, but they are not of much importance and amount to less than 3 per cent of the iron-ore production of the United States.

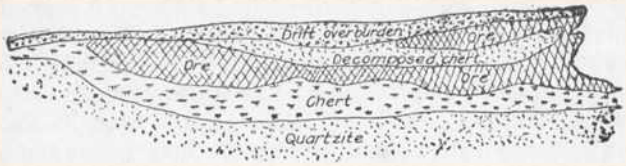


Fig. 65.—General occurrence of iron ores in the Lake Superior region.

Magnetite ores are important in New York, in New Jersey, and at the east end of the Mesabi range, Minnesota. They amount to only 5 per cent of the total of iron ore, so the prospector had best confine his attention to hematite.

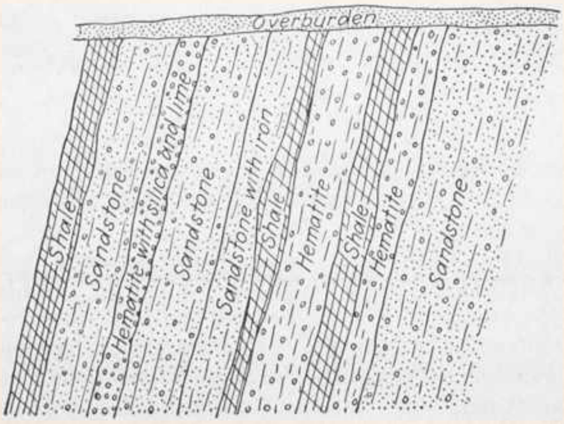


Fig. 66.

The simplest form in which hematite occurs is in horizontal or gently inclined beds or lenses a few inches to 12 feet thick. Their outcrops frequently may be found at intervals for several miles, if the associated formation—shale, sandstone, and limestone—is followed. In Alabama the ore-beds lie 80 to 175 feet below the black shale. In prospecting, trenches or pits are dug at right angles to the strike of the formation, sufficiently deep to reach solid rock. In the Alabama type of deposit there is little soil and clay overburden, and ore is soon reached, at a depth of 5 feet in some instances. These outcropping beds are generally soft and badly weathered, so a pit, slope, or tunnel should be driven to enter the hard ore. At this point its characteristics at depth will be better understood; and if extended prospecting of this bed and others is desired, core-drilling to 1000 feet or so is the next step.

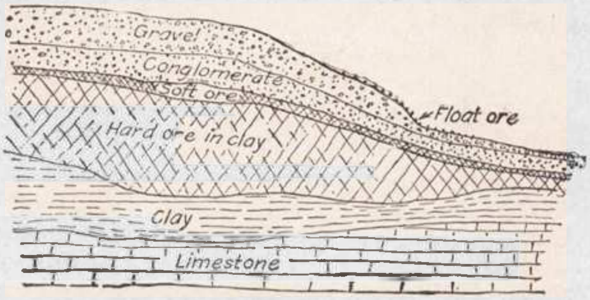


FIG. 67.—Occurrence of limonite ores.

Figure 68 shows the occurrence of iron ore at Cadia, New South Wales, Australia. It is estimated that 36 million tons lie there. A fair tonnage has been and is being reduced to pig iron in blast furnaces. The andesite country is highly altered, and the ore is mainly hematite carrying 57 to 65 per cent iron. Note the occurrence of gold near by.

Iron-ore deposits of Eyre Peninsula, South Australia, contain more than 100 million tons of high-grade material, are up to 1200 feet above sea-level, and rise to 640 feet above the plain. They are mainly of hematite, with little to high manganese, and lie in an area of micaceous schists. The schists in contact with the ores of three deposits are generally weathered to limonite clays, which are red-brown to yellow and "greasy." At the fourth deposit, both clay bodies and recognizable schists are in contact with the ore. At two deposits, hematite quartzites are interbedded with schists, sometimes as lenses within them.

Iron ore of northern Venezuela, South America, consists of ferruginous quartzites and of hematite and magnetite. The outcrops of the quartzite are generally covered by a thick layer of fragments of ore, clay, and quartzite cemented with iron oxide. One type of rock is dark brown or red and not magnetic. Another type is largely of magnetite, with hematite, goethite, and limonite, and has the appearance of scoria or volcanic eruptive matter. At a third place the outcrops are large masses of bluish hematite containing up to 69 per cent iron. The country rocks are norite and granite. At this place are also a hematite gneiss and conglomerate.

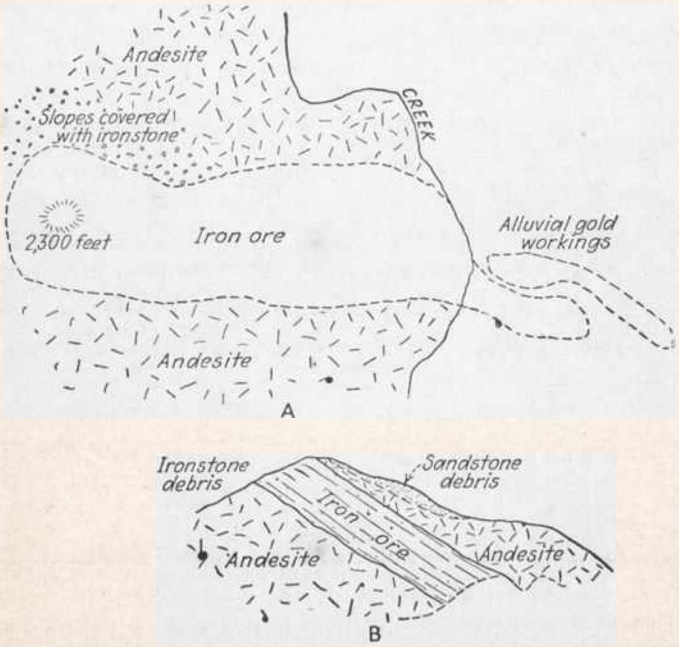


FIG. 68.—Occurrence of iron ore in New South Wales, according to the State Geological Survey. *A*, plan; *B*, transverse section.

Markets

Iron ore to be salable must be low in phosphorus and silica. Sulphur is also objectionable and must be low. Generally speaking, the ore should contain more than 50 per cent iron. The price of the ore will depend upon its iron content and the amount of impurities. About $5 per ton is an average price at Lower Great Lakes ports.

LEAD

Lead is a common, useful metal. It is heavy and pliable and has a bright bluish color, easily tarnished to a dull gray. It melts at a low temperature (620°F.) and may be easily hammered or rolled into thin sheets when cold. The metal is produced in large quantities all over the world. Its specific gravity when cast is 11.4, and a cubic foot weighs 700 pounds.

Occurrence

Lead is sometimes found in veins produced by hot waters coming from igneous rocks; in such cases there is usually some silver in the ore. It may also be found in veins formed by ordinary surface water soaking through the ground; then there is usually no silver. It is also found in deposits formed in rocks near an igneous rock. Lead and zinc frequently occur together, often with silver. Antimony is also an associated metal with lead ores.

Lead is found (1) as clean lead ore; (2) with copper, gold, and silver; (3) with silver (oxide ore); (4) with silver (sulphide ore); (5) as sulphide silver-lead ore with less than 10 per cent zinc; (6) as sulphide silver-lead ore with more than 10 per cent zinc; (7) as an iron sulphide-copper sulphide ore, with silver and some zinc; (8) as oxides of iron and manganese carrying silver; (9) as lead, with pyrite and zinc; and (10) as lead, with silver, zinc, and barite. Metallic lead in ores is uncommon; some is found in Sweden.

Perhaps the cleanest lead ore mined is that in southeastern Missouri, in St. Francois County. The characteristic ore of the district is dolomite with disseminated (scattered) galena and a little pyrite. The silver content is almost negligible. The ores of the Leadwood mines contain some zinc. Deposits at Fredericktown in the Potosi limestone have more complex ores containing copper, nickel, and cobalt.

The disseminated ores (see Fig. 69), which alone make the district of importance, occur in the Bonne Terre dolomite, usually within a few feet of the underlying sandstone, also frequently at various levels in upper strata of the same dolomite as far as 300 feet above the sandstone.

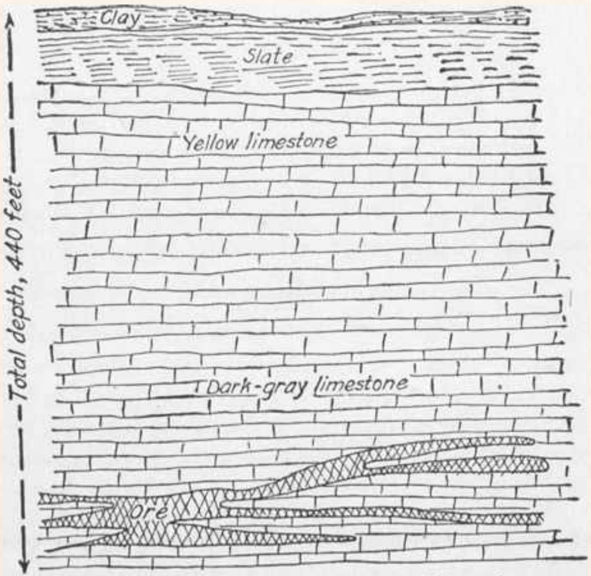


FIG. 69.—Lead ore in southeastern Missouri.

The orebodies are most persistent horizontally—that is, they are tabular and follow the stratification and as worked vary from 7 to over 50 feet in height, with an average of perhaps 14 feet. The grade (average grade is 5½ per cent lead) of the ore fluctuates rapidly in the areas of wide, flat dissemination. It has proved the best policy to break the whole and follow a regular system within the limits of the orebodies outlined by exploration, even though locally the ore may be obviously too poor, as a few rounds may break into good ore again, which either would not be found or could not be extracted otherwise. In the northern part of the field orebodies are found which are narrow and thick in proportion to their width—say, 200 feet wide and many hundred feet long—and the ore is somewhat finer grained. In these, ore of good grade ends abruptly at the margins.

The diamond-drill is employed for prospecting and outlining these orebodies. Churn-drills are used to reach solid rock. A solid bit is used excepting in that part of the Bonne Terre dolomite in which ore is anticipated. The sludge indicates any ore encountered while working with solid bit. The cores, corresponding to about one-fourth of the hole, are assayed by some companies but by others are estimated by trained visual (eye) inspection and are preserved as records.

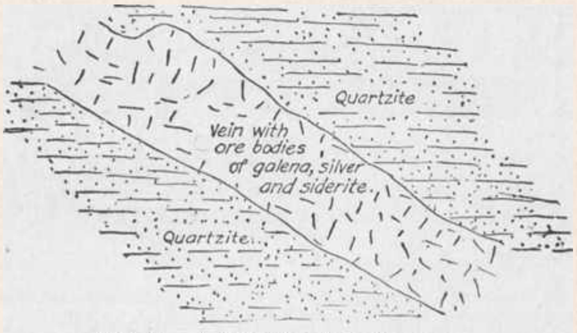


FIG. 70.—A deposit of lead-silver ore.

An example of occurrence 2 of lead is at Silverton, Colorado, where the orebodies are veins in eruptive rock. Occurrences 3 to 8, inclusive, are found at Leadville, Colorado. Figure 70 is an example of occurrence 4. Some of the Idaho deposits come under the head of occurrence 9, and occurrence 10 finds examples at Aspen, Colorado.

For notes on the zinc-lead deposits of Kansas, Missouri, Oklahoma, and Wisconsin, see the description under Zinc. There, the lead is subordinate to the zinc, although the total lead output is large. The ore averages about 0.23 per cent lead in Kansas and Missouri and 0.90 in Oklahoma. Examples of irregular shoots in limestone are as in Fig. 71*a* and *b*.

The lead-silver-zinc lode of Broken Hill, New South Wales, Australia, which has yielded more than £160,000,000 ($770,000,000), may be considered as an intimate mixture of silver-bearing galena and blende or marmatite (a zinc-iron sulphide), with either calcite or rhodonite, lying in sillimanite-gneiss. At the surface are pegmatite and manganese. At depth it is easy to distinguish between ore and country, and little sampling is necessary. The

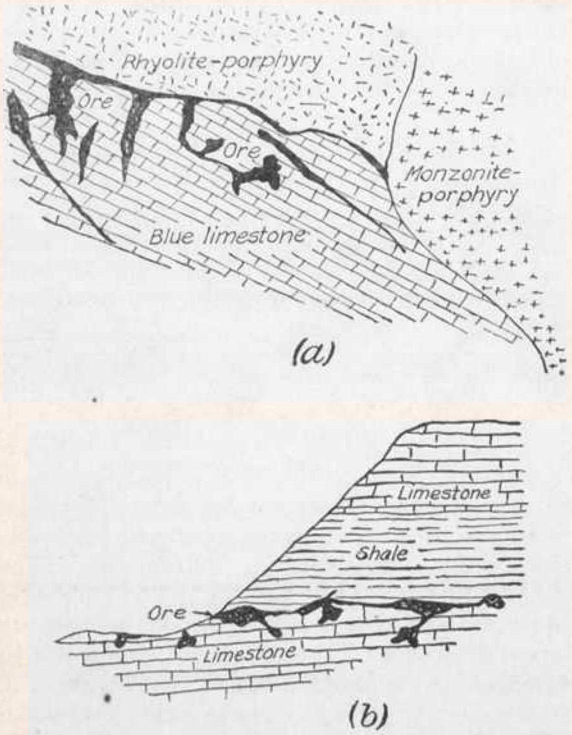


FIG. 71 (*a–b*).—Irregular shoots of lead ore in limestone.

weight and appearance of ore and rock are distinctive. This is an example of occurrence 6; so is the great deposit at Mount Isa, Queensland. There the outcrops of shoots are not prominent, but they range from a few thousand tons to ones 2000 feet long, 200 feet wide, and 1200 feet deep. The country consists of shales lying between quartzites dipping up to 60 degrees. The silver, lead, and zinc sulphides are interbanded with pyrite and pyrrhotite. The main orebody averages nearly 5 ounces of silver and 8 per cent each of lead and zinc.

Tests

Powder a lead mineral and mix it with a little sodium carbonate and melt the mixture; use the inner part of a blowpipe flame. A small coating will appear on the charcoal on which the melting is done. This coating is yellow near the powder and white farther away, and of course a globule of metal also remains.

A better test is the following: Grind some of the ore very fine. Boil in dilute nitric acid (3 parts water to 1 part acid) for 2 minutes. If the solution does not settle clear on cooling, it must be filtered through paper. Regular filter-paper is best, but napkin paper folded several times will serve. To the clear cold solution add a few drops of dilute hydrochloric acid and shake. If a white precipitate forms, silver or mercury or lead is present. Anybody familiar with the test can distinguish the lead from these metals, as it forms clear but small granules. Otherwise heat the solution, and lead will dissolve, while the mercury and silver will not. The lead separates out again on cooling.

In the case of anglesite this test will not work unless the ore is first melted with sodium carbonate.

A rapid and reliable test for the presence of lead is to grind some ore very fine, place about enough to cover a 10-cent or 6-penny piece in a glass beaker or enamel basin, add two drops of concentrated nitric acid, and allow to act for a moment; add two tablespoonfuls of cold water, then some potassium iodide, about as much as will cover the tip of a knife-blade. If lead is present, a yellow precipitate results. This test is sensitive to very small quantities of lead and takes only 2 minutes.

Lead Minerals

Galena is the principal mineral of lead; anglesite, cerussite, and other compounds are of minor importance.

Galena. Galena is a lead sulphide and contains 86 per cent metal. Its color and streak are lead-gray, and it has a bright metallic appearance. It is brittle, and, when it is broken, right-angle corners are always present, although occasionally a magnifying glass is needed to see them. Galena has a hardness of 2.5 to 2.75 and specific gravity of 7.5. A cubic foot will weigh over 450 pounds. It is easily melted in a blowpipe flame. Either test given above will show that lead is present, and galena also gives a test for sulphur.

Once familiar with galena a person seldom confuses it with any other mineral. It is frequently associated with sphalerite and, except in the particular type of deposits in Illinois, Kansas, Missouri, Oklahoma, and Wisconsin, carries silver in varying amounts.

Galena weathers slowly to anglesite or cerussite. In some gold areas of California, Maryland, Australia, and New Zealand it is a good indication and should be followed. Exceptionally good galena crystals in small quantities are in demand by dealers.

Anglesite. Anglesite is a lead sulphate and carries 68 per cent metal. Its color is white, yellow, green, blue, or dark gray. It is soft—its hardness is 2.75 to 3.0—and it is heavy—its specific gravity is 6.3. The streak is white. It melts easily in the blowpipe flame.

The test for lead, by melting with sodium carbonate and noting the deposit formed on the charcoal, works well, but the acid test does not work well unless the mineral powder is first melted with sodium carbonate.

Anglesite looks much like cerussite, barite, and celestite. Cerussite bubbles in hot concentrated hydrochloric acid (barite will not give a test for lead); it melts with more difficulty and usually flies to pieces when an effort is made to melt it. Celestite can be easily identified by the brilliant-red color it gives to the blowpipe flame when it is melting.

Anglesite is formed by the weathering of galena.

Cerussite. Cerussite is a lead carbonate mineral with 77 per cent metal. Its color is white, gray, or brown, and its streak is white. Its hardness is 3 to 3.5. It is heavy, a cubic foot weighing 400 pounds; its specific gravity is 6.5. Cerussite is very brittle and has a conchoidal fracture. The luster inclines to the pearly.

If cerussite is powdered and put in hot concentrated hydrochloric acid, it bubbles; and when the acid cools, small white crystals form in it. Either test for lead already given should work easily with cerussite.

Cerussite looks something like barite, anglesite, and strontianite, but none of these bubbles in the acid. It is formed by the weathering of galena but is not common.

Pyromorphite. Pyromorphite is a lead phosphate. Its color may be white, green, gray, brown, yellow, or black. Its streak is white or light yellow. Its hardness is 3.5 to 4 and specific gravity, 6 to 7. It melts easily in a blowpipe flame. If the powder is boiled in dilute nitric acid, and a few drops of this solution added to some ammonium molybdate solution, a yellow color forms slowly (a test for phosphate). The phosphate test is the easiest to use to distinguish pyromorphite from mimetite.

Mimetite. Mimetite is an arsenate of lead. It is like pyromorphite in appearance but is slightly heavier and gives no phosphate test. Pyromorphite and mimetite are usually formed as crystalline crusts in cracks and cavities in rocks. They are seldom found at a depth of more than a hundred feet.

Wulfenite. Wulfenite is a lead-molybdenum mineral described under Molybdenum.

MAGNESIUM

Magnesium may be extracted from magnesite or, as generally done, from magnesium salts, principally the chlorides, which occur as brine in salt beds as in Michigan and in Germany. It is also being recovered commercially from sea water. Magnesium is never found as a metal. Its production from the ore or salts is, like that of aluminum, rather complex. Magnesium has a specific gravity of 1.74, weighs 109 pounds per cubic foot, and melts at 1204°F. (Corresponding figures for aluminum are 2.70, 166, and 1218.)

The use of the metal and its alloys is growing, and in engineering it may be substituted for aluminum and its alloys where a lighter material is required.

MANGANESE

Manganese is a hard, brittle, grayish-white with red tinge, heavy, non-magnetic metal, never existing as such in nature and little used as a metal. In the form of ferro-manganese or spiegeleisen it is used in steel-making. About 14 pounds of manganese is used in every ton of steel made, and manganese steel contains 12 per cent manganese. This is the principal consumption of manganese, but other alloys, chemicals, dry batteries, and paints use a large quantity. The metal has a specific gravity of 8 and weighs 500 pounds per cubic foot.

Occurrence

Manganese deposits are of several types; Fig. 72 shows some of them. Perhaps the most common type is that formed by the weathering of a rock or vein which contains a little manganese and is enriched by the removal of the worthless parts of the rock by natural processes of solution. Manganese is sometimes found in veins, in sedimentary rocks much like some iron ores, and as nodules, concretions, or bunches in clayey deposits as in Virginia, Cuba, and South Dakota.

Brazil, India, Africa, and Russia produce the bulk of the world's manganese from large deposits. There are numerous smaller deposits in many parts of the world. In Montana, Colorado, Arkansas, Alabama, and Minnesota are noteworthy deposits. The Minnesota ores are not mined for manganese alone but for iron and manganese together. They are found in the Cuyuna iron range and are classed as manganiferous-iron ores. American deposits are widely scattered and comparatively small but in the aggregate make a large tonnage. Mining methods are simple, as the ores generally persist to shallow depths only.

Manganese also occurs in some copper, gold, silver, and zinc deposits. In these the ore may be mined only for the metals contained, and the manganese acts as a flux in smelting. Man-

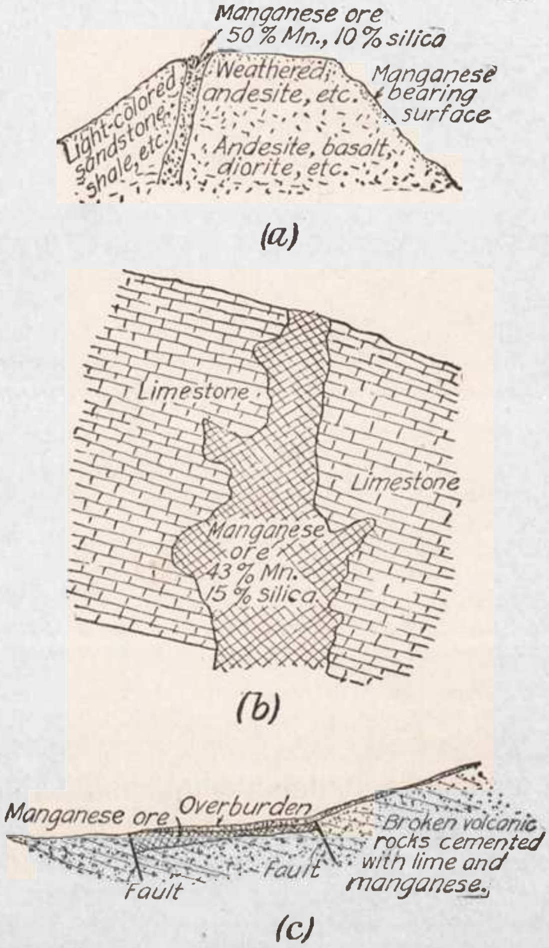


FIG. 72 (*a* to *c*).—Types of manganese deposits.

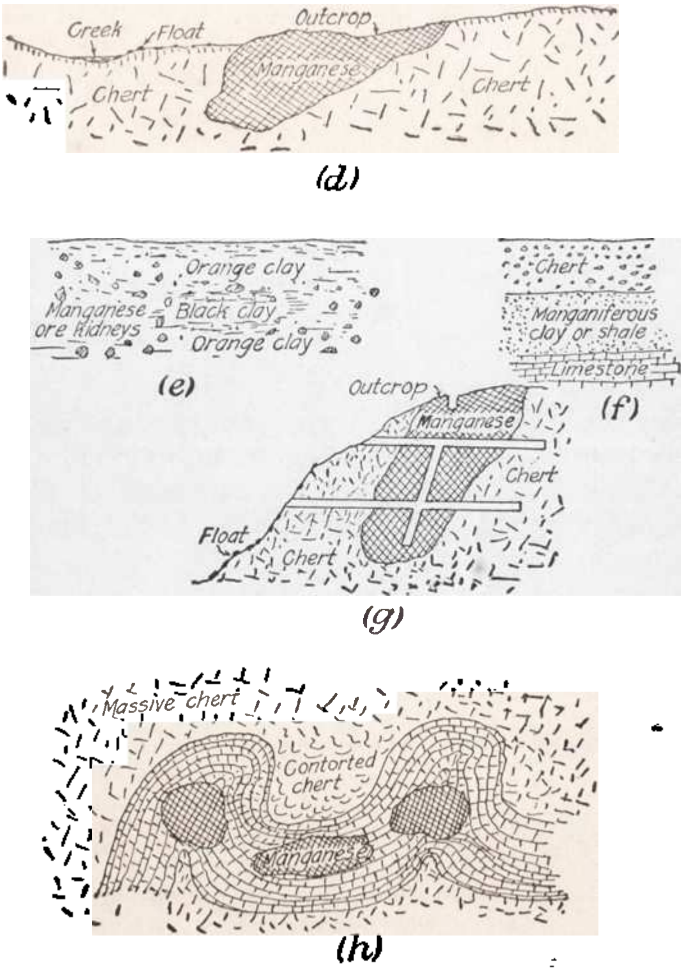


FIG. 72 (*d* to *h*).—Types of manganese deposits.

ganese-silver ores are somewhat difficult to treat, as in Nevada, Mexico, Sumatra, and New Guinea. A manganese outcrop in a copper district should be examined carefully. Instances of manganese with copper, silver, and zinc are the deposits in the Superior district of Arizona; in Tombstone, Arizona; Leadville, Colorado; and Jalisco, Mexico; and in Butte, Montana, and Franklin, New Jersey, respectively.

The Postmasburg manganese deposits in Cape Province, South Africa, are of sheet-like and irregular mass types of large tonnage and high mineral content. The ore is hard and heavy—8 cubic feet to the ton in place. Large shipments carried 44 to over 52 per cent manganese, 15 to 7 per cent iron, and 5½ to 6 per cent silica. The ore is either a gray to black amorphous psilomelane or a steel-gray to blackish finely crystalline braunite. The deposits are associated with cherty breccia, dolomitic limestone, and ironstone.

Classes of Manganese Ores. There are four marketable classes of manganese ores, as follows:

1. The oxide, used in making chemicals and in electric dry batteries. Such ore must be high grade—80 to 95 per cent oxide—and commands a high price.
2. High-grade ore for making ferro-manganese. This must have more than 35 to 40 per cent manganese and less than 5 per cent iron and 15 per cent silica. Such ore commands a fairly good price.
3. Low-grade ores for making spiegeleisen. These contain 10 to 35 per cent manganese, 20 to 35 per cent iron, and less than 20 per cent silica.
4. Other low-grade ores containing manganese in such form that it can easily be concentrated and be of marketable importance.

Normally, only the first two grades have an assured market.

Tests

An easy and sure test for manganese is to make a bead of sodium carbonate in a loop on a platinum wire and sprinkle on it a small amount of powdered mineral. If too much is added, the bead will be too black to identify the coloration. Melt again and use the tip of the blowpipe flame. If the bead is bluish green when it is cold, manganese is present. With borax in the oxidizing flame the bead will be reddish violet. There are about 100 minerals that contain a little manganese but only a few that contain large quantities. If a person experiments on a number of minerals containing different quantities of manganese, he can soon learn to judge whether there is only a little, a medium amount, or much manganese in the ore by noting the shade of green of the bead. Iron gives the bead a reddish-brown hue.

If a teaspoonful of hydrochloric acid is added to a little manganese dioxide and heated, chlorine gas will be given off and detected by its suffocating odor.

Minerals

Of the many manganese minerals, only the four most important will be described here:

Pyrolusite. Pyrolusite is a black oxide of manganese containing 63 per cent metal. It is soft—hardness 1 to 2.7. It soils the fingers, as it is a soft, black material. It is dull black. It is not very heavy; it has a specific gravity of 4.7 and weighs 300 pounds per cubic foot. It cannot be melted in a blowpipe flame, but it does become brown on heating. Pyrolusite is found as an earthy material or as radiating fibrous crystals. It gives a strong test for manganese.

Wad, another manganese mineral, somewhat resembles pyrolusite, but there is no need to distinguish between the two, as they are both good ores.

Pyrolusite is formed by the weathering of other manganese minerals; it is also deposited in beds or marsh bottoms and in veins by cold rain waters that have dissolved manganese from the surrounding rock. Pyrolusite is mostly used as the chemical ore.

Psilomelane. Psilomelane is an oxide of manganese containing a little water and 40 per cent metal. It is hard, about 6, and its specific gravity is 4. It is gray, shiny-black to coal-black in color. Psilomelane's streak is black or brown-black. It cannot be melted in a blowpipe.

Wad, braunite, manganite, and other manganese minerals somewhat resemble psilomelane, and they are closely similar in composition.

Any of these minerals may be tested roughly for purity by boiling a little of the mineral powder in strong hydrochloric acid, when they give an obnoxious odor of chlorine as they dissolve. All that does not dissolve is impurity, but it must be remembered that any iron present will also dissolve. This test is given because a great many rocks that contain only 10 per cent manganese look like rich ores, and this simple test will show the large percentage of impurities.

Rhodochrosite. Rhodochrosite is a carbonate of manganese and contains 66 per cent metal. It has a beautiful pink color (*rhodo* is Greek for red) and is prominent with the zinc-silver ores of Butte, Montana. Its hardness is medium, about 4; its specific gravity is 3.5. A cubic foot will weigh 220 pounds. Its streak is white, and it breaks with flat shiny surfaces.

Rhodochrosite may be tested for manganese as described. It does not melt in a blowpipe flame. It may also be tested by powdering some of the mineral very fine and putting a little in a little concentrated hydrochloric acid. When the acid is warmed, it starts to bubble vigorously and the mineral dissolves. No other pink mineral does this.

Rhodochrosite is confused with rhodonite and manganiferous dolomite. Rhodonite looks much like rhodochrosite, but it will not bubble and dissolve in hot hydrochloric acid, and it can be melted. Manganiferous dolomite is really an impure rhodochrosite or a mixture of rhodochrosite and dolomite, which can not be distinguished easily from the pure rhodochrosite; it may sometimes be identified as follows: Put some dilute hydrochloric acid in a test-tube; boil it and let it cool just a little; then add the mineral powder; dolomite will bubble, but rhodochrosite should not. Dolomite is a magnesian limestone.

Rhodochrosite weathers to the black manganese minerals described. When it is heated, the carbon dioxide contained passes off and a higher grade ore results.

Rhodonite. Rhodonite is a silicate of manganese, with 42 per cent metal. It is pink in color, and its streak is white. It is hard, about 6, and its specific gravity is about 3.5. It breaks with shiny flat surfaces. It blackens and melts easily in the blowpipe flame. It may be tested for manganese as described above, and this, together with the properties of the mineral as mentioned, is sufficient to identify it.

Rhodonite resembles rhodochrosite and manganiferous dolomite, both of which dissolve in hot concentrated hydrochloric acid. It also resembles pink feldspar, but this mineral gives no test for manganese.

Rhodonite has too much silica in it to be of any value as an ore unless mixed with purer ores. It weathers to the black minerals of manganese previously described. Rhodonite accompanies the silver-lead-zinc ore of Broken Hill, Australia.

There are many other manganese minerals. Franklinite is the only other which is a source of manganese, and it is described under Zinc. Hübnerite contains much manganese but is of more value for the tungsten that it contains. None of the others is of value for manganese.

MERCURY (QUICKSILVER)

Mercury is a very heavy, silver-white, liquid metal, found in nature in small quantities as the metal but generally as the sulphide cinnabar. Everybody is acquainted with this peculiar element, the only metal that is liquid at ordinary temperatures. The prospector uses it in what are known as amalgamation assays in testing free-milling gold ores, also in his small stamp-mill, both in the mortar-box and on the copper plates. The blasting cap that detonates a charge of dynamite placed in a drill-hole contains fulminate of mercury. Mercury is also consumed in paints, drugs, mirrors, boilers, and electric transformers and for numerous scientific purposes. It is almost indispensable in some industries. The metal is sold in flasks which hold 76 pounds, provided with screw-plug or stopper, but small lots are marketed in 1-, 5-, and 10-pound jugs or bottles. Mercury has a specific gravity of around 13 and weighs over 800 pounds per cubic foot.

Mercury Mineral

Cinnabar. Strictly speaking, cinnabar is the only compound of the metal worth considering; almost the whole supply of the world is derived from it. Cinnabar is mercury sulphide and contains 86 per cent mercury and 14 per cent sulphur. It has a cochineal-red or crimson color—especially if wetted. The streak is scarlet. It crystallizes in the third system, also as acicular or needle-shaped crystals. Cinnabar may be cut somewhat easily with a knife. The hardness is 2 to 2.5, its fracture is uneven, and its specific gravity is 8 or more. A cubic foot weighs 560 pounds. The luster inclines to be metallic when the mineral is of dark color.

Although the appearance of cinnabar should be sufficient to distinguish it, many people confuse it with the following:

1. Cuprite (copper), which gives a green color to a blowpipe flame.
2. Hematite (iron), which contains no mercury and is not so bright in color.
3. Realgar (arsenic), which gives an odor of garlic when heated.
4. Proustite (silver), which gives an odor of garlic when heated.
5. Zincite (zinc), which has no mercury and is found with franklinite in New Jersey and in Utah.
6. Cobalt bloom, which is generally earthy, not crystalline.

Other mercury minerals are meta-cinnabarite, also a sulphide but grayish black with a black streak; calomel, the chloride; and the tellurides, coloradoite and kalgoorlite.

Tests

Cinnabar is easily identified, but a few simple tests may be given.

1. If a rock containing metallic mercury is powdered and rubbed on clean copper coin, the coin will become silvered or amalgamated.
2. If cinnabar is heated in the blowpipe flame, the metal contained will volatilize or go off as fume.

3. If cinnabar is finely powdered, moistened with hydrochloric acid, and rubbed on a clean copper penny, the coin will be coated with mercury so that it looks like silver. (Note: A dirty copper coin can be cleaned by dipping it in nitric acid.)

4. If the mineral is placed in a closed tube in the blowpipe flame, a black coating or deposit forms; and if it is heated in an open tube, globules of mercury and sulphur fumes are formed.

Fig. 73.—Sketch of a mercury district.

5. The ore may be crushed fine and panned similarly to gold ore.

6. If mercury is suspected and a dark mineral is present, break the sample to expose a fresh surface which might show the red sulphide.

Occurrence

Mercury deposits may be found in rocks of any composition or age, including serpentine, shale, slate, sandstone, limestone, andesite, basalt, granite, and rhyolite. It is considered that hot springs have been the means of carrying and depositing cinnabar, so these and districts where there are sulphur deposits should be prospected. Bitumen also exists in the vicinity. As a rule, mercury deposits do not persist to great depth. Figure 73 is a sketch of a mercury district in California.

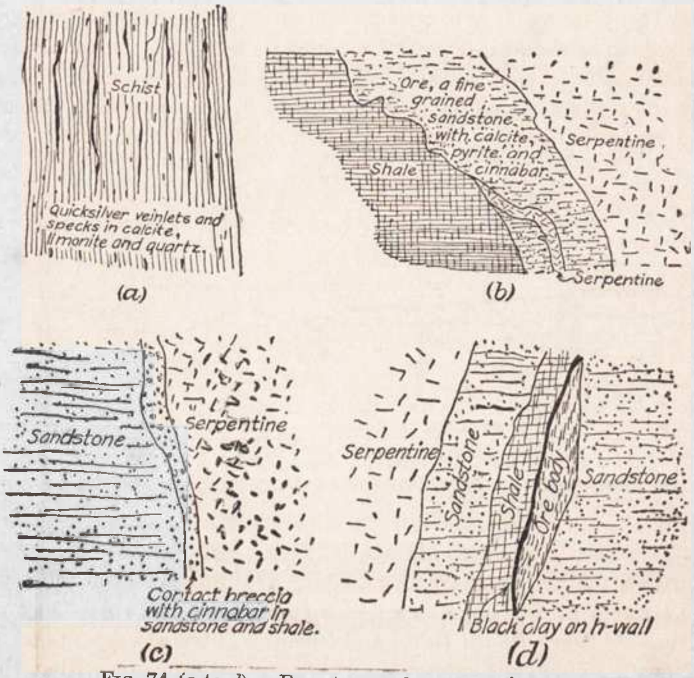


FIG. 74 (*a* to *d*).—Four types of mercury deposits.

Orebodies may be in the form of fissure veins, reticulated veins (network), stockworks (numbers of small parallel veins), and impregnations, as in Fig. 74.

The Arizona, Nevada, and Texas deposits are in arid country, as a rule some distance from rail.

Nearly all the California deposits are in, at, or near the contact of serpentine and dike rocks, such as rhyolite. Chromite is mined from some of this serpentine, also magnesite. This serpentine is reddish, which indicates iron, and on it grows fairly abundant underbrush. Where the rock is pale blue or green and soft, little growth is noticeable.

C. N. Schuette, a specialist in the geology of mercury deposits and treatment, San Francisco, believes that mercury orebodies are of primary origin. Their source is deep-seated, and the alkaline carrier solutions were trapped near the surface by an impervious caprock of shale, silicified rock, or clay, this resulting in the cinnabar being precipitated in voids in a receptacle rock as sandstone, limestone, breccia, or other rock. The caprock is more dense than the receptacle rock in which the ore forms. Figure 75 shows a simple occurrence in Texas. In general, the more perfect the trap the larger and richer are the orebodies under it. Examples of this are a number of mines in California, Oregon, Texas, Mexico, Peru, Italy, and Spain. There are exceptions in Nevada, where although mercury mineralization is extensive, the mercury-bearing solutions came up faults, reached the surface quickly and had less breccia in which to form and less gouges under which to be trapped; hence the deposits are small in tonnage and area and generally shallow.

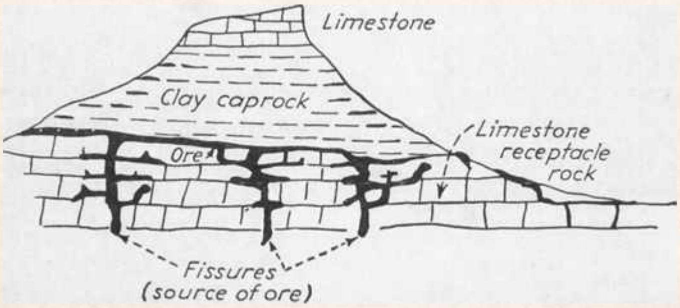


Fig. 75.—Formation of mercury ore. (*According to Schuette.*)

The principal minerals associated with mercury ore (cinnabar) are quartz (common), pyrite (common), calcite (abundant), dolomite, serpentine, and marcasite. Free sulphur is found in some deposits and arsenical pyrite in others.

Cinnabar in Arkansas was identified in 1931. It occurs mainly as fractures in brown-gray sandstone, which may be vertical, horizontal, and bending—fractured and faulted. The fractures are filled with vein quartz, cinnabar, and dickite—a kaolin mineral. G. C. Branner, State Geologist, suggests close examination of rock in place and loose sandstone on crests and slopes of ridges. Cinnabar in this float has generally led to discovery of parent rock. Fresh surfaces are necessary because the cinnabar turns black after exposure to the weather. The soil should be panned. Fractured and broken zones should be examined, also sandstone-shale contacts and sandstone lying between shale beds. The United States Geological Survey agrees with this. Figure 76 shows the types of cinnabar occurrences in Arkansas.

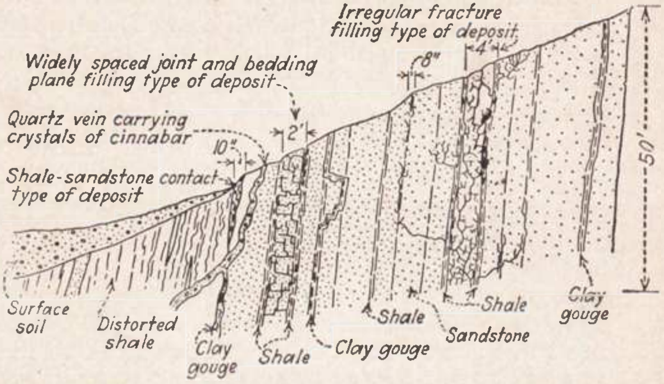


Fig. 76.—Types of cinnabar occurrences in Arkansas. (*According to Branner.*)

Cinnabar in Oregon was first detected by gold-placer miners.

Ore Treatment

Normally, the process of recovering mercury from its ores is easy and cheap, and the product is rather high priced ($1 or more a pound), so low-grade ores may be worked. Under favorable conditions ¼ per cent ore can be mined at a profit, but in many cases a ½ or 1 per cent ore is not payable; in terms of weight of metal these percentages are equivalent to 5 to 20 pounds per ton. European and Mexican ores are several times richer than those of the United States.

If a prospector finds rich enough ore, he must treat it locally, as there is no known custom plant that receives mercury ore.

The process is described under Ore Dressing and Treatment, page 439.

There is little need for close sampling and assaying of mercury ore at prospects and small mines. Samples fairly taken, crushed, and panned will reveal approximately the amount of cinnabar in the retort feed and discharge. Cinnabar is brittle and breaks away easily from the gangue. Panning is made simpler by its specific gravity of 8 and that of 2.6 for silica and limestone.

MOLYBDENUM

Molybdenum is a metal of the chromium group. It resembles iron in its white color, malleability, and high melting point. Its principal use is in special steels, alloys, and chemistry. The metal has a specific gravity of 8.6 and weighs 530 pounds per cubic foot, nearly double that of its mineral molybdenite.

Occurrence

Molybdenum minerals are more plentiful than tungsten. Deposits large and rich enough to mine have been found in a number of foreign countries. In the United States the chief deposits are in Colorado, New Mexico, Arizona, and Utah (a by-product from copper ore), and a small production from California as a by-product metal in tungsten ore.

As molybdenum is chemically much like tungsten, it is to be expected in the same kind of deposits. It is frequently found in or near granite rocks or pegmatites, but there are more exceptions to this rule than with tungsten. Molybdenum often exists with the same minerals given under Tungsten—that is, cassiterite (tin), bismuth minerals, pyrite, chalcopyrite, fluorite, beryl, topaz, quartz, and tungsten minerals. Also it is frequently associated with galena and the rarer lead minerals. Molybdenum is seldom found in stream beds.

In general it may be said that the principal mineral molybdenite is found in pegmatite dikes, in quartz veins of all sizes, in masses of granular and porphyritic rocks through which it has been disseminated by fluids following cracks, and in contact-metamorphic deposits (changed rock along contacts of igneous and sedimentary rocks).

The ores of molybdenum may be rich locally, but probably few large deposits average more than 1 per cent of molybdenite. The great deposit near Climax, Colorado, carries 1 per cent molybdenite. It has the form of a pipe of silicified granite which enlarges downward. The deposit near Questa, New Mexico, consists of narrow and irregular veins in granodiorite. It averages 5 per cent molybdenite. Both of these mines are at high altitude —12,000 and 8700 feet. Figure 77 shows three types of molybdenite occurrences.

In general, molybdenite occurs in coarse granite, as pipes of quartz or granitic material. In northern New South Wales, Australia, the deposits occur in this manner, irregularly around the margin of the containing granite and dipping, as a rule, parallel to the general plane of contact of the granite and associated rock masses. The molybdenite also occurs in true veins in granite near their intrusive junction with other rocks; again, as flakes irregularly disseminated in drusy quartz and feldspar.

In the Kingsgate district of New South Wales the topography is moderately rugged at an altitude of 3750 to 5000 feet. There is a good growth of eucalypts. There is intimate relationship between the marginal areas of the granite and distribution of the molybdenite and bismuthinite. Tin and wolfram are also found in this district. The molybdenite is a remarkable occurrence of pipe-veins or oval masses of quartz of variable thickness, persisting more or less vertically in granite. Bismuthinite is found as nests or bunches. The quartz is coarsely crystalline and carries the molybdenite in patches in the solid gangue; but carbonate and oxide lie chiefly in joint fissures in quartz. One vein contains arsenical pyrite and molybdenite. Pipes are worked to an inclined depth of 500 feet. They may branch upward, outward, or downward. At one property the ore carries 3 per cent molybdenite

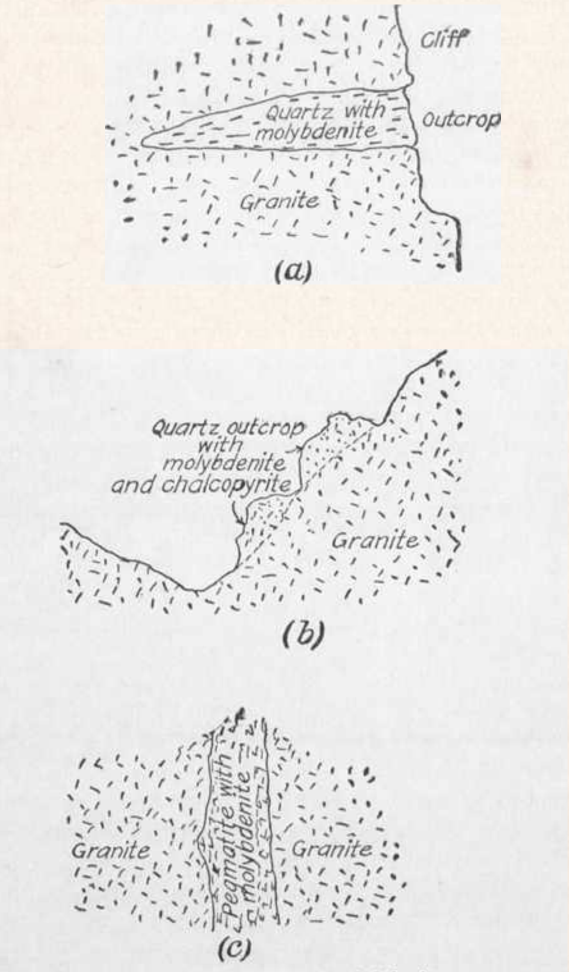


FIG. 77 (*a*, *b*, *c*).—Three types of molybdenite occurrences.

and bismuthinite in quartz or siliceous granite. It is crushed in a rockbreaker and rolls and passed over a Wilfley table. The molybdenite concentrate carries 85 per cent molybdenum sulphide and 8 per cent bismuth sulphide, and the bismuthinite concentrate carries 45 per cent metal. Figure 78 is an ideal section at Kingsgate, according to *Mineral Resources* 24 (1916), of the State Geological Survey.

Wulfenite, lead molybdate, is found in the western parts of the United States and northern parts of Mexico. The ores carry greatly varying percentages of molybdenum, but the average is probably less than 1 per cent. Vanadium is frequently associated with wulfenite, also copper minerals.

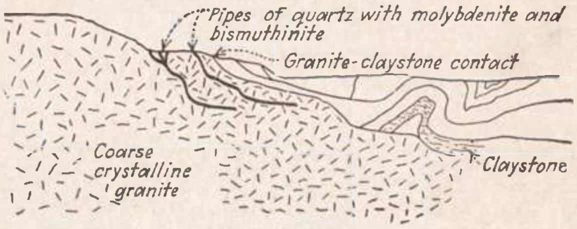


Fig. 78.—Molybdenite (and bismuthinite) occurrence in New South Wales.

Molybdite, the oxide of molybdenum, is in a few places abundant enough to be considered an ore mineral, as at Climax, where considerable quantities of molybdenite have been oxidized.

Tests

The following tests are easily made in the field:

1. A thin fragment of a molybdenum mineral held in the forceps and heated in the outer part of the blowpipe flame always gives a peculiar green-gray (yellowish-green) color to the flame. If no such color appears, there is no molybdenum present; but if it does, you cannot be sure that molybdenum is present, because lead, arsenic, antimony, barium, boron, and phosphates all give nearly that same color.
2. Crush fine a bit of the mineral. Put a little of the powder, about as much as a pea, into a test-tube and drop in a scrap of

paper not more than 1/16 inch square. Add three drops of water and five drops of concentrated sulphuric acid. Then carefully heat the tube over a flame until a heavy white smoke comes out. When cool, a bright-red color may show, which indicates molybdenum; yet if it is not red, it is not at all possible to be sure that there is no molybdenum present. When making this test do not hold the test-tube anywhere near the face while heating it, as it may break and cause the liquid to fly. A small drop in the eye may cause blindness.

3. When heated in an open tube molybdenite gives off sulphurous fumes, and a pale-yellow crystalline sublimate of molybdenum trioxide is formed.

4. On charcoal in the oxidizing flame of the blowpipe, crushed molybdenite gives a strong odor of sulphur and leaves the charcoal coated with crystals of oxide, which are yellow while hot and white when cold. Near the heated mineral the coating is copper-red; and if the white coating is touched occasionally with the reducing flame, it becomes a beautiful azure color.

5. Molybdenite is decomposed by nitric acid and leaves a white or grayish residude—the oxide.

6. Wulfenite crackles when heated in the blowpipe flame and fuses easily. With borax in the oxidizing flame it gives a colorless glass which, in the reducing flame, becomes black or dirty green. With the phosphorus salt these flames give yellowish green and dark green respectively. The powdered mineral, on heating with soda on charcoal, yields metallic lead. Wulfenite is decomposed when heated to dryness with hydrochloric acid, and on adding some water to the residue and a little metallic zinc an intense blue coloration results.

Molybdenum Minerals

There are only two common minerals of molybdenum—namely, molybdenite and wulfenite. Molybdenite or molybdic ocher is rare.

Molybdenite. Molybdenite is a sulphide of molybdenum containing 60 per cent of the metal. It is a soft, shiny, gray or black mineral usually in flakes or plates; its hardness is 1 and specific gravity, 4.8. A cubic foot will weigh up to 300 pounds. It will make a mark on paper like graphite. The flakes may be minute or as large as 2 or 3 inches. When they are large enough to handle, they may be separated into thin leaves like mica. When first parted they have a peculiar purplish tinge. If molybdenite is rubbed on glazed white porcelain like an ordinary glazed porcelain dish, it leaves a greenish mark. It will not melt in a blowpipe flame but when white hot gives the greenish color as described under the tests.

Molybdenite is easily confused with graphite, which also resembles flaky specular hematite. Graphite will not give the flame color of molybdenum, and when rubbed on glazed porcelain it leaves a shiny gray or black mark rather than a green mark. Molybdenite will give a test for sulphur, but graphite will not. Molybdenite and specular hematite are never confused except when fine-grained. The latter, when finely powdered, is a dark red-brown; it will not give the molybdenum flame color and will not give a sulphur test.

Molybdenite sometimes occurs with copper, as in Arizona. Their separation is rather troublesome, as the specific gravity is almost equal. Copper is undesirable in concentrates, and steel-makers may refuse them on this account. Vanadinite also occurs with molybdenite and gives trouble.

Wulfenite. Wulfenite contains both lead (60 per cent) and molybdenum (26 per cent) and is known as a lead molybdate. It is bright yellow to orange in color and usually is found as small plate-like crystals. It is rather soft—its hardness is 4.5—its specific gravity, 6. It is easily melted in a blowpipe flame.

Vanadinite, crocoite, and several rare uranium and vanadium minerals look much like wulfenite. Except for the first two, none of them gives the molybdenum flame color. Vanadinite and crocite both give the greenish flame color because they contain lead; these minerals are seldom in platy crystals, while wulfenite almost always is.

Wulfenite is usually found lining holes or cracks in rocks. Molybdite or molybdic ocher is a yellow earthy powder frequently found in molybdenum ores. It is of little importance, as it is seldom abundant.

Grade of Ore and Preparation for Market

Ores with less than 2 per cent molybdenum sulphide can be mined at a profit only when they occur in large quantities; usually the ore must be better than 5 per cent. In the case of molybdenum-lead ores there may be as little as 1 per cent molybdenum oxide in the ore. Such ores are mined and smelted to obtain the lead, however, and then the slag is treated for the molybdenum; this slag may contain 20 per cent molybdenum oxide. In selling molybdenum ores the miner may be confused, as some are sold on the basis of molybdenum sulphide content, some on the basis of content of molybdenum oxide, and some on the actual molybdenum metal content. Ore containing 1.65 per cent molybdenum sulphide is equal to ore carrying 1.50 per cent molybdenum oxide, and either of these is equal to an ore with 1 per cent molybdenum metal. Molybdenum sulphide and molybdenite mean the same thing.

Where molybdenum ore carries the mineral in large enough flakes, a good deal may be hand-sorted, as on King Island, south of Australia; but if in fine particles, some local treatment must be tried. Ordinary concentrating tables are not very successful, as the molybdenite floats away, so in many cases it is separated from the enclosing rock by water or oil flotation. Wulfenite presents few difficulties, as it is so heavy, and the machinery used for lead and zinc ores gives a high recovery.

The value of molybdenum concentrates varies from day to day. Frequently they can not be sold at any price; but when sales are made, the price is, say, about 40 cents a pound of molybdenum sulphide for 85 per cent or richer concentrates. In other words if the seller has 100 pounds of concentrates containing 85 per cent molybdenum sulphide, he will have the equivalent of 85 pounds of material, for each pound of which he will receive the quoted price. In Australia the concentrate has been selling at 40 shillings a unit.

NICKEL

Nickel is a hard, malleable, ductile, nearly silver-white metal, which is attracted by the magnet and finds its greatest consumption in special steels, monel metal, plating, and coins. It is a heavy metal, the cast product having a specific gravity of 8.6 and a weight of 510 pounds per cubic foot. There are no workable nickel deposits of value in the United States. Small quantities of nickel, generally a few pounds per 100 tons of blister copper, are found in the great copper sulphide deposits, and the nickel is saved in the electrolytic refining of the copper. This forms the only present source of nickel in the United States.

Occurrence

Nickel is found in two principal types of deposits—(1) pyrrhotite (magnetic iron pyrite) deposits, which carry small quantities of pentlandite, the nickel-iron sulphide; and (2) nickel-magnesium silicate (genthite or garnierite), formed through the oxidation and disintegration of dunites, serpentines, and similar rocks. To the first class belong the great deposits at Sudbury, Ontario, and to the second the deposits of New Caledonia. The Sudbury ores average 3 to 5 per cent nickel and 2 per cent copper, with considerable quantities of platinum metals. A new deposit in British Columbia averages 1.4 per cent nickel and 0.46 per cent copper.

Nickel-copper ore of Sudbury, lies at or near the edge of where basic norite is in contact with greenstone and granite. Pyrrhotite is the most abundant sulphide, then chalcopyrite and pentlandite. The last two are intimately associated with the first and with each other. Chalcopyrite is easily distinguishable, but the pentlandite rarely. Platinum-group metals are by-products.

Besides these there are veins carrying sulphides, arsenides, and antimonides of nickel, usually in more easily recognizable forms than in the pyrrhotite deposits, and iron ores, such as those of Mayari, Cuba, which carry about 1 per cent nickel. The nickel passes into the steel made from this ore and is thus utilized.

At Fredericktown, Missouri, nickel is found with sulphides of zinc, lead, iron, copper, and cobalt in sandstone and dolomite.

In southern California there is some nickel in gabbro near its contact with schist. In North Carolina the dunite contains veinlets which carry nickel, and the mass averages 0.5 per cent. In Douglas County, Oregon, nickel occurs in an igneous rock and is accompanied by chromite and magnetite. In southern Nevada some nickel arsenite has been uncovered. The nickel-copper content is 0.8 to 1 per cent.

Serpentine in large masses carries from 0.25 to 1 per cent nickel and some day may form a source of the metal.

Nickel and cobalt usually exist in the same ore; and frequently chromium, silver, and platinum metals are found with them. The chief minerals, other than nickel ones, likely to be found in nickel ores are pyrrhotite, chromite, serpentine, magnetite, ilmenite, olivine, pyroxene, sperrylite, and chalcopyrite.

Nickel Minerals

The principal forms are pentlandite, niccolite, millerite, and garnierite. Chloanthite, linnaeite, and genthite are also important.

Pentlandite. Pentlandite is an iron-nickel sulphide. It has a yellow-bronze color, and its streak is dull black. The powder is not attracted by a magnet; but if a small piece is melted on charcoal in a blowpipe flame and then allowed to cool, it will become magnetic. It melts easily. On charcoal, if the mineral is heated in the tip of the blowpipe flame until red hot, an odor of burning sulphur will be evident; its hardness is 3.7 and specific gravity, 4.7. It may be tested for nickel as directed later. Pentlandite looks like pyrrhotite; moreover, it almost always comes as very fine grains in pyrrhotite, but that does not mean that if one finds some pyrrhotite, it will contain nickel, because most pyrrhotite does not carry any. Pyrrhotite that does have pentlandite in it is sometimes called nickeliferous pyrrhotite, as explained below.

Niccolite. Niccolite contains nickel and arsenic. When freshly broken it has a pale, copper-red, metallic color. It is easily melted on charcoal and gives off a dense white smoke which smells like garlic, a test for arsenic. It is rather hard but can be scratched with a knife; its hardness is 5.3. Niccolite is very heavy, as its specific gravity is 7.5. A cubic foot weighs 460 pounds. It yields to the test for nickel. Niccolite resembles copper, pyrrhotite, and bornite, but none of these gives a white smoke or the odor of garlic when melted.

Millerite. Millerite contains nickel and sulphur. It has a brass-yellow color, and its streak is a green-black. It is rather soft, as it has a hardness of only 3. It is a rather heavy mineral (specific gravity 5.7), about the same weight as pyrite. It melts on charcoal in a blowpipe flame. Millerite has a distinctive appearance, that of lines radiating from several central points.

Marcasite or white iron pyrite is the only mineral other than millerite that has this appearance, but it contains neither nickel nor copper. The test for nickel is satisfactory for millerite.

Garnierite. Garnierite is a complex nickel-magnesium silicate. It is a brilliant dark to pale-green mineral, sometimes just a stain on the rock and sometimes forming masses in the rock. It is fairly soft, as its hardness is 3 to 4, and not heavy—it has a specific gravity of only 2.5. It will not melt, but if heated it usually flies to pieces. It may be tested for nickel.

Malachite and chrysocolla both look like garnierite; these are both copper minerals and may be tested for copper. It is seldom that garnierite is found with copper; if the latter is present, the mineral is almost certain not to be garnierite.

Garnierite almost always is found in serpentine rock, which looks somewhat like garnierite, but it does not contain any nickel. Garnierite is formed by the weathering of other nickel minerals. It is mined in Brazil and New Caledonia.

Chloanthite and linnaeite are described under Cobalt.

Genthite and garnierite are almost the same, and there is no reason for distinguishing them.

Nickeliferous Pyrrhotite. This is not really a mineral but is a mixture of two minerals—pyrrhotite and pentlandite. It looks like pyrrhotite but has small specks of pentlandite mixed in, which can not be seen except with a microscope. Ordinarily pyrrhotite is of bronze color and medium hard. It can be scratched with a knife; its streak is black, and it is moderately heavy. If heated on charcoal with a blowpipe flame, it gives a strong odor of burning sulphur. If the mineral is powdered and put into some dilute hydrochloric acid and warmed, there is a strong odor like rotten eggs—only sphalerite (zinc blende) and pyrrhotite do that. No other mineral the color of pyrrhotite gives that odor. Nickeliferous pyrrhotite looks like ordinary pyrrhotite, but it will also give a test for nickel.

Tests

There are no simple satisfactory tests for nickel; however, the following will work well when there is no copper in the material: Grind very fine and put as much as a pea in a test-tube with one-quarter test-tube of strong nitric acid. Heat until about half has boiled away. After the liquid is cool, pour in ammonia until a brown jelly-like substance has formed, which is an iron compound. Let it settle until some of the liquid shows clear. If it is blue, there is copper or nickel or both.

To determine if there is any copper, moisten some of the fine powder with concentrated hydrochloric acid, put a little of this material on a platinum wire, and hold it in the blue flame of a gas or an alcohol burner. If the flame is colored bright green, there is copper present; if there is no green color in the flame, then the blue color seen in the other test was caused by nickel.

A test for cobalt often reveals the presence of nickel. Nickel compounds become magnetic when heated on charcoal in the reducing flame. All nickel ores should be roasted before trying bead tests with the blowpipe.

OSMIUM AND OSMIRIDIUM

See Platinum and Platinum-group Metals

PALLADIUM

See Platinum and Platinum-group Metals

PITCHBLENDE

See Uranium

PLATINUM AND GROUP METALS

The name platinum is derived from *plata*, the Spanish for silver, because it was regarded in South America at the time of its discovery in 1735 as an impure ore of that metal. It is a heavy metal; when cast it has a specific gravity of 20.3 and a weight of 1268 pounds per cubic foot. It has a steel-gray color. It has a greater specific gravity than gold but is somewhat harder; its hardness is 4 to 4.5. It is both malleable and ductile. Like gold, platinum is dissolved only by a mixture of hydrochloric (muriatic) and nitric acids, but its melting point is much higher than that of gold, 3100°F. as compared with 1950°F.

Owing to the great demand and high price, platinum is worth finding, but prospects are not good in the United States. Mining has been carried on by many placer miners working alone or in small groups and using crude appliances. The platinum content of river and beach sands (black) has been overrated, and this is so stated in *Technical Paper* 196 and *Information Circular* 7000 of the Federal Bureau of Mines. Beyond a few spots, the Pacific Coast sands are not worth wasting time on. Neither is there any of this metal in the Grand Canyon of the Colorado, as proved by the United States Geological Survey, although a boom was started there in 1918.

Twenty years ago the price of this metal was the same as that of gold—just over $20 an ounce. Gradually it rose to $40; that was in 1914. During the period of the First World War platinum prices soared to $110 and were as high as $130 in 1919. In 1921 it could be purchased for $75, about 3¾ times the value of gold, and from 1923 to 1927 the price was over $100; then, owing to supplies and production from Transvaal deposits and by-product metal obtained from Ontario nickel ores, the price fell to around $35 an ounce. Speculation then raised the price to $70, and at the present time it is around $35, the price of gold.

The world's normal production of platinum up to 1914 was 320,000 ounces per year. Of this, 290,000 ounces came from the Urals, the dividing range between Russia and Siberia. The remainder came mostly from Colombia, South America, with a few hundred ounces each from the United States, Canada, Australia, and Transvaal. On account of disturbed conditions the Russian output had fallen to a third of what it was. Meanwhile Colombia has helped to maintain the yield with more than 30,000 ounces a year, Canada with 300,000, and Transvaal with 40,000 ounces.

In the United States some platinum comes from dredges and a few thousand ounces a year comes from the refining of gold and copper. The Alaskan output is increasing each year and is becoming more important, being around 35,000 ounces a year.

Occurrence

In regard to the occurrence of platinum it might be said that much of it is found native—that is, as a metal, about 65 to 90 per cent pure. It has been found in Nevada in a fine-grained quartzose replacing dolomite and in Wyoming in basic dikes of diorite intruding granite-gneiss with some quartzite and granite. Considerable prospecting has been done to find the metal in place in rock, as it is termed, but usually without avail. In the Urals the "mother" rock was found to contain considerably under 1 grain per cubic yard. In British Columbia much drilling has failed to reveal any deposits.

Platinum deposits were found in Transvaal during 1924 and are now of much importance. Placer platinum was first found, then the metal in lode formation, which assays from a fraction of a pennyweight to 7½ pennyweight, all from the outcrop or just below it. The lodes are in norite—a gabbro rock—which is a basin-shaped sheet. In the lower part of this zone the platinum is in two apparently well-defined horizons. The lower is frequently associated with the chromite zone, and in it the platinum is found as a primary constituent of an iron-rich dunite, an iron-magnesian rock. Mills are now treating the ore which yields other platinum-group metals.

The platinum minerals of Transvaal are cooperite and sperrylite, both arsenic-bearing; stibiopalladinite; palladium (70 per cent); and antimony. Cooperite is white to gray-yellow with a hardness of 4 to 5, is insoluble in hot aqua regia, and when heated in an open tube leaves a sublimate of arsenic. Sperrylite is mentioned later. The palladium mineral has a gravity of 9 and hardness of 4 to 5, is soluble in hot aqua regia, and gives off sulphur dioxide and white antimony oxide in an open tube.

The source of platinum in Russia is dunite. Rivers have eroded or cut down and disintegrated it, freed the platinum, and concentrated it along the river-beds and flats. It exists mostly as rounded grains. The metal is saved by crude hand methods or by modern dredges. One property in the Urals has recovered 32 cents of platinum per cubic yard of gravel dredged.

In Alaska, platinum metals occur in a number of placers, especially in one large producer in the southwest, and mostly as palladium in an ore as basic sulphide with gold, copper, and silver in the southeast. Here the ore is crushed, ground, and floated, and the concentrates are sent to a smelter. These are important producers.

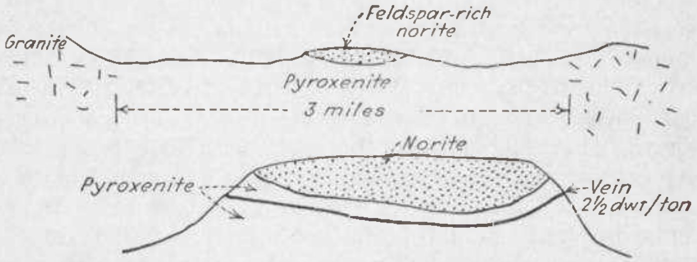


FIG. 79.—Platinum occurrence in Southern Rhodesia. (*According to E. Golding in Journal of the Chemical, Metallurgical and Mining Society of South Africa in* 1932.)

In Colombia, the placer deposits yield 75 per cent platinum and 25 per cent gold by dredging. As in Russia, the rivers have eroded the original rock and concentrated the metal in the gravel.

Platinum occurs in the Wedza mine, Southern Rhodesia, as sperrylite, a platinum-arsenic mineral containing 56 per cent metal. The district is granitic, and within this is an area of pyroxenite, which is a granular, igneous rock consisting mostly of silicate of calcium and magnesium, also iron, but with little or no feldspar or olivine. In the center of this belt is a feldspar-rich norite under which, lying in pyroxenite, is the vein. Norite is a variety of gabbro, itself a fine to coarse crystalline igneous rock, mainly a lime-soda feldspar. Figure 79 shows the occurrence.

At Sudbury, Ontario, sperrylite occurs with the nickel-copper ores and each year yields many thousands of ounces of platinum and other platinum-group metals.

Sperrylite has a gravity of 10.6 and a hardness of 6 to 7. It is slightly soluble in hot aqua regia and when heated in an open tube gives off sulphur dioxide and white arsenic.

Hints for Platinum Prospectors

The placer deposits containing platinum are all, so far as known, in the vicinity of areas of basic igneous rocks, and in any search for new deposits of platiniferous gravels the first step is to find outcrops of peridotite, pyroxenite, dunite, and serpentine. When these have been found, the gravels in streams flowing out should be washed to ascertain if platinum is present. The heavy concentrates found in gravels carrying platinum are usually rich in chromite and olivine. The character of the rock particles often gives a clue to the source from which the gravels were derived. Platinum as it occurs in placer concentrates is ordinarily a silvery-white metal, which could be confused only with silver and possibly pieces of iron or steel. It can be distinguished from both of these metals, as they are soluble in dilute nitric acid; crude platinum can be dissolved only in concentrated aqua regia, a mixture of 3 parts hydrochloric (muriatic) acid and 1 part nitric acid. In some placer deposits the grains of platinum are coated with a dark film and somewhat resemble the grains of the dark minerals chromite, magnetite, or ilmenite, from which they are separated by careful panning, as the specific gravity of platinum is greater than that of any of those minerals.

Chromite is occasionally found with platinum and occurs in similar rock—serpentine. Sometimes, high chromite content means more platinum.

Platinum will not amalgamate with mercury alone but will if sodium is added. In ordinary mercury the flakes of platinum float on the surface and can be removed. If sodium amalgam is used, the platinum may be separated from gold by agitating the amalgam with water until all the sodium is used up to form sodium hydroxide (caustic soda); then the platinum will come out on the surface of the amalgam, provided, of course, the amalgam is sufficiently liquid. Platinum can be scratched with a knife. It is so malleable that it can be pounded without heating into very thin sheets. It is almost infusible; the grains can not be melted together as can particles of gold

Platinum is more or less associated with other metals of its group—namely, iridium, osmium, osmiridium, palladium, rhodium, and ruthenium. Gold is also recovered from Transvaal platinum ores and osmiridium from the gold ore. Ontario, Transvaal, and United States platinum yield these other metals. Tasmania produces osmiridium.

Tests

Platinum grains are generally smaller than those of gold. Careful panning will reveal the platinum, because owing to its greater specific gravity it lags behind gold in the pan. There are practically no metals that may be confused with platinum. A nickel-iron grain, found in river sand of northern California, has confused prospectors, but it is magnetic, whereas platinum is not.

A field test is to dissolve, say, 50 grains of the material suspected in aqua regia (3 parts muriatic and 1 part nitric acid) and evaporate the liquid to dryness. The residue is gently heated until all fumes of nitric acid disappear. It is then dissolved in water and filtered. A few drops of potassium iodide added to the clear liquor give platinum iodide, which dissolves and produces a deep rose-colored solution.

If no filter is at hand, do not evaporate to dryness, but just until the pulp is thick. Then add clear water, with a few drops of sulphuric acid and potassium iodide. The test shows wine red for considerable platinum and less deep color with less metal.

A solution of ammonium chloride added to the aqua regia solution gives yellow crystals if platinum is present.

RARE-EARTH METALS

There are nearly 20 metals that have been termed "rare earths," but few of them have any value for manufacturing purposes. Paul Tyler of the Federal Bureau of Mines says that the rare earths are not rare but difficult to separate; also many of their uses are filled by cheaper minerals.

Thorium, the most important rare-earth metal, is used in making gas mantles; with it is a little cerium—the proportions are 99 to 1. A fraction of 1 per cent thorium is used in tungsten-filament wires for electric lamps; it makes them last longer. Cerium chemicals are used in flaming arc-lamps to give a brighter light. Small quantities of all the rare-earth metals are used to make certain chemicals for experimental purposes. Some of them are used to make sparkers for lighting gas lights or gas stoves; cerium is one of these and is used in the igniter pins of certain flame safety lamps for coal mines and for pocket igniters for smokers.

Occurrence

The rare-earth metals occur in minerals containing several of these metals—that is, you will not find a mineral containing only cerium; it will also carry some of the other rare-earth metals. They are found in pegmatites and sands. In the former such minerals as quartz, feldspar, mica, topaz, tourmaline, beryl, zirconium, and apatite will be found with the rare-earth minerals. In the sands, magnetite, cassiterite, rutile, garnet, and the pegmatite minerals may be found.

The principal deposits are in Brazil and India. Some monazite is also found in the Carolinas, Florida, and Idaho. The market value is due to the presence of a small quantity of thoria.

Sands mined in the Carolinas carry about 4 per cent thoria; those from Brazil, 6 per cent; and sands from India, 8 per cent. Before being used the sands are concentrated by washing and by magnetic separation.

The monazite deposits of value in North and South Carolina are within an area of 3500 square miles. The principal rocks are gneiss and schist, with massive granites, quartz-diorite, diabase, garnet, mica, and graphite. Many of the formations have been changed considerably and are often concealed by a thick mantle of overlying soil. No workable veins have been found in the gneiss and schist; placers are the only deposits of value. They are richest where granitic rocks and pegmatized gneiss and schists abound. The best indications are in porphyritic pegmatized gneiss; this is a granitic gneiss with large crystals in a fine mass, which may be crystallized or glossy or both.

The Brazilian deposits occur under much the same conditions.

Tests

There is no simple test to show whether or not any rare-earth metals exist in a rock; if this is suspected, send a representative sample to a good analyst.

Rare-earth Minerals

Monazite. This is by far the most important mineral of the rare-earth group. It contains 3 to 9 per cent thoria. Thorite and samarskite are not uncommon, as there are a large number of rare materials that contain these metals.

Monazite is a rare-earth metal phosphate, generally found in sands yet sometimes in pegmatites. The sands are opaque to translucent, in some cases transparent grains and crystals. They are usually a yellow-brown color. It is a brittle mineral, and if broken there will be some flat shiny surfaces. Freshly broken grains have a resinous luster. The streak is white. Monazite will not melt in a blowpipe flame but does turn gray. It is heavier than most other light-colored minerals and is twice as heavy as quartz; its specific gravity is 5.3, equivalent to more than 300 pounds per cubic foot. It is rather hard, 5, but can be scratched with a knife.

Besides being tested for the rare-earth metals as just described, monazite can be tested for phosphate by melting some of the fine powder mixed with sodium carbonate and then dissolving in nitric acid. Let it settle and pour off the clear part. To the clear liquor add ammonium molybdate; if any yellow appears (it may take 10 minutes before it shows), there is phosphate in the mineral. Of course any other phosphate mineral will do that too.

Monazite is easily confused with several minerals, none of which, except scheelite, breaks and has flat shiny faces. To tell whether or not it is scheelite, test for tungsten.

Thorite. This is a rare-earth silicate. It looks much like zircon but is softer, as it can be scratched with a knife; its hardness is 4.5. It can not be melted in a blowpipe flame. It can be tested for rare-earth metals as described above. It will not give a test for phosphate as monazite does.

Samarskite. This contains the rare-earth metals and tantalum and columbium. It is shiny coal-black. It will not break with flat surfaces but rather with rounded ones. It can be scratched if a knife is of good steel; its hardness is 5. It is rather heavy, about twice as heavy as quartz, its specific gravity being 5.7. A very thin splinter may be melted on the edge in a blowpipe flame. It may be tested for both columbium and the rare-earth metals. No other shiny-black mineral is so heavy except uraninite (pitchblende). The streak of pitchblende is greenish, but that of samarskite is brownish.

SELENIUM AND TELLURIUM

Selenium and tellurium ores as such do not exist, and ores are not mined for these minerals. Both occur in copper and gold ores and are recovered as by-products. Twenty times as much selenium as tellurium is produced in the United States. In a copper refinery they are to be seen as muds, then as metals—selenium, gray and brittle; tellurium, white, fibrous, and brittle. Several years ago, a well-known metallurgist wrote of these two metals as being almost useless, but of late, like many other materials, both have found extensive and growing use. Selenium salts are consumed in coloring glass and in dyes, also in rubber and the metal in photoelectric devices. Tellurium in small amount (less than 1 per cent) is found to toughen rubber, to render copper more machinable, to increase the hardness and strength of tin. However, there are no selenium and tellurium ores to prospect, but not forgetting gold telluride ores.

SILVER

Silver is a white, ductile, very malleable, and heavy metal. It is easily cut. Its hardness is 2.3 to 3 and specific gravity, 10 to 11; a cubic foot weighs 652 pounds, about half the weight of gold. It often occurs in veins in native form but appears tarnished and dark. Arsenical pyrite resembles native silver, but it breaks under the hammer and gives off smoke when heated, whereas silver flattens and melts.

Tests

1. *Reduction to Metallic Silver.* The pure metal may be obtained from high-grade silver minerals by fusion on charcoal before the blowpipe. Mix a little finely powdered mineral, such as argentite or pyrargyrite (about the amount held on the tip of a knife-blade), with three times that volume of sodium carbonate (baking soda). Transfer this mixture to a piece of charcoal and fuse it before the blowpipe until a silver globule results. This globule is bright when hot or cold and is malleable. It should be further tested for silver as explained in the next test.

2. *Precipitation as Silver Chloride from Nitric Acid Solution.* Take a test-tube or some other glass or porcelain receptacle and pour into it about one-half teaspoon of concentrated nitric acid and one teaspoon of water. Into this pour a little finely powdered silver mineral, such as argentite, proustite, or cerargyrite (about the amount held on the tip of a knife-blade), the silver globule resulting from test 1 or a small piece of metallic silver. Heat the solution; and when the silver has been dissolved, cool and add a few drops of concentrated hydrochloric (muriatic) acid to it. This will throw down a white curdy mass (silver chloride), which turns purple if exposed to light and is very soluble in ammonia—that is, if an excess of ammonia (until the solution smells strongly of it) is poured into the silver chloride solution, the white curdy mass will disappear. (Note: It is sometimes better to use hot concentrated nitric acid instead of the dilute acid for dissolving the silver.)

3. *Hypoing.* A test for silver is known in the Calico district of San Bernardino County, California, as "hypoing." A test-tube is a quarter filled with crushed ore and then filled with a saturated solution of sodium hyposulphite. After shaking well, the solution is allowed to stand until clear, when a drop of the calcium solution is added, which throws down the silver as a brownish-black precipitate—a silver sulphide. The silver content is estimated by observing the density of the color. The test is useful with free-

milling ores, chlorides, bromides, and native silver, if the last mentioned is in fine grains.

Minerals

There are a number of workable silver minerals, and from the outcrop of a vein downward they are as follows:

Cerargyrite. Cerargyrite, or horn silver, the chloride, contains 75 per cent metal. It will melt in a candle flame and yield silver when heated with soda or charcoal with the blowpipe. It cuts easily, like horn. The streak is gray and shiny, and the natural color is greenish to brownish. The specific gravity is 5.5, and it weighs 340 pounds per cubic foot.

Pyrargyrite. Pyrargyrite, or ruby silver, is an antimonial-silver ore, with 60 per cent silver, 22 per cent antimony, and 18 per cent sulphur. *Proustite* is a ruby silver, but the antimony is replaced by arsenic. Pyrargyrite is dark red to black in color. The streak is red; its hardness is 2.5; and its specific gravity is 5.7. If some of the ground ore be heated with nitric acid, and a little common salt added to the clear liquor, a white deposit of silver is thrown down. When heated by the blowpipe flame, pyrargyrite gives off antimony, while proustite yields arsenic fumes. *Stephanite* is another antimony-silver ore, much the same as proustite, except that it is grayish and a little heavier. *Polybasite* is silver mineral of variable composition, with 62 to 74 per cent silver, also copper, antimony, and arsenic. It is frequently mistaken for stephanite. (See also under Antimony.)

Hessite.—Hessite is a telluride of silver, which grades into *petzite*, a telluride of gold and silver, both of which mainly exist in a few gold deposits.

Argentite. Argentite, or silver glance, is the most important and common of silver minerals. It is the sulphide and contains 87 per cent silver. It is found in all of the deposits discussed later and causes the bluish to blackish coloration in the quartz of the veins. The streak is the same color, and so is its powder. Argentite has a hardness of 2.5 and a specific gravity of 7.2. A cubic foot weighs 450 pounds. When the blowpipe flame is directed upon it, sulphur is given off and a bead of silver remains.

Occurrence

As will be seen from the following notes, silver ores are found practically only in eruptive rocks. If silver is found in a region containing lead and zinc ores, it will usually be associated with the lead and zinc minerals. In a copper-bearing district it may be found in limited quantity in the gossan above the copper veins.

A few silver deposits are found in sedimentary rocks, but the silver is considered to be accidental, is variable in quantity, and will not persist to any great depth. This type of deposit is thought to be dependent upon some eruptive rock such as andesite. Such is the case at Parral, Mexico, where the veins are in shale and limestone, associated with quartz-andesite rocks.

Silver occurs commonly in ore deposits as a sulphide, such as argentite and stephanite. These sulphides are changed to sulphate by oxidation near the surface—that is, within the range of the ground water, which contains free oxygen. If salt comes in contact with silver sulphate, silver chloride is formed. In the arid region between the Rocky Mountains and the Sierra Nevada the surface waters contain salt, which on reacting with silver sulphate forms the relatively insoluble chloride, a waxy mineral known to miners as "horn silver." That is why prospectors in the Southwest have been called "chloriders." Too much salt in the drainage will cause the silver chloride to pass into solution, and that may be why veins rich in horn silver or cerargyrite are at their best a few feet below the surface.

Figure 80 shows an occurrence in Yavapai County, Arizona, where the country rock is schist. The orebodies lie between two parallel and nearly vertical dikes of quartzite which cut across the property. The shoots are in narrow veins with the silver occurring conspicuously as the chloride, cerargyrite.

The commonest type of the rich silver outcrop is composed of spongy, iron-stained quartz, plastered with horn silver and carrying thin flakes of native silver. The great Barrier lode in New South Wales, Australia, was discovered when a campfire on the outcrop melted some of the horn silver. At depth the silver is associated with galena, sphalerite, rhodonite, and garnet.

Silver may be found in veins (1) as straight silver ore; (2) with gold; (3) with copper, say 1 ounce to each 1 per cent copper; (4) with lead, say 1 ounce to each 1 per cent lead; (5) with zinc; (6) with zinc and manganese; (7) with scheelite (tungsten); (8) with manganese; (9) with lead and zinc; and (10) with tin, as in Bolivia. This section is discussing a silver ore with more or less gold, as the other types are covered under their respective heads, although it might be said that a manganese-silver ore is troublesome to treat. The deposits at Cobalt, Ontario, described later, are exceptional in every respect.

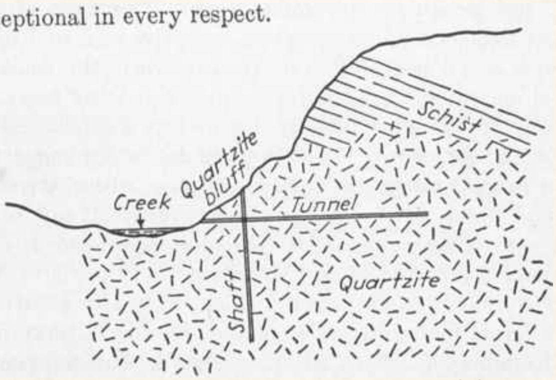


Fig. 80.—Silver ore in quartzite, in schist, Arizona.

An important silver district in the United States was Tonopah, Nevada. The veins persisted to great depths. The proportion of silver to gold averaged 100 to 1. Outcrops of white quartz in the andesite were first discovered and were found to be high in silver. The veins were largely in andesite and trachyte (an andesitic rock); but as depth was attained, some of them were partly or wholly rhyolite. Faulting was prevalent.

The following occurrences of silver are similar to that of Tonopah in many particulars:

In the Silver City district of southwestern Idaho the silver deposits are normal fissure veins, chiefly in rhyolite, although there are some in granite and basalt. The general proportion of silver to gold is 30 to 1. There are a number of veins here but fairly close together.

In the Mogollon district of New Mexico, which has produced 14 million ounces of silver and 6 million dollars in gold since 1904, the mineral-bearing veins are fillings in fault fissures, the gangue being mostly quartz and calcite. In one mine this material is in andesite breccia, and the silver exists as argentite with pyrite, sphalerite, and galena. In another mine calcite is the principal gangue, with inclusions of andesite fragments. Quartz here is in small quantity and is more abundant in ore-shoots than in other parts of the vein. Copper minerals are present but do not interfere much with cyanidation. The veins form prominent outcrops.

Austin, Nevada, has produced rich silver ore, but the vein system is complicated by fractures and short ore-shoots. The veins are in quartz monzonite and quartzite. The latter are more persistent. Some outlying lodes carry small amounts of gold, copper, lead, and zinc.

In the Coeur d'Alene district, Shoshone County, Idaho, is a silver-bearing area in mountainous country and with a score of properties in various stages of development. There are possibilities in the belt, but they will be discovered only by persistent prospecting, as was done in the Sunshine, Crescent, and Polaris mines, now producing silver. The common vein minerals are siderite and quartz associated with silver-bearing tetrahedrite, galena, and pyrite. The country rock consists of shales and quartzites.

In Beaverhead County, Montana, the Quartz Hill mine has a vein of quartz, calcite, and barite at a limestone-shale contact. The only important mineral is freibergite, the silver-bearing variety of tetrahedrite.

The deposits at Divide, 6 miles south of Tonopah, Nevada, are true silver-bearing lodes. The prevailing rock is a rhyolite-breccia, into which have been forced dikes of rhyolite and andesite. The orebodies are zones of fracturing and shearing in the rhyolite-breccia. The principal silver mineral is cerargyrite or horn silver. Little quartz is present, although at Tonopah there is an abundance of it. The outcrops are soft and unpromising to look at; one vein is stained with red and yellow iron oxides. The gangue is largely kaolinized breccia (eruptive rock partly changed to kaolin or clay).

At Rochester, Nevada, the prevailing country rock is rhyolite. The chloride and sulphide of silver occur with gold, in quartz veins and as a network of narrow veinlets. Little was mined below 1000 feet (see Fig. 81).

Most of the Mexican silver deposits proper are in eruptive rocks, generally some form of andesite. They are fissures, and the gangue is quartz, calcite, a little chalcopyrite, and manganese. Rhyolite covers the andesite in some places and often occurs as dikes. Quartz outcrops carry pyrite and oxides of manganese, with silver and gold.

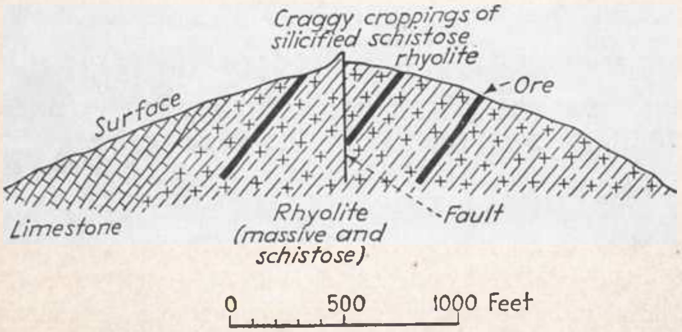


FIG. 81.—Silver ore in rhyolite, Rochester, Nevada.

The great Comstock lode of Nevada is in andesite, associated with dacite, rhyolite, and basalt above it. It is a single, strong lode, containing rich and fair ores in irregular shoots. The proportions of silver and gold are 57 and 43 per cent, respectively.

In Peru, South America, the silver-bearing formation is sandstone, intruded by altered andesite, also veins in rhyolite.

In Japan there are important silver veins in andesite.

On the island of Sumatra, Netherlands Indies, one notable vein is in andesite. The proportion of silver to gold is 10:1. The bullion contains 4 per cent selenium, which is a mineral of the Tonopah district, and of Waihi, in New Zealand, where the silver-gold lodes are in tuff, andesite, and rhyolite.

Figure 82 is a generalized occurrence of silver ore.

It will be seen, therefore, that the prevailing formation in which to find silver is andesite, more or less associated with rhyolite and basalt. The accompanying minerals are quartz, calcite, manganese, galena, pyrite, chalcopyrite, and others. The quartz is generally bluish, with the well-known streaks of the sulphide mineral argentite. Silver veins are generally high in silica.

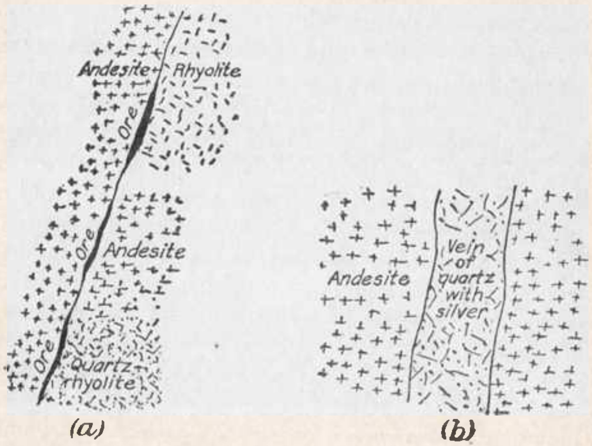


FIG. 82 (*a*, *b*).—Silver occurrences.

The three following deposits are more or less exceptions to the andesite rule, yet they are associated with intrusive masses, such as rhyolite or granite:

The remarkable Kelly silver deposit near Randsburg, California, discovered in 1919, was tramped over for many years and attracted no attention until a piece of the outcrop of horn silver was accidentally broken off and later assayed. The total output exceeds 10 million dollars. The mill is still running. The quartz vein is on the footwall side of a rhyolite dike, about 200 feet wide, which outcrops through granite-schist. The quartz outcrop is of reddish color, from the iron oxides, but the clean quartz is dense, hard, and bluish, with a good deal of fine pyrite. There is a considerable quantity of quartz float, and many veins cutting through the granite-schist. Near by is the Yellow Astor gold mine, where the gold is in similar formation and yielded several millions; and 3 miles farther on is the Atolia tungsten mine, in unaltered granite, which produced more millions. The Kelly ore is a remarkably rich, clean, silicious silver ore and alters to pyrargyrite and argentite at depth. This is an unusual collection of ores in one district.

The extraordinary silver veins of the Cobalt district of Ontario lie in a conglomerate and intrusive diabase, also in altered diabase, intruded by granite. The veins consist mainly of calcite, with a little quartz, and carry native silver and the arsenides of cobalt and nickel—smaltite, cobaltite, and niccolite. These veins are from half an inch to several inches in width and run in every direction. Faulting is common. They yielded 10 to 3000 ounces per ton. It is said that of the over 2000 veins in the district only 1 per cent contained workable ore and about 10 per cent carried a little silver. Minute calcite veins serve as leaders in searching for rich ore. On the surface the cobalt veins are traced by the delicate pale reddish-blue color of cobalt bloom (the arsenate of cobalt).

At Guanajuato, Mexico, is a large vein, a calcareous agglomerate (a limy mass of eruptive rock fragments) associated with rhyolite, andesite, and granite.

According to Christopher Riley in *The Canadian Mining Journal* the silver and radium-bearing ores of the Great Bear Lake district, northwest Canada, are found in an area of basic dikes and sills, quartz veins, rhyolite-porphyry, granite-porphyry, granite, dioritic intrusives, sediments, and volcanics. The area is mostly bare of vegetation. Gossans are good indicators, and granite-diorite contacts should be well examined. A quartz vein-diabase dike association is a feature. Most of the large quartz veins are barren, but iron or copper pyrite occurs in the wall-rock near veins or some distance off. Pitchblende is associated with manganese carbonate.

STRONTIUM

Occurrence

Strontium is a silver-white metallic element, never found as such but usually as strontianite, the carbonate, or celestite, the sulphate. From these the nitrate, used in flare-lights and fireworks, is made. Strontianite is more or less associated with barite and calcite, as they are of the same group, but too much of these minerals detracts from the marketable value of strontium. The ore is always associated with soft or dolomitic limestone, and in quarrying lime rock the celestite or strontianite, which occur as crystals, may be hand-sorted and saved in jigs. The specific gravity is 2.5, and the weight is 160 pounds per cubic foot.

Tests

The strontia minerals impart a brilliant red color to the flame when heated by the blowpipe, which is made more intense by adding a drop of hydrochloric acid to the mineral. The flame from calcium is a yellowish red, which distinguishes the strontia minerals. A drop of acid on strontianite makes it effervesce. Both minerals fuse and are harder though a little lighter than barite; a knife will scratch them. Celestite crystals are bluish to reddish; strontianite crystals are white, yellowish white, and greenish white.

THORIUM

See Rare Earths

TIN

Tin is of great industrial importance, and for some purposes it is practically irreplaceable. As is well known, it is a white, malleable metal, never found in native form. The specific gravity of the cast metal is 7.29, and it weighs 450 pounds per cubic foot. Tin is consumed mostly in making tin-plate, solders, and alloys and in weighting silk. The United States uses over half of the world's production but produces almost none, except Alaska, whose output is increasing. In 1940 a small amount of tin was recovered from small deposits in South Dakota, Montana, and New Mexico. Other states having some record of output since 1940 are California, North Carolina, South Carolina, Texas, and Wyoming. Thus deposits should be sought.

Occurrence

Tin is often found like gold placers in stream gravels. When in rock it is always in pegmatites or in veins near granite. The dark mineral is prominent in the rock and easily noticeable, but other black minerals, such as tourmaline and pyroxene, may be mistaken for it. In parts of Australia both gold and tin are recovered in the sluice-boxes, and occasionally diamonds, thus showing a possible common origin. In Bolivia tin-silver ores are mined in large quantities. Tin is frequently found with tungsten, quartz, tourmaline, mica, topaz, fluorite, beryl, apatite, molybdenum, and many rare materials.

Figure 83 shows six types of tin deposits. From *d* the sluices saved concentrates of which 90 per cent was tin, the remainder being garnet, gold, ilmenite, limonite, magnetite, and pyrite. Sketch *f* is a generalized section of occurrences in Malaya. There, a granite ridge is the backbone of the peninsula; and, in general, decomposed granite forms the bedrock for the tin-bearing wash. Although this rock varies from 16 to 120 feet below water, the average is 30 to 35 feet. The bedrock is sometimes soft kaolin or slate and sometimes hard and rough limestone. Dredging is easy on the soft bottom, but pumps are best on the hard rock. The tin-bearing wash consists of granite boulders, large cobbles, decomposed granite, quartz pebbles, and sand. Above this material is the overburden of 20 to 30 feet of sandy clay and tough clay. The cost of working such tin deposits is as low as 1 penny (2 cents) and as high as 5 pence (10 cents) a cubic yard.

Tin at Blue Tier, northeast Tasmania, occurs as cassiterite disseminated in granite in various stages of alteration to true griesen. It is low grade for ore, about 0.2 per cent or 4 pounds per ton.

The prolific tin deposits of the islands of Bangka, Billiton, and Singkep, Netherlands Indies, occur as disintegration matter or ore

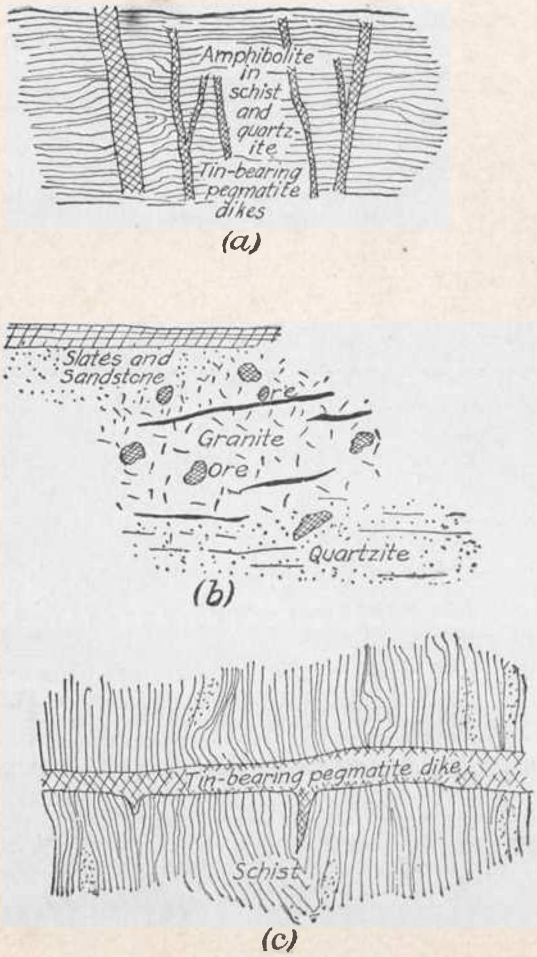


FIG. 83 (*a*, *b*, *c*).—Types of tin deposits.

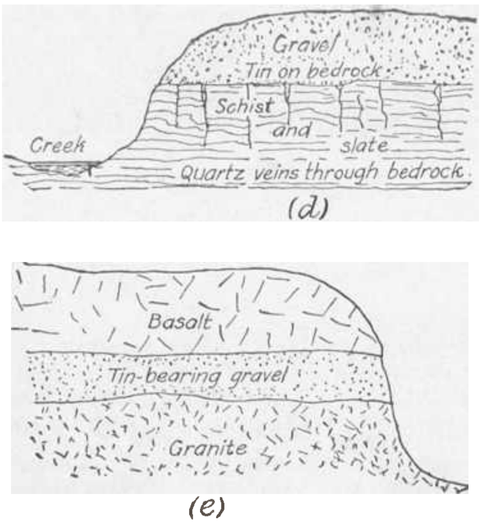


FIG. 83 (*d*, *e*).—Types of tin deposits. In (*d*) the sluices saved concentrates of which 90 per cent was tin, the remainder garnet, gold, ilmenite, limonite, magnetite, and pyrite.

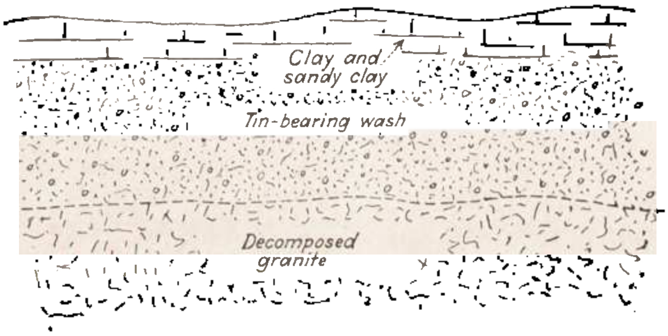


FIG. 83*f*.—Generalized tin deposit of Malaya.

in loose ground and loose ore-beds and as bedrock deposits, as veinlets in granite, or as networks of veinlets in sediments or in fracture and fault-fissure veins in sediments of the character of lodes or quartz bodies in granite or in greisen (a cellular rock of quartz and mica).

In 1900, stream tin was found in the sluice-boxes of placer-gold operations of the York region, Seward Peninsula, Alaska. Work has been continued since, and in 1940 the mine output of tin (content) from placer deposits in Alaska totaled 41 long tons against 33 tons in 1939. The tin placers lie near the contacts of granitic intrusions into limestone. Cassiterite is the only mineral in this area likely to be of importance. As other common and some uncommon minerals occur, the cassiterite has been mistaken for some of them. Grains from Buck Creek are brown and may contain cavities lined with clear, glassy, yellow crystals. Quartz adheres to many of the larger nuggets. Tourmaline is common and is regarded as an indicator for cassiterite. Wolframite is also associated with the tin mineral. Although lode tin is found, so far only the placers are workable. The gravels of fine wash are shallow, yet over 100 feet wide. The best lies on clayey shale bedrock and is difficult to wash. The tin was derived from the erosion of quartz stringers. The lodes have been prospected by adits, but this should be done only after surface work has shown the presence of a tin deposit. It is useless to start underground work in fresh, unaltered granite. In granite areas, tin may be sought in quartz veins or in any altered portion of the granite, according to the United States Geological Survey.

Like gold-bearing gravels and ores, low-grade tin material may be worked profitably. For instance, tin gravel containing as little as 1 pound tin oxide per cubic yard is hydraulicked or dredged; and ore with ½ per cent or 10 pounds can be mined, milled, and smelted, but generally 20 to 60 pounds per ton.

Tin Materials and Tests

There are only two tin minerals—cassiterite and stannite. The former is the source of the world's tin, and the latter is uncommon.

Cassiterite. Cassiterite is a tin oxide. It is also known as "black tin" in Australia, England, and Malaya and "barrilla" in Bolivia. When pure it contains 79 per cent tin. It does not weather and may be panned like gold; Cornishmen are adept with a shovel. The product recovered from placer mining or from concentrations is usually dressed to assay 65 to 72 per cent metal. It is usual to say that the gravel or rock contains so much tin oxide, not the metal, so calculations are on that basis.

The color of cassiterite is usually brown or black, but it may be white or red. It is too hard to scratch with a knife, as its hardness is 6 to 7. It is very heavy, as its specific gravity is 7; a cubic foot weighs up to 440 pounds. The streak is white or nearly so. It seldom breaks with flat shiny surfaces. It can not be melted alone in the blowpipe flame. If a piece of cassiterite is put in a test-tube with granulated zinc and dilute hydrochloric or sulphuric acid and boiled for a minute or two, the mineral becomes coated with bright, silvery, metallic tin, which may be made lustrous by rubbing with a piece of cloth. No other similar mineral does this. Hydrogen gas is evolved during this test, and it has a somewhat choking effect. If heavy minerals remain in a pan, test for tin by putting them in a tray or cup made of bent zinc sheet. Add acid—hydrochloric preferably—and, if tin is present, the grains will be reduced to metallic tin where they are in contact with the zinc.

When powdered, cassiterite shows a light color; but if iron is present, the hue will be reddish brown. South Carolina and South Dakota tin ore powders are purplish. If a little of this powder is mixed with twice its bulk of charcoal and three times the amount of washing or baking soda, moistened, placed in the hollow of a piece of charcoal and heated with the blowpipe, metallic tin will be reduced. When struck with a hammer this metal will flatten.

If some tin ore is mixed with several times its weight of potassium or sodium cyanide and melted in a crucible in a forge or other fire, metallic tin will be reduced. (Cyanide is a deadly poison, so care is required.)

When bent, a stick or slab of tin emits a "cry"; it is the only metal that does this. Tin-plate contains only 2½ per cent tin; the remainder is black-iron sheet. Solder is half tin and half lead.

Because of the dark color and metallic luster of some cassiterite, numerous dark and heavy minerals are mistaken for it. The iron ores hematite and ilmenite are examples. Hematite is magnetic, but ilmenite is feebly so.

Cassiterite is sometimes confused with rutile (a titanium mineral) and wolframite (a tungsten mineral). Rutile is not so heavy as cassiterite. Neither rutile nor wolframite gives the white coating with hydrochloric acid and zinc.

Stannite. Stannite is a sulphide of copper, iron, and tin. It is a steel-gray, metal-like mineral. It can be scratched with a knife, as its hardness is 4. It is not unusually heavy (specific gravity 4). It is easily melted in the blowpipe flame. If stannite is melted and then moistened with hydrochloric acid and put in the blowpipe flame again, it will color the flame green (a test for copper). If it is finely powdered and boiled in dilute nitric acid, the acid becomes green.

Stannite resembles tetrahedrite (a sulphide of antimony and copper with some arsenic), arsenopyrite, chalcocite (a sulphide containing copper), and bournonite (a sulphide containing copper, lead, and antimony). If heated on charcoal, tetrahedrite and arsenopyrite will give off a dense white smoke which smells like garlic. When chalcocite is scratched with a knife, a shiny cut is left, as when silver is scratched; when stannite is scratched, no such cut shows. When heated on charcoal with the blowpipe, bournite gives a dense smoke and a white coating on the charcoal at some distance from the mineral. Stannite does neither, although it may give a white coating close to the mineral.

TITANIUM

Titanium is a rather common element in the earth and is the tenth or eleventh most abundant. It is found in nature only in combined form, generally as the minerals rutile and ilmenite.

Titanium is consumed in making the alloy ferro-titanium for use in steel, electrodes for arc lamps, glazing, dyeing, pigments, white paint, and enamel.

Titanium Minerals

There are several minerals containing titanium, but only two are ever a source of that metal, namely, rutile and ilmenite.

Rutile. Rutile is an oxide of titanium. It is a hard mineral; hardness about 6.5. It does not weather. Its color is red-brown, red, yellowish, or sometimes black; it is glassy or stony in appearance. Its streak is light brown. It breaks rather irregularly. It is much heavier than ordinary rock minerals; its specific gravity is 4.2, and a cubic foot of it weighs 260 pounds. It can not be melted in a blowpipe flame. Either of the chemical tests for titanium may be used. It is distinguished from other titanium minerals by its streak and color.

Rutile resembles cassiterite and garnet in outward appearance If there is doubt as to whether a mineral is rutile or cassiterite, test as described under Tin and test for titanium as described above. Cassiterite is much heavier than rutile. To distinguish garnet from rutile, test for titanium; rutile will give a strong test; garnet will not. Rutile is used as a gemstone when clear red.

Rutile may be found in any kind of igneous rock and in contact metamorphic rocks—that is, rocks which have been changed by escaping fluids from igneous rocks—in gneiss, schist, quartzite, granular limestone, and dolomite. It is also found in some sands and in some veins, especially those veins formed under conditions of high pressure. Although it is found in all these different conditions and is so common, the rocks seldom contain enough to make the deposits valuable. In the United States the chief rutile mines are in Nelson County, Virginia, where the ore is composed of feldspar, blue quartz, and an iron-magnesian rock hypersthene. This blue quartz is known as "rutilated quartz" and is a good indicator for the prospector.

Ilmenite. Ilmenite is an iron-titanium oxide. Its color is iron-black, and its streak is a brownish black. It is rather hard (about 5.5), and its specific gravity is almost 5. It weathers slowly to limonite or hematite. It cannot be melted in a blowpipe flame. If heated in the inner part of the blowpipe flame, it becomes strongly magnetic. It may be tested for titanium as directed.

Several minerals are much like ilmenite and can be distinguished from it with difficulty; they are (1) hematite, which has a brighter red or brown streak; (2) franklinite, which contains manganese; (3) chromite; and (4) magnetite, which is strongly magnetic. Ilmenite is frequently found in magnetic ores, in black sands of the Pacific Coast, and in sands from crystalline rocks. All of these minerals, except hematite, are magnetic to a noticeable degree, and only a test for the metals present can distinguish them.

Tests

Make half a dozen beads by melting a mixture of 5 parts sodium carbonate with 1 part finely pulverized mineral in a loop in a platinum wire. Grind the beads to a powder and put it into a glass tube or dish. Add a teaspoon of dilute sulphuric acid, and when the bubbling has stopped put in 4 or 5 spoonfuls of water. Add several drops of hydrogen peroxide (the ordinary peroxide will serve) and watch for a change of color. If a yellow or brown color forms, there is titanium in the mineral, and the darker the color the more titanium is present.

If the titanium mineral is treated by the same test as described for Tungsten, a peculiar purple color will show. This latter test is not easy to make, and the first is recommended.

TUNGSTEN

Tungsten is a metal with a specific gravity of 17 and weighing 1060 pounds per cubic foot. It is used in making special steels. It is somewhat tougher than ordinary steel and keeps its temper even when red hot. Tungsten wire is also used in making electric light filaments, in X-ray machines, and in electric contact points. The valves of certain motors are made of tungsten steel. Tungsten chemicals are used to make fireproof paint and for other purposes. Tungsten carbide is used for machine tools, and the demand is active.

Occurrence

Tungsten minerals are found in many parts of the world. In the United States the principal deposits are in Arizona, California, Colorado, Nevada, and South Dakota. Some tungsten has been found in other States.

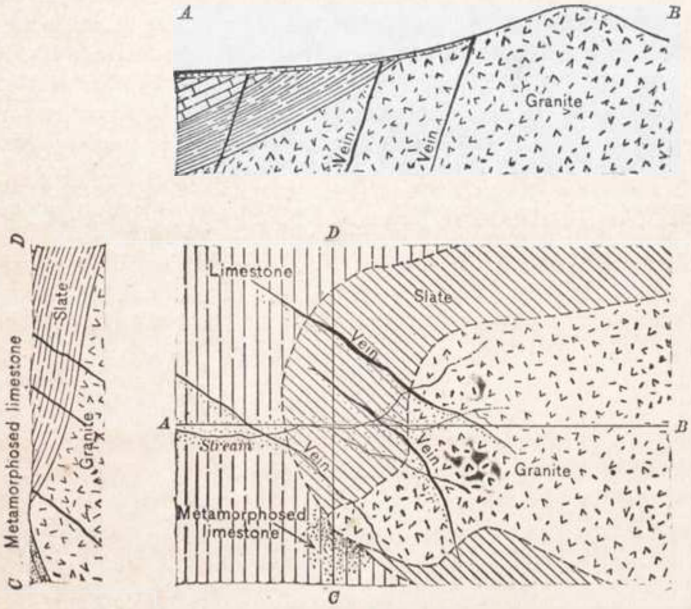


FIG. 84.—Relation of tungsten veins to country rocks. Dotted areas along veins represent residual placers and along creeks stream placers. Contact-metamorphic deposits are represented as metamorphosed limestone. (*According to Hess.*)

The minerals of tungsten are almost always found in or near granite rocks and are not likely to be found more than 1 or 2 miles from such rocks. They may be traced by panning.

Frequently some of the following minerals are found in tungsten ores: cassiterite, molybdenite, bismuth, tantalite, columbite, pyrite, chalcopyrite, fluorite, beryl, topaz, quartz, and sometimes gold and silver. The areas to search are those of quartzose granitoid rocks, but not all such rocks contain tungsten. Tungsten minerals may be found in veins or in pegmatites or in scattered patches in rock, particularly in limestone and granites, or they may be found in stream gravel, just as gold sometimes is. Some typical occurrences are:

1. Scheelite veins in quartzite, limestone, sandstone and conglomerate, biotite-granite, quartz in and which has replaced limestone, garnet and epidote, quartz and mica, contact-metamorphic deposits, replacements in monzonite, mica-schist.
2. Wolframite in quartz, flesh-colored biotite-granite, a compound vein of gray quartz interleaved with gray mica-schist, and replacements in dolomite.
3. Ferberite in horn rock (fine-grained quartz), as at Boulder, Colorado.

Tungsten float is found just as the float of other minerals. The first scheelite produced at Atolia, California, was float picked up in the desert sand. The author found some high-grade float ore in Tehama County, California, one piece weighing a pound. Outcrops of tungsten veins resemble those of other veins, but tungsten minerals do not stain them. Figure 84 shows typical tungsten occurrence.

Tungsten Minerals

The principal minerals of tungsten are wolframite, ferberite, hübernite, and scheelite. Others are tungstite and cuproscheelite.

Ferberite. Ferberite is an iron tungstate—that is, it contains both iron and tungsten. It is black and metallic looking. The unusual weight of the mineral, however, makes it easily recognized. Ferberite is three times as heavy as quartz; its specific gravity is 7.2 to 7.5. Its hardness is 5 to 5.5, and it can be scratched by a good knife, which gives a dark-brown color. The crystal forms of ferberite are numerous, so it is difficult to recognize the mineral by the shape. When ferberite is broken, some flat shiny surfaces may be seen. It will melt in a blowpipe flame, after which it is attracted by a magnet but not before.

Specularite, magnetite, ilmenite, columbite, tantalite, and even tourmaline and hornblende are sometimes confused with ferberite. None of these is so heavy, and none contains tungsten. Except for hornblende, these minerals are all harder than ferberite, and it is almost impossible to scratch them with a knife. Columbite or tantalite is hardly affected by the blowpipe, but ferberite is easily melted. The streak of hornblende is light green. Specularite, magnetite, and ilmenite can not be melted by the blowpipe.

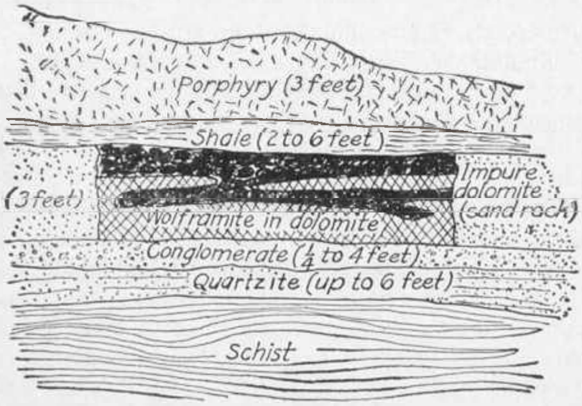


Fig. 85.—Wolframite in dolomite.

Wolframite. Wolframite contains tungsten (76 per cent), also iron and manganese, and is a tungstate of iron and manganese. It is closely similar to ferberite, but it may be either dark brown or black in color. Frequently, though not always, it has blade-like crystals. Its hardness is 5 to 5.55 and specific gravity, 7.2 to 7.5. It weighs up to nearly 500 pounds per cubic foot. The prospector seldom needs to distinguish wolframite from ferberite, as he does not care which he has found so long as he knows that it is tungsten. The tests for ferberite all apply to wolframite, and the same minerals are confused with wolframite as with ferberite.

In South Dakota, wolframite occurs near tin and tantalum. Figure 85 shows wolframite in dolomite.

Hübnerite. Hübnerite (pronounced heeb-ner-ite) is what the chemist calls tungstate of manganese—that is, it contains both tungsten and manganese. Hübnerite resembles wolframite and ferberite in every way except in color; it is reddish brown. Like the other tungsten minerals it is very heavy. Its hardness is 5 to 5.5 and specific gravity, 7.2 to 7.55. A cubic foot of it will weigh 450 pounds. It is frequently confused with sphalerite and garnet. Sphalerite will dissolve in warm hydrochloric acid and gives a strong odor of rotten eggs. Garnet, if finely powdered, will be almost white; it can not be scratched with a knife. Fig. 86 shows an occurrence of hübnerite.

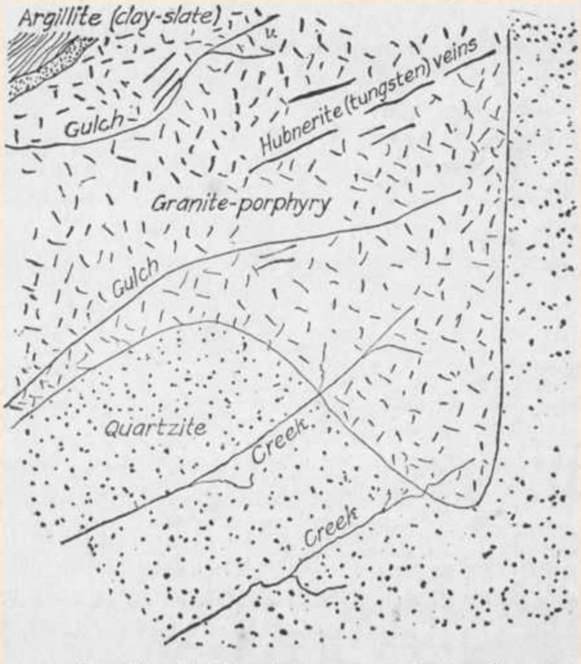


FIG. 86.—A hübnerite occurrence in Nevada.

At the surface of a vein containing any one of the minerals, weathering may have changed the tungsten mineral to limonite, tungstite (page 272), or pyrolusite. Tungsten minerals will not weather so easily as copper minerals.

Scheelite. Scheelite contains calcium as well as tungsten and is known as a tungstate of lime. Scheelite is glassy or has a stony appearance and is light colored, gray, yellowish, or light brown. It is a very heavy mineral, though not as heavy as wolframite. Its specific gravity is 6. It will weigh 370 pounds per cubic foot. It can be scratched with a knife and is 4.5 to 5 in the scale of hardness. When scheelite is broken, some smooth, flat, glassy surfaces will be seen. It is almost impossible to melt scheelite even in a blowpipe flame. The chemical test given will work, but an easier test is to grind the scheelite to a very fine powder and boil it with hydrochloric acid. If a piece of zinc is dropped into the liquid, a blue color will appear. Minerals that look like scheelite are epidote, garnet, apatite, barite, calcite, and quartz. None of these gives the test for tungsten. Barite and calcite are much softer than scheelite. Calcite makes hydrochloric acid bubble when put into it, and it is not heavy. Barite may be distinguished from scheelite because it melts in a blowpipe flame and gives a pale-green color to the flame. Epidote and garnet are harder than scheelite. Apatite is most easily distinguished in that it gives no test for tungsten.

Tungstite. Tungstite is a bright-yellow powder frequently found with other tungsten minerals.

Cupro-scheelite. Cupro-scheelite resembles scheelite but has a greenish color. If it is held in a colorless flame from a gas or alcohol burner, it gives a green color caused by the copper.

The scheelite in the Bishop district of Inyo County, California, occurs as shown in Fig. 87. The mineral is in a blackish garnet rock, which contrasts noticeably with the prevailing gray and reddish granite on the bare hills. The orebodies are the result of the replacement of limestone, which remains near the smaller deposits and supplies the calcium needed for growth of the garnet, also to convert the tungsten into the lime or calcium tungstate (scheelite) according to the United States Geological Survey.

Scheelite and wolframite are frequently found in gold ores. Well-known instances are scheelite at Fairbanks, Alaska; Golden

Chest mine, Murray, Idaho; Province of Otago, New Zealand, as stringers, pockets, lenses, and masses in quartz, with pyrite; and the Union Hill mine, Grass Valley, California; and wolframite at the Homestake and Wasp no. 2 mines in South Dakota. Scheelite also exists with silver in the Snake Range of White Pine County, Nevada, and in several districts of Arizona. In all cases the tungsten minerals are more or less of a nuisance to save with the gold, and special equipment must be installed to recover them. It is well, though, when a white material entangles the gold, to test it for tungsten, as it may pay to sort the ore or concentrate it.

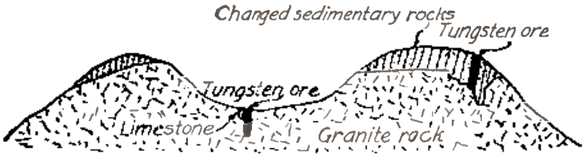


FIG. 87.—A Californian occurrence of scheelite, the result of careful prospecting.

Value of Tungsten Ores

To be of marketable value a tungsten-bearing rock must contain 2 per cent or more tungstic oxide. Where there are large quantities of ore, 1 per cent is profitable; indeed, some ores at Atolia, California, carry less than this. Before the ore can be sold, it must be concentrated to 50 or 60 per cent tungstic oxide. At a price of, say, $16 or 66 shillings per unit or 1 per cent, 60 per cent concentrate is worth $960 or £200 per ton. Any copper, arsenic, antimony, tin, lead, bismuth, or zinc in the ore reduces the demand and price, as a penalty may be imposed.

Tests

If rock containing tungsten is crushed and panned, the tungsten minerals will remain in the pan just as do gold and black sand. The simplest test is to pour a teaspoon of strong hydrochloric acid into a test-tube or other receptacle and to this add enough crushed ore to cover a 10-cent piece. Heat and boil for 30 to 60 minutes or until a canary-yellow residue is formed. This is tungstic acid. Then add a piece of tin, zinc, or aluminum to the liquor and boil. The yellow coloration turns to a deep blue and finally to brown. Instead of adding these metals add an excess of ammonia, which will dissolve the yellow residue if it be tungsten.

As wolframite dissolves slowly, a sure test is to grind a small sample extremely fine in a mortar. Mix with it about twice as much sodium carbonate as there is powder. Melt some of the mixture on a platinum (or iron) wire; this can be done if the wire at the end is bent in a small loop about ⅛ inch across. It will be necessary to use a blowpipe to melt the material, which on melting will form a bead. Crush the sodium carbonate-sodium tungstate bead and treat with water only. If filter-paper is available, filter off the insoluble residue of iron and other minerals, as the subsequent test will be more distinct. Next, add some powdered or granulated zinc and a slight excess of dilute hydrochloric acid. If the solution turns blue, tungsten is present. However, as several other minerals give a blue coloration, the test is not certain.

URANIUM AND RADIUM

Uranium ores are the source of radium and of some vanadium, described under its own head. Uranium is not found native. It is a very heavy metal of the chromium group but has little use as such. Its specific gravity is 18.3, and it weighs 1140 pounds per cubic foot. Some of it is consumed as a coloring agent in pottery. As much ore as 47,000 tons may yield only 20 tons of uranium or about 23 tons of the oxide. Uranium and vanadium were chiefly produced as by-products in the extraction of radium in the United States. Radium is really the main objective in mining uranium ores, although the vanadium also produced amounts to a considerable sum each year. Radium is used largely in the treatment of cancer and in making luminous paints, such as are put on the dials and hands of watches and clocks. For such purpose a little radium is mixed with zinc sulphate as a paint and then put on. It takes 10 to 200 tons of ore to obtain 1 gram (15 grains) of radium or 300 to 6000 tons to give 1 ounce, worth approximately $750,000. As many tons of chemicals are consumed as ore is treated for this result.

Uranium Minerals

All uranium minerals contain radium, and many of them contain vanadium. There are 15 uranium minerals, but only two —carnotite and uraninite—are of importance.

Carnotite. Carnotite is an oxide of uranium and vanadium, with either or both lime and potash. It is radioactive and was the principal source of radium in America. It is a dull to resin-like, canary-yellow powder or earthy substance (mineral mixed with quartzite sand) usually found in cracks or in small openings in rocks. It melts easily in the blowpipe flame and becomes black. It is soft (hardness 1) and has a specific gravity of 4.5. Carnotite resembles sulphur, orpiment (arsenic), and some of the rarer minerals. Sulphur and orpiment smell of sulphur if heated. Only an expert can distinguish between carnotite and some of the other uranium minerals.

Uraninite. Uraninite or pitchblende is a mineral containing uranium, radium, lead, and some rare metals. It exists as crystals but mostly in massive form. It is pitch black in appearance, has an olive-green streak, is rather hard (5.5), is brittle with a conchoidal fracture, and is heavy, the specific gravity varying from 6 (massive) to 10 (crystals). It occurs usually in cracks or small openings in rocks. Uraninite can not be melted in a blowpipe flame. A borax bead made on platinum wire with a little uraninite has a yellow color if made in the outer edge of a blowpipe flame and pale green if made in the inner.

Uraninite is sometimes confused with obsidian (volcanic glass). The latter is light, but the former is very heavy. Some asphaltic materials look like uraninite, but all these give an odor of burning oils and are light.

Occurrence

In general it may be said that uranium (carnotite), also vanadium, deposits are likely to be found in sandstone and shale in semi-arid regions, more or less similar to those in which oil-shale exists; in fact, the Colorado and Utah uranium and oil-shale are not very far apart. Considerable care should be exercised in sampling and drilling for carnotite, as the prospector may easily be misled as to its value.

It is considered that the minerals originated in the sandstone and were concentrated on it by reason of being near the surface and conditions arising from the dry climate. Some of the Colorado carnotite deposits occur as follows:

On Coal Creek, Rio Blanco County, the ore is in the lower bed of a group of beds of massive white limestone, which underlies a conglomerate. In several pits the rock was of a light-green color, in streaks and layers, due to chromium, not carnotite. In another pit there was no carnotite, but a black to dark-brown sandstone, rich in vanadium. On Skull Creek, Routt County, are hogbacks of white sandstone. Red clay and shale underlie the carnotite and vanadium-bearing strata, which are under a conglomerate. In another section the sandstone was strained green, due to malachite, the copper carbonate. Figure 88 shows an occurrence of carnotite in Routt County, Colorado.

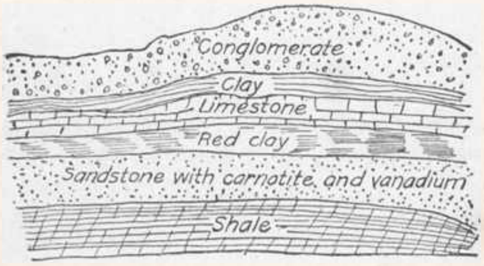


FIG. 88.—Occurrence of carnotite in Routt County, Colorado.

The deposits of Paradox Valley, in San Miguel and Montrose counties, contain from 2¾ to 6½ per cent uranium and vanadium oxides. The typical ore is a sandstone so impregnated with yellow carnotite that the color is decidedly noticeable. Kidneys constitute a large part of the ore, and these pockets yield several tons. Shale and conglomerate overlie the sandstone. The ores have many colors; some change on exposure to the weather and thus require skill in sorting.

In Utah, west and south of Green River, most of the deposits are exposed by gullies. The carnotite is always in rather coarse sandstone, overlain with fine conglomerate. Much petrified wood is present, also bones and fossils. The ore averages from 1 to 2 per cent uranium oxide and 2½ per cent vanadium oxide.

Shipping ore in either State should assay from 2 to 3 per cent uranium oxide to be profitable and acceptable to buyers.

No pitchblende is found nearer the carnotite deposits than close to Central City, Gilpin County, Colorado, more than 100 miles away. Five mines, from 200 to 600 feet deep, which were originally worked for gold, yielded pitchblende. The occurrence in all is quite similar, and Fig. 89 gives an idea of conditions existing.

Fig. 89.—Vein with pitchblende in a gold mine.

The ore was exceedingly rich—20 tons averaged 35 per cent, 100 tons 3 to 4 per cent, and some of it 60 to 80 per cent uranium oxide.

Uraninite was discovered in the Katanga copper district of Belgian Congo, Africa, in 1922, and so much radium is being extracted therefrom that the market for American carnotite has been affected. The main deposit is reported to be of vein origin but shows the minerals (pitchblende; torbernite, a uranate of copper and phosphorus; curite, a lead silicate; and kasolite, a silica uranate) in irregular veins, seams, and pockets. The enclosing rock is shale. The mineral varieties are black, green, yellow, and orange in color. The ores being shipped to Belgium for treatment contain more than 50 per cent uranium oxide.

At Great Bear Lake, near the Arctic Circle and 1200 miles by air from Edmonton, Alberta, Canada, is an important deposit of pitchblende and silver. After the ore is mined, sorted, and concentrated, the concentrate is transported to Ontario for recovery of the radium and silver.

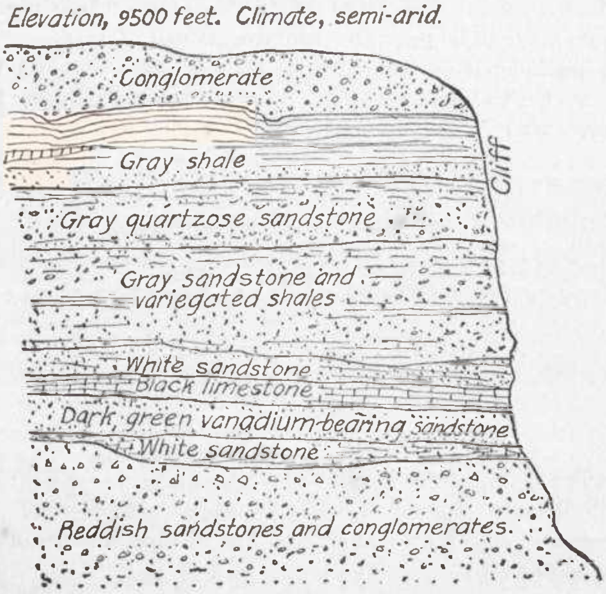


FIG. 90.—Section of vanadium-bearing sandstone country near Placerville, Colorado.

Some ore is mined and radium extracted therefrom in South Australia and in South Africa.

VANADIUM

Vanadium is in demand as an alloy metal in toughening steel. American deposits, so far discovered, are small, and the annual production of ore is small and irregular. This is extracted from vanadium ore in San Miguel County, Colorado; from the uranium ore of the Paradox Valley, Montrose County, Colorado, and Grand County, Utah; and from lead-silver ores in New Mexico and Bisbee, Arizona. Peru supplies the American demand for the metal, but carnotite deposits are again being worked.

Occurrence

Vanadium does not exist in the native form but in the minerals roscoelite, carnotite, vanadinite, descloizite, volborthite, and patronite. Except for patronite, which occurs in fine shale, these ores are all found in sandstone.

While the deposits of Paradox Valley and adjacent regions are really uranium ores carrying vanadium, those of the Placerville district of San Miguel County are essentially vanadium deposits. Figure 90 is self-explanatory and shows under what conditions the vanadium exists. The mineral is roscoelite. Normally, the lower bed of sandstone is light buff in color with patches and stripes of pale pink, probably caused by iron oxide; but when this sandstone contains vanadium, it becomes a dark olive-green, especially when the cliffs are wet.

Vanadium Minerals

While vanadium is contained in some uranium minerals, all of which carry radium, no vanadium minerals contain uranium or radium.

Roscoelite. Roscoelite is a mica which contains up to 29 per cent vanadium oxide, on which basis it is sold. It is olive-green, has an almost white streak, and is soft (about 2) and light, its specific gravity being 2.9. It is micaceous—that is, splits into thin sheets when found in large pieces. It is sometimes in very small flakes, giving sandstone a green color. No other known mineral of this appearance gives a test for vanadium.

Carnotite. Carnotite (described under Uranium) is a mineral containing vanadium and uranium, with either or both lime and potash, and yields a good proportion of the vanadium of this country. The vanadium content, as oxide, is 20 per cent.

Vanadinite. Vanadinite is a lead-vanadium mineral, carrying 19 per cent of the oxide of vanadium. It has a deep-red color, usually in distinct crystals—red, yellow, or green. Its streak is white; it is brittle with an uneven to flat and conchoidal fracture; its hardness is 3 and specific gravity, about 7. Vanadinite weighs 420 pounds per cubic foot. It melts and forms a black mass, although it crackles when heated. It gives either test for vanadium, also a test for lead, and dissolves in nitric acid.

Vanadinite resembles the lead minerals minetite and pyromorphite, from which it may be distinguished by testing for vanadium. Its vanadium content, as oxide, is 19 per cent.

Descloizite. Descloizite is a vanadate of lead and zinc, found only in the oxidized parts of veins, as in the Shattuck-Arizona mine, Bisbee, Arizona. It is olive-green, reddish to black; its hardness is 3.5 and specific gravity, 6. The coating left on charcoal reacts for zinc when cobalt nitrate is added. The vanadium content, as oxide, is 20 per cent.

Volborthite. Volborthite is a vanadate of copper, barium, and calcium. Its color is olive-green to lemon-yellow, and its streak is yellow. When heated in a closed tube it gives water and turns black. The vanadium content, as oxide, is 14 per cent.

Patronite. Patronite is the sulphide of vanadium, the ore found at Minasragra in Peru, in pockets and veins in shale. A section of the country rocks shows green shales, thin beds of limestone, and red shales. Vanadium is found only in the red shales, where, to a depth of 20 feet, it is largely in the form of red calcium vanadate, rather brighter than that of the calcium vanadate of Colorado and Utah. Patronite is black to grayish-black in color, with a hardness and specific gravity of about 2.5. This ore carries 34 per cent vanadium as the oxide. The Peruvian concentrate is melted in electric furnaces near Pittsburgh, Pennsylvania, and combined with iron to make ferro-vanadium.

There is a regular market for vanadium ore.

Tests

There are a number of reliable tests for vanadium, some of which are as follows:

1. When there is not too much iron present, the following test is satisfactory: Grind the ore fine and put a little into strong boiling

hydrochloric acid. A brown or straw color, which disappears when water is added and re-appears when hydrogen peroxide is added, is a sure sign of vanadium. As iron gives an unchanging brownish color, this indication may be obscured.

2. Another test is to grind the ore very fine and melt it in an iron dish with sodium carbonate and sodium (or potassium) nitrate. After melting, dissolve in water, let it settle, and pour off the clear liquid into a dish. Into this dish pour acetic acid very slowly until all bubbling stops, then add lead acetate. The formation of a pale-yellow powder in the liquid indicates vanadium. Chromium gives a dark yellow.

3. The most positive test for vanadium is to fuse the finely ground ore with sodium carbonate. Boil the fused mass with water, filter, add hydrochloric acid in excess, and cool. The addition of hydrogen peroxide to the cold solution will give a brilliant-red color if vanadium is present.

4. Vanadium can usually be detected by the color that it imparts to the fluxes. Take a piece of platinum wire fastened in a holder; make a small loop and heat this looped end in a flame until it gets red hot; while it is hot, dip the loop into some powdered borax or salt of phosphorus, and make the usual bead. Add a little of the vanadium mineral, such as vanadinite or descloizite, to the bead by touching a very little of the powdered mineral with the hot bead.

If the bead made from salt of phosphorus and vanadium is then heated before the blowpipe in the reducing (yellow) flame, a bead is produced which has a dirty-green color while the bead is hot but which on cooling changes to a fine green. If the salt of phosphorus bead is heated before the blowpipe in the oxidizing (bluish) flame, the color of the bead is amber or light yellow.

If the borax is used instead of salt of phosphorus for making the bead, and the same operations as outlined above for the salt of phosphorus bead test are followed, the color of the bead formed, when the reducing (yellow) flame of the blowpipe is employed, is a fine green when the bead is cold; and if the oxidizing (bluish) flame is used, the bead is a very light yellow, almost colorless when cold.

5. With potassium acid sulphate in a closed tube vanadates give a yellow mass. Mix a little finely powdered vanadium mineral, such as vanadinite or descloizite (about the amount held on the tip of a knife-blade), with an equal amount of potassium acid sulphate (potassium bisulphate). Take a closed tube, pour a little of this mixture into it, and heat thoroughly. This will produce a yellow mass.

6. Some vanadium minerals, when dissolved in concentrated sulphuric acid, yield a greenish-yellow solution. Zinc, if added to this solution diluted, gives a liquid that shows some tint of green which changes through various shades to lavender-blue. To make this test, take a test-tube or some other glass or porcelain receptacle and pour into it about 1 teaspoon of concentrated sulphuric acid. Into this pour a little finely powdered vanadium mineral (almost as much as held on the tip of a knife-blade). Heat this solution to boiling, when a greenish-yellow coloration shows. If a spoonful or two of water is added and a small piece of zinc, the color changes to a greenish tint, then to lavender-blue.

7. Some vanadium minerals are soluble in cold concentrated hydrochloric acid and evolve chlorine gas and yield a deep wine-red coloration, which, on adding water, changes to green, or the color may disappear if too much water has been added.

ZINC

Zinc is a bluish-white metal of great industrial importance, never found in the native state but always as a compound. Large deposits of zinc ores are worked in all parts of the world. Cast zinc has a specific gravity of 6.8 and weighs 427 pounds per cubic foot.

Zinc and lead are frequently found associated in the same deposit, which is mined for both of these metals. Silver is often associated with both of them. Zinc ores usually contain some lead mineral, and lead ores usually contain zinc; yet there are well-known deposits of each that are devoid of the other metal or the silver. The Mascot, Tennessee, deposit is an example of zinc alone in limestone; the latter also finds a market for construction purposes. Zinc deposits are generally found in limestone formations, quartzite, or slate, and shale, as shown in Fig. 91. The zinc-lead deposits of the Tri-State region of Kansas, Missouri, and Oklahoma, known also as the Joplin district, differ from the regular type, although those in Wisconsin resemble them. The region has a gently rolling, prairie-like surface. The orebodies have definite relations to certain geologic formations and are mainly in a cherty limestone, as shown in Fig. 92.

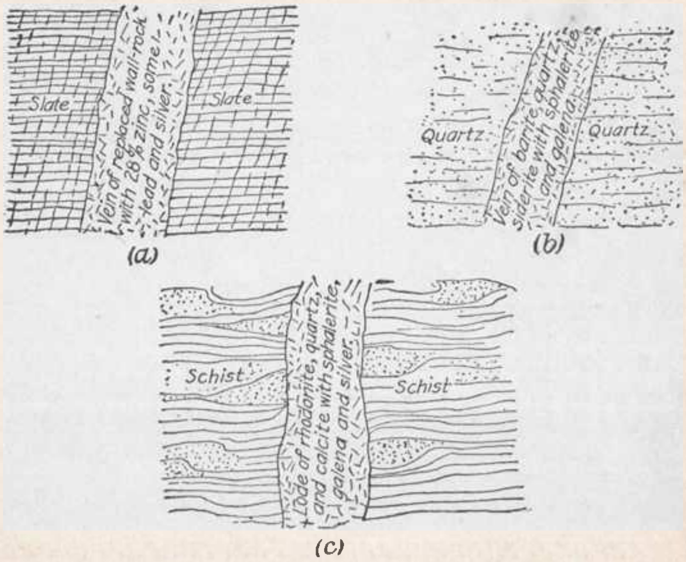


FIG. 91 (*a*, *b*, *c*).—Three types of zinc deposits.

The well-defined bodies are known as "sheet-ground" deposits, and the irregular ones as "runs." The ore-bearing beds are 6 to 20 feet thick. Ore carries about 2 per cent zinc and 0.22 per cent lead, although in Oklahoma the lead content is nearly 1 per cent. In Missouri the juncture of limestone and shale is prospected. The shallow deposits were opened by windlass and horse whim, but they have been mostly worked out, so churn-drills are now largely used in prospecting. Holes average about

20 feet depth and cost up to $1.50 per foot. Careful sampling and assaying are necessary.

Chert and dolomite are the most important gangue minerals. Limestone, shale, soapstone, and mud are less important. In some of the deposits the chert and dolomite are intimately mixed, and the sphalerite is embedded in a black secondary chert that cements the gangue and sphalerite. Chert or flint is the characteristic gangue material of the ore deposits and can be recognized in three different varieties: the white chert, the blue to gray chert, and the black or secondary chert. The blue chert is known as "live-flint," and its occurrence usually indicates the presence of zinc. The black variety, which fills cavities and the interstices of the brecciated rock, is generally found in the brecciated areas closely associated with sphalerite or in places with galena and as a cementing material or matrix for the blue and white cherts with zinc sulphite. The so-called "cotton rock," a decomposed chert,

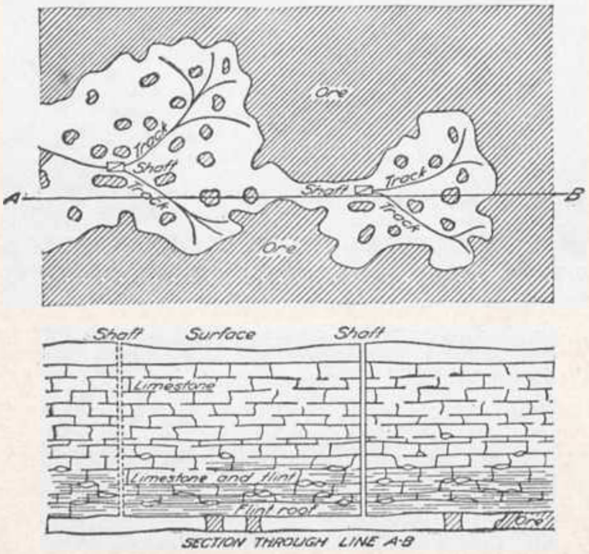


FIG. 92.—Plan and section of sheet-ground mine in Joplin district, Missouri.

dead white in color, often forms layers several inches thick near the surface or overlying the orebodies. It is noticeable in the roof of some of the sheet-ground mines, where it usually has to be taken down as waste with the ore or has to be propped with posts at frequent intervals.

Generally the oxidized ores of zinc and lead lie above and near the level of ground water; the sulphide of zinc becomes dominant below, the proportion of galena grows less, and that of iron sulphides greater as the depth increases. Sphalerite is seldom found in the weathered zone, for it becomes oxidized by the action of surface waters, generally to silicate or carbonate of zinc. As the general course of these waters is downward; and as the sphalerite is more soluble and more easily oxidized than galena, it is found at a greater depth, below the influence of the oxidizing agents. Hence, the finding of a large body of galena with sphalerite scattered through it indicates the probability of a good deposit of zinc being found below. In crevices in some of the mines are small deposits of what is called coal tar or asphalt, a sticky mass at the ordinary underground temperature.

These deposits call for a special system of mining. In general the orebodies are mined from one level, as the deposits themselves are usually flat and seldom more than 20 to 30 feet thick. Where possible a system of underhand stoping (Fig. 93) is practiced in the district, especially in the sheet-ground mines, if the face of the ore is high enough to warrant it. A machine-drill is set on a 7-foot column placed at the upper part of the face near the roof in order to advance a heading about 6 to 8 feet high, leaving a bench beneath of 8 to 12 feet thick above the floor of the stope. When the heading or breast has been advanced 15 to 20 feet, the bench is drilled and blasted.

Generally speaking, prospectors and miners are called upon to exercise a good deal of ingenuity in the Joplin district, as many of the deposits are suitable only for small parties of men.

In the Wisconsin fields the ores occur either in crevices, joints, and openings or disseminated or scattered through the ore-bearing rock, a limestone. Pitches and flats are characteristic of the district, most of the zinc sulphide ore and associated minerals existing in this type of deposit. Flats are horizontal sheets of ore connected by a series of fissures or joints, the pitches. When an area is being selected for prospecting, the chances of finding zinc ore are greater in regions where lead has already been found above water-level than in areas where lead is not known to exist above it.

In New York State at the Balmat mine, development has opened deposits of sphalerite, pyrite, and galena in crystalline dolomite, as steeply dipping and rather short lenses. The ore averages 12 per cent zinc, 1.7 per cent lead, and 13 per cent iron.

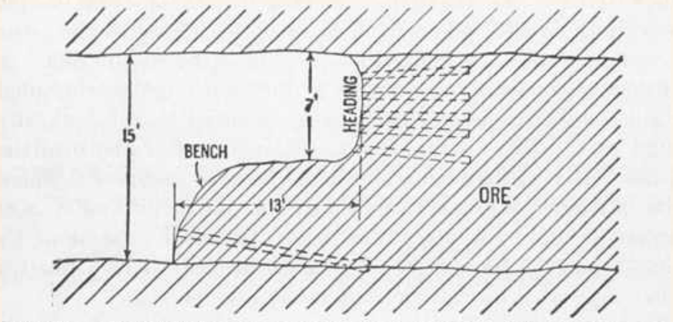


Fig. 93.—Underhand stoping as practised in Joplin district, Missouri.

Tests

There is no simple test by which the presence of zinc can be recognized, but fortunately its minerals have properties by which the metal is easily recognized. The test usually employed is difficult to perform successfully, but it is given here, as it is the best now known: Powder the mineral and mix it in a mortar with twice as much sodium carbonate. Pick up some of this powder on a loop in a platinum wire, hold it about ¼ inch from a piece of charcoal on a table, and heat to a white heat in the inner part of a blowpipe flame. Take the flame away and notice the charcoal and watch for a white coating, which is yellow before it cools. Heat the white deposit (if there is any) in the outer part of the blowpipe flame and if there is still a white coating left, which is pale yellow when hot, there is zinc in the mineral. If the coating after being moistened with a drop of cobalt nitrate solution is again strongly heated before the blowpipe in the oxidizing (bluish) flame, the coating will assume a green color, which is best seen when it is cold.

Zinc Minerals

Sphalerite. Sphalerite (sometimes known as blende, zinc blende, black jack, rosin jack, ruby jack, and steel jack) is a sulphide of zinc and contains 67 per cent metal when pure. Its color is resinous to black; its streak is white to yellowish brown. When broken it has many flat, mirror-like surfaces. Its hardness is 3.7 and specific gravity, 4. A cubic foot weighs 250 pounds. Sphalerite is melted in a blowpipe flame only with difficulty. It is one of the few minerals which, when powdered and put in warm hydrochloric acid, gives the obnoxious odor of rotten eggs (pyrrhotite also does this). These characteristics easily distinguish sphalerite from all other minerals.

Small quantities of sphalerite are found in many places in many kinds of rock, but the ores are found chiefly as described for zinc in general. Sphalerite is by far the most important of all zinc minerals. It weathers slowly to smithsonite and calamine.

Smithsonite. Smithsonite is a carbonate of zinc and assays 52 per cent metal when pure. It is brown, green, yellow, gray, or white. Its streak is white; its hardness is 5; its specific gravity is 4.4. A cubic foot varies up to 270 pounds. Smithsonite's luster is vitreous to pearly; it has an uneven fracture and is brittle. It can not be melted in the blowpipe flame. If the mineral is powdered and put in concentrated or in hot, dilute hydrochloric acid, it bubbles vigorously, but it will not do this in cold dilute acid. No other mineral as hard as smithsonite bubbles in this way. The appearance of smithsonite is varying; sometimes it is a watery-green crust on a rock, and sometimes it is a porous material looking like an old dry bone.

Smithsonite sometimes looks like calamine, prehnite (calcium and aluminum), or siderite (iron). Calamine and prehnite do not bubble in acid, and siderite will bubble only when the acid is concentrated and hot.

Smithsonite forms from the weathering of sphalerite. It is not an important ore of zinc but is significant, as it may indicate a body of sphalerite deeper down. It is seldom found below a depth of 20 feet.

Calamine. Calamine is a zinc silicate and carries 54 per cent zinc when pure. Its color is white, yellow, green, or brown; its streak is white; its hardness is 4.5 or 5; and its specific gravity is 3.4. A cubic foot weighs 250 pounds or more. It is brittle, with an uneven fracture. It can not be melted in a blowpipe flame. A coarse radiating structure is often found in the mineral.

A test that may show the presence of soluble silicate is as follows: Grind the material very fine, put a little (as much as a pea) in a test-tube, and half fill the tube with hydrochloric acid. Boil until all but a few drops have evaporated, then set the test-tube down and do not touch until it is cold. After that shake the tube and see if the acid has turned to jelly, which indicates calamine; however, a great many other silicate minerals will give the same result.

Calamine, smithsonite, and prehnite sometimes look alike. Prehnite melts in a blowpipe flame, and it will not give the jelly test described above. Smithsonite bubbles in hydrochloric acid. Chalcedony (silica) also may look like calamine, but it gives no jelly test; the former is distinctly harder than calamine.

Calamine forms by alteration from sphalerite and seldom exists below a depth of 20 feet. It is mined in fairly large quantities in the Joplin district.

Franklinite, Zincite, and Willemite. Franklinite, zincite, and willemite are three zinc minerals which are mined at Franklin, New Jersey. They are not common anywhere else and are nearly always found in the same deposits. Some zincite has been found in eastern Nevada.

Franklinite is black and looks like magnetite. Its hardness is 6, specific gravity 5.15, and weight 310 pounds per cubic foot. It is somewhat magnetic. Its streak is dark brown. It may be tested for iron, manganese, and zinc. Franklinite's magnetic properties, its dark-brown streak, and the fact that it is found with zincite and willemite distinguish it from magnetite.

Zincite is a bright-red mineral which gives a test for zinc. It looks like cinnabar but contains no mercury and gives no test for it. Its specific gravity is 5.5, and a cubic foot weighs 340 pounds.

Willemite is a zinc silicate with specific gravity of 4. Its color is yellow-green. When the test described for testing calamine is made, willemite will produce a jelly like that produced by calamine.

Marmatite. Ore of the Sullivan mine, British Columbia, is a sulphide replacement in quartzites—zinc, lead, silver, and iron. Marmatite, a zinc-iron mineral carrying a little lead and silver, forms part of the large daily tonnage. It is black and heavy, having a gravity of 4 and a hardness of about 4.

ZIRCONIUM

Zirconium is a rare metal found only in combined forms, such as its silicate, zircon, or the oxide, baddeleyite. One of its large uses is as an abrasive. Some is used as an alloy metal in steel, as special cement, and for enameling. Zirconium minerals are also used to make zirconia (the oxide), which has some use as a refractory to withstand a high heat. It is possible to melt platinum in dishes made of zirconia. When zircon has a clear-orange color it is sometimes used as a gemstone and is then called hyacinth.

Occurrence

Minute traces of zirconium are present in a large number of rocks, but it is rarely that there is enough in a rock that it can be seen. This metal may be present in any igneous rock (rock solidified from a molten condition) but it is not found in workable deposits except in pegmatites. Sands and gravels formed by weathering and stream wear on the pegmatites may also contain zirconium. Beach sands in New South Wales contain zircon.

Zirconium Minerals

By far the most abundant and widely distributed mineral of zirconium is zircon, the silicate of zirconium, although its zirconium content is not so great as that of baddeleyite, the oxide.

Zircon is harder than quartz—that is, quartz will not scratch it; on the scale of hardness it is 7.5. It is a little heavier than ordinary minerals, though not so heavy as scheelite; its specific gravity is 4.7, and a cubic foot of it weighs 290 pounds. It looks glassy; its color is white, brown, gray, and even green or red. The streak of zircon is white. It can not be melted in a blowpipe flame.

Zircon is sometimes confused with thorite, monazite, and garnet. Thorite and monazite may be tested for rare-earth metals as previously described, but zircon will not give this test. Garnet and zircon are alike in color, hardness, weight, and other properties, but they differ very much in the crystal shape. Of course, if only a fragment of mineral is at hand, it may not show the crystal shape, but a large piece may do so. Zircon usually forms crystals shaped like those shown in the section on Crystallography.

Zircon does not often weather to any other mineral, although it does sometimes change to baddeleyite.

Baddeleyite. This is the natural form of zirconia or zirconium oxide. Its color may be white, yellow, brown, or black. It can not be scratched with a knife but can be by quartz, as its hardness is 6.5. It is a heavy mineral, heavier than zircon; its specific gravity is 5.5. It is rare except in Brazil where rather large quantities are found. As a rule it occurs with zircon.

Tests

There is no good simple test for zirconium. If tested as directed for rare-earth metals, zirconium will usually, but not always, give a white cloud in the liquid, which will disappear in a few seconds. The rare-earth metals give this effect, which remains and will settle out as a white substance.

It is difficult to say just what grade of ore is mineable. It is generally, except in Brazil, saved in mining monazite or ilmenite. Before the ore can be used to make a finished product, it must be concentrated until it is nearly pure. The pure powdered metal sells for $7 per pound.

CHAPTER XVIII

B. NON-METALLIC MINERALS

Definition.—A non-metallic mineral may be defined as one that contains no metal as such, nor is the mineral worked for any metal. Non-metallic minerals are of incalculable importance in modern construction, agriculture, and chemical industry. Production of non-metals greatly exceeds that of metals. Alphabetically, following are the non-metallic group:

List of Non-Metals

- Abrasives (corundum, emery, millstones, sandstones, diatomite, garnet, tripoli, and others).
- Abestos.
- Barite.
- Borax.
- Building stones.
- Cement rocks.
- Clays (bentonite, kaolin, fuller's earth, fire-clay).
- Coal.
- Cryolite.
- Diatomite and tripoli.
- Feldspar.
- Fluorspar.
- Gem minerals.
- Graphite.
- Gypsum.
- Hydrocarbons (natural).
- Kyanite.
- Lime.
- Magnesite.
- Mica.
- Mineral fillers.
- Mineral fuels.
- Natural gas.
- Nitrates.
- Petroleum.
- Oil-shale.
- Phosphate rock.
- Potash salts.
- Pyrite.
- Salt and salt lakes.
- Sand and gravel.
- Stone.
- Sulphur.
- Talc and soapstone.

As is well known, the foregoing minerals can be put to use as such, or with some preparation, and many products can be extracted therefrom, but not easily.

ABRASIVES

At least a dozen minerals are used as abrasives or for cutting, grinding, and polishing, but only a few of them are to be discussed. Artificial abrasives are supplanting some of the natural minerals.

CORUNDUM AND EMERY

Corundum is an oxide of aluminum. It often contains a little water, silica, and iron. The pure varieties are gems—sapphire and ruby—the impure variety is emery, which is a mechanical mixture of corundum and magnetite (iron ore). Emery is used as an abrasive. Many names have been given to the gem and abrasive varieties of corundum and emery.

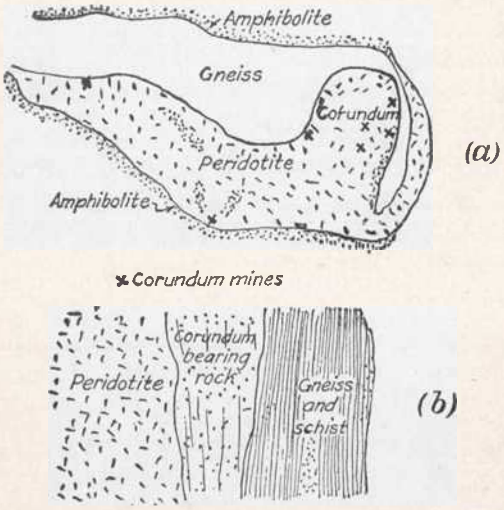


FIG. 94 (a).—Corundum-bearing country and (b) vein in North Carolina.

Corundum crystallizes in two forms, one of which is prismatic. Its fracture is irregular, and its hardness is 9, next to the diamond, which is the hardest substance known. The specific gravity of corundum is 4, and a cubic foot weighs 250 pounds. It is not affected by acids and is infusible in the blowpipe flame. The mineral may be found in large or small masses, crystals, and as sand.

Occurrence

American deposits of corundum and emery are in North Carolina, New York, California, Colorado, Idaho, South Carolina, Georgia, Virginia, and Montana. Turkey and Greece produce large quantities.

As it is an ore of aluminum, it might be thought that corundum should be found in rocks similar to those in which bauxite occurs—clay or kaolin—but it is not. It is found in igneous and metamorphic rocks and in alluvial deposits or placers. Under igneous rocks come peridotite (a granular rock), andesite, granite, syenite (granite without quartz), and pegmatite (giant granite). Under metamorphic rocks come amphibolite (hornblende schist), serpentine, gneiss, mica-schist, quartz-schist, and crystalline limestone. Associated with the peridotite are particles of chromite, near the borders of the former. Also associated with corundum deposits are 93 minerals, the common ones being asbestos, beryl, calcite, chalcedony, chalcopyrite, garnet, graphite, ilmenite, magnesite, magnetite, opal, pyrite, rutile, talc, tourmaline, and zircon. Figure 94*a* and *b* gives an idea of the corundum country of North Carolina and one of the deposits. The European emery is embedded in a bluish, coarse-grained marble or limestone, which lies on mica-slate and schists. The occurrences are irregular.

The sapphire and ruby varieties of corundum are discussed under Gem Minerals.

Owing to their weight the grains of corundum and emery are easily separated from the containing rock by crushing, grinding, and washing.

Diatomite, formerly termed diatomaceous earth, is a friable, white, earthy material, composed of about 89 per cent silica, with alumina and lime. It is sometimes incorrectly called infusorial earth, kieselguhr, and tripoli. It consists of silicious skeletons of small water plants called diatoms. Its apparent specific gravity is less than 1—it floats on water until its pores get filled therewith.

Diatomite is used for polishing metal, in filters, and as an absorbent and insulator, mostly as the last.

Tripoli is a white, finely granular, very porous, silicious rock usually derived from the decomposition or alteration of chert but sometimes derived as a residual product from the decomposition of silicious limestone. It is loosely coherent and may thus be easily crumbled in the hand, but its individual grains are so hard that they will scratch steel. The grains are double-refracting (change of direction of light) and are probably chalcedony. A good sample will contain 98 per cent silica with a little water. Unlike diatomite, tripoli will not float on water, and its grains are rounded whereas the others are shell-like. Tripoli quickly absorbs one-third of its weight of water. It is mostly used in making water filters of all sizes, also for polishing, in molds at foundries, as a filler in paint, and in rubber. It is found as horizontal beds 2 to 20 feet thick covered by an overburden of loose dirt, gravel, and decomposed tripoli, about 5 feet deep.

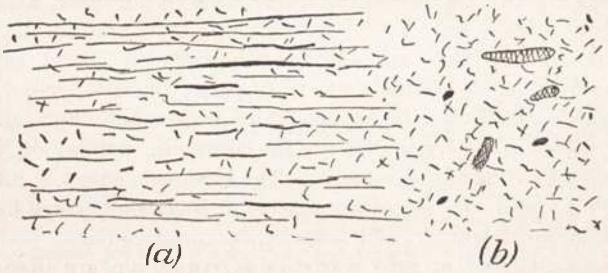


FIG. 95.—Occurrence of asbestos. (*a*) Schistose serpentine containing asbestos: the whole has to be milled; (*b*) massive serpentine adjoining contains chromite.

ASBESTOS

Although the United States consumes great quantities of this non-metallic mineral it produces little; the province of Quebec supplies most of our needs. That which has been developed in the United States is generally of good quality but the tonnage is small.

Asbestos is a hydrated silicate of magnesia, in fibrous form. The common mineral is chrysotile, a silicate of magnesia and iron.

Its specific gravity is 3.3, and a cubic foot weighs 200 pounds. Any belt of serpentine rock may contain asbestos. Veinlets are ½ to 6 inches wide, running in all directions. One deposit in Arizona is in serpentine associated with limestone altered by intrusions of diabase. The Canadian serpentine yields 6 per cent asbestos. Figure 95 shows two varieties of serpentine containing

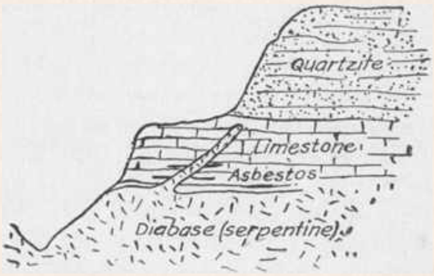


FIG. 96.—An unusual type of asbestos in Arizona.

FIG. 97.—Characteristic occurrence of chrysotile asbestos in serpentine. New Amianthus mine, eastern Transvaal, South Africa. (*From South African Mining and Engineering Journal.*)

asbestos and chromite; Fig. 96 shows another type in Arizona which yields long fiber; and Fig. 97 illustrates a type in Transvaal.

Most asbestos is associated with serpentine. As it resists weathering, although it may be discolored by exposure, outcrops of asbestos are more or less prominent. Of the three types of deposits (1) that with cross fiber consists of many strands that generally extend across the lode from wall to wall; (2) that with slip fiber has the strands generally parallel to the lode walls; and (3) that with mass fiber has fibers of no definite arrangement.

As to the uses of asbestos, the electrical industry requires it free from iron. Long fibers are used in spinning yarn and cloth; short ones are used in boards or sheets including admixture with cement, shingles, brake bands, and insulating material. The principal consuming industries are motor vehicle and insulation.

BARIUM MINERALS

Barium never occurs as a metal, nor is it used to any extent as such. The chief minerals are barite, also known as barytes or heavy spar, the sulphate; and witherite, the carbonate. As a rule, in Georgia, Kentucky, Missouri, Tennessee, and Virginia the barite deposits are associated with sedimentary rocks, chiefly clays representing a disintegration of limestone and dolomite. In California the barite and witherite occur together as veins. Barite is largely mined by hand methods from shallow depths. In Georgia and Tennessee the ore is screened, run through a log-washer, trommel, picking belt, and jigs. Gold is said to occur with barite in the Fiji Islands and also in Montana.

Barite is brittle; has a good cleavage, a white streak, and a pearly luster; and varies in color from white to light shades of yellow, brown, red, or blue. It is slightly harder (hardness 3) than the finger nail but may be cut easily with a knife. Its principal characteristic, which makes it easily distinguishable from other similar white minerals and is generally responsible for creating the idea of unusual value, is its weight. It is very heavy (specific gravity 4.4 and weight per cubic foot 270 pounds, but the metal is only about one-tenth of this). It weighs nearly twice as much as a piece of feldspar of the same size. In small quantities it is of no value, but if pure and in large, easily minable deposits near a good market it finds a steady sale for the manufacture of lithopone, paint, rubber, paper, linoleum, soap, and numerous other uses, including use in steel. It should be as low in iron, lime, alumina, and silica as possible.

Tests

Barite is sometimes confused with scheelite, the tungstate of lime, but the latter will scratch the former; and whereas scheelite will hardly melt under the blowpipe, barite will. Barite is also mistaken for calcite, but it is heavier and will not effervesce when hydrochloric acid is applied. Barite is frequently found with strontianite.

BORAX

Borax, as occurring chiefly in Nevada and California, is the general term for the borate minerals borax and kernite (a borate of sodium), colemanite (a borate of calcium), and ulexite (a borate of sodium and calcium). Borax and kernite are the important minerals now; formerly colemanite was. Borax occurs in small quantities as incrustations or in alkaline marshes, in the brine of lakes, and as beds between clay and shales, limestone, sandstone, and conglomerate, all in arid regions.

Tests

Borates are white to yellowish, of light weight (up to 160 pounds per cubic foot), and a hardness of 4. Deposits are not common; therefore when discovered, they find a ready sale. If a few drops of sulphuric acid are put into a glass or cup containing some dissolved mineral, then some alcohol, and lighted, the flame will be a bright green if borax is present. Borax has many industrial and domestic uses.

BUILDING OR DIMENSION STONE

Rocks coming under this head may be required for buildings, paving, curbing, dams, walls, and monuments. Not all rocks are suitable. Color is important for buildings and monuments, as are also freedom from cracks and constituents such as pyrite that weather and cause disintegration. In every country such stones are in demand. There are many deposits, but many of them are not solid and have impurities and seams filled with decomposed rock. To be valuable, building stones should be near railroads and large centers of population where construction is continuous; although, if the rocks found possess special qualities, they may bear the cost of a long haul to market. On the other hand if dams are being built in isolated places, a deposit would be valuable. (See Oliver Bowles' book, "The Stone Industries.")

The six classes of stone to be briefly described are closely similar in specific gravity and weight. They range from 2.5 specific gravity and 160 pounds per cubic foot for sandstone to 2.8 specific gravity and 173 pounds for marble.

Granite

Granite suitable for building purposes must be free from jointing, with grain not too coarse; it must have straight cleavage; and it must be capable of taking a good polish. If there are many joints in a deposit, large blocks can not be broken. Color is another important point, although many different colors are used.

The granitic rock termed gabbro, which usually occurs as an intrusive rock in granite, is in demand when it is of the orbicular (concentric rings) type. The peculiarity of this stone is the rings of white feldspar surrounding dark masses of crystalline hornblende. When polished, this material is highly ornamental, as it has rich coloring and is uncommon.

Limestone

Millions of cubic feet of limestone is used every year in buildings. The blocks are rough, semi-finished, or completely dressed or cut; rough blocks may sell for one-fifth as much as the cut stone. Indiana oölitic (small, round grains or concretions) limestone is one of the principal types of stone used in the United States. Enormous quantities are available. It is blue to buff in color and of granular texture. The trade desires low silica, iron, and alumina content, not more than 2½ per cent.

Marble

A good marble must be low in silica. It may be of any color—from white to black. It should be compact, finely crystalline, with good luster. Care should be exercised in quarrying, as heavy charges of explosives will cause cracks and seams in the marble, however sound it may be.

Onyx marble is composed of lime, magnesia, and iron carbonates and should not be confused with onyx, the banded variety of quartz or silica. Onyx marble takes a brilliant polish and is translucent—that is, some light passes through it but one can not see through it.

Sandstone

Sandstone is a sedimentary rock composed of sand grains cemented together. The silica content may be almost 100 per cent. The rock mainly consists of the grains which vary in size and composition. When the quartz grains are very small and the cementing material is prominent and of a clayey nature, sandstone is classed as shale; but when the grains are as large as pebbles, the rock is a conglomerate. The cementing materials are clay, iron oxide, quartz, and calcite.

In sandstone for building the preferred colors are blue-gray or buff and red-brown. The grain should be fine, and yellow iron oxide spots are not desirable. This rock hardens on exposure to the weather after being dressed.

Sandstone is found in almost every State, particularly good rock being mined in California, Connecticut, Pennsylvania, Tennessee, New Jersey, and New York.

The city of Sydney, New South Wales, Australia, stands on sandstone and the harbor is deeply "carved" out of this rock, although the stone has been uplifted. For many buildings and houses it is unnecessary to purchase stone because blocks can be excavated from the site. The sandstone is soft but hardens on exposure. This rock covers a large part of the State, and at a depth of 2000 feet in Sydney harbor it has a coal bed, also at Lithgow in the Blue Mountains miles west, and near Newcastle

100 miles north. Near Lithgow the sandstone also contains workable ledges of oil-shale.

Serpentine

If found in large and compact pieces, this greenish-yellow or greenish-gray rock finds a good market, as it is of pleasing color for interior decoration. The dark-green serpentine, criss-crossed with veinlets of magnesium and calcium carbonate or having patches of these minerals, is often called marble and is used for inlaying floors, for pillars, and for monumental purposes.

Serpentine often contains asbestos, chromite, magnesite, and mercury.

Slate

Slate is largely used for roofing purposes, but large quantities are consumed in making table tops, switchboards, tubs, flooring, and such. Deposits are worked in 20 States but mainly in the East. Slate is a dense, fine-grained rock whose separate minerals can not be distinguished by the eye. It has a parallel cleavage—that is, it may be split easily in thin pieces. The composition is 60 per cent silica, 15 per cent alumina, with some iron, magnesia, lime, soda, and potash. The newest and a satisfactory method of quarrying slate is by what is known as the wire saw, introduced into the United States from Europe by the Federal Bureau of Mines. This method is also being introduced into the limestone and other quarrying.

In Georgia, slates alternate with beds of quartzite. Black slates owe their color to carbon; red slates, to iron; and purplish slates, to a mixture of these with a green magnesia mineral.

Good slate should give a distinct ring when tapped. If it effervesces when hydrochloric acid is put on a piece of its powder, lime is present. Too much pyrite is undesirable. The presence of clay may be determined by breathing on slate, when it gives a clayey odor.

Slate should be examined for antimony, coal, gold, lead, pyrite, and zinc-lead deposits.

Other Rocks

Rocks such as a yellowish trachyte; a light, fine-grained rhyolite; basalt; and soapstone are also used for building purposes.

Of the foregoing rocks granite, limestone, sandstone, and basalt are used in the crushed or broken form for ballast, concrete, and road-making.

CLAYS

Clay consists essentially of silica and alumina combined with water and is found everywhere. Ohio is the leading American producer of various clays; much of its clay is mined from coal beds. Clay is the resul of the decay of older rocks, particularly granites. When left at the spot where the original rock disintegrated they are termed "residual" clays. Where they have been transported by glaciers, they occur in mounds or moraines and are usually mixed with sand, gravel, and boulders. The purest clays are those that have been sorted over and transported by water. They are to be found on level or dissected planes which represent ancient sea beds, or they may occur along old river beds or flood planes.

Wet though stiff clay in place weighs 118 pounds per cubic foot; loose and dry lumps weigh half of this.

Clay is in demand for making brick, tile, and pottery and is used in graphite crucibles and paper. For high grades of china and pottery the finest clay is demanded. A large quantity of clay is used in the manufacture of portland cement, of which it constitutes about 20 per cent. Clay for this purpose should be free from gravel and sand and contain not less than 55 per cent silica, preferably up to 70 per cent. The combined alumina and iron oxide should not exceed half the quantity of silica.

Types of Clay

Kaolin or china clay is the purest of the clays. It is imported in large quantities and is in good demand. Fireclay, which is high in silica, is used in large quantities in refractories. Fuller's earth is a clay high in magnesia and may or may not be plastic.

It is used for decolorizing oils and fats and has the property of retaining the coloring matter therein.

Clays are classified under the following heads: whiteware clays (plastic and non-plastic); refractory or fireclays; pottery and stoneware clays; medicinal clays; low-grade clays and shales; brick clays and shales; gumbo clay (ballast and brick); slip clays (for glazing); fuller's earth; and bentonite, a clay-like substance which expands several times on being wetted and is in considerable demand as mud in drilling oil wells and in stopping leaks.

CRYOLITE

Cryolite is a fluoride of sodium and aluminum used in the production of aluminum metal. Greenland has the only known workable deposit. It is white, with occasional patches of galena and sphalerite. The specific gravity is 2.9; hardness is 2.5 to 3; and it weighs 180 pounds per cubic foot. With the blowpipe a suffocating odor of fluorine is given off; and if the fume is played on a test-tube, it will be etched. Cryolite melts at 1742°F.

FELDSPAR

Although this is the name given to a group of rock-forming minerals, there are several varieties of industrial importance. The trade name applies to potash feldspar.

Occurrence

Feldspar exists in nearly all igneous rocks, especially in pegmatite (giant granite), where it occurs as large crystals. This is the present source of the rock. Quartz and mica are the principal associated minerals.

The composition of feldspar varies, but the potassium mineral contains 17 per cent potash, 64 per cent silica, and 18 per cent alumina. (See under Potash.) Its hardness is 6, and it breaks irregularly with a glassy luster. The color is white to reddish. Acids do not affect feldspar, and the blowpipe melts it with difficulty.

Good feldspar has a market at potteries, glass and enameling works, also for bonding emery and corundum wheels. It is a future source of potash. The sodium feldspars with peacock-color iridescence, bluish-green hue, reddish color, and a moonstone with cat's-eye effect are salable as gems.

FLUORSPAR

Fluorspar or fluorite is a fluoride of lime and contains 51 per cent lime as calcium. Clean ore assaying 85 per cent calcium fluoride and under 8 per cent silica has a ready sale for the chemical, pottery, and steel industries and in the making of hydrofluoric acid, essential to the manufacture of artificial cryolite, used in the production of aluminum. Its specific gravity is 3.2 and hardness, 4. A cubic foot weighs up to 200 pounds.

Occurrence

Fluorspar occurs in veins cutting both sedimentary and igneous rocks—from limestone, sandstone, and shale to rhyolite. Barite, calcite, and quartz often accompany it. In Colorado, the fluorspar is of good quality; so it is in Arizona, Illinois, and Kentucky, but here it has to be separated from lead, a simple process, as galena is more than twice as heavy as fluorspar. If sphalerite is present, its separation is troublesome, as its specific gravity and that of fluorspar are close. Flotation has solved one such problem.

Fluorspar is found in crystals which take the isometric form or first system of crystallization. Its color may be white, bluish, greenish, or pink. Calcite, the lime carbonate, resembles fluorspar but is slightly softer and effervesces with hydrochloric acid, while the fluoride does not. If warm sulphuric acid is added to some ground fluorspar, hydrofluoric acid is formed, which etches or corrodes glass.

The fluorspar deposits of southern Illinois occur in a region of sandstones and limestones; the veins are either in rock or at the contact. They form typical fissure veins of tabular shape and average 11 feet in thickness. Faults are common in the district. The fluorspar is always accompanied by calcite or calc-spar. The calcite is there considered as an indicator of fluorspar. Fluorspar (calcium fluoride) is called "spar" in Illinois, and calcite or calc-spar (calcium carbonate) is called "calc." The national war program resulted in the exploitation of many small fluorspar deposits in Southern Illinois and Western Kentucky in early 1941.

In Transvaal, fluorspar occurs massive or friable in replacement of chert and dolomite or as impregnations in dolomite and as gash veins.

FULLER'S EARTH

Fuller's earth is a clay of fairly complex composition but consists mainly of silica, alumina, magnesia, iron, and alkaline earths. It is not plastic, which means that it can not be molded or worked like ordinary clay. Its principal use is in filtering oils to take out their coloring matter. The same earth may be used repeatedly, as it is carefully burned after a certain period of filtering.

Occurrence

All the United States deposits (Arizona, Arkansas, California, Colorado, Florida, Georgia, Massachusetts, South Carolina, South Dakota, and Texas), except that in Arkansas, occur under much the same conditions as any clay bed, under more or less overburden similar to bauxite. Beds may be from a few inches to more than 20 feet thick. The Arkansas deposit is found in veins and has been derived from dikes of basalt.

The color of fuller's earth ranges from white and cream to brown. It is slightly acid and will turn neutral litmus paper red. Fuller's earth has a specific gravity similar to other clays, but it is somewhat lighter and more porous. A rough field test might be to dry the earth well to rid it of water, place it in a funnel or other receptacle through which a liquid will pass, and pour on oil that has a brown or yellowish color. If the material is fuller's earth, the oil filtering through should be clear and nearly colorless.

Fuller's earth has a specific gravity of 2 and weighs up to 150 pounds per cubic foot.

GEMSTONES OR MINERALS

Although he may keep his eye open for gemstones the prospector, in North America at least, rarely goes out with the sole intention of looking for them. In South Africa, South America, and Australia the case is different. Gemstones may be found in place or in gravels. Granite pegmatite is an important source of many varieties of precious stones. Stream gravels are by far the most important secondary sources of gems—that is to say, after gems recovered from associated rocks. Diamonds account for more than 90 per cent of the value of the world's production of precious stones. Gems from gravels are generally of higher quality than those extracted from rocks. Only the more common gems are described here. Several common minerals yield marketable gemstones, even stream and beach pebbles. As in other industries, artificial (and reconstructed) stones, excluding diamonds are seriously affecting the market for genuine stones.

A precious stone is one that has high marketable value because of its beauty, rarity, and permanence. The trade regards only the diamond, emerald, opal, ruby, and sapphire as precious. A semi-precious stone is one that is precious to a lesser degree. This class includes agate, beryl, coral, feldspars, fossil wood, garnet, jade, jasper, jet, malachite, quartz as amethyst, serpentine, topaz, tourmaline, turquoise, and zircon. Most of the precious and semi-precious stones make desirable gems when properly cut and mounted as jewelry or in the form of other ornaments. Of the world's yearly output of gemstones nine-tenths are precious, the diamond accounting for most of this total.

Gemstones are found in many parts of the world, but the sources of most of the better grades are South Africa, Gold Coast, Belgian Congo, Brazil, and British Guiana for diamonds; Colombia for emeralds; Australia for opals; that country and Montana for sapphires; and Burma for rubies.

As to the United States, the mining of gemstones is irregular and of small importance, yet that which is won from domestic deposits is varied and of good grade. Montana sapphires have contributed the greater part of the value of the domestic gem output. In the past Alaska has yielded garnet; Arizona, agate, copper-ore gems (azurite, chrysocolla, and malachite), garnet, jasper, obsidian, opal, peridot, and turquoise; Arkansas, diamond; California, beryl, diamond, epidote, kunzite (tourmaline), lazurite, obsidian, quartz, rhodonite, spodumene, topaz, and vesuvianite; Colorado, amazon stone, aquamarine, calamine, fluorite, garnet, hematite, opal, pyrite, quartz, satinspar, topaz, and turquoise; Hawaii, peridot in decomposed lava; Maine, amethyst, beryl, garnet, rock crystal, topaz, and tourmaline; Montana, agate (moss), chalcedony, garnet, iceland spar, sapphire, and topaz; Nevada, opal, turquoise, and variscite; New Mexico, turquoise; New York, garnet; North Carolina, corundum gems, diamond, garnet, and zircon; South Carolina, beryl; Texas, agate, opal, and topaz; and Utah, topaz, utahlite, and variscite.

Agate

Agate is a variegated waxy quartz in which the colors are in bands, in clouds, or in distinct groups. Gems are made from this mineral, particularly the moss agate, which contains brown or black moss-like dendritic (branching) forms due to oxides of manganese or iron distributed through the mass. Large pieces of agate are polished for table tops. Agate is also shaped into small pestles and mortars for laboratory use. Its specific gravity is 2.6.

Beryl (Aquamarine and Emerald)

As stated under the metal Beryllium, the gems aquamarine and emerald are of the beryl family. Beryl is of some shade of green, from faint to dark. Its specific gravity is 2.6. It may be found in pegmatites, clay-slate, mica-schist, or feldspar.

Aquamarine. The aquamarine is a beautiful gem in its pale-green color. Colorado has produced some fine stones.

Emerald. In Colombia, South America, the emerald deposits are on the east slope of the Andes at an altitude of 8000 feet. The emeralds occur irregularly in narrow (3-inch) veins of iron pyrite and a granular or sandy albite (sodium feldspar) lying in shales. After the veins have been exposed by a method of washing off of the surface with water, the stones are picked out by hand. *Morralla,* an emerald mineral of no value, is the indicator that stones may be near. The five colors of emeralds range from no. 1, very dark green, which brings the highest price; to no. 5, very light green and of low value.

Diamond

The diamond is simply pure carbon and is the hardest substance known; it is colored by minerals such as iron and finds its principal use, when cut, as a gem. Stones are described and sold as weighing so many carats (1 carat is a little more than 3 grains). Some of the blue and reddish diamonds bring high prices.

There is never a scarcity of diamonds, and the market has been long oversupplied until a restricted output was observed in Africa. Business activity and recessions have considerable effect on the sale of these stones.

In judging whether a stone is a diamond, it may be said that a diamond does not sparkle in the rough; nothing can scratch it, but it will mark other things. If rubbed, it becomes electrified and will pick up small pieces of paper, and when cut and polished it possesses the highest power of refraction, which means the change of direction when a ray of light passes through it.

Occurrence. The diamond takes the isometric form of crystal. The rocks in which stones are generally found are talcose-slate and serpentine, underlain by igneous rocks, in which the diamonds were probably originally formed. The stones may be in the surface or weathered rock or at depth and are frequently accompanied by quartz, garnet, iron, opal, jasper, agate, and other minerals. Some diamonds have been found in gold placers of California, in igneous rocks in Arkansas, and with tin in Australian placers. Figure 98 shows an occurrence in Arkansas, which state has to date produced many stones averaging ¼ carat each.

Pure, water-clear, colorless crystals of quartz and white sapphires are often mistaken for diamonds and, in fact, are sometimes cut as imitation diamonds. Such crystals are of value only if absolutely clear and pure and then find only a limited market at a relatively low price, as they are common. Their power of refraction is much less than that of the diamond. As the specific gravity of quartz or other pebbles is 2.6 and of the diamond 3.5, the difference should easily be noted.

In the Gold Coast Colony, West Africa, many small yet good diamonds are found in stream gravels and clays. The mode of prospecting is to sink shallow pits in a line across the alluvium. The material excavated is washed in rockers or jigs. According to E. D. Candlish in *The Mining Magazine* (London) for June, 1931, the rocker resembles an old-fashioned cradle 54 inches long, 20 inches wide, and 30 inches high, mounted on rockers shod with hoop iron. There is a top sieve of ⅛-inch mesh and an intermediate one of $\frac{1}{16}$-inch mesh fitted as trays with handles. Gravel is shoveled on to the top sieve, and water is poured on while the rocker is given a sidewise motion from either or both ends, depending on the help available. When the rocker is fairly full of wash, the feed is stopped, but rocking is continued until the compartments contain clean, sized gravel which is next removed by sizes for concentration. One side of the bottom compartment of the rocker has a screen to allow the residue to wash out. The jigs used consist of four main parts: a jigging compartment fitted with sand screening, a wooden lever about 16 feet long, a trestle or horse on which the lever works, and a trough. The trough is about 50 inches long and 20 inches wide, and the jig compartment is 36 inches long and 18 inches wide. This compartment is partly filled with gravel and then moved up and down in the water of the trough. From time to time the top layer of the jig is skimmed off, and jigging is resumed until only concentrates remain. These are examined for diamonds. By either rocking or jigging, the amount of concentrates is no criterion as to the probable diamond content; a small amount may be rich; a large amount may be almost barren. Including gold and tin, there may be two dozen minerals in the concentrates; the gem minerals spinel, garnet, and zircons may be among them.

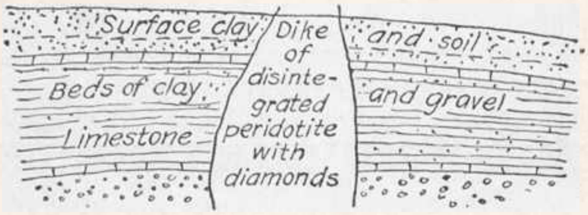


FIG. 98.—Occurrence of diamonds in Arkansas.

The diamond is an important industrial gemstone, and its use is growing, particularly for diamond-drill crowns. For this purpose the South African and Belgian Congo white diamond is superseding the Brazilian carbon or black diamond. The latter's specific gravity is 3.15 to 3.40, compared with 3.44 for the African gemstone.

Some famous diamonds have been unearthed during the present century, but the greatest are those of 3030 carats found in 1905 and 726 and 500 carats found in 1934, all in Transvaal. The first mentioned was three times heavier than any previous stone found.

Garnet

The garnet consists of a group of silicate minerals which include several with chemical structure commonly crystallizing in the isometric (cubic) system. They are essentially silicates of iron, alumina, lime, magnesia, and manganese. They are vitreous to resinous and transparent to sub-translucent, with colors ranging from red-brown or black through green to white. Garnets are all brittle. Their hardness is 6.5 to 7.5 and specific gravity, 3.5 to 4.3. They may be found as crystals in crystalline limestone, granite, gneiss, or quartzite. The iron-aluminum variety is extensively used as an abrasive; and the lime-aluminum, magnesia-aluminum, manganese-aluminum (hyacinth), and magnesia-iron-aluminum (rhodolite) varieties are salable as gems.

Alaska, Colorado, Idaho, New York, North Carolina, and Vermont have yielded garnets. Large garnets occur in the lead-silver-zinc ore of Broken Hill, Australia; in the gneiss country rock; and in the gold-quartzite ore of the Cardinal Mine, California. Garnets also occur in crystalline schists in the state of Mysore, India, and in some localities in South Africa.

Jade

A type of jade or greenstone, really the mineral nephrite, is found in north Westland Province, South Island, New Zealand. It is a deep-green, more or less transparent stone with dark patches and occurs as rounded segregations averaging 12 inches in size, in talc or serpentine. It is cut into various useful ornaments for wear and household decoration. The natives (Maoris) once had large charms and implements made from nephrite; some still have them.

Opal

Opal is composed mostly of silica with varying amounts of water. It never exists in crystal form. Its specific gravity is 2.2, compared with 2.6 for quartz, and its hardness is 5.5 to 6.5. Quartz will scratch opal. It is infusible and generally milk-white. When opal shows a play of colors or opalescence, it becomes the gemstone.

Occurrence. Opal is commonly formed in seams of certain volcanic rocks such as andesitic lava, also in limestone and metalliferous veins. A valueless stone called "false opal" is likely to confuse the prospector, but he will soon learn to distinguish the real gemstone. However, it is an indicator.

In Australia (New South Wales and Queensland) some opals are found in sedimentary rocks, and others in vesicular basalt. The desert sandstone deposits are unique. On weathered ridges and slopes a loose cover of gravel, soil, and pebbles overlies a light and porous sandstone. Black opal occurs at various depths—from near the surface to 50 feet. There is seldom any surface indication to guide the prospector. In the northern occurrences opal is found in ironstone bands, also in sandstone boulders, being encased in a sandstone shell in the latter.

Ruby and Sapphire

Sapphire is the purest form of the mineral corundum and contains 99.5 per cent alumina. It is an oxide of aluminum and when clear and of a good blue color can be sold as gems. Sapphires have about 60 trade names, such as oriental emerald and oriental topaz. The ruby is the red variety of sapphire and the most valuable, but there are other stones with all shades of color. White sapphires are often sold as imitation diamonds. The hardness is 8 to 9 and specific gravity, around 4. Sapphires are mined principally in Australia and Montana, and rubies in

Burma. They are more or less associated with igneous dikes, weathered basalt, and limestone and are recovered from the rock and gravels. Hydraulicking, dry sieving, and rockers are used just as at gold placers.

Tourmaline

Tourmaline is a silicate of alumina, with boron, lithium, and other elements. It occurs in long, striated prisms in ancient crystalline rocks, also in granite, slate, and pegmatite veins. The clear pink, blue, and green tourmalines are in demand for gems. Such are found in Southern California and are called kunzite. Its hardness is 7 to 7.5 and so can not be scratched with a knife. It is rather brittle. The specific gravity is 3.1.

Turquoise

Turquoise is a rare copper mineral with a specific gravity of 2.75. It has been found in Nevada, Colorado, Arizona, and New Mexico. Fine stones are mined from the veinlets along joints or fissures in limestone and shale in the Candelaria silver district. These are of knife-blade thickness to ½ inch wide and are short. The ground is hard, and explosives must be used.

Other Sources of Gemstones

As stated in the introduction to this section, several common minerals yield gemstones. Among these are the sodium **feldspars** having peacock iridescence, bluish-green hue, and reddish; **marcasite**; the red **rutile**; **silica onyx**; and the clear, orange-colored **zircon.**

Marketing

The marketing of gemstones differs from that of most other materials. First, their value denotes wealth in exceedingly small bulk; second, there is a wonderful variety of stones, found over a wide territory and obtained with difficulty; hence the supply is uncertain. After the stones are found, the actual marketing processes depend largely on the special methods of treatment and preparation suitable to the fashions of the time.

In recent years artificial and reconstructed gems have affected the market for real ones. These are mainly rubies, sapphires, and spinels. An artificial gem is one that is made from some other material, such as alumina; a reconstructed gem is one that is made by fusing chips from real gems; both products are cut as usual and sell at low prices.

Precious stones suitable for cutting may often be recognized as such because of their extreme hardness, even though it may be difficult to distinguish the exact species. Most of them will scratch quartz, which itself is hard enough to scratch glass readily. Other gem materials usually have an attractive color or unusual markings which serve to indicate their possible value.

GRAPHITE

There are three forms of carbon—namely, charcoal, graphite, and the diamond. Graphite is a soft, steel-gray to black, more or less impure, native carbon. It is frequently incorrectly called "lead," as in "lead" pencils, but there is no lead in graphite. Pencils simply contain a mixture of graphite and fine clay in varying proportions to make them hard or soft. The same applies to crucibles used in melting metals. Graphite is also consumed in lubricants, rubber tires, foundry molds, polish, and other industires. The United States has large deposits, but imports of graphite are considerable.

The characteristics of graphite are as follows: It is not affected by acids, has a greasy feel, soils the fingers, marks paper, and is less than 1 on the scale of hardness. It exists in two forms, as crystalline and amorphous, which means as crystals or flakes and without any particular form. As to weight the flake variety averages 26 pounds, and the solid variety 13.5 pounds per cubic foot.

The prospector often mistakes graphite for molybdenite, as both mark paper and feel greasy; but graphite is unaltered under the blowpipe flame, whereas molybdenite gives off sulphur. The value of graphite-bearing ores depends on the percentage of carbon.

Occurrence

Graphite occurrences are confined to the oldest rocks. Crystalline graphite may be found in veins or as flakes through the country rock, usually associated with granitic intrusives, such as in quartz-schist and feldspar-quartz schist, carrying 5 to 7 per cent graphite in New York State; in graphitic schist rich in weathered lime-silicate minerals in Pennsylvania; and in schist accompanied by quartz, feldspar, and mica in Alabama. The disseminated type of deposit in which the graphite occurs as small flakes scattered through a foliated rock, such as crystalline limestone or schist, is of much importance in North America and Germany. The amorphous form of graphite may be found wherever coal or other carbonaceous beds have been altered by adjacent bodies of igneous rocks or by earth movements, as in Rhode Island, Colorado, and Nevada. In the first-mentioned State it is termed "super-anthracite," or "meta-anthracite," but it will not burn. Crystalline graphite is found in Texas.

Graphite sometimes occurs in gold-bearing ores whose veins are in schistose rocks, and it is of no value in such cases, and is a source of trouble in treating the gold ore.

The log-washer, as described under Manganese, is used in somewhat modified form for the preliminary preparation of graphitic ores. Jigs, concentrating tables, and water-skin flotation may be employed for rough separation.

GYPSUM

Gypsum is a sulphate of lime. It is used in large quantities in many industries but especially in building construction (plaster and board) and cement manufacture. It exists as beds in certain rock strata, such as sandstones and clays; in fissures; and on the bottom of lakes in arid regions; also as large crystals. In New York the gypsum lies interbedded with shale and shaly limestone. The mineral forms lenses. The color is generally a light brown, and it may or may not be transparent. Gypsum is one of the softest of minerals. It is only 1.5 on the scale of hardness and can be cut with a knife. Gypsum's specific gravity is 2.2, and it weighs 135 pounds per cubic foot. It does not melt under the blowpipe or effervesce in hydrochloric acid. It often accompanies rock salt or halite and frequently contains sulphur beds, as in Texas and Louisiana. Chief producing states are New York, Michigan, Iowa, Texas, California, Nevada, Oklahoma, Utah, and Colorado.

HYDROCARBONS (THE NATURAL)

The natural hydrocarbons are gilsonite, elaterite, wurtzilite, glance pitch, manjak, grahamite, albertite, ozokerite, and many other minor varieties. With the exception of ozokerite and the other mineral waxes they all more or less resemble asphalt in that they are dark-brown or black bituminous substances of organic origin, generally with a resinous luster. Ozokerite, generally light in color with a waxy luster, is closely allied to the others of the series but is usually considered separately.

The occurrence of these mineral waxes is as follows:

Gilsonite is found in a belt in the Uinta Basin from Rio Blanco County, Colorado, to Uinta County, Utah. In the former locality the mineral occurs as veins in sandstone. It is in demand for use in many common articles. Because of its flammable nature, open flames should be kept off in mining.

Ozokerite occurs in Utah near Colton, Utah County, and Soldier Summit, Wasatch County. This mineral has a specific gravity of 0.94, and a cubic foot weighs 54 pounds, about similar to coal. Its streak is brown, and its melting point is 150°F.

LIMESTONE AND LIME

Limestone is the general name applied to rocks composed essentially of calcium carbonate. Lime is an alkaline earth and consists of the oxide of calcium, made from limestone by burning it. The occurrence of limestone is nation-wide. As much as 150 million tons are mined each year for use in agriculture, chemical industries, fertilizer, lithographic stone, flux at smelters, plaster, glass, building purposes (see under Building Stones), and portland cement. Many metals, such as copper, lead, and zinc, are found in limestone formation Limestone has many colors—generally white, gray, yellow, or red. The compact rock has a hardness of 3 and specific gravity of 2.7 and weighs 165 pounds per cubic foot.

There are 12 varieties of limestone, but each may represent a mixture of several of them. These varieties are based on the high calcium content (93 to 99 per cent carbonate of lime) and the proportions of magnesia, clay, iron, and silica present. The marketable classes are chalk, limestone, marble, marl, and whiting.

Chalk

Chalk is a fine-grained limestone composed of finely comminuted shells. When much silica is present, a silicious or cherty limestone results. Hence flint pebbles are found in chalk, in demand at ore-treatment plants for grinding. Zinc deposits in Oklahoma occur in cherty limestone. Chalk has a specific gravity of 1.5 to 2.8 and weighs 95 to 170 pounds per cubic foot. Chalky lime with up to 97 per cent carbonate of lime is salable as whiting. It is used in pottery, paint, putty, and rubber products.

Marl

Marl is the name applied to a loosely cemented mass of lime carbonate formed in lake basins. It is granular in texture, is practically a pure limestone, and contains up to 94 per cent carbonate. Marl is in great demand for the manufacture of portland cement, of which it constitutes up to 75 per cent. In many parts of the country a soft rock, containing greensand used for fertilizer, is called marl.

Iceland Spar

Iceland spar is a name given to a pure crystallized form of calcite which is sufficiently transparent and free of defects to be used in the manufacture of optical instruments. While the actual demand is small, the degree of purity and physical perfection demanded renders it somewhat difficult to obtain suitable material. The crystals must be free of cracks, cloudiness, and twinning. Physical properties of iceland spar that have a direct bearing on the mining methods employed are its perfect rhombohedral cleavage (a cleavage in three directions at oblique angles to each other) and its susceptibility to abrasion or scratching. The crystals cleave so readily that light blows will shatter them into fragments; and as they are soft enough to be readily scratched with a knife, extreme care must be taken in handling them. In Modoc County, California, these crystals occur in veins, pockets, and cavities in basalt, near the surface. In Sweet Grass County, Montana, they exist as two wide and long veins and consist almost entirely of calcite. Prices of $1 to $20 per pound have been realized.

Prospecting Hints

While in limestone country the prospector should look for cement rock which is in demand by cement-making firms. The Lehigh Valley of Pennsylvania has extensive deposits. Close to the sea north of Auckland, New Zealand, is an immense reserve of cement rock being mined by open-cut by a cement company. The soil overburden is from none to 24 inches deep. The material is an argillaceous limestone containing 72 per cent calcium carbonate, 22 per cent silica, and 6 per cent alumina and iron oxide. Seams of calcite are fairly common and may be termed an indicator for such rock, which is fairly soft.

In the same district as just mentioned, this cement company has a coal mine whose roof is of sandstone above which is limestone. The lime rock carries 97 per cent calcium carbonate and a trace of silica and magnesia. Shark's teeth have been found embedded in the rock, it being, like the cement rock, not far from the sea. This rock has been much eroded and dissolved, leaving fantastic shapes and blocks in various positions. It is hard and tough.

Tests

A few drops of cold dilute hydrochloric acid on limestone starts an effervescence, a sure indication for this rock, which distinguishes it from other carbonates, as dolomite, which effervesce only with strong acid or when powdered or scratched.

Australia has probably the greatest area of limestone in the world. This is the Nullabor Plain in South and Western Australia. It is 330 miles long and of unknown width but perhaps 300 miles.

The region is flat and treeless, growing only saltbush, which resembles sagebrush. It contains caves and some water. On the South Australian side are sandhills and gold-bearing diorite (170 miles distant), and on the Western Australian side is granite which contains gold-bearing formations (also 170 miles distant). Float limestone lies everywhere, but much of it is of a chalcedonic or cherty nature. Thirty miles from the western edge of the plain is some good limestone which is quarried, calcined, and railed to the goldfields 200 miles distant. There it is chiefly used in ore treatment.

LITHIUM MINERALS

Lithium is a white metal and has an atomic weight of 7, the lowest of the metallic elements, beryllium being 9, boron 11, magnesium 24, and aluminum 27. A cubic foot weighs 34 pounds, and the metal is softer than lead. Although as metal, lithium has little use, it is of value when alloyed with calcium and as a salt. Of the 17 lithium minerals, amblygonite, spodumene, lepidolite, and zinnwaldite are the principal ones. According to Frank Hess, all but one of the minerals are found in pegmatites. Their composition is complex. Cassiterite and columbite accompany some lithium minerals. In one deposit in the Boulder Dam area, lepidolite lies below spodumene and quartz and quartz-mica-schist. Amblygonite occurs in South Dakota; spodumene in that state and in North Carolina; and lepidolite also in Manitoba. Some lithium salts are used in medicine; lepidolite is used in glassware, and spodumene is used in pottery.

MAGNESITE

Most people have seen magnesium, a silver-white light, ductile, and malleable metal, in the form of a powder or ribbon, which burns with a brilliant-white light. When it is mixed with aluminum, an alloy called magnalium is made. Its specific gravity is only 1.75, and a cubic foot weighs 109 pounds. Magnesium as a metal was in great demand in 1941 and 1942, with producers in California, Washington, and Nevada increasing output to meet the needs of a national war program. Magnesium compounds are being recovered from sea water in a plant of the Dow Chemical Co., Freeport, Texas. It is estimated that 6500 tons of magnesium metal will be available from this source. Magnesite, and the hydrated oxide, brucite, are also in larger demand for furnace linings, brick, plaster, for mixing with asbestos to make board, and for chemical purposes.

Magnesite is white to yellowish in color, is opaque, has a conchoidal fracture, is smooth, has a hardness of 3.5 to 4.5 and a specific gravity of around 3, and weighs 180 pounds per cubic foot. It consists of 52 per cent carbon dioxide gas, and the remainder is magnesia. Before use in industries this gas must be driven off by heating or calcining.

The carbonate of magnesium and calcium—dolomite or magnesian limestone—is often mistaken for magnesite. So is calcite, the lime carbonate. The hardness of these three minerals is about 3, but calcite and dolomite are somewhat lighter than magnesite. Cold hydrochloric acid has no effect on magnesite, but it effervesces on the others, owing to the liberation of gas.

Brucite is a crystalline mineral, whereas magnesite is rarely found in such form. It is greenish to brown in color.

Occurrence

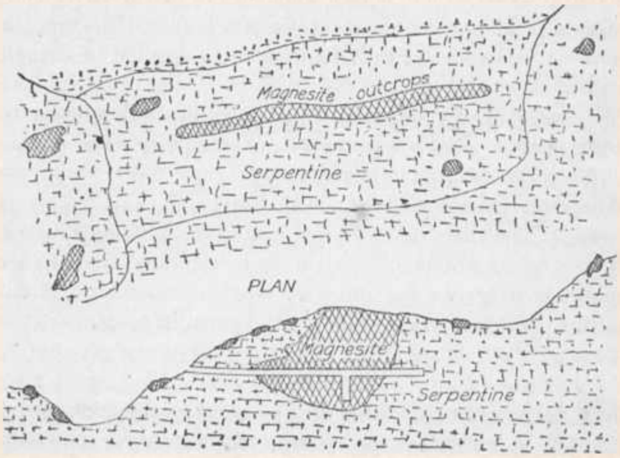
Magnesite occurs somewhat in the same manner as chromite and in the same rock—serpentine. A search for one should include the other. Magnesite outcrops are generally white, which makes them prominent however small they may be. They shed float as usual. Deposits may be mere lenses or large and well-defined veins. Figure 99 shows these features. The scattered outcrops appeared as if they would persist at depth, but they did not. The long outcrop yielded about 12,000 tons to a depth of 100 feet.

Some of the Californian deposits are well defined and easy to mine; a few are difficult to work, as they are a succession of short irregular shoots or of concretionary form or nodules, while others are badly folded and difficult to follow.

More than 3 per cent silica and 1 per cent lime is undesirable, while 1 to 5 per cent iron commands a bonus.

MICA

Both sheet and scrap mica of good quality are in demand. This mineral is flexible and elastic and does not conduct heat or electricity, properties that no other mineral has. Makers of electrical machinery and goods and paint makers are large consumers. Leading domestic producers of mica are located in North Carolina, Connecticut, and New Hampshire.



LONGITUDINAL SECTION

FIG. 99.—Magnesite occurrences.

Properties

Mica, sometimes incorrectly called isinglass [isinglass properly is a pure gelatinous substance resembling mica, made artificially from air bladders of sturgeons (fish) or from seaweed], is found in several varieties, all of which, however, are complex silicates of aluminum and iron, magnesium, sodium, and potassium. All micas are soft (hardness 2 to 2.5) and can usually be scratched with the finger nail. The specific gravity is 3, and a cubic foot will weigh 180 pounds. The most common characteristic of mica is its property of splitting in one direction only into thin transparent plates. These plates may vary in size from that of a pin-point up to several square feet in area. The color varies from white through yellow, amber, pink, purple, green, and brown to black. Very small plates embedded in rock are often mistaken for gold, silver, or other valuable minerals, from which mica is easily distinguished under a hand lens by its platy cleavage or by powdering it.

Occurrence

Mica commonly occurs in pegmatites (see Fig. 100), which consist of large crystals of feldspar and quartz; it constitutes but a small proportion of the total rock mined. Much of the feldspar thus thrown out during the process of mining is pure and of high quality, and it has been suggested that some of it could be utilized for ceramic pottery purposes.

Mica in the form of biotite and muscovite is a rock-forming mineral. The name of the mineral is often prefixed to the name of the rock containing it, such as mica-basalt, mica-trachyte. Mica-schist is a rock composed of alternate layers of quartz and mica in varying proportions. This rock has some market for lining furnaces. If good blocks of mica-schist are minable, smelting companies and foundries will buy it for this purpose. Mica-schists yield some scrap mica of marketable value. Muscovite is a good indication for tin, as it always exists in the granite in which tin is found.

Mica as muscovite occurs in Central Australia, 150 miles northeast of Stuart (Alice Springs), the present railhead. It is with feldspar as a lode formation in a micaceous-schist country rock. The district consists of mica-schist, sandstone, and granite. The area is flat to hilly. The mica "books" are with the feldspar and are 2 by 6 to 12 by 20 inches, but more than half is lost in dressing the material. Although stained, the mica has good insulating property.

Since 1925 the mineral vermiculite has become of industrial importance. The term is applied to a group of micaceous minerals that are generally alteration products of biotite and other varieties. The mineral occurs in Colorado, North Carolina, Pennsylvania,

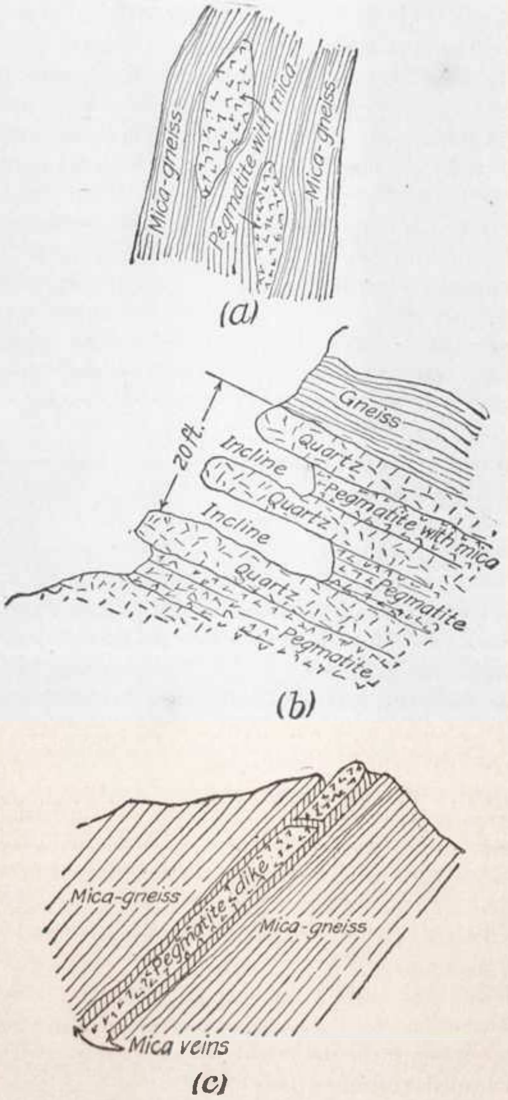


Fig. 100 (*a*, *b*, *c*).—How mica may be found.

and Wyoming, but the most important deposit is near Libby, Montana. The only surface indication is a slippery soil composed of mica-like flakes. The orebody is of dike-like form in altered igneous rock. Vermiculite is not used as mined, because on heating it expands and unfolds to twenty times its original bulk, changes in color to silvery or golden, and decreases in specific gravity from 2.5 to 0.09 and in weight from 100 to 6 to 20 pounds per cubic foot. Microscopic inclusions of free water within the laminated structure and water of crystallization are changed to steam upon sudden heating, thereby causing puffing or swelling of the mineral particles. The treated mineral is mainly used for insulating purposes, but vermiculite is suitable in plaster, roofing composition, cement, lubricant, and "gold" paint.

MINERAL PIGMENTS OR FILLERS

Ocher, umber, and sienna are clays with more or less iron, aluminum, and manganese. They are known as mineral pigments or fillers, mainly used in paints.

Ocher

Ocher is a clay permeated with limonite (iron oxide). It has a specific gravity of about 3.5 and a golden-yellow color. In character it is loose, earthy, and pulverulent, and particles when magnified appear flocculent and uniform. Good grades should contain 20 per cent or more iron oxide, but the iron content of material marketed as ocher varies widely.

The yellow ocher, which occurs only in natural form, can be burned to form so-called "red ocher." The burning converts the iron oxide from the hydrated to the anhydrous form. Red ocher occurs naturally and can be made artificially.

Umber

Umber, sometimes called "brown ocher," consists of iron and aluminum silicates containing manganese oxide, which affects its color according to the content of manganese oxide. Raw umber is drab but turns reddish-brown on burning. The burned material is called "burnt umber."

Sienna

Sienna is composed essentially of silicates of iron and aluminum, with less manganese oxide than umber, and is of a lighter color. Raw sienna is deep yellow and when burned becomes dark red.

Occurrence

Georgia and Pennsylvania are the principal producing States. Most of the ocher mined in Georgia comes from the Cartersville district. The deposits are closely associated with those of manganese and iron ores of the same area.

The ocher is confined to a quartzite, which has been greatly fractured and faulted and occurs principally as replacement deposits in the quartzite. In places the quartzite is interbedded with silicious shale, when replacement of silica by iron oxide has formed ocher of lower grade and darker color than that from the quartzite proper, because of the larger proportion of admixed clayey matter in the shale. The quartzite sometimes contains much pyrite as grains and crystals, both in the quartzite and in the interbedded shale. Much of the ore carries manganese oxide finely disseminated; often this is not entirely removed in refining and thereby imparts, it is said, a faint greenish cast to the ocher.

The deposits are extremely irregular in form and extent and are composed largely of branching and intersecting veins, which occasionally expand into bodies of large size. Mining is by both open-cut and underground. In many places the workings are merely small trenches, tunnels, or pits. In some workings the ore where enclosed in quartzite requires blasting, but where enclosed in clay it is soft enough to be removed with pick and shovel.

Ocher is found in many parts of Pennsylvania. It is closely associated with limonite iron ores and is found as irregular pockets and bands in clay lying on or enclosed in limestone. Ocher has been mined in Pennsylvania for many years, principally in the Easton-Reading district. Workings are generally small because of the pockety nature of the ore and the shallow depths of the deposits. The ore is mined both by open-cuts and by shallow shafts with drifts and small stopes. The mineral is also picked out from clay in Maryland, between Baltimore and Washington, where a plant grinds it for market.

In both Georgia and Pennsylvania the log-washer is used to remove the coarser impurities. The overflow is settled in troughs and then is dried for shipment. (See description of this machine under Manganese.)

MINERAL FUELS

A mineral fuel may be defined as one that can be burned as it is or one from which fuels can be extracted. All ranks of coal, petroleum, and natural gas are mineral fuels and may be burned as such; oil-shale has to be heated to yield the fuel that it contains. Coal, when heated, yields other fuels, as coke, gas, and tar; petroleum yields other fuels, as gasoline (petrol), kerosene, residual oil, and coke; natural gas yields other fuel, as gasoline.

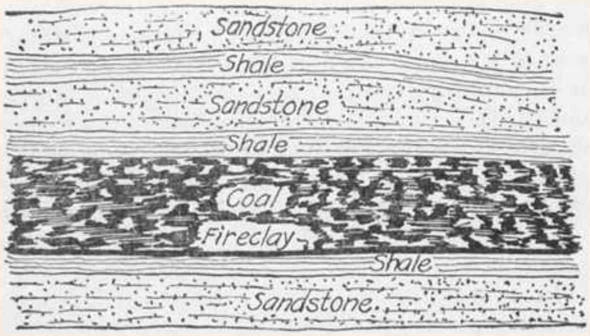


FIG. 101.—General occurrence of coal.

COAL

The United States has produced more than 600 million tons of coal in a year and has given employment to 750,000 men; but the figure for 1940 was around 502 million tons. Coal areas on the public domain may now only be located under the Leasing Law of February, 1920.

Coal occurs as brown coal, lignite, sub-bituminous, bituminous, semi-bituminous, and anthracite. Outcrops may be recognized by the presence of smut or coal blossom and may be found by tracing float. Trenches are sometimes cut, and drilling may be done by an auger, such as is used in coal mines, to a depth of 15 feet or so. The outcrop of a coal bed is frequently found at the rear of a terrace, known as a coal terrace. This is formed by the more rapid erosion of the coal and immediate roof material than the underlying rocks. Little prospecting is done for coal by individuals, as the coal areas of the country are well known.

The outcrop of a horizontal bed of coal may show an apparent dip owing to the swelling of underlying beds and the pressure of the overburden back from the outcrop. The bed may be thicker or thinner at the outcrop than elsewhere, which depends upon the pressure and the character of the overlying and underlying beds.

Coal beds are nearly always associated with shale, slate, and sandstone, and some limestone. Frequently they are underlain by fireclay. Coal was formed from vegetable matter which was laid down in swamps and covered. Layers or seams of shale, called "bone," are found running through coal beds. Figure 101 shows the general condition under which coal occurs.

Although many and extensive coal beds are practically flat and at shallow depth, many are undulating and folded and deep.

Brown Coal

Brown coal is probably the next stage of coal formation after peat. Germany and Victoria, Australia, have similar and enormous deposits. The coal is 40 to 65 per cent water. The shallow overburden consists of sand, clayey sand, and gravel. In the coal are many small pieces of wood and large logs. Brown coal is burned as is in power plants and is made into briquets for household and industrial purposes.

Lignites

There are large deposits of lignite in North and South Dakota and Texas, also in Canada and Manchuria, but there is little demand for it except locally, for it can not be stored or shipped long distances. It contains up to 55 per cent fixed carbon and 40 per cent moisture, but its ash content is low. The overburden is clayey and sandy material. Lignite is light, its specific gravity being 1.15. When briquetted it may be stored and shipped.

Bituminous Coal

Bituminous coal averages 55 per cent carbon and is in great demand for homes, steam and gas and in the making of coke. It has a black color, a specific gravity of 1.2 to 1.4 (a cubic foot weighs 75 to 90 pounds), and a hardness of 1.5 to 2. It soils the hands and emits considerable smoke when improperly burned in furnaces or stoves. Powdered coal is brownish-black in color.

Anthracite

Anthracite is a hard coal, seldom less than 90 per cent carbon, and is 2 to 2.5 on the scale of hardness. Its specific gravity is 1.6 (weighing up to 100 pounds per cubic foot); its color is gray-black; and it often breaks with a conchoidal fracture. When burned it gives off no smoke and does not soil the hands. Pennsylvania produces the anthracite of the United States. There is a little in Colorado, Virginia, and New Mexico, Wales, and New Zealand.

Opening a Coal Deposit

If coal is exposed or outcrops at the face of a cliff or hill, it may be opened by a drift; if it dips from the hillside, it may be opened by a slope or incline shaft; if it is deep coal, a vertical shaft should be sunk. The simplest form of mining the coal is by room and pillar, which means that a pillar of coal is left between each pair of rooms to support the top. Later, while retreating, the pillars are mined. All lignite and bituminous mines liberate gas—methane or marsh gas. When mixed with air in the proportions of 5 to 15 per cent, the atmosphere becomes explosive and any open light such as a candle, carbide lamp, match, or pocket-lighter will ignite the gas. Only a permissible (approved by the Federal Bureau of Mines) flame safety lamp or electric cap-lamp should be carried in coal mines. Therefore ventilation is necessary, and there should be at least two parallel entries in a mine, separated by a pillar with doors and stoppings. Air can enter one entry and come out the other, helped by an outside fan of some type.

PETROLEUM AND NATURAL GAS

There is an enormous and increasing demand for oil, and the search is world-wide. There are as many incentives for finding oil as for finding gold and silver, but much more skill and knowledge of geology are necessary—in fact, prospecting for oil is really a specialty.

Origin

The most generally accepted theory of the origin of oil is that plant or animal remains were covered and decomposed in sedimentary formations, such as shales and limestones, while later on the hydrocarbons were squeezed out by pressure from the overlying strata and at suitable temperature into porous beds for storage, such as sandstone. These earth movements produce the folding in which the oil accumulated, so in the search for oil an anticline is looked for in an area of such rocks. The process in the sedimentary formations probably took place at the bottom of the sea, as salt water always accompanies accumulations of oil and gas. Enormous deposits of rock salt underlie some of the oil in Texas and Louisiana. An ideal occurrence of oil is shown in Fig. 102. Natural gas generally occurs in the same area as petroleum. Some gas is too high in carbon dioxide.

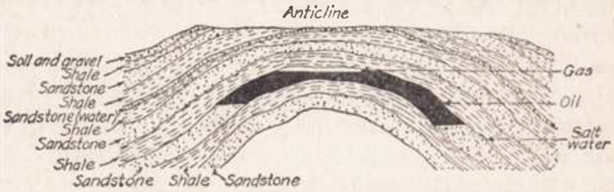


FIG. 102.—An oil-bearing anticline.

Prospecting

The occurrence of oil-shale disregarded, the most likely regions to search for petroleum are those in which the strata consist largely of shale, with some sandstone and limestone. There may or may not be surface indications of oil. Oil-seeps, an odor of oil, gas emanations, and asphalt deposits are indications but do not always mean large quantities of oil. Drilling is the only ultimate way to prospect an anticline. Edwin Drake, who first found petroleum in the Americas, in Pennsylvania in 1858, was a real prospector, and he drilled a shallow hole. Sandstones buried in shales must form the reservoir for the oil, and shales must underlie the sandstones, as they are its source. A section of an oil field is shown in Fig. 103.

Never prospect for oil in regions of igneous rocks such as andesite, basalt, granite, rhyolite, or trachyte. These are the result of volcanic action, and organic matter could never have been laid down in them. At the same time the existence of an oil exude in the Mexican coastal plain invariably means the close proximity of a volcanic plug or dike, whether visible or hidden underground. Most of the exudes are near such basaltic dikes, and a great many are found at the contact between the volcanic and sedimentary rocks, the latter always shale, sometimes overlaid by limestones and sandstones. Of course this does not mean that oil will be found in volcanic rocks, but in this case these act as outlets for seepages.

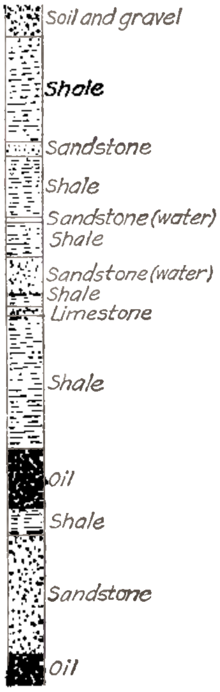


FIG. 103.—Typical occurrence of oil in an Oklahoma field.

Films on the surface of pools, swamps, or slow-moving streams are frequently thought to be indications of oil, but they seldom are. It is best to prospect for oil in warm weather, because the oil leaves its containing rock more freely than in cooler periods.

Tests

A simple qualitative test for petroleum in sand is as follows: Procure a sample of 1 to 5 pounds; crush it fine and mix. Dry in the sun—not over a fire. Put a couple of ounces into a small bottle and add chloroform or carbon tetrachloride until the material is saturated and covered. Shake for 15 minutes. Place a white filter-paper into a glass funnel and a white plate below the funnel. Pour the pulp on to the filter; when the pulp has drained, put the dish containing the liquor in the open so that it can evaporate. After the liquor has evaporated, and if anything remains, it is oil. Also examine the paper. If oil is present, it will appear as a brown or black ring on the paper.

Oil areas may be located in the United States only under the Leasing Law of February, 1920, as explained in the chapter on Mining Laws.

OIL-SHALE

In the Rocky Mountain States—Colorado, Montana, Utah, Wyoming, and Nevada—are estimated to be several hundred million tons of oil-shale which contain an average of about 20 gallons of oil per ton. Kentucky has great reserves of lower grade yet cheaper mined shale. When the resources of ordinary petroleum are exhausted, these shales will be mined and treated. It is not a poor man's business; yet the prospector may locate claims under the Federal Leasing Law of February, 1920, and interest capital.

Oil-shale contains no oil as such, yet carries the essentials, which, on being heated and condensed, yield oil and distillates of good quality. The theory as to the origin of oil-shales, similar to that as to the formation of coal beds, is one of sedimentary deposits or clays that contain organic remains.

Occurrence

Oil-shales occur in more or less horizontal ledges, either as massive (thick) or paper (thin) deposits, in sandstone, in arid regions of high altitude in the United States. The thick shale of Colorado weighs 120 pounds per foot in place, compared with 160 pounds for sandstone, 168 pounds for limestone, 120 pounds for clay, and 75 to 90 pounds for bituminous coal. Sandstone generally lies between the shale strata.

Shale of the Colorado and Utah deposits is of a light- to a dark-brown color, has a velvety luster, and gives a light-brown streak when scratched. When examined under a hand lens the streak is seen to have a vitreous luster. When broken, shale exhibits splintery or sharp edges. A sliver inserted in a flame burns with a sooty smoke and gives an odor of burning petroleum. Complete combustion—that is, if the fixed carbon is burned out—leaves a gray residue, composed mostly of clay, lime, and sand. The shale which yields the most oil when subjected to distillation is that which weathers into massive benches of grayish-blue color but which is dark brown to black on a freshly broken surface. The oil-yielding shale is confined almost entirely to the middle part of the Green River formation, as shown in Fig. 104.

FIG. 104.—Typical oil-shale formation in Colorado and Utah.

Oil-shale in New South Wales, Australia, occurs in sandstone at an altitude of 3000 feet. It is several times richer than the American deposits, but the ledges are much thinner. This sandstone also contains coal.

Sampling and Testing

The specific gravity of massive shale is 1.6, and the richer the shale the lower is the gravity, because of the oil content. Massive shale gives a brown or brownish-yellow streak and has a conchoidal fracture. Freshly broken surfaces have a strong odor of oil, which quickly disappears. If fairly rich in oil material, shale will ignite and burn. It curls like bitumen on being cut, and the richer the shale the more it curls. Paper shale is gray to brown, or even black, and is flexible if warmed.

Owing to weathering it is advisable to sample oil-shale from a depth of 10 feet. This may be done by sinking a small shaft, cutting a trench, or drilling a hole. If the face of an exposed ledge is to be sampled, the shale should be cut back so as to get a fresh face.

Oil-shale is fairly easy to test in the field, and many prospectors would rather try it themselves than send samples to outsiders; but if a man lacks experience with apparatus, the best procedure is to take samples and send them to a reliable assayer for quantitative test, one who has followed the progress in development of this new industry, and who has apparatus for distillation (sometimes termed "eduction"). The Federal Bureau of Mines has devised a convenient and reliable retort for assaying shales. It is an adaptation of the apparatus used by D. E. Winchester of the United States Geological Survey. All of the parts used can be easily obtained from any dealer in chemical supplies and readily assembled by anybody.

NITRATES

Under this head may be placed both potassium and sodium nitrates. The former is not common. India once produced considerable quantities. The sodium salt exists in enormous quantities in the arid regions of Chile. Rain rarely falls. All dry districts should be examined for nitrates. They are used mainly as fertilizers and in explosives, and the discovery of a domestic deposit would be worth a great sum.

Nitrate-bearing lands of the United States come under the Federal Leasing Law of February, 1920, so permits must be obtained to develop them.

Occurrence

In Chile the nitrate or *caliche*, as it is termed, occurs as shown in Fig. 105. Its specific gravity is 1.9.

Tests

Both the potash and sodium nitrates tinge the blowpipe flame; the former gives a green and the latter a yellow color. (See under Potash for another color test.) Prospectors in Chile judge the grade of the nitrate by the number of sparks emitted when ground material is thrown on glowing charcoal or a fire. Many sparks indicate a good nitrate; few sparks, a poor mineral. This method is affected more or less by interfering minerals. *Caliche* with less than 5 per cent nitrate gives no sparks; with 6 to 10 per cent, sparks are barely visible; with 10 to 20 per cent, sparks are more visible and numerous; if 20 to 30 per cent is present, sparks are more visible and numerous; and if more than this is present, sparks are visible in full sunlight; with more than 35 per cent, there will be complete deflagration or bursting into flame. Ordinary salt or sodium chloride decrepitates or crackles when thrown on glowing fuel.

FIG. 105.—Section of a Chilean nitrate deposit. The overburden may be from a few inches to several feet deep, after which may be several feet of low-grade caliche (nitrate), then up to 6 feet of the workable caliche, and underlying the whole is volcanic rock.

As far as studied, indications in the United States do not favor deposits of any size, yet when in arid and semi-arid districts a prospector should look for deposits of *caliche.* These consist of blankets a few inches thick and to a depth of 12 inches from the surface. They are irregular in thickness and richness. They also are commonly associated with clay and are best developed on the flatter and more gently sloping portions of clay hills. Caliche is not related generally to any particular bed that may be regarded as a source. Another type of deposit in arid areas is the playa. Some nitrate may be in the clay just under the surface of a dried-up lake. A playa is a level place where rain accumulates and then dries up by evaporation (in Australia a "clay-pan"). A third type of nitrate deposit is that found in caves, recesses in canyon walls, or cliffs protected from the weather. Cave deposits are not restricted to arid climates. Both the potassium and sodium compounds may be found. Such deposits are merely surface accumulations sometimes a few inches thick. They may be found on a wide variety of rocks—sedimentary to igneous (see Fig. 106).

The brown-ring test, according to G. R. Mansfield and L. Boardman of the United States Geological Survey, will readily disclose the presence of very slight amounts of nitrate. The reagents needed are a few ounces each of chemically pure ferrous sulphate crystals and concentrated sulphuric acid, and the equipment consists of two 6- or 8-ounce reagent bottles, two ½- by 6-inch test-tubes, a small glass funnel, filter-paper, and a metal plate 3 or 4 inches across. A hammer and a canteen or water-bottle are necessary.

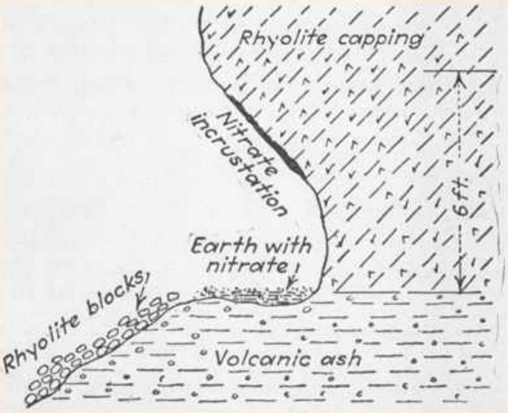


FIG. 106.—Nitrate occurrence in Texas, according to the United States Geological Survey. Crusts contained 0.72 per cent potassium oxide, a low amount, yet an indication.

Two or three ounces of the crystals are made into a saturated solution with distilled water, plus a few drops of acid. This will make 3 or 4 fluid ounces, which should be renewed once a month.

The rock to be tested is pulverized on the metal plate, and as much as will occupy ¼ inch on a knife-blade is put into the test-tube. Add ½ or ¾ inch of water and shake well. If cloudy, filter the solution into another test-tube. Add an equal amount of ferrous sulphate solution and shake well. Hold the test-tube at an angle of 45 degrees and slowly pour in a little sulphuric acid. It should not mix much with the solution and should collect on the bottom of the tube. If nitrate is present, a brown ring will form at the junction of the two liquids. The ring will be well defined, even with low nitrate content. Unless the reaction is well marked, the nitrate content will not exceed 1 per cent; if 3 per cent is present, the solution will rapidly turn dark, almost black, and begin to boil, with evolution of brown fumes of nitric oxide.

PHOSPHATE ROCK

If deposits of phosphate rock are found reasonably near to works where sulphuric acid is made and near where the manufactured product may be sold to farmers, they are worth attention. Some phosphate rock is ground and applied raw to the soil. Its specific gravity and weight vary from 2.9 to 3.2 and 180 to 200 pounds per cubic foot, respectively.

In the United States permits must be obtained from the Federal Government under the Leasing Law of February, 1920. Florida, South Carolina, Tennessee, Idaho, Utah, Wyoming, and Montana contain enormous deposits of this rock; so do Nauru and Ocean Islands in the Pacific Ocean, and their product is shipped to Australia and New Zealand.

Occurrence

Phosphate rock is a sedimentary rock containing lime phosphate, the active ingredient in soil after acid is mixed with it. In the southeastern States it exists in clayey, gravelly, or compact beds below the surface of the earth or in beds of streams, also as a hard rock. In the West it occurs in bedded deposits of hard rock phosphate.

Tests

A simple test is to moisten the fresh rock surface with a drop of nitric acid, after which place a small crystal of ammonium molybdate on the moist spot. If phosphate is present, the crystal on the rock will turn yellow.

Another field test is to pour about 2 tablespoonfuls of dilute nitric acid on to ¼ spoon of finely ground rock in an enameled cup. Pour off the clear liquid or filter it into a glass bottle. Add three times as much water as there is clear solution and a little ammonium carbonate. If the solution becomes cloudy, a little nitric acid will clear it and make it acid. Next, warm the solution, stir it, and drop in some ammonium molybdate and allow to stand for 15 minutes. If the rock is a phosphate, a bright-yellow granular precipitate will be formed.

Apatite is one of the phosphate minerals and contains up to 42 per cent phosphoric acid, combined with chlorine or fluorine. It is colorless to violet and gives a white streak. The hardness is 5. Nitric and hydrochloric acids dissolve it quietly. The blowpipe melts apatite with difficulty. This mineral occurs in veins in limestone, sometimes in granite and schist, as concretions or in distinct masses, and as prisms. Apatite frequently accompanies beryl and mica.

For preliminary treatment of pebble phosphate rock, the log-washer as described under Manganese is often used.

Phosphate rock is valued according to its phosphorus content, expressed as tricalcium phosphate. Marketable grades contain 60 to 77 per cent. In Florida the deposits are hydraulicked; in Tennessee some are mined by open pit; and in Idaho and Wyoming they are mined by underground methods.

POTASH

Potash is widely distributed in nature, but to be useful in commerce it must be soluble in water, and most of the minerals in which it occurs are insoluble. Apart from the potash recovered from the brine or salt water of certain lakes—not a subject for the prospector—search might be made for alunite, feldspar, and leucite.

Minerals

Alunite is a hydrous sulphate of aluminum and potassium and contains 11 per cent potash. The principal deposits are at Marysvale, Utah. Some has been found in Arizona and Nevada. It occurs in granite-porphyry and dacite and is formed by the action of acid water on feldspar (a silicate of potassium and aluminum), a constituent. Alunite is a pink crystalline rock. **Feldspar** carries up to 17 per cent potash and is a possible future source of that salt but is in demand for china and porcelain industries. **Leucite** occurs in large quantities in Wyoming, but prospecting for it requires special knowledge. Leucite is a potash-aluminum mineral and contains 21.5 per cent potash. **Polyhalite,** a complex salt of potassium, magnesium, and calcium sulphates, was first identified by the United States Geological Survey in 1921. Drilling during 1928–1929 revealed beds of it in Texas at depths of 437 to 1283 feet and in New Mexico at 335 to 760 feet. The salt dissolves slowly in water, but if calcined at 840 degrees it dissolves easily in boiling water. A large tonnage is now being mined.

Tests

Equipment for trying potash salts in the field is simple and consists of a gasoline or alcohol lamp, a piece of platinum wire with loop at one end and the other fitted into a holder, a Merwin color screen, some barium chloride, and a small porcelain crucible and holder. This lot costs little at any dealer in assay supplies.

To test alunite, boil a little powdered mineral with water or hydrochloric acid for a few minutes to remove soluble sulphates. Settle and pour off the clear liquid. Add more water or acid to the sediment and boil again. Dry the final sediment and heat to a dull red. Boil again and pour off some of the clear solution. To this solution add a grain or two of barium chloride, which will throw down a heavy white cloud or precipitate if alunite is present. Before making this test try the water for purity by adding a drop of barium chloride. If it becomes cloudy, it will not do for the test.

Waters and brines may be tested by cleaning the loop of the platinum wire by dipping it in hydrochloric acid and heating it in the lamp flame; then dip the loop in the water or brine, evaporate it carefully above the flame, and finally give it full heat. Hold the Merwin screen close to the eyes; and if the flame appears reddish to reddish violet, potassium is present. If the coloration persists and is deep, the brine may be of high grade.

Feldspar, leucite, and alunite may be tested by powdering a sample, mixing with an equal quantity of gypsum, and moistening with dilute hydrochloric acid. Place some of the mixture on the platinum wire, ignite, and observe through the Merwin screen whether the flame is reddish violet, which indicates potassium.

PYRITE

Iron pyrite is used as a source of sulphur, of which it contains 53 per cent, when pure; iron comprises the remaining 47 per cent. The white iron pyrite (marcasite), magnetic pyrite (pyrrhotite), arsenical pyrite (arsenopyrite or mispickel), and chalcopyrite (copper-iron pyrite) need not be considered here; mispickel is discussed under Arsenic, and chalcopyrite under Copper. Pyrite is widely distributed in ore deposits and is found in some coals. It is found in 40 States but in workable deposits in only a few.

Pyrite is a hard (hardness 5.5), heavy (specific gravity 5), shiny, yellow mineral, generally existing in cubic crystals (the isometric system). Quartz will scratch pyrite, but a knife will not, yet pyrite will mark glass. A cubic foot weighs 300 pounds.

Pyrite decomposes if exposed to the weather, forms sulphuric acid, and leaves a brownish drusy or powdery mass of iron oxide, often mixed with sulphate.

Distinguishing Tests

Pyrite may be distinguished from the copper mineral chalcopyrite; the former is a paler yellow and gives a black powder when crushed, whereas the latter yields a yellow powder. Pyrite contains 46 per cent iron and 53 per cent sulphur, but chalcopyrite has 30 per cent iron, 35 per cent sulphur, and 35 per cent copper, when pure. Both have a greenish-black streak, but pyrite is the harder. Ore of the Horne mine, Quebec, contains 7 per cent chalcopyrite, 52 per cent pyrrhotite, and 22 per cent pyrite.

There is no mistaking pyrite for pyrrhotite, as the latter is reddish brown and is sometimes magnetic, but pyrite is not magnetic until heated. Pyrrhotite often carries nickel.

Pyrite and gold are often confused; gold always exhibits the same color from whatever point it is viewed, but pyrite is dull when looked at from an angle. Pyrite crushes to a powder under the hammer, but gold flattens. Pyrite crackles and gives off sulphur under the blowpipe flame, but gold melts into a globule.

When fine crystals of pyrite exist in a quartz vein or lode formation, they are a fair indication of the possible presence of gold. The large crystals are generally of no value. Gold is not chemically combined with pyrite, only mechanically. If crushed pyrite is dissolved in nitric acid, the gold is freed and is visible.

Arsenopyrite is a white mineral with a gray streak but in hardness and specific gravity approximates pyrite. It contains 34 per cent iron, 46 per cent arsenic, and 20 per cent sulphur. When heated, mispickel gives off fumes having the odor of garlic.

Marcasite crystallizes in a different system from pyrite, and it is slightly lighter. Its color is really tin-white or grayish white. Good specimens are in demand for gems. To distinguish between marcasite and pyrite clean them with dilute hydrochloric acid.

Occurrence

Pyrite deposits are generally found in belts of schist and gneiss or in altered schists such as mica-schist and chlorite-schist, close to pegmatite or granite dikes.

The ore at the surface is often entirely altered to gossan, caused by oxidation and leaching out of the sulphur. This gossan may carry up to 50 per cent iron, and in Georgia and other States it has been mined as an iron ore. A high-grade gossan is highly porous and has a blue to purplish-red color. It is principally hematite and limonite. Gossan outcrops should be tested for gold and silver and at depth may contain copper. One deposit in California is now being cyanided.

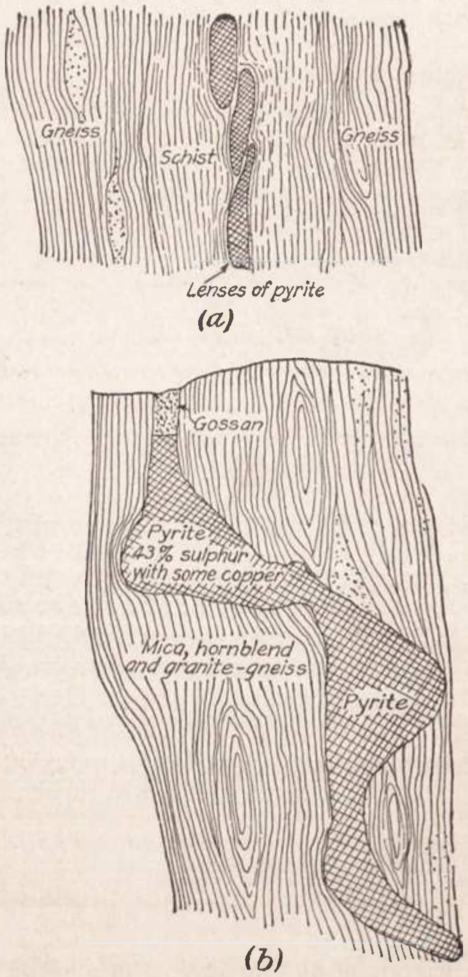


FIG. 107 (*a* and *b*).—Types of pyrite deposits.

Figure 107 shows several occurrences of pyrite.

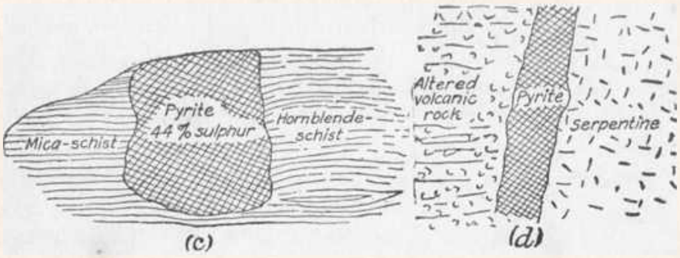


FIG. 107 (*c* and *d*).—Types of pyrite deposits.

SALT AND SALT LAKES

Salt is recovered from evaporation of liquor from salt lakes, as in California, Nebraska, Utah, and South Australia; from brines, such as in Michigan; or from rock salt, as in Michigan, Kansas, Louisiana, and New York State. In the latter instances the rock in mined in the ordinary way. Enormous deposits of salt have been drilled through while prospecting for petroleum. Rock salt

FIG. 108.—A dry salt lake in Australia.

or halite usually exists in sandstone and clays. It has a specific gravity of 2.1 and weighs 132 pounds per cubic foot.

In the arid regions of the West, in Nevada, for example, salt lakes are found, the product of long-continued evaporation. (Figure 108 shows one in Australia.) At the time of rains these are covered with brine; in the dry season they are usually a glittering mass of salt crystals weighing around 50 pounds per cubic foot, though often these are mixed with dirt which was washed or blown in. In addition to ordinary salt or sodium chloride these lakes often contain sodium sulphate, magnesium sulphate, borax, and a great variety of other salts. In some cases such deposits can be mined profitably, but generally not, because many of these salts are produced as by-products in manufacturing other things and the price is not high enough to bear the cost of transportation to markets. If a prospector finds a salt deposit which he thinks may be of value, he should consult a competent chemist before expending much time or money on it. The muds or solid materials in dry lakes do not carry metallic minerals.

SAND AND GRAVEL

As a side line in the search for minerals the prospector should keep an eye open for deposits of sand and gravel. Even in a year of dull business the United States used 65 million tons of sand and 90 million tons of gravel. More than a third of the former is building sand, and a large tonnage is glass sand and molding sand. To quote J. R. Thoenen of the United States Bureau of Mines in its *Information Circular* 6668 (1932), "To be of commercial value, sand and gravel deposits must contain sufficient tonnage to warrant the erection of a recovery or treatment plant." In a general way such materials occur as (1) residual deposits—unstratified, heterogeneous mixtures of rough boulders, pebbles, and sand—and should be free or mostly free of clay; (2) fluvial deposits—as river bars and flats with smooth pebbles—(3) marine and lake deposits—well-sorted and well-rounded, dull, coarse, and fine particles in dry land—the deposits paralleling the shore line of the ocean or a lake; (4) glacial deposits —largely unstratified, heterogeneous accumulations of angular to rounded boulders, gravel, and sand with grooved surfaces—and should be free or mostly free of clay.

Whether a prospector is looking for sand and gravel deposits as a side line to minerals or for these materials only, he either sets out to find a visible deposit or depends on topographic, physiographic, or geologic knowledge to guide him to likely localities. Various excavations, natural or by man, may show sand and gravel, or they may be seen in clear, shallow water. If a deposit has been found, the prospector should, by digging holes or pits, determine the size, shape, and character of the sand and gravel. A 2- or 2½-inch pipe can be driven into the material, and samples withdrawn, as well as the depth determined. A ¾-inch bar or pointed pipe driven down will also indicate the limits but will not give a sample. A 3- by 5-foot rectangular or a 3- to 4-foot circular shaft may be sunk, using a windlass after 7 feet. For safety the shaft should be timbered; as a rule, sand and gravel run. Samples should be carefully taken, and screen analyses made, if the prospector has a set of sieves. The material should be examined for soft, friable, and unsound particles, also for coatings as lime or clay. River sand and gravel have specific gravities of around 1.8 and weigh 110 pounds per cubic foot. If and when the prospector is satisfied that he has a good deposit, he should, if he has the surface rights, offer it to a building contractor or railroad or other firm interested in sand and gravel.

SILICA

Silica is the oxide of silicon, which is a non-metallic element and next to oxygen the chief elementary constituent of the earth's crust. Silica occurs in deposits of importance in many different forms such as vein quartz, as a constituent of pegmatites; as sand, sandstone, quartzite, or flint; as tripoli; and as diatomite (formerly called diatomaceous earth). In some forms such as rose, smoky, and amethystine quartz it has value as gems. Other forms of silica are agate, chalcedony, chert, opal, and onyx.

Chalcedony is a more or less translucent crystalline quartz, often lining or filling cavities in rocks. It varies from white to brown in color. If in quantity and near cement works or gold and silver mills where tube-mills are used, chalcedony is of value for grinding purposes. Generally it must be rounded before use. Chert is a rock formed from chalcedonic silica by organic agencies. Chalcedony and chert are allied to flint, which is a fine-grained form of silica, very tough, and breaks with a conchoidal fracture and sharp edge. Flint occurs as collected nodules or boulders in sandstone or limestone. Agate is a variegated chalcedony, used as a gem and for small grinding mortars.

Onyx is a crystalline variety of quartz, made up of white, yellow, black, and red layers. For this reason, as it is in demand for decorative purposes, search is worth while. One variety of limestone is the onyx marble, but this is calcium carbonate, whereas onyx is silica.

Deposits of silica suitable for glass-making are worth search.

With other minerals, silica forms an important group of silicates, some of which are described in this book. Many silicates are rock-forming minerals; others are of marketable value. The feldspars and leucites are mainly potassium-aluminum silicates; spodumene is a lithia-aluminum silicate; beryl is a beryllium-aluminum silicate; nepheline syenite (or syenite, but do not confuse with kyanite or cyanite, an aluminum silicate, or even cyanide, a chemical compound for treating gold and silver ores) is a sodium-aluminum silicate; garnet is a silicate of varying composition; zircon is zirconium silicate; topaz is an aluminum-fluorine silicate; sillimanite is an aluminum silicate.

SODIUM

See Nitrates and Salt Lakes

Deposits of sodium sulphate occur in Arizona and Saskatchewan, the former as nearly flat beds in hard, blue clay, almost a shale. North Dakota also has extensive deposits.

SULPHUR

Sulphur is an element but not a metal. It may exist native or as the sulphide of a metal, many of which are described elsewhere. The only sulphides used directly as a source of sulphur are the iron compounds pyrite and pyrrhotite, described under Pyrite.

Sulphur given off as sulphur dioxide from zinc and copper smelters which are reducing sulphide ores is often collected and converted into acid.

Tests

Sulphur is easily identified by its bright-yellow color (yellow to reddish), blue flame, and characteristic odor when burning. Several minerals that look alike may be distinguished by heating them in a blowpipe flame, the resultant fume or odor showing whether it is a sulphide or not—graphite and molybdenum, for instance. The luster of sulphur is resinous, and its hardness is 1.5 to 2.5. Its specific gravity is 2, and a cubic foot weighs 120 pounds. The streak is white. The melting point is 240°, and the ignition temperature is 500°F.

Occurrence

Sulphur may be found as crystals, crusts, powder, and masses. In most cases it has been deposited by hot springs or by gases permeating rocks with cracks and crevices favorable for deposition. Few of this type of deposit persist to any depth, and they are generally irregular; neither do they produce much sulphur in America or New Zealand, although in Italy and Japan they do.

Sulphur may be found in limestone; and when it constitutes 30 to 50 per cent of the rock, it becomes workable. It also impregnates rhyolite and exists as incrustations in irregular open fractures in lava, also cementing surface débris derived from the lava.

The greatest deposits in the world are in the coastal regions of Texas and Louisiana. There the surface is characterized by domes or undulating ground of all sizes. They were drilled for oil, and many were found to consist of a dome-shaped core of rock salt, frequently associated with masses of cavernous limestone stained or saturated with oil and nearly always with lenses of gypsum and sulphur. The salt and sulphur are thought to have been derived from solutions coming from masses of cooling igneous rocks. The oil came in the porous rock at a later period. In no case are the three minerals mined together, but each one separate where its concentration is in workable quantity. As the sulphur lies at a depth of about 1000 feet, it is recovered by the Frasch process of forcing hot water down to the beds of gypsum, from which the sulphur is melted and then comes to the surface in pure condition. It will be seen from this mode of occurrence that like petroleum and rock salt, prospecting is more or less of a specialized nature; yet the other type of deposit should be sought.

TALC AND SOAPSTONE

Talc is a magnesia mineral of the same family as serpentine. It is 1 in the scale of hardness and may be cut easily or scratched with the finger nail—that is, when pure. Its specific gravity is 2.7. It is little affected by heat and not at all by acids. The mineral is usually white with a greenish tinge, although it ranges from pure white to dark green. The luster is pearly. Its general characteristics enable it to be identified without trouble. What is known as talc-schist is a schistose rock chiefly composed of talc and quartz.

A large quantity of ground talc is consumed each year, and the American production has totaled 200,000 tons in a year. The principal uses are for filler in paper and rubber, face powders, medicinal purposes, pencils, electric insulators, and paints. The fibrous form of talc is required for the paper industry and paints, and the finest grades for toilet purposes and pencils. The increasing use of talc in fire-resisting paints and in ceramic whiteware mixture provides a good market for the future. A good talc should be almost free from silica and lime.

New York, Vermont, California, and North Carolina are the principal producing States for talc, but deposits have been opened in Montana, Nevada, and other western States. Virginia produces most of the soapstone, which is mainly sold as blocks.

Occurrence

The vein form for talc is not common, so deposits that are derived from (1) altered sedimentary rock and (2) altered igneous rocks are of importance. Talc is always associated with highly disturbed and altered rocks. It is usually a secondary mineral

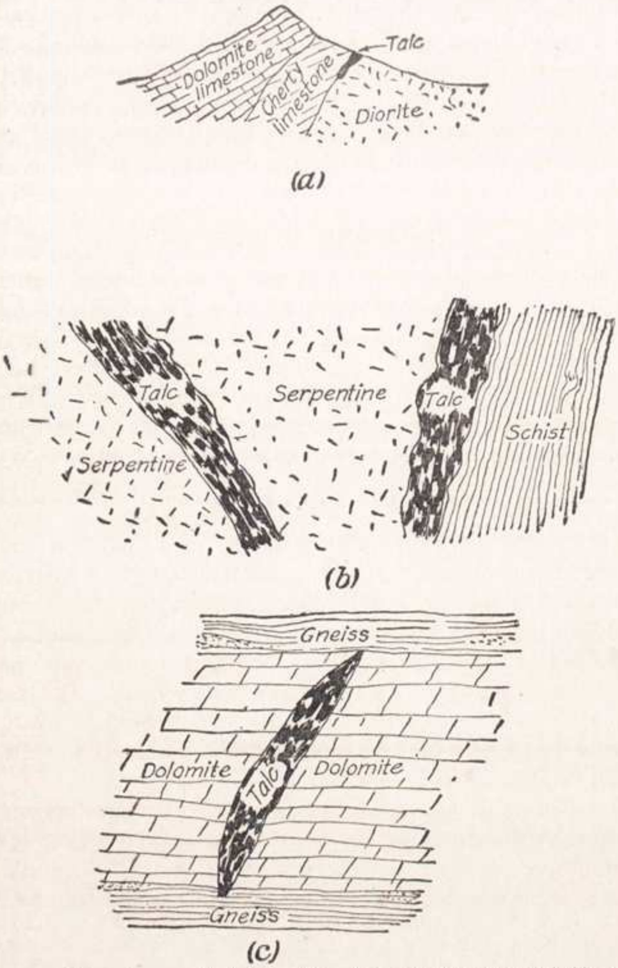


FIG. 109.—Three types of talc deposits. (*a*) In California; (*b*) in Vermont; (*c*) in Ontario.

resulting from the alteration of other magnesian silicates or occasionally carbonates. In New York State and in North Carolina class 1 deposits are related immediately with crystalline limestone and schists. The lenses of ore vary from a mere fiber up to those 50 feet thick and several hundred feet long. Under class 2 basic rocks, such as basalt, are altered, and talc is found therein, with soapstone. These two minerals are frequently found together. Figure 109 shows three types of talc deposits.

Talc also is an alteration product of serpentine, and in North Carolina it is found as lenses and sheets in blue and white marble. Soapstone is also derived from the alteration of basic rocks but is not so pure as talc and occurs in massive form. It is mined and sawed into blocks of various sizes for use in table tops, tubs, switchboards, scientific laboratories, fireless cookers, and for electrical purposes. Soapstone is not interchangeable with talc in the uses mentioned under the latter.

TRIPOLI

See Diatomite and Tripoli

PART IV

CHAPTER XIX

ORE-DRESSING AND TREATMENT

Dressing an ore means preparing it or part of it for treatment. All the ore may need treatment; or only the concentrates may require treatment, in which case the remainder is discarded. With limited funds, and perhaps knowledge, the prospector and small operator is often at a loss what to do with his ore; therefore this chapter has been prepared to suggest some method of handling ores. That such information is wanted is borne out by the following suggestion from a group working a small mine and mill:

> We find it difficult to get reliable information for a prospect mill and had hoped that someone would write a book describing the relative merits of small mill machinery and devices such as Taggart has done on large installations, because we need to know better how to stretch our dollars than do large companies, as our mistakes are fatal.

ACKNOWLEDGMENT

This chapter has been written from the author's experience, observations, correspondence with engineers and equipment firms, and general reading. It has been reviewed by the Denver Equipment Company which has supplied several flow-sheets. As it is impossible to show and describe all types of machines, a few only are given. Such details are to be found in handbooks and bulletins of manufacturers. No one make has been favored. Credit for information is given at suitable places in the text.

WHEN TO ERECT A PLANT

If enough ore is developed in a prospect or small mine, some type of dressing and treatment plant may be more suitable than regularly shipping the ore to custom works. The advisability of having such a plant depends on the type and grade of ore, on local conditions, and on the financial resources of the claim-owner. The ore should be properly tested by qualified laboratories or by equipment makers who have laboratories.

If an ore is rich enough, and a custom mill or smelter is fairly near, shipments may be sent to such treatment plants until enough money has been accumulated to pay for a mill at the mine. As far as the author knows, the sampling and assaying of ores and products are well done and the treatment charges are fair. Penalties are made if an ore carries certain ingredients, and bonuses are paid under certain conditions. Payments for metals are not made in full because complete extraction is not attained by any process anywhere in any country.

Small Smelting Furnaces Unsuitable

The smelting of ore or concentrates in an electric furnace, or in any type of furnace, by the owner of a small mine is ill advised. Both power and fuel may be cheap; yet smelting is involved and expensive. Besides requiring some one skilled in the art, a smelter should be run continuously and have a large supply of ore. Smelting is only part of the problem; gold and silver ores and concentrates must be smelted with copper or lead, which collect them. Then the copper matte or lead bullion must be refined locally in another furnace or sent to a refinery. The furnace reduction of zinc ore or concentrates to metal at small mines is not feasible. Some operators have an idea that tin concentrates can be easily reduced to metal, but this is not so, because several other metals occur with tin and have to be separated.

The Federal Bureau of Mines has looked into a number of such proposals to smelt ores and concentrates, and also into the general problems involved, and has found that nowhere have such operations been successful on a small scale, and only at a few places on a large scale. Yet some day suitable electric and blast furnaces may be available for small operations. One small operation at Mambulao, Luzon Island, Philippine Islands, involves two 4- by 10-feet, Mace sintering hearths and a no. 4 Mace blast furnace to smelt the sinter. Concentrates contained the following approximate analysis: gold, 4.75 ounces; silver, 10 ounces; copper, 4.25 per cent; iron, 34.50 per cent; zinc, 3.6 per cent; lead, 3.1 per cent; sulphur, 41.50 per cent; and insoluble, 9.70 per cent. About 10 to 12 tons of concentrate was reduced to 1 ton of matte.

Used or New Equipment

If a prospector or miner or group of men can afford the expense of installing a plant of used or new equipment, and the ore requires complete local treatment, at least to the point of producing concentrates for shipment, the owners should be prepared to run a crusher, stamps or ball-mill, corduroy or copper-plate tables, shaking tables, classifiers, flotation machines, and cyanidation equipment, not all in the same plant but a combination of several of these machines. (The Denver Equipment Company has issued a booklet showing and explaining 50 different flow-sheets.) As a rule, homemade milling installations cause much trouble, loss of time and patience, and expense; such equipment means miscellaneous parts picked up here and there. Dealers in used machines and makers of new machines will give full instructions for their erection and operation; but after they are working, the claim-owner must rely on his observation and judgment when any unusual problem arises, although equipment firms will give advice. Ores and water change in composition sometimes and upset the regular running of a plant. Makers of flotation reagents and cyanide also give instructions and may be called on in time of trouble.

Some firms specialize in small, complete portable concentrating mills which are valuable in developing a prospect. They are put together at the factory and then knocked down for shipment. Their erection at the time is a simple matter. These plants range in capacity from 5 to 100 tons in 24 hours.

A Denver firm makes a complete plant for crushing and concentration on a motor-truck, but there is no information regarding its work. It has a capacity of 5 to 10 tons a day and uses 13 to 15 horsepower. The equipment, excluding truck and power, costs $2500 to $4000.

Instruction in Milling and Treatment

And as mentioned in the first chapter of this Handbook, several western schools of mines offer, under certain conditions, free instruction for prospectors and miners during a few weeks of the summer. This would be a suitable time to try to include some practical study of milling, cyaniding, and flotation. Inquiry should be made of the School of Mines at Berkeley, California; Butte, Montana; Golden, Colorado; Moscow, Idaho; Rapid City, South Dakota; Reno, Nevada; Salt Lake City, Utah; Socorro, New Mexico; Pullman, Washington; Tucson, Arizona; Rolla, Missouri; and Houghton, Michigan. (If possible, a skilled millman should be employed to instruct the owners. His salary will be more than compensated for by better results and freedom from shut-downs.)

In addition to such instruction, there are available at low price several books that include elementary and advanced description of laboratory work and plant operation, and several of the makers of equipment give excellent bulletins free or at low charge. The following publications, which are listed because of the general information they contain, can be procured:

"Denver Equipment Index," 1936, 160 pages, 8¾ × 11⅛ inches, Denver Equipment Company, 17th St., Denver, Colorado. Also the same information free in pocket-book size, 1938, with 50 different flow-sheets and descriptions.

"Gold Extraction," 1936, 62 pages, 5½ by 8½ inches, free from Imperial Chemical Industries, Ltd., Millbank, London, S.W.1, England.

"Ore-dressing Notes" 6 and 7, 1937, 28 and 19 pages, 8½ by 11½ inches, free from American Cyanamid Company, 30 Rockefeller Center, New York City.

"The Trend of Flotation," by Arthur J. Weinig and C. B. Carpenter, 4th ed., 1938, 189 pages, 6 by 9 inches, Colorado School of Mines, Golden, Colorado.

The first three firms listed test ores for suitability to dressing and treatment. One makes equipment of all kinds; two make cyanide; and one of them makes flotation reagents.

The first book listed contains signed articles on milling practice—cyanidation and/or flotation, including one on small plants, even to one of 5- to 10-ton capacity on a motor-truck. This information is followed by a number of flow-sheets with costs of installation. The principles of cyanidation and flotation are explained and how tests are made. Thirty pages of useful information complete the book. (This firm also issued, in 1938, a bulletin entitled "Marketing Concentrates" and pamphlets "Amalgam ABC," "Cyanide ABC," and "Flotation ABC," all free.)

The second booklet consists of notes on cyanidation for the small operator. Although prepared by a British firm, which has been connected with and making cyanide for 53 years, it is entirely suitable for American operators. Nothing like it has been published for the purpose. Gold deposits; stamp-milling; amalgamation; blanket tables; concentration and treatment of concentrates; everything in connection with the cyaniding of sand, slime, and concentrate, including difficulties to be encountered; and the making up and testing of solutions are all given in simple and practical language.

The third publication is in two parts. One is entitled "Cyanidation of Concentrates." Some precious-metal-bearing concentrates are not amenable to direct cyanidation and require preparation therefor, or they are best sent to a custom plant. This problem is the first thing discussed in this report. Then, with flow-sheets and detailed sketches of certain machines, is described current practice, including plants for 5 tons a day. Cyaniding concentrates differs from cyaniding ores; so this is covered. Then come laboratory testing and the action of cyanide on minerals commonly present in concentrates, as antimony and arsenic, copper, carbon, iron, lead, mercury, tellurides, and zinc. The assay of cyanide solutions completes the work. The other publication is an excellent explanation of flotation, including the reagents and how much is used.

The fourth bulletin has been and is a useful practical treatise on flotation. Everything pertaining to the methods employed on different ores is given. The fundamentals of the process are explained, as are the reagents used and their function. Equipment for flotation and information on where to get it are given. Then follow details of the practice at many western mills treating a variety of ores, costs, plant control, marketing concentrates, custom mills, and other essential information.

Where to Procure Machinery

The prospector or operator of a small mine may need a mill, reagents, and equipment of some type and may not know where to inquire regarding it and the cost thereof; so we list a number of reliable firms:

Abbe Engineering Company, New York (ball and pebble mills).
Allen-Sherman Hoff Company, Philadelphia, Pennsylvania (rubber-lined pumps).
Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin (crushers, stamps, ball-mills, jigs, screens, log-washers, and mining equipment).
American Cyanamid Company, 30 Rockefeller Plaza, New York (flotation oils).
Austral Otis Engineering Company, Melbourne, Australia (mine equipment).
Barrett Company, The, New York (flotation oils).
Babb Machinery Company, Picher, Oklahoma (used machinery).
Bendelari, F. N., Joplin, Missouri (jigs).
Bethlehem Foundry & Machine Company, Bethlehem, Pennsylvania (Bethlehem-Wedge roasting furnaces).
Braun Corporation, Los Angeles, California (laboratory and assay equipment).
Coeur d'Alene Hardware and Foundry Company, Wallace, Idaho (mining supplies).
Colorado Iron Works, Denver, Colorado (crushers, rolls, screens, classifiers, driers).
Colombian Steel Tank Company, Kansas City, Missouri.
Consolidated Products Company, Newark, New Jersey (used machinery).
Cummins Diesel Co., Columbus, Indiana (diesel engines).
Deister Concentrator Company, Ft. Wayne, Indiana (concentrating tables).

Deister Machine Company, Ft. Wayne, Indiana (concentrating tables).

Denver Equipment Company, Denver, Colorado; El Paso, Texas; Salt Lake City, Utah; San Francisco, California; New York; Vancouver, British Columbia; Toronto, Ontario; and representatives in Mexico, D. F., London, Johannesburg, and Melbourne (crushers, ball-mills, barrels, jigs, copper plates, cyanidation plants, flotation plants, pumps).

Denver Fire Clay Company, Denver, Colorado (assay furnaces).

Dominion Engineering Company, Montreal, Quebec, Canada (mills).

Dings Magnetic Separator Company, Milwaukee, Wisconsin.

Dorr Company, The, New York City; Denver, Colorado; Chicago; Los Angeles; Toronto, Ontario; London; Tokyo; Johannesburg; Melbourne (classifiers, agitators, thickeners, pumps).

Dwight & Lloyd Sintering Company, New York (ore roasting equipment).

Eagle Iron Works, Des Moines, Iowa (log washers).

Earnshaw Docks & Honolulu Iron Works, Manila, Philippine Islands.

Eimco Corporation, The, Salt Lake City, Utah (new and rebuilt mining and milling machinery).

Engineering Equipment & Supply Company, Manila, Philippine Islands.

Fairbanks Morse & Co., Chicago (pumps).

Fraser & Chalmers Engineering Works, Kent, England (represented in all countries—mining and metallurgical equipment).

Galigher Company, Booth Thompson Division, Salt Lake City, Utah (mill design and equipment).

General Engineering Company, Salt Lake City, Utah.

Gibson, W. W., Alameda, California (crushers, ball-mills, rod-mills, flotation machines).

Great Western Division, The Dow Chemical Company, San Francisco, California (mill design and equipment).

Gould and Company, H. W., San Francisco, California (D-retorts and rotary kilns for mercury, arsenic, and antimony ores).

Hadfields Limited, Sheffield, England (crushers).

Hardinge Company, York, Pennsylvania (ball-mills and classifiers).

Hendrie and Bolthoff Manufacturing and Supply Company, Denver, Colorado (standard makes of crushers, stamps, ball-mills, concentrators, jigs, classifiers, cyanidation plants, flotation plants, and mine equipment).

Hoskins & Company, Perth, Western Australia (mine plant).

Kennedy-Van Saun Mfg. & Eng. Corp., New York (crushing, grinding and screening equipment).

F. Long Limited, Orillia, Ontario, Canada (mine machinery).

McLanahan Stone Corporation, Hollidaysburg, Pennsylvania (log washers).

Mace Co., The, Denver, Colorado (smelters 5- to 210-ton capacity).

Merrill Co., The, San Francisco, California (clarification and precipitation).

Mine and Smelter Supply Company, Denver, Colorado; El Paso, Texas; Salt Lake City, Utah; Seattle, Washington; Phoenix, Arizona; New York (crushers, ball-mills, concentrators, complete milling plants).

Mill & Mine Supply Co., Inc., Seattle, Washington (general equipment).

Morse Brothers Machinery Company, Denver, Colorado (reconditioned mining and milling machinery; also new flotation machines).

Nichols Engineering & Research Corp., New York (roasting, calcining, and drying equipment).

Newport Industries, Inc., New York (flotation oils).

Oliver United Filters, Inc., New York (drums and disk filters).

Patterson Foundry & Machine Company, East Liverpool, Ohio (ball and tube mills).

Pacific Foundry Company, San Francisco, California (D-retorts and hearth furnaces for mercury and other ores).

Pan-American Engineering Co., Berkeley, California (jigs and flotation machines).

Peacock Bros., Montreal, Quebec, Canada (mining and milling equipment).

Ruwolt Proprietary, Charles, Melbourne, Australia (milling equipment).

Sharples Chemicals, Inc., Philadelphia (flotation oils).

Smith Engineering Works, Milwaukee, Wisconsin (crushing equipment).

Stearns-Roger Manufacturing Company, Denver, Colorado (mill machinery, including Edwards' roasting furnaces and Richards' jigs).

Straub Manufacturing Company, Oakland, California (stamps, ball-mills, concentrators, and small crushers).

Sutton, Steele & Steele, Inc., New York (air separation tables for dry concentration of ores and minerals).

Southwestern Engineering Company, Los Angeles, California (mill design, construction, and equipment).

Thompsons Engineering & Pipe Company, Castlemaine, Victoria, Australia (mining and dredging plants).

Traylor Engineering & Manufacturing Company, Allentown, Pennsylvania (crushers, rolls, ball-mills).

Tyler, W. S. Company, Cleveland, Ohio (screens).

Western Machinery Company, Sacramento, San Francisco, and Los Angeles, California; Phoenix, Arizona; Denver, Colorado; Salt Lake City, Utah (new and used mining and milling equipment).

Western Precipitation Corporation, Los Angeles, California (Cottrell electrical precipitators).

Wilfley, A. R. & Sons, Inc., Denver, Colorado (centrifugal pumps).

Williamson Company, San Francisco, California (grinding mills).

Several American and British firms have representatives with manufacturing plants in Africa, Australia, and other countries and make equipment or handle special supplies under license.

When equipment is ordered, it should be stated whether a machine is to be run right-hand or left-hand; if two machines are required, they should be right-hand and left-hand. This is a matter of operating convenience, and there is no extra charge for either drive. Do not hesitate to give the manufacturer too much information about your requirements for equipment instead of too little.

REMOVAL OF WASTE AND IMPURITIES BEFORE SHIPPING OR MILLING

Prospectors or miners who have ore worth shipping to a custom plant or for local milling would do well to investigate its suitability for removal of waste rock by weathering or sorting or of impurities by log-washing, classifiers, stationary or shaking screens, or revolving trommels which are screens in effect. But before any sorting is attempted, a miner or millman should know his ore thoroughly, particularly what part of it is barren or of uncommercial grade.

Weathering

Some ores disintegrate or break up or the clayey and sandy materials on them break off when they are weathered awhile. By this action much waste may be discarded before any sorting or washing is done and a nuisance avoided; in fact, weathering alone might be sufficient to get rid of the impurities.

Sorting

Sorting or selection is an old and important part of the concentration of mineral, rock, or ore. When the high-grade material is picked out, this is termed "selection"; when the waste rock is discarded, this is termed "sorting." If an ore is adaptable to sorting, at a cost of a few cents per ton, the grade is improved and impurities and barren rock are discarded, thus saving expense in handling and transportation.

Sorting may mean the picking out and discarding of waste without breaking any rock, or rejecting waste after breaking the rock or cobbing and selecting marketable minerals from their enclosing rock, such as asbestos, fluorspar, manganese, and mica.

The discard should be examined or sampled and panned or assayed to make sure that no valuable ore is being rejected. At some mines the waste is of less value than the mill tailings; at other mines it is about the same or somewhat higher.

Sorting is made easier if the ore is sprayed or washed before or after it has been crushed. The wet fines and sludge should be saved because generally they are valuable, frequently more so than the original ore. Dry fines should also be saved.

Hand-picking is not easy or economical for ore less than 2 inches in size.

Ores may be given a rough sorting underground, where the waste is built into walls and used as filling. A second sorting may be done on the surface, on the crusher floor, or after being crushed.

Ores in which the minerals, such as chrome, copper, gold, pyrite, and tellurides, are well scattered or disseminated are unsuited to sorting.

Where narrow veins are mined and the ore is diluted with wall-rock, the waste should be sorted out; but where veinlets cross the country rock, especially in all directions, little or no sorting is possible and the whole orebody must be milled.

Prospectors and miners working for themselves will often find that the throwing out of waste, poor rock, impurities, or minerals for which a penalty is charged at custom plants is profitable work.

The range of waste discarded is between 5 and 50 per cent, depending upon the ore and its occurrence. Most minerals lend themselves to selection, sorting, or cobbing, the following being examples: asbestos, barite, calcite, chromite, coal, copper, feldspar, fluorspar, gemstones, gold, graphite, iron, lead, limestone, magnesite, manganese, mercury, sillimanite, silver, stone, tin, tungsten, and zinc.

It is important to remember that in sorting, the assay of the final milling or smelting ore will be higher than the assay of face samples of ore upon which a claim-owner bases the value of his mine and also that the ratio of waste to ore varies.

Log-washing

Log-washing may be defined as an all-wet process of removing clay, soil, sand, and other worthless material from certain ores—barite, bauxite, clay, fluorspar, gold ores, graphite, gravel, iron ore, iron oxides, kaolin, limestone, manganese, phosphate rock, sand and gravel, to mention a few. Figure 110 is a sketch of a log-washer, and Fig. 111 shows one at work.

The log-washer consists of a slightly inclined wooden or iron trough in which revolves a thick shaft or round log, to which are attached wood, iron, or steel blades set at an angle to the axis. Ore is fed in near the lower end, and water at the upper or lower end or along most of the length of the log. The blades convey the lumps of clayey ore uphill against the current and discharge them at the upper end, while the clay is broken up or puddled and floated down to overflow at the lower end. Some washers have two logs,

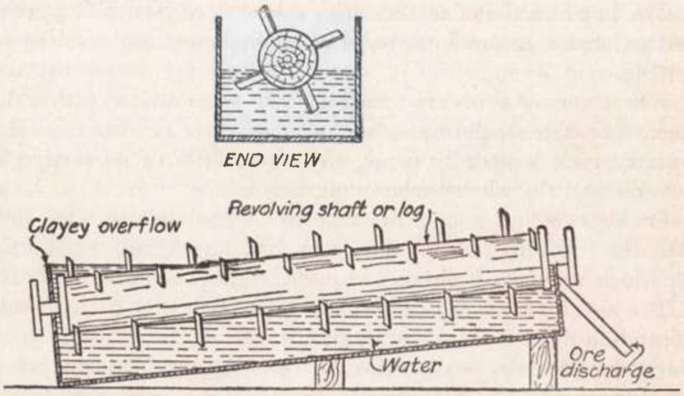


FIG. 110.—Sketch of a log-washer. Although only water is shown in the box or trough, after working a while this fills with ore, and the log works in a bed of ore.

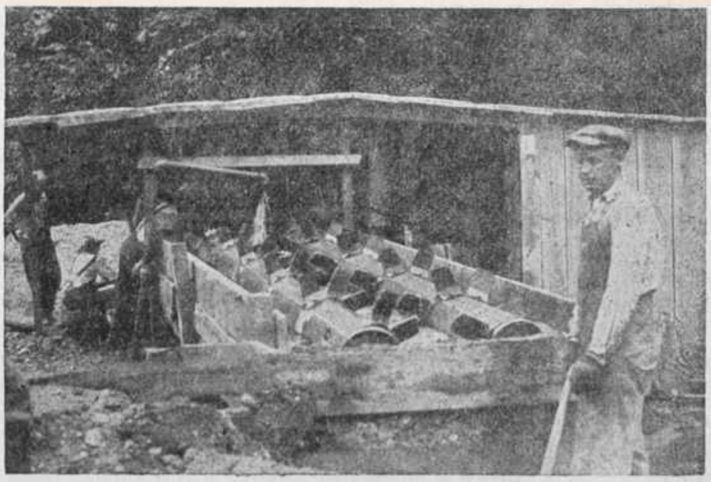


FIG. 111.—A double log-washer at work.

but a single machine 24 feet long, 2 feet deep, and 2 feet wide, with a slope of 1 inch in 20 or 14 inches in 24 feet, will wash up to 100 tons in 24 hours. The cost of operation is low—normally under 10 cents a ton. The machine may be geared or belt-driven according to conditions.

If a "log" is made strong enough, it will churn the ore and cut off and pulp the clay or other impurities which flow to a pond, the clear water to be re-used, if required. The clean ore is piled, drained, and dried in the sun or in trays heated by some fuel.

The speed of a log depends upon the type of ore being washed—high speed for fairly free material and slow speed for sticky, tough material.

Sometimes small washers, say 12 inches by 10 feet, for certain ores, such as barite, are operated in series.

Iron. Lenses of the brown iron ore of Alabama occur with lime-clay, sand, or gravel which has to be separated from the ore. This is done by crushing, screening, sorting, and log-washing. Ore of less than 2- to 3-inch size is freed of clay in 25-foot logs set at 1 inch in 12 inches and revolving at 20 revolutions. The box is of sheet steel.

Some washers have 18-inch logs with 9-inch blades and are 20 to 30 feet long, running at 12 to 15 revolutions per minute. The box may be 7 feet wide, 2 feet deep at the upper end, and 4 feet deep at the lower end.

Manganese. In the Batesville district, Arkansas, the practice has been to pass the material over a 5- by 6-foot grizzly composed of 10 to 14 railroad rails spaced 4 inches apart. What will not pass through is examined, and the lump ore is broken to pass the grizzly. A double log-washer, 28 feet long, with a slope of 1 inch to 1 foot, discharges to a revolving screen, 6 feet by 30 inches with ¾-inch holes. The overflow from the washer goes to the dump. The oversize from the screen goes to a pickig belt, from which the ore is taken to a bin, while the undersize from the screen goes to jigs. A log-washer revolves from twelve to fifteen times or more a minute, uses up to 75 gallons of water in that time, requires 25 horsepower, and should yield up to 50 tons of concentrate a day.

Ready-made log-washers—new or used—may be procured from makers or from machinery dealers. Not counting the cost of erection and woodwork, the 4½- by 20-foot and 4½- by 25-foot sizes, new, cost over $1700. The bottom of the box and the shafts of logs are parallel and inclined. Average log speed is 27 revolutions, and a double washer uses 30 horsepower but washes 50 tons an hour.

Screens and Classifiers

Screens of the shaking type with stout wire or punched holes—round or square—and of the revolving type (trommels) with punched holes, with ample water for washing, are used successfully.

Classifiers of the rake, drag, or spiral type are found to be more or less suitable for washing the types of ores handled by log-washers.

ORE REDUCTION

Ore reduction means breaking or crushing and grinding ore to a size suitable for ore-dressing and treatment. Reputable equipment companies will recommend well-tried machines and an erecting engineer.

Breaking or Crushing

Crushers. Generally, for a small mine a jaw-crusher will be found most satisfactory. The discharge opening may be adjusted. The fine-reduction crushers of two firms will reduce coarse ore to 1½-, 1¾-, ½-, or ¼-inch size. A crusher may be placed on a platform below an ore-bin for mine-run ore or with a platform where ore is dumped, the ore in both cases being shoveled into the crusher. Depending on the topography of the country, the crushed ore is elevated to or dropped into a storage-bin. Figure 112 shows a jaw-crusher.

Milling

Ore that has been broken to 2- or 3-inch size by hammers or has been broken finer by a crusher is next milled to suitable fineness by stamps or ball-mill and rod-mill for hard ores and by Chilean mill or Huntington mill (Figs. 113 and 114) for soft ores. Used or new machines of these type are procurable from the firms mentioned.

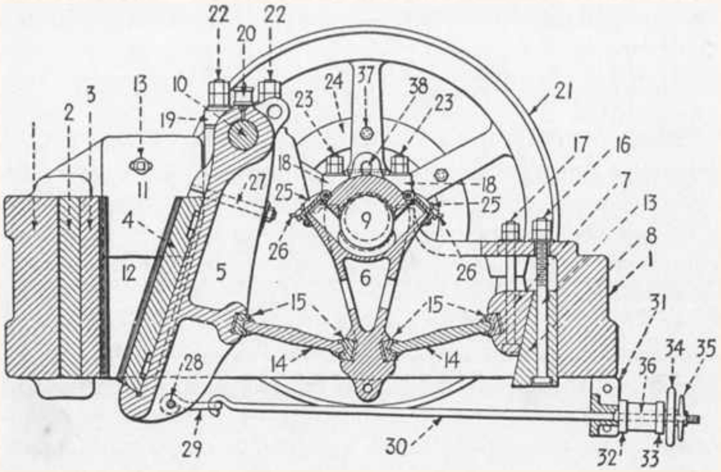


FIG. 112.—Details of a jaw-crusher.

1. Main frame
2. Round back
3. Fixed jaw plate
4. Swing-jaw plate
5. Swing jaw
6. Pitman
7. Toggle block
8. Wedge
9. Eccentric shaft
10. Swing-jaw shaft
11. Upper half cheek plate
12. Lower half cheek plate
13. Bolt for cheek plate
14. Toggle
15. Toggle bearing
16. Bolt for wedge
17. Bolt for toggle block
18. Cover for main bearing
19. Cover for swing jaw shaft
20. Grease cup
21. Balance wheel
22. Bolt for swing-jaw shaft cover
23. Bolt for main bearing
24. Pulley
25. Grease-box cover
26. Bolt and thumb screw
27. Bolt for swing-jaw plate
28. Shackle pin
29. Spring-rod shackle
30. Spring rod
31. Spring bar
32. Washer
33. Washer
34. Hand wheel
35. Thumb nut
36. Rubber spring
37. Bolt for pulley
38. Grease-box cover on main bearing

Stamps. Although the use of stamps has been decreasing in recent years and few mine-owners install them now, some prospectors and owners of small mines prefer them to other equipment for crushing gold ores—even for other ores. Several firms make

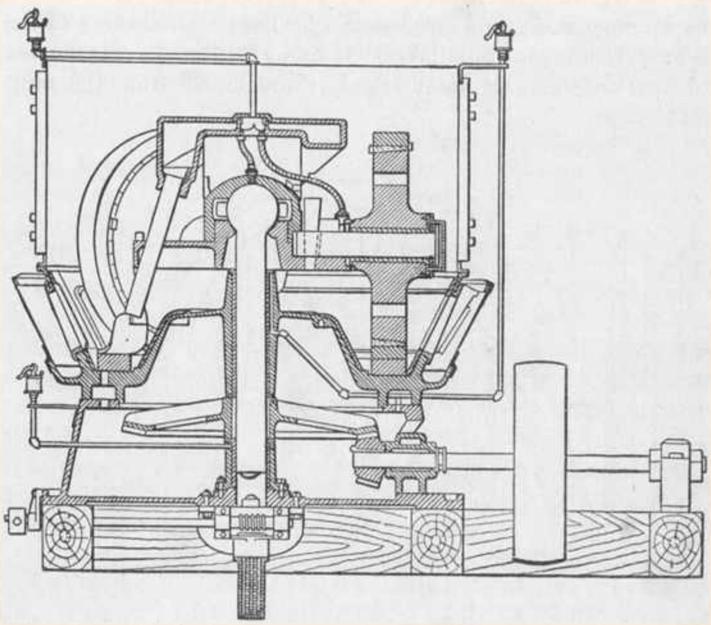


FIG. 113.—Section of a Chilean mill.

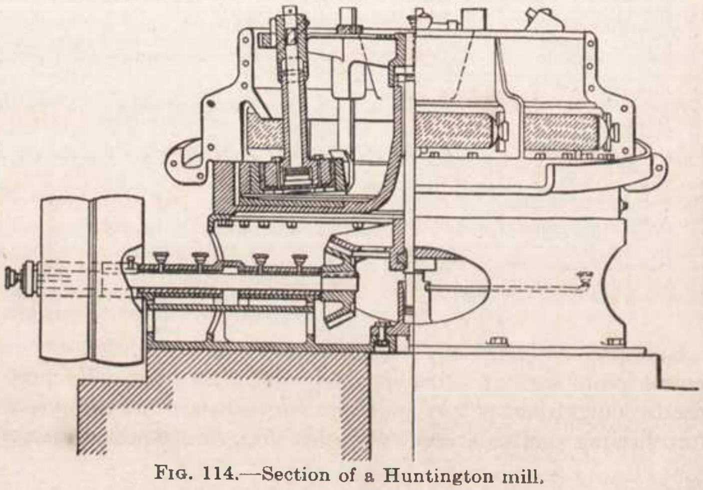


FIG. 114.—Section of a Huntington mill.

stamp mills, and certain dealers in machinery have them in stock. A two-stamp, self-contained, steel-frame mill of one maker has been a favorite. The total weight is 3000 pounds, and it is easily erected and moved. The stamps weigh 300 pounds apiece, crush 300 pounds of ore an hour, and consume 2 horsepower. Another firm makes a mill consisting of three 250-pound stamps

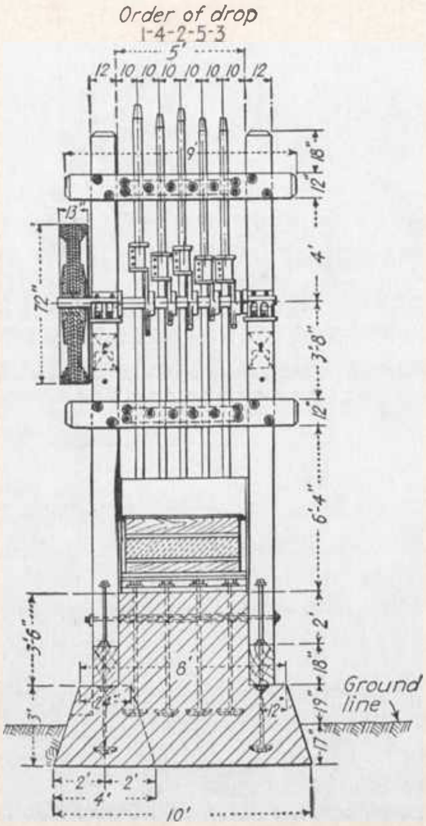


FIG. 115.—A Joshua Hendy standard five-stamp mill of 1000 pounds each.

working in a mortar weighing 1000 pounds. The mill can crush 3 tons of hard ore in 10 hours. A third type of mill consists of 10 small stamps which are lifted by a circular cam and crush in a circular mortar. It will crush 10 tons of quartz a day and uses 7½ horsepower. It is easily erected and is recommended. Then there is the standard 5-stamp mill, as in Fig. 115.

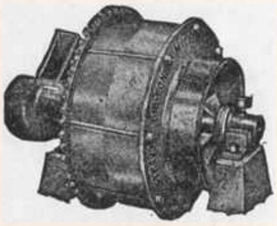


FIG. 116.—Straub Rib-Cone ball mill.

The stamp is a good crusher of hard ore, as quartz, but is not so suitable for soft ore as the Huntington mill (see Fig. 114), which is popular in Australia for this type of material and will be found adaptable to North American ores or those in other countries.

Mills. A mill consists of a steel shell supported at each end by a hollow trunnion running in a bearing, lined with steel plates, and driven by belt and gears or by motor and gears. The mill is set at a slight slope and is fed with finely crushed ore and water through one trunnion. When ground fine enough by the load of balls, the pulp is discharged through the other trunnion and run where desired for further treatment. In some plants a ball-mill or rod-mill will reduce the ore to, say, 100 mesh and a tube-mill will finish the grinding to 200 mesh or finer. In other plants a ball-mill or a tube-mill will do all the grinding, but it must be fed with fine ore—say, ⅛ to ¼ inch—to do this properly. Grinding coarse ore in a ball-mill is done by steel balls of three sizes (5, 4, and 3 inches); fine ore is ground in a tube-mill by 2- and 1½-inch balls or by flint pebbles or by hard, rounded mine rock such as quartzite. These grinding media wear to small sizes, and new ones must be added regularly to make up the weight. When a mill is in closed circuit with a classifier, it will handle a circulating load of several times the amount of the original feed. The correct operation of a mill with proper load of balls and pulp or ore feed is determined by sound or by power meter. Normally, the sound is a rumble, whereas from a more or less empty mill there is a rattle. The speed of mills depends upon their diameter; a ball-mill of 3 feet revolves 35 times a minute, and one of 5 or 6 feet, 29 or 27 times. Tube-mills run at a revolution or two faster (see Fig. 117).

Some ores require much finer grinding than others to liberate the minerals, and this increases the milling cost.

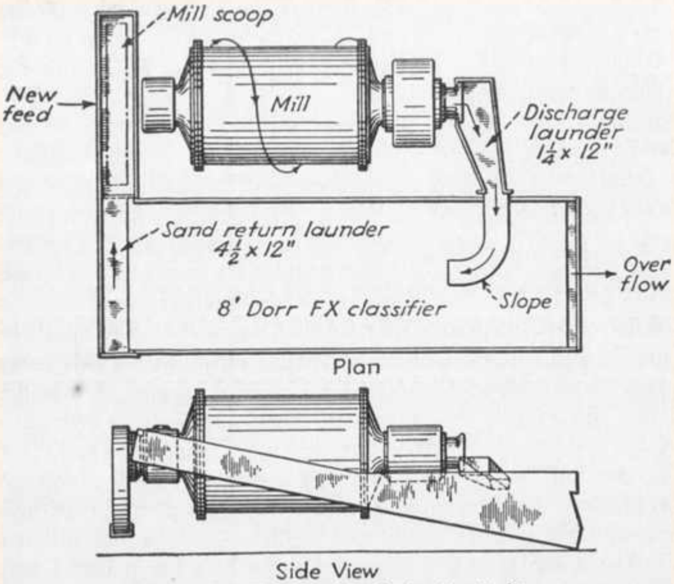


FIG. 117.—Typical closed-circuit grinding.

Classifying

One passage of ore through a mill is seldom enough grinding to release gold and silver or other minerals from the gangue that encloses them; therefore, a classifier is worth installing to separate the sand from the slime and return the former for further grinding or for their separate treatment. Classification may be done in cones or in drag, rake, screen-wheel, spiral-within cylinder, and spiral-in-trough classifiers.

When a classifier is operated to separate the sand for further grinding, it is arranged in closed-circuit with a mill, which means that the coarse pulp is circulated and ground until it passes out of the classifier as slime. The classifier controls the size of the finished material. But when a classifier is arranged in open-circuit with a mill, the sand and slime are separated and flow, without further grinding, to their respective treatment. Unless such products are desired, open-circuit grinding is inefficient.

If unclassified pulp is sent to shaking tables or to flotation machines or other equipment, they do less effective work, which means losses; therefore, pulp should be separated into at least two grades—sand and slime—before being fed to any machine. Even collecting tanks in cyanide plants should receive sand pulp and slime pulp if two products are to be treated, although in some plants the whole pulp is run into one collector and the slime overflows to its own tank, leaving the sand sometimes more or less slimy in the collector where it is now and then treated or discharged and filled into a treatment vat.

Rake and Drag Classifiers. The Dorr is the example of the rake, and the Esperanza of a drag. The former consists of a shallow rectangular tank in which are reciprocating rakes. There are several designs of the Dorr machine. The slime overflows at the lower end, and the sand at the upper end. In the drag type are scrapers affixed to an endless metal belt. The products of this type are sand and slime. These machines have large capacity or circulating loads and can be adapted to washing ores and sands of not too large a size (see Fig. 117 for a mill and classifier in closed circuit).

Spiral Classifiers. The Akins, Denver, Hardinge, and Western Machinery are examples of the spiral. The first two consist of a spiral rotating in an open steel trough or box set on a slope, the spiral working the sand to the upper end and the slime overflowing at the lower end. Spirals of 8 to 12 inches diameter are available for small plants. The 12-inch size is good for 12 tons a day. A 24-inch spiral will handle 35 tons. These machines have large capacity or circulating loads and may be used for washing ores and sands of not too large a size. The third make of classifier consists of a spiral within a sloping and rotating drum. The feed enters by pipe about mid-way up the drum and is separated into sand and slime like the other machines. The last classifier ranges in size

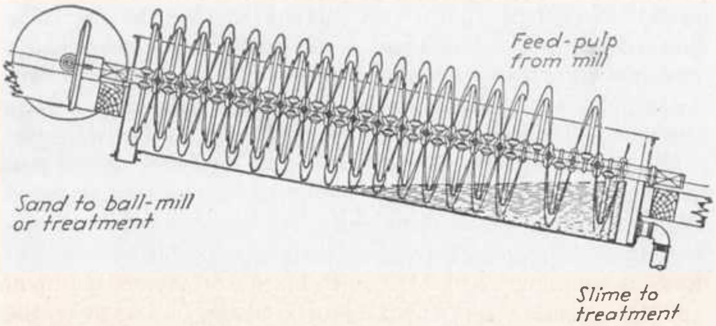


FIG. 118.—A section, and the position of a spiral-type classifier.

FIG. 119.—Latest model of a Straub 10-stamp mill with capacity of 12 to 15 tons ore per day.

from 12 to 48 inches. Wash water is fed in at the top end. The flow of water and fines is countercurrent to the movement of the sand (see Fig. 118).

Classifier Ball-mill. There is also on the market a rib-cone screening ball-mill whose "classifier," as it may be termed, is part of the mill. Capacities for prospectors are 2 to 4 and 4 to 8 tons through 35 mesh in 24 hours, requiring 1½ to 3 horsepower. The screen is as the discharge end of the mill. Washed oversize is returned to the inside by the action of the mill, and the fine material passes out to be treated. Figure 119 shows this mill.

Cones. Cones classify pulp by hydraulic movement or by the density of the particles.

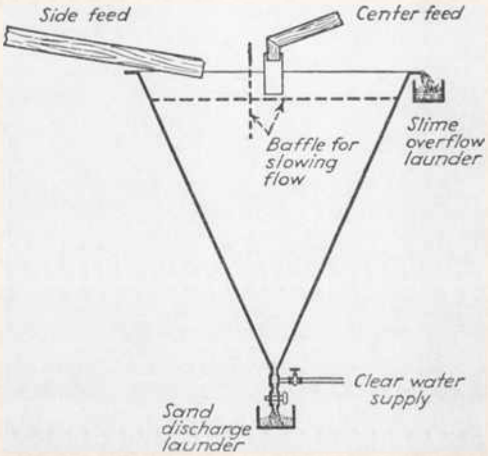


FIG. 120.—Sketch of a cone classifier. The feed may be at the side or at the center, with a baffle for either, as shown.

The inverted cone, made of wood or sheet iron, with a rising current of water, is the simplest classifier. The pulp enters the top, strikes a baffle partly submerged and fixed half-way across the cone, moves toward the converging sides, and is met by the clean water. The slime overflows at the top, and the sand passes straight down through the cone and pipe outlet which is fitted with a plug-cock. The wash water, for such is the rising current, enters this same outlet pipe through a T and is adjusted by means of a valve (see Fig. 120).

Figure 121 shows the Mosher cone, a simple device for separating sand from slime or for thickening slime. The pulp flows directly into the cone, rises through the central cylinder, and overflows by means of a spout attached to it. The stream enters the cone at the point of greatest area, where the force of the current is readily dissipated. The rising current in the cylinder is of low velocity and entirely free from air bubbles. The cylinder is divided by a partition extending to near the point of the cone. This prevents the whirling motion that would otherwise be formed by the discharge of the spigot. The space between the side of the cone and the cylinder is ½ to ⅝ inch.

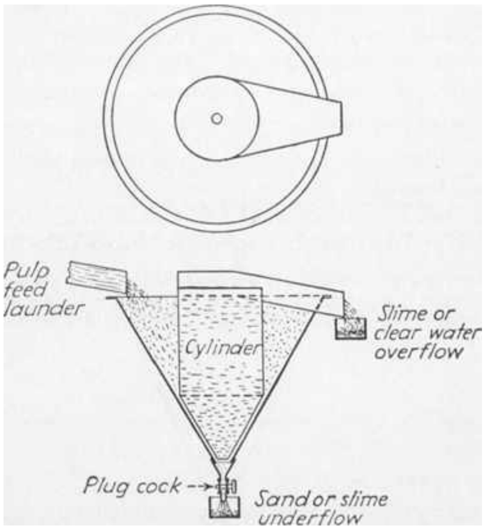


FIG. 121.—Cone (not to scale) that may be used for separating sand from slime or for thickening slime.

WATER SUPPLY

Water for mining and milling may be obtained from underground workings, from wells, from springs, from a stream, from a lake, or even from the sea as in the El Saladocyanide plant in Chile, which has 15 per cent sodium chloride content. The chief difficulty is to thicken the slimes of oxidized ores. Quartz ore presents no serious difficulty with salt water. Some of these waters may be of good quality or highly acid or highly alkaline, both with undesirable salts which affect equipment and ore treatment. As mentioned elsewhere, acidity or alkalinity is simply and approximately determined by means of litmus papers and corrected with lime. If the water is too bad, advice should be sought.

Water from a mine may flow by gravity from an adit or tunnel or be hoisted or pumped up a shaft. In either case the water should be settled in a tank of a type from which any sediment can be washed out easily. A plunger or centrifugal pump or air-lift is suitable for lifts such as are found in small mines. The cost of pumping amounts to only a few cents per 1000 gallons if the flow is fairly large and continuous and higher if it is small and intermittent. Pumps and their motors should be protected from water dripping from the roof and sides, and a weir with trash screen should be built to give them a steady supply. Air-lifts require at least 50 pounds pressure of compressed air and a ¾-inch air-pipe which is central in the 4- or 6-inch water pipe.

For a water supply obtained on the surface a weir should be built. A plunger pump driven by any available power is suitable. A small shed should be built over it.

Although laborious to operate, good hand pumps of surprising capacity are available.

Men who have lived in well-watered regions probably have used or seen a hydraulic ram. The ram is useful for lifting or pumping clean water, but there must be plenty, because this self-acting machine is rather wasteful. In operation, the flow of water is automatically and momentarily interrupted by the opening and closing of a valve (impetus valve). The water is forced into an air chamber as on a pump and then continues where wanted. Another valve (check valve) wastes the excess water, a third or more of the original water.

A ram will raise 300 to 500 gallons a day to a considerable height. The necessary condition is plenty of water free of coarse grit and leaves or other vegetation which may keep the valves from closing. Beyond casual inspection, the ram needs no attention. In districts where rams could be operated, general stores may stock or order them, but mail-order houses as Sears, Roebuck and Company, Chicago, and machinery firms as The Mine and Smelter Supply Company, Denver, usually have them in stock.

CONCENTRATION

Pan Test

A rough guide to the suitability of jigging and tabling an ore is obtained by crushing a weighed lot—a pound or two—through different sieves, say 30, 60, and 80 mesh, and panning it carefully. The concentrate in the pan should be dried and weighed, and the percentage calculated against the weight of the sample crushed. While crushing and sieving, do not overcrush before sieving; this will lessen the amount of slimed minerals. Panning is described in chapter 17.

Specific Gravity

It should be remembered that, when the milling and concentration of ores is under consideration, the gravity machines will not be satisfactory if the specific gravity of minerals and gangue or waste is close to one another. This means that their weight per unit volume is similar. Their separation depends upon their specific gravity. For instance, the commonest gangue mineral is silica and siliceous minerals, whose gravity is around 2.6; therefore it is rather easy to separate these from stibnite, whose gravity is 4.6; from arsenopyrite, 6; bismuthinite, 6.5; chromite, 4.6; chalcocite, 5.8; bornite, 5; chalcopyrite, 4.2; tetrahedrite, 4.5; hematite, 5; magnetite, 5.2; galena, 7.5; molybdenite, 4.8; platinum minerals, 15; pyrargyrite, 5.7; argentite, 7.2; cassiterite, 7; tungsten minerals (scheelite, 6; others, 7.3); rutile, 4.2; sphalerite, 4; pyrite, 5; pitchblende or uraninite, 9. The gravity of other minerals is to be found in chapters 17 and 18.

The recovery of some minerals is lessened by their sliming properties; and despite their higher gravity than silica, the slime causes losses even if slime tables are operated. Malachite, molybdenite, limonite, tungsten minerals, stibnite, and cinnabar slime rather badly; so do clays and serpentines.

A lead-silver-zinc ore is easy to concentrate for its galena (7.5); but when the sphalerite (4) is to be separated from a rhodonite gangue (3.5), the respective gravities are too close for anything but low recovery.

Likewise, chalcopyrite (4.2) and sphalerite (4) cannot be much separated by gravity concentration, nor can a mixture of galena, chalcopyrite, and sphalerite and many other combinations.

As a rule, the lower the concentration ratio (original mineral content into concentrate) the lower is the grade of concentrate and the saving, and conversely.

This is where concentration by flotation succeeds. Although the process is not simple and requires careful attention, by the use of correct reagents on ore ground to suitable size remarkable separations of closely associated minerals and gangue matter are effected. Gravity has nothing to do with this process, whose principle is the wetting or not wetting of minerals by the reagents in solutions. One mineral at a time may be floated, and the other or others depressed to await their turn to be floated; or if only two minerals are in an ore, one—chalcocite, say—may be floated and saved while barren pyrite is depressed and wasted.

Jigging

The use and satisfactory results from jigs for many minerals is growing. The millman has the choice of the Allis-Chalmers (Woodbury improved), Bendelari, Cooley, Cottrell, Denver, Harz, Neill, Pan-American, Richards and Southwestern jigs. All are mechanically operated excepting the last three, which are hydraulically worked. Jigs give good service in acting as scavengers and collectors of coarse minerals and gold from mills. The concentrated material may be continuously or intermittently drawn off for grinding or further treatment. This removal from the mill circuit and separate treatment result in improved recovery from the other portion of the pulp. In the handling of gold ores it may eliminate the need of cyanidation (see Figs. 122 and 123).

Any jig may be placed below the stamps or ball-mill and between it and a classifier, but the pulp should be as thick as possible. Sometimes jigs are placed in series or one below the other. They save coarse and some fine gold, also heavy sulphides, which are run out of the hutch or pointed box at intervals or continuously, as desired. Unscreened and unclassified pulp may be fed to a jig, although the Harz type should have classified feed. The pulsating or jigging action is produced by a diaphragm or plunger

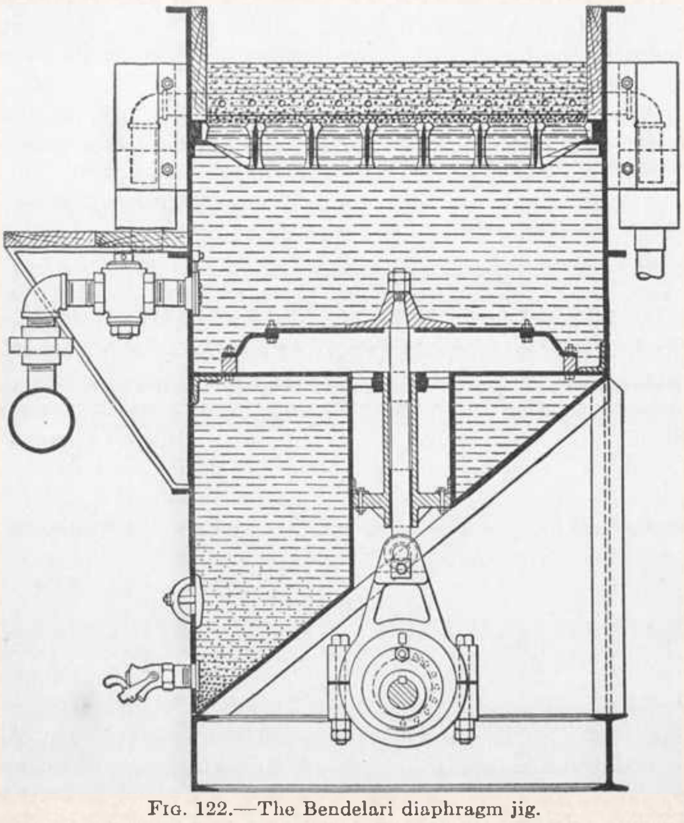


FIG. 122.—The Bendelari diaphragm jig.

operated rapidly in short strokes by an eccentric on a line shafting. In the Pan-American hydraulic jig the impulse is caused by water under a few pounds pressure moving a rubber diaphragm and a valve on the same spindle in a chamber. The pulp is fed on to a removable sieve assembly through which the heavy minerals pass to the hutch below. Feed as coarse as ¾ inch or finer than 40 mesh may be jigged. A 26-inch single jig will handle 5 tons of new fine feed an hour, plus a circulating load of five to six times the original feed. An 8- by 12-inch jig has a capacity of 15 to 50 tons

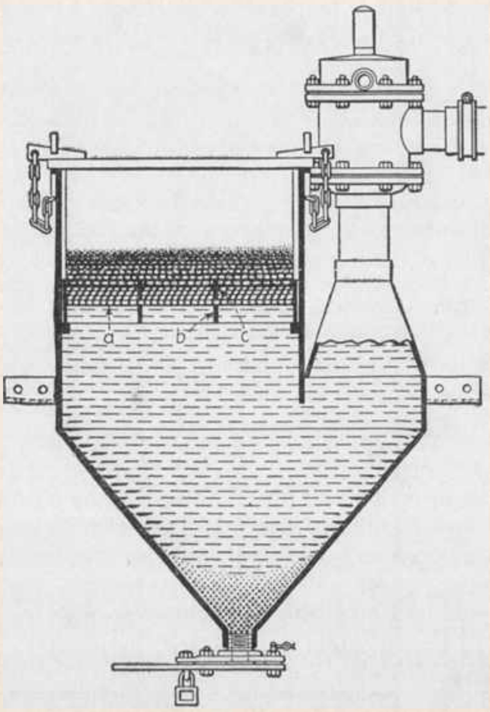


FIG. 123.—Simple hydraulic jig cross section normal to direction of pulp flow. (*a*) Screen supporting shot bed; (*b*) grids supporting screens; (*c*) shot-retaining grid, which clamps down screen. (*Pan-American Engineering Corporation.*)

of total fine feed in 24 hours. On coarse feed, say ⅛ inch from a ball-mill, a hydraulic jig will take 170 tons in 24 hours. The Richards jig depends on a pulsating movement imparted by a rotating valve in the main feed water line.

The action of jigging is described as follows by Hayward in his "Outline of Metallurgical Practice" (D. Van Nostrand Company, Inc., New York):

> If a mixture of minerals is placed several inches deep in a box with a screen for a bottom and suspended in a tank of water, a separation of the minerals into layers may be obtained by moving the box up and down in the water. A quick downward plunge forces the water upward through the ore, causing a classification. The succeeding upward motion accentuates [speeds up] the operation, causing the water to exert a greater downward pull on the heavier particles. Continuous machines have been developed for carrying on this operation with automatic discharge of the separated products. Jigs, as a rule, operate on coarser material than classifiers but utilize the same fundamental [basic] principles.

Hand-jigging, according to Taggart's "Handbook of Ore-dressing" (John Wiley & Sons, Inc., New York), is an indispensable operation in preliminary field testing of ores, ranking with panning and vanning. It is frequently done in treating ores from prospecting and small-scale development when the owner is trying to make a mine pay its way. In certain districts, particularly parts of the middle United States zinc-lead fields, jigging is the only method of concentration of many small properties.

> For field testing, any small sieve such as a testing sieve, a bucket or tub of water, and a small metal scraper or skimmer, are all that are necessary. The screen is filled one-half to three-quarters with the material to be tested, then, after careful submergence and thorough wetting, it is held firmly in two hands with bottom horizontal and top just submerged and moved up and down in such a way as will bring the material into part suspension on the down-stroke and allow it to settle back on the up stroke. This requires an accelerated [faster] down-stroke and retarded [slower] up-stroke. The usual speed is 60 to 100 strokes per minute. After a small number of strokes, depending on the size of particles and relative specific gravities of the com-

ponents of the bed, the impoverished [lower grade] surface layer may be scraped off and new feed added, and the process repeated until the top of the middling layer becomes so high as to leave insufficient room for new feed. This layer is then scraped off and set to one side and concentrate is removed from the screen. Middling may then be put back to form the bed for further operations. The fine material that passes through the sieve and overflows the top is collected separately. If the jig screen is fine, this material is best cleaned up in a pan or plaque; if the screen is coarse, the fines may better first be re-jigged through a bed of coarser concentrate on a fine screen, in this work accentuating [hastening] the start of the up-stroke and working with the top of the jig-sieve box always out of water. In this way, considerable suction through the bed is induced and fine heavy mineral is thereby drawn through. Slime may be separated from this concentrate by decantation and be treated separately on a plaque.

Tabling

There are several makes of shaking tables. They all work more or less on the same principle of the specific gravity of minerals but differ in riffling, tilt of the top, and head motion. Well-known machines are made in sizes to suit several capacities. They are covered with one-color linoleum (the newest Wilfley has a rubber-covered deck). Wooden riffles are tacked down and taper from ¼-inch height at the feed end to a knife-edge at the other end. One table has a stroke of ¾ inch and runs at 240 strokes a minute. The tilt is adjustable and is altered to suit the class of material being fed. This machine will handle up to 20 tons a day and is made right-hand or left-hand. Figure 124 shows a table in operation.

Following are names of makers of the well-known tables: Butchart—Butchart Manufacturing Company, Joplin, Missouri; Deister-Overstrom—Deister Concentrator Company, Fort Wayne, Indiana; James—James Ore Concentrator Company, Newark, New Jersey; Overstrom-Universal—Straub Manufacturing Company, Oakland, California; Plat-O—Deister Machine Company, Fort Wayne, Indiana; Wilfley—The Mine and Smelter Company, Denver, Colorado; Salt Lake City, Utah; El Paso, Texas; New York.

The Deister Machine Company builds three types of Plat-O tables, one of which is shown in Fig. 125.

The triplex Plat-O sand table is equipped with three plateaus, arranged in successive steps toward the concentrate discharge end of the deck from the junction of the lowest one with the primary concentration zone. Through the plurality of plateaus, this table is said to combine the functions of both a rougher and a finisher and will treat unclassified, classified, or deslimed feeds as coarse as minus ¼ inch, making a clean high-grade concentrate of substantially all the free mineral, with a capacity of 50 to 150 tons per 24 hours.

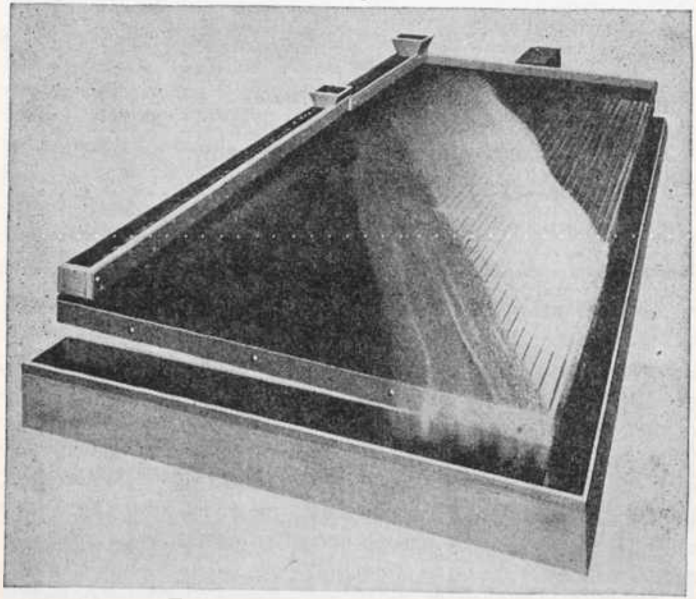


Fig. 124.—A Wilfley table in action.

The Plat-O fine sand table is of the single plateau type. It is usually intended for the treatment of minus 30-mesh materials and has a capacity of 30 to 40 tons per 24 hours.

The Plat-O slime table is of the single plateau type, has a comparatively low plateau, and is equipped with corrugated displacement riffles. It is usually intended for the treatment of minus 80-mesh material and will have a capacity of 15 to 30 tons per 24 hours.

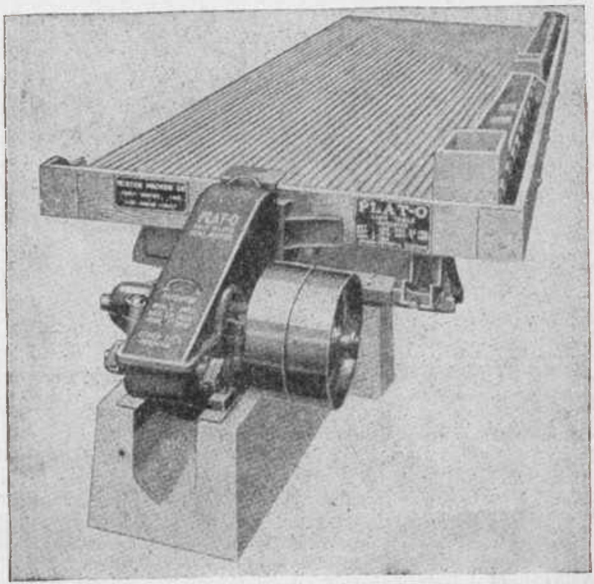


FIG. 125.—A Deister Plat-O concentrating table.

The feed to tables should not exceed 35 per cent solids (20 to 25 per cent is general practice). Dressing water requirements are 5 to 8 gallons per minute.

Power requirements average ¾ horsepower per table for continuous operation. When the tables are driven from line shaft (including line-shaft friction), 1 horsepower per table should be used as basis for figuring motor requirements. For individual motor drives, 3 horsepower motors are recommended for each table.

Concentration on Corduroy

Details of the use of corduroy are given in the section covering gold and silver, but there is no reason why this material should not be used by the small miner in the concentration of any sulphide ore—silver, mercury, copper, lead, antimony, and sphalerite, for example. Corduroy forms part of the concentrating equipment of the platinum ores of Transvaal, South Africa, whose value occurs in the metallic state in the oxidized zone and as sulphide at depth. At a small mine in the development or even the regular production stage, corduroy could form a temporary means of saving sulphides until the mill is enlarged and other suitable concentrators are installed—jigs, tables, or flotation cells. A high recovery could not be expected, but average results should be satisfactory; the expense of building sloping tables for the corduroy and their operation would be low. Experience with an ore and the pulp

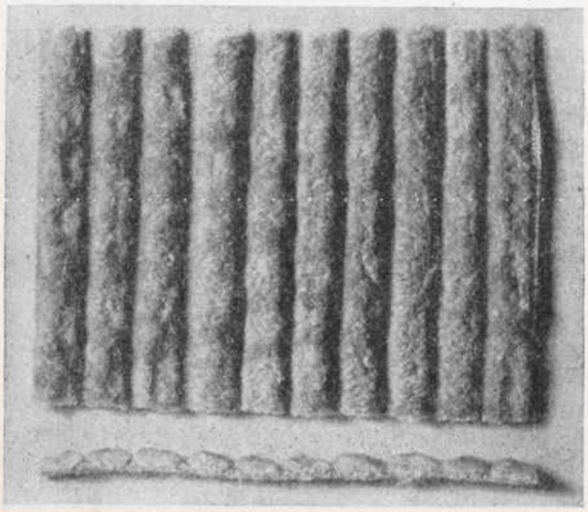


FIG. 125*A*.—Top and end views of corduroy. It should be laid with the high side facing the flow of pulp. Gold and sulphides are caught in the furrows between the ribs.

flow would show how much load the corduroy will carry and how often it should be washed. Tables for average gold-quartz ores with, say, 5 per cent sulphides (pyrite and arsenopyrite, gravity 5 to 6) require a slope of 1½ inches per foot, but argentite (7), galena (7½); and cinnabar (8), may need a greater slope than chalcopyrite and sphalerite (4); stibnite (4½), and chalcocite (5½). Figure 125*a* shows corduroy clearly.

Flotation

Wetting and not wetting or water-absorbing is the principle of flotation. Some minerals are wetted, whereas others are not wetted. Wetting is a variable property of minerals and depends upon the surface properties of the solid, liquid, and gaseous conditions. Minerals that are wetted do not float, whereas those which are not wetted float well. Therefore, all metal sulphides and most non-metallic minerals float, while the gangue or enclosing mineral sinks—galena and quartzite, for example. Gold of minus 40 mesh also floats, and such flaky materials as graphite and molybdenite are good floaters. With the recent developments in flotation reagents it is now possible to separate non-metallics.

In general practice, ores are crushed and ground fine in water (at least through 100 mesh and 25 to 50 per cent solids in the pulp), an oil or chemical is added to the pulp and thoroughly mixed, and the sulphides become attached to the reagent and float, but the gangue, peculiarly, is wetted by the water and sinks. During this operation, air is beaten into the pulp by rapidly driven propellers or agitators, and the oil-coated sulphides attach themselves to the bubbles of air and are carried upward. The consumption of oil and chemicals is generally low.

To quote an Australian engineer, in whose country the practicability of flotation was first done on a large scale:

> The art of flotation is to cause one mineral in a pulp to float while the other minerals do not float. In a mixture of galena, sphalerite, pyrite, and quartz, it is generally practicable to float the three useful minerals in succession.

In floating copper ores and lead-zinc ores, depression of the iron pyrite is important; but in floating gold-silver ores, the free gold and the iron pyrite are floated. The surface of iron pyrite may be altered while broken underground or on its way to the mill or during cyanidation and therefore needs special attention.

Reagents. Flotation reagents may be classified in three principal groups: frothers, collectors, and conditioning agents. The third group includes acids and alkalies for acidity or alkalinity control, sulphidizing agents, activating agents, and depressing agents. Excepting a few, all reagents are added as 5 to 10 per cent solutions; oils and acid are undiluted. They are fed regularly to the grinding circuit, to the flotation circuit, or to the conditioning tank.

Collectors are the reagents that enable the desired mineral to become attached to the air bubbles in the pulp and thus float. The quantity of collectors used varies from $\frac{1}{100}$ to $\frac{1}{2}$ pound per ton of ore.

For sulphide minerals the most commonly used collectors are the xanthates, usually potassium or sodium ethyl xanthate, and the corresponding amyl salts. For certain ores, thiocarbanilid, T-T mixture, and Aerofloat (phosphocresylic acid) are highly effective. Various coal-tar creosotes, coal tars, and pine tars are also used.

Frothers are the reagents necessary to produce the mineral-carrying froth. The quantity consumed is $\frac{1}{20}$ to $\frac{1}{5}$ pound per ton of ore.

For sulphide flotation various wood oils have been used, the most common being pine oil, particularly steam-distilled. Cresylic acid is a common frother of another type. Frothers should be used in as small quantity as is necessary to produce the best concentrates. Excess frothers give misleading results, in that too much froth is produced, gangue minerals may be floated, selectivity is poor, and recovery is misleading.

In non-sulphide flotation, frothers used may be the same as for sulphides, or sodium oleate, Emulsol X-1, Ninol, or an alcohol derivative may be used. When oleic acid is used, it alone may produce enough froth and also act as a collector.

It will be found, in general, that most frothers act as collectors to some extent; but if proper quantities are used, this tendency is not important.

Conditioning or modifying or regulating agents include soda ash, time, sodium silicate, caustic soda, sodium sulphide, sulphuric acid, and others—½ to 10 pounds per ton for the acidity or alkalinity of pulp; sodium sulphide for sulphidizing—½ to 5 pounds per ton; copper sulphate and sulphuric acid for activating —½ to 2 pounds per ton; sodium cyanide, starch, lime, and others for depressing—1/100 to 10 pounds per ton.

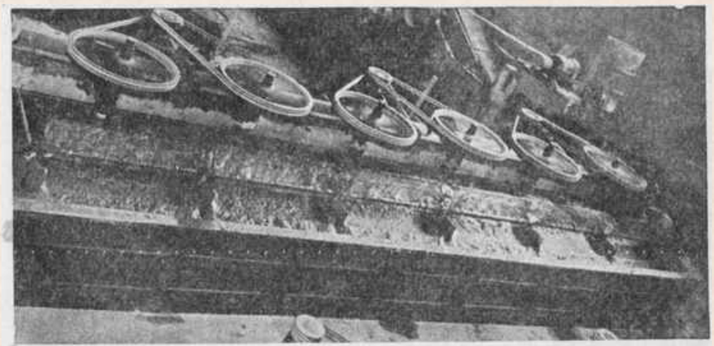


FIG. 126*A*.—First 6 cells of an 18-cell Minerals Separation counter-current flotation machine. Note the heavy froth. (*Minerals Separation North American Corporation.*)

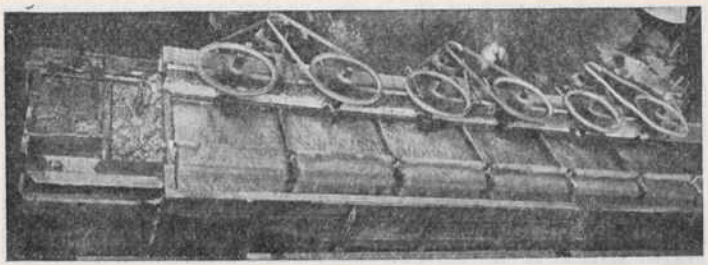


FIG. 126*B*.—Last six cells of the machine shown in Fig. 126*A*. Note the thin froth. This machine was floating zinc-lead ore. (*Minerals Separation North American Corporation.*)

Figure 126 *A* and *B* shows a flotation machine at work, and Fig. 127 shows what is going on in the cells.

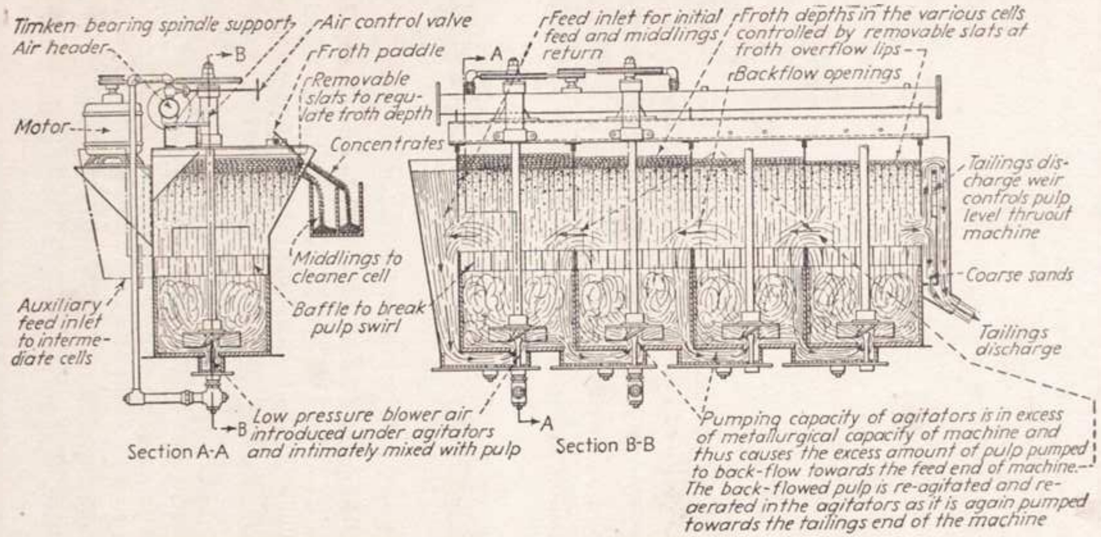


FIG. 127.—Sketch of a Minerals Separation counter-current flotation machine at work.

There are several well-known makers of flotation reagents in the United States: American Cyanamid Company, New York (also makers of cyanide); Dow Chemical Company, Midland, Michigan (seller); E. I. du Pont de Nemours & Co., Inc., Wilmington, Delaware (also makers of cyanide); Emulsol Corporation, Chicago; Great Western Electro-chemical Company, San Francisco, California; Hercules Powder Company, Wilmington, Delaware; Röhm and Haas Company, Philadelphia; and Sharples Chemicals, Inc., Philadelphia.

Makers of reliable flotation machines include the first-named in the previous paragraph; the Colorado Iron Works and Denver Equipment Company, Denver, Colorado; General Engineering Company, Salt Lake City, Utah; W. W. Gibson, San Francisco, California; Joshua Hendy Iron Works, San Francisco, California; Pan-American Engineering Corporation, Berkeley, California; Southwestern Engineering Company, Los Angeles, California; Stearns Roger Manufacturing Company, Denver, Colorado.

All the firms mentioned make tests on ores and give advice on the flotation of ores. Some of them make testing machines.

Filtering

The filtering of pulp and cloudy solutions is described under the subhead Cyanidation.

Magnetic Separation

Magnetic separation was first applied to ores about a century and a half ago, but not to any extent until the past 50 years. Several hundred patents have been issued for machines, but only a small number of well-known types are worked and a few manufacturers supply them. The range of use in individual plants is from several hundred tons to less than a ton of material a day, taking the iron minerals out of certain products and concentrating magnetic iron ore by removing the magnetite from waste and raising the grade from, say, 25 per cent iron to as high as 60 per cent. Magnetic separation may be done dry or wet, cold or hot, fine or coarse, at good recovery. In a table of the relative magnetic force of minerals, magnetite follows iron (100) with 40, franklinite with 35, ilmenite with 25, pyrrhotite with 7, biotite with 3.2, siderite with 1.8, hematite with 1.3, zircon with 1, followed by six minerals that are weakly magnetic. Many others follow that are practically non-magnetic in themselves; but if an iron mineral is present, some separation may be done. Minerals in these last two groups may be rendered amenable to some degree of separation by a light to high calcination or roasting. Most ceramic and other non-metallic products require low iron content, and magnetic separation may be applied. To see whether or not an ore is magnetic, crush some to a small mesh and pass a magnet over the surface of the material spread out. Many refinements have been made in magnetic separation equipment, and it is well for a small operator to obtain advice before setting out to try magnetic separation of metals or non-metals. Some makers are Dings Magnetic Separator Company, Milwaukee, Wisconsin, Sterns-Magnetic Mfg. Co., Milwaukee; Ritter Products Co., H. B. Johnson, Rochester, New York.

MOVEMENT OF ORE, PULP, SOLUTIONS, AND WATER

Provided the owner of a small mine can afford to get used or new plant, he needs certain equipment for the movement of solids and liquids. It is important that installations be well bolted down to wooden or concrete bases or foundations and accurately lined and set; otherwise the moving machines will give trouble.

As a rule, coarse and fine ore and also dry residues are carried by belt conveyer. An angle between 20 and 30 degrees is the limit of lift. Ore may be elevated to the top of a bin and to any machine by belt. Belt-and-bucket or chain-and-bucket elevators will make a vertical lift or one at a slight angle therefrom.

Pulp, which means sand, sand and slime mixed, or slime only with water or solution, is pumped in any direction by centrifugal pumps rubber-lined to resist abrasion. Plunger pumps can do this but wear rapidly. Diaphragm pumps are satisfactory for lifts of a few feet. Centrifugals and plungers (see Figs. 128 and 129) are good for clear solutions and water.

Residues or Tailings Disposal

The disposal of mill residues or tailings costs 2 to 6 cents per ton, however carefully it is done. Residues may be moist sand which can be conveyed by belt or trucked to a dump, moist solid slime which can be handled somewhat similarly, or pulp which can be pumped to a suitable place. The handling of sand and slime does not call for any special comment. With rails, a dump may be extended outward or it may be circular, the latter method being preferable. Pumps suitable for pulp have already been described. Pulp should be dammed in a dump made of the drained material. As the solids settle (a little lime or cement added to the pulp helps) and more or less clear water flows to one point for discharge to waste or for re-use in the mill, walls of the slime are built up with a good batter. If they are too steep, they might collapse. On some well-made dumps, every shovelful of slime can be seen up the side of the walls. The author has seen such dumps containing 10,000 to 2 million tons.

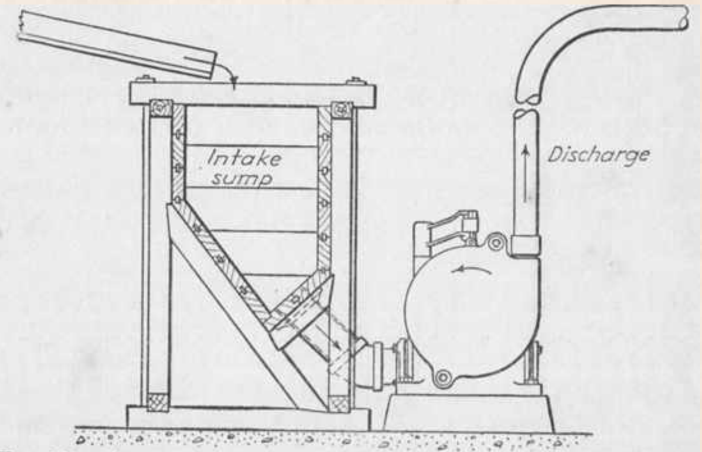


FIG. 128.—Arrangement recommended for placing a Wilfley centrifugal pump for liquids or pulp. This is suitable for any other make of pump.

A tailings pile should not become the dumping ground for all the discarded equipment, ash, cans, useless lumber, trees, shrubs, and other waste, because some day it might be profitable to treat the old residue and such trash not only would render "mining" difficult but would cause difficulties in treatment.

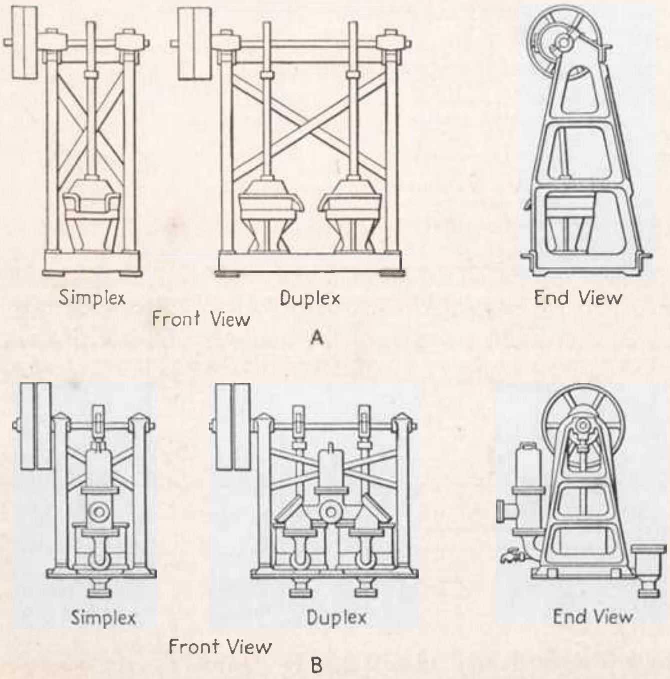


FIG. 129.—Dorrco pumps. (*A*) Two sizes of diaphragm pumps for low lifts of pump as from a thickener to an agitator. (*B*) Two sizes of pressure pumps for lifting water, solutions, and pulp where desired. The pulleys may be on either side and the drive shafts' rotation in either direction.

Dumps should not be too close to a mill because of possible additions to it and because of the dust nuisance; neither should they be built in a ravine or gulley which can be washed out by heavy rain and thus possibly cover ground held by others below.

As legislation against stream pollution becomes more widespread, particularly in agricultural and horticultural regions and where the water is used for domestic and stock purposes, the dumping of residues has to be done carefully, especially if solutions of cyanide and flotation reagents are used in treating ores.

EXAMPLES OF ORE-DRESSING AND TREATMENT

Following are general examples showing how a number of the common ores may be dressed and treated, but it should be remembered that each ore requires particular tests and no one process is entirely suitable for similar ores. There is *a* process for every ore, but there is no *the* process for all ores.

ANTIMONY ORE

Stibnite is the common ore of antimony. If an ore is naturally rich or can be sorted and improved in grade, the best procedure is to sell the product. Antimony smelters in the United States are operated by the Texas Mining & Smelting Co., Laredo, Texas; Menardi Metals Co., El Sequndo, California; and the Bunker Hill & Sullivan Mining & Constructing Co., Kellogg, Idaho. The local smelting of stibnite by the liquation process is not difficult, yet it requires experience. Stibnite has a gravity of 4½ and may be crushed, ground, and jigged and/or tabled, but the mineral slimes. If gold is contained, its recovery is difficult.

Ore from Lander County, Nevada, tested by the Federal Bureau of Mines, assaying 8½ per cent antimony in quartz and other gangue, gave up nearly 96 per cent of the antimony by grinding through 150 mesh and floating the stibnite, using copper sulphate for activating the solutions. The concentrate assayed 64 per cent metal. Tabling was unsatisfactory because the stibnite slimed too much.

CHROME ORE

Chromite may be of shipping grade as mined; it may be sorted to raise the grade; or it may be of low tenor and need concentration. The author visited a deposit in northern California where the chromite was scattered through serpentine similarly to chalcocite in porphyry. A stamp-mill and shaking tables were run for a period during the First World War. Sliming of the serpentine was troublesome. This ore assayed 6 per cent chromic oxide.

The Federal Bureau of Mines reports tests on chromite from Montana that carried 25 per cent chromic oxide in serpentine and other gangue. A considerable amount of mineral was freed at 10 mesh, and all at 100 mesh. By crushing, classifying, and tabling, the recovery was 93 per cent and the concentrates contained 44 per cent chromic oxide, a desirable grade for market. Tabling is fairly satisfactory for chromite; so is jigging, or both.

Demand for chrome ore has increased greatly since 1940, and the Federal Bureau of Mines and United States Geological Survey have investigated deposits in Stillwater County, Montana; Siskiyou, Shasta, and El Dorado Counties, California; and Chester and Lancaster Counties, Pennsylvania. Near Red Lodge, Montana, the United States Vanadium Company started the first unit of a 400-ton mill, late in 1941, treating chrome ore mined by open-pit methods. The ore is crushed to 1 inch, conveyed to 20-mesh vibrating screens, oversize going to ball-mills and undersize to classifiers. Sands from the classifiers go to tables, the concentrates from which are sent to a smelter. Slimes from the classifiers are sent to thickeners, and pulp goes to flotation.

In Stillwater County, Montana, the Anaconda Copper Mining Company started managing operations in 1941 for the Defense Plant Corporation in exploiting and recovering chrome from a low-grade deposit estimated to contain, based on first results of drilling and exploitation, about one million tons of chrome ore.

The Rustless Mining Corporation, a subsidiary of the Rustless Iron and Steel Corporation, Baltimore, Maryland, in 1942 started exploitation of chrome deposits in California, Oregon, and Washington.

COPPER ORE

Most of the common copper ores will bear more or less sorting, depending on their occurrence. The disseminated type—chalcocite (5.6) with pyrite in porphyry, for example—is unsuitable for sorting, and all must be milled. Chalcopyrite (4.2) and tetrahedrite (4.7) respond to concentration. These disseminated types of ores are easier to concentrate than are the massive types such as where chalcopyrite, pyrite, and pyrrhotite are intermixed, because with the first type only one mineral has to be recovered whereas with the other type the copper mineral has to be separated from the iron minerals which are a nuisance unless they contain gold and silver. The pyrite group is discussed under that head.

Some copper minerals, particularly malachite, slime badly and are unsuited to tabling.

In general, gravity concentration, which seldom saved more than 60 or 70 per cent of the copper with low-grade concentrate, has been replaced by flotation, which recovers up to 90 per cent with high-grade concentrate. Flotation is also satisfactory on fine metallic copper as in Michigan and in Chile.

When copper exists as the oxide or carbonate, it may be leached in place in a deposit or after it has been rather coarsely crushed and put into vats. Water may be used as a solvent for the ore in place, and weak sulphuric acid for the crushed ore. If conditions are favorable, the copper may be recovered at low cost.

GEMSTONES

Some gemstones (aquamarine, beryl, diamond, quartz, ruby, sapphire, spodumene, topaz, tourmaline, zircon, and particularly the diamond) are found in gravels; these and other gemstones (chrysoberyl, emerald, garnet, opal, spinel, and turquoise) are also found in their respective formations—igneous rocks, pegmatites, limestone, shale, and metamorphic rocks. The alluvial or placer stones are washed free of clay and gravel on screens and in jigs or pans, and the gems are sorted out by hand. The oversize material is discarded early in the operation. Diamonds occurring in rock formation in South Africa are finally saved on grease tables, which, strangely, do not hold pebbles or even glass.

FLUORSPAR

Fluorspar is adaptable to sorting underground and on the surface. Log-washing is commonly done on ore that is mixed with clayey material. If the mineral is accompanied by galena, jigging and tabling will make a fair separation because the gravity of the latter is more than twice that of the fluorspar. Classification should precede tabling. But if the spar has a gangue of calcite and quartzite, their gravity is almost similar and tabling is unsatisfactory. Flotation is suitable for such separation, the gangue being depressed and the fluorspar floated. Barite and sphalerite are sometimes troublesome with fluorite. The sizes required for the iron and steel industry are 1 inch for open-hearth furnaces, ½ to 1 inch for electric furnaces, and lump for foundry cupolas.

Mines in Illinois and Kentucky are the largest producers of fluorspar in the United States. The largest producer is Rosiclare Lead and Fluorspar Mining Co. at Rosiclare, Illinois. This company, produces by screening, jigging, and flotation, four grades of fluorspar most commonly desired by customers: the acid lump containing 98 per cent calcium fluoride for making hydrofluoric acid; the foundry lump, used in electric furnaces and foundry practice, containing 85 to 90 per cent calcium fluoride; the fluxing spar (no. 2 gravel), used in open-hearth steel furnaces, containing 85 per cent calcium fluoride and 5 per cent silica; the enamelers' and glass-makers' grade (no. 1 ground) containing from 95 to 98 per cent calcium fluoride and maximum of 2.50 per cent silica

GOLD AND SILVER ORES

An ore may be free-milling, which means that the gold can be recovered by simple amalgamation and/or cyanidation; it may contain gold and silver, which renders it more difficult to treat; or it may be refractory, which means that the gold is locked up with other minerals, generally sulphides and/or tellurides. Throughout the world there is much free-milling gold ore.

Silver with gold makes treatment slower and somewhat uncertain because the silver minerals do not respond so readily as does gold alone. Silver accompanies gold in gold ores, and they are extracted together, and conversely; but the quantity of each varies from low to high proportions. Also, gold and silver occur in copper ores, and they are recovered as by-products. Again, silver is a by-product of lead and zinc ores which seldom contain gold in pay quantities. It can be understood how gold and silver are intermixed; and in the extraction of gold from its ores, the silver, which is not so easily recoverable, must be carefully considered.

GOLD ORES

Assuming that we have crushed and ground a gold or gold-silver ore, let us proceed to recover as much of the precious metal as is possible.

Traps, Jigs, and Unit Cells

A growing and satisfactory practice in plants that treat gold and silver ores, particularly when the gold is coarse and with sulphides and tellurides, is to place a hydraulic cone or trap, mechanical jig, or unit flotation cell in the grinding circuit. These machines catch the heavy gold and minerals and hold them safely for 12 or 24 hours or for any desired period during the day. No mercury is used. The function of these is to relieve the pulp of such heavy and rich material, so that the finer gold may be caught on copper plates or on blanket or corduroy tables.

Figure 130 shows a simple trap with upward water current and locked top and discharge valve, as described by Ernest Gayford in an American Institute of Mining and Metallurgical Engineers (A.I.M.E.) paper on small mines.

In milling, when the mineral or a middling product is free, remove it from the circuit. Many millmen believe in all-sliming and do not remove anything until the ore is all fine, but even this method does not save some of the minerals; hence recoveries may be unsatisfactory. Jigs or unit flotation cells will remove the minerals freed from the gangue in the ball-mill and should be placed at the discharge of the mill. These machines will collect coarse and fine gold, silver minerals, and sulphides, all of which will be low in silica. The pulp from the jigs or cells may then be ground and amalgamated in a barrel and run over copper plates or corduroy, a shaking table or flotation cells, to a cyanide plant. It is possible, and it has been done, to eliminate cyanidation if the metal and minerals are recovered in this manner, the tailings being wasted. But such operation requires good control and testing of residues.

Amalgamation

Mercury or quicksilver fed into stamp mortar-boxes and riffles or applied to copper plates has been for ages the method of catching free gold. Many millions of ounces of gold have been saved thereby, and the mercury has been returned to circulation with small loss. Amalgamation is still practiced, but the recovery of gold by traps, jigs, cells, and cloth is lessening the amount so

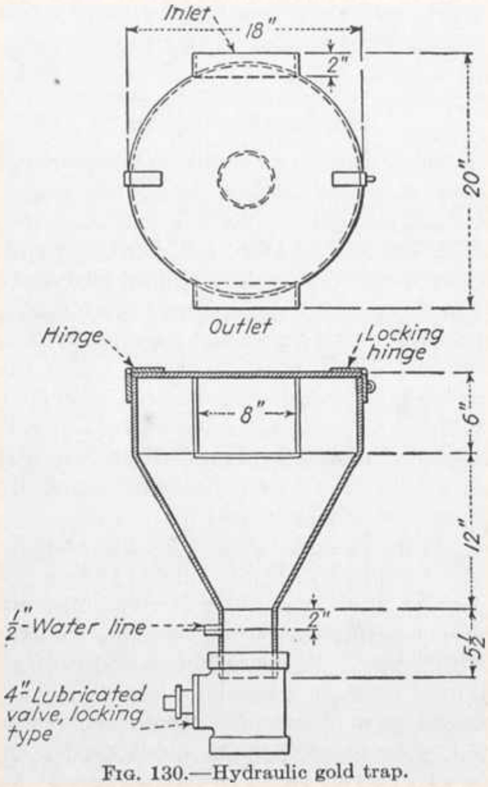


Fig. 130.—Hydraulic gold trap.

saved, although gold from these appliances is amalgamated for cleaning up.

Amalgamation is affected more or less by some pyrite minerals, especially if decomposed, also by antimony, bismuth, and copper. If such is the case, tabling could precede amalgamation or corduroy should be substituted.

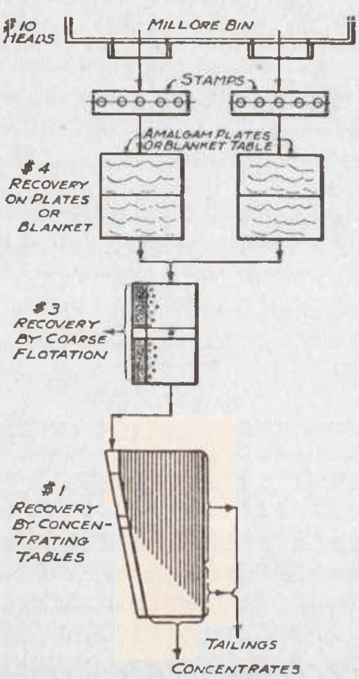


FIG. 131.—Flow sheet for gold recovery in a stamp-amalgamation-tabling plant.

Mortar-box. If a mine has a stamp-mill and inside amalgamation is desirable, mercury is added to the mortar-box in quantity enough to form a spongy amalgam therein and not enough to work out on to the copper plates and make them sloppy with mercury.

Copper Plates. Pure copper, 7/64 inch thick, is rolled into plates or sheets for the amalgamation of gold; 2 to 4 square feet is used per ton of ore per day. New or used plates are procurable, but care should be taken in selecting old ones because they may be uneven or thin and have small holes.

Copper plates are scoured with sand, washed with a strong solution of soda ash, and then rubbed with a rag in a 1 per cent solution of sodium cyanide. The plates are then washed with water, and a mixture of fine sand, mercury, and sal ammoniac is applied with a stiff brush until the plate acquires a thin film of mercury. Half an ounce or more of mercury per square foot of plate is then squeezed through fine-woven cloth on to the plate and rubbed in with a piece of rubber or a cloth soaked in a ½ per cent solution of cyanide, and the plate is again washed with water.

A coating of silver amalgam (made by dissolving silver foil in mercury or adding a 10 per cent solution of silver nitrate to the mercury) is advantageous, according to the Denver Equipment Company.

Best amalgamation will be obtained when:

1. The ore is finely enough ground to liberate the gold.
2. The pulp is dilute enough (20 per cent solids or less) to allow the metallic particles to settle to the mercury.
3. The slope (of plates) is enough to prevent sand accumulation (¾ to 1½ inches for soft ore and 1½ to 2½ inches for heavy ore). The pulp should flow in a series of waves.
4. The amalgam (also on plates) is pasty and bright.
5. No oil or grease is allowed to come in contact with the mercury.
6. The amalgam on the plates is not allowed to get thick enough to scour off.
7. The gold is clean, not tarnished.

(Use care in handling cyanide, which is a deadly poison.)

If copper plates become discolored while pulp is flowing over them, the ore or mill return water may be acid. A cure for this is to add wood ash or lye, if available, or lime to the ore as it is fed to the stamps or ball-mill.

Examples of Amalgamation. If the gold in an ore is free or mostly so, there is no reason why a high recovery may not be obtained, and two examples will be given from reports of the Federal Bureau of Mines:

1. At the Yellow Aster mine, Randsburg, California, gold lies in small fractures and joint-planes in granites which are mostly soft and oxidized. The gold is free and fine, and a little pyrite, arsenopyrite, and scheelite are seen sometimes. Silver occurs in the proportion of 1 ounce to 3 ounces of gold. The sorted ore is crushed by 1080-pound stamps through 30-mesh slot screens. Each battery of five heads has a chuck-plate, lip-plate, splash-plate, and a 5- by 14-foot apron-plate, with riffles at the lower end. Mercury is fed to the mortar-box and to all plates. Apron-plates are cleaned daily, and a general clean-up is made once a month. The loss of mercury averages 0.9 ounce per ton of ore

milled. During a period of over 30 years, amalgamation recovered 0.167 ounce of gold per ton and left 0.0325 ounce in the tailings. This means a saving of 80 per cent. The tailings are now being cyanided in simple manner at low cost.

2. At the Gold Hill mine, northeast of Boise, Idaho, the ore assays $6 to $8 per ton, and 92 per cent is saved by amalgamation. The gold is free in quartz but closely associated with a lead-bismuth mineral. The ore is crushed through 35 mesh in a ball-mill, and the first gold is caught in hydraulic traps in this grinding circuit. The pulp is next distributed to mercury-coated copper plates, which are followed by more traps, and then goes over rougher shaking tables. Middlings are ground finer and are sent to copper plates followed by traps. This pulp then flows over slime tables, and high-grade cut is taken from them. All the material caught in the traps and that from the slime tables are ground with mercury; this and the amalgam from the plates are retorted; and the gold is melted. Consumption of mercury is 0.045 ounce per ton of ore. The copper plates save 24.2 per cent of the gold; slime tables, 22.4 per cent; hydraulic traps, 38.7 per cent; and ball-mill elevators, 14.7 per cent. The total cost of milling is 62 cents or 31 pence per ton.

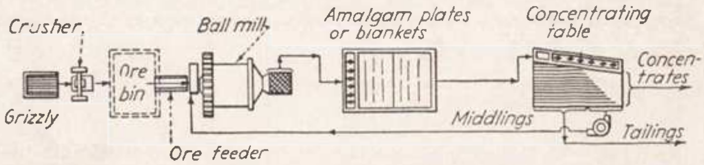


FIG. 132.—Amalgamation and gravity concentration. This flow-sheet is the lowest priced possible and can be used on an ore with a high percentage of free gold, and where it is unlocked at reasonably coarse grinding. A 5- to 10-ton plant costs $1500 to $1750.

Figure 131 represents the flow-sheet of a 10-stamp mill for crushing and concentrating a $10 gold ore containing some coarse gold and sulphides, as suggested by the Denver Equipment Company. As shown, 80 per cent is recovered; but if a re-grinding mill and classifier, with more flotation cells and another table, are installed, an additional $1.75 per ton may be

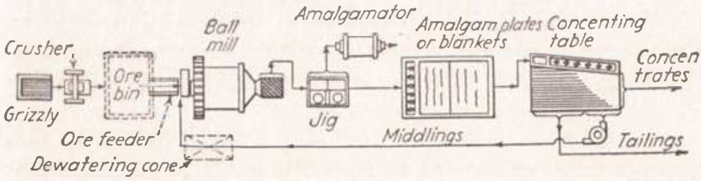


FIG. 133.—Mineral jig ahead of amalgamation. This is an inexpensive plant where gold is coarse but coated or filmed and will not amalgamate readily on plates. The jig recovers rusty gold in a high-grade concentrate for forced amalgamation treatment in an amalgamator. On these ores, blankets, corduroy, or matting usually is substituted for amalgamation plates and their concentrate is also treated in amalgamator. A 5- to 10-ton plant costs $2200 to $2500.

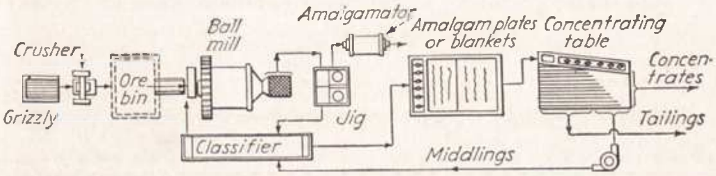


FIG. 134.—Jig in ball mill-classifier circuit. This flow-sheet with the addition of the classifier allows finer grinding and the jig used in the closed grind circuit has increased efficiency. It will give the highest recovery possible for amalgamation and gravity concentration. A 5- to 10-ton plant costs $2500 to $2750.

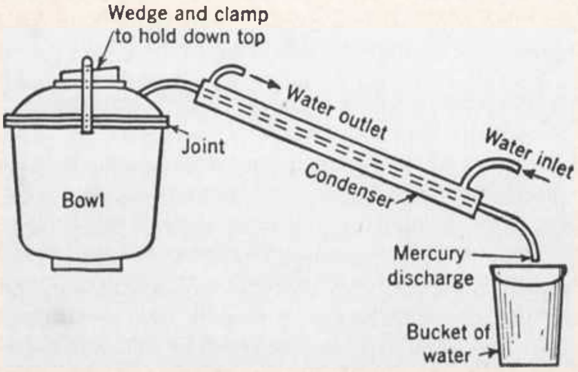


FIG. 135.—A retort for amalgam or mercury containing gold. This represents one of ½-gallon volume and holds 50 pounds of mercury; the retort weighs 25 pounds.

recovered. A jig could be used instead of the flotation cells shown, or the shaking table alone could follow the plates or corduroy, but perhaps the recovery would not be so high as with the cells or jig.

Figures 132, 133, and 134 are flow-sheets of amalgamation-concentration plants for a gold ore containing some sulphides as suggested by Denver Equipment Company, Denver, Colorado.

Cleaning and Retorting Amalgam. Mercury that has collected gold on copper plates, sluices, barrel, pan, or cloth materials should first be cleaned of sand, iron, and other material. This is done by skimming them off in the riffles or in a mercury bucket, adding more mercury to make the whole liquid. The clean metal may be all retorted, or it may be squeezed through any close-woven cloth or a chamois skin, leaving a ball of amalgam which is retorted.

If pipe and tools are available on a claim, a homemade retort and condenser may be built. Otherwise, it is better to buy one from a machinery firm or assay and chemical supply house. Retorts are made in sizes of 1-pint to 1-gallon water capacity and cost several dollars. Figure 135 gives details of a retort setup.

A furnace using any type of fuel may be made of brick or of rock, or a forge may be used. The retort should stand on a brick with the fuel all around it. Before the amalgam is placed in the retort, the inside of the bowl should be washed with a thick clay or lime emulsion or lined with paper. The lid should be clamped right, using a clay or lime joint. Heat the retort gently at first. and later increase the heat greatly.

The curved pipe from the retort top may be cooled for condensing the mercury vapor by means of wetted sacks or by a regular condenser that surrounds the pipe and through which cold water circulates. The condensed mercury runs into a bucket of water. All condenser discharge pipes should have a piece of burlap tied over the end and hanging in the bucket which is collecting the mercury. The end of the pipe should never be submerged in the water which is in this bucket; only the burlap. When the mercury stops, retorting is finished. The fire by this time has been allowed to burn down.

The hot retort is lifted out of the fire, and the top removed. (At this time a little mercury vapor will rise from the bowl; so stand aside.) The retorted gold is taken out and sold locally or sent insured and with instructions to the Mint at San Francisco, Denver, or Philadelphia. There is no need to melt it.

Final Cleaning of Copper Plates. Because of the need for cash or because a mine is to be abandoned, the copper plates are cleaned of all amalgam that has been absorbed. This may be done by covering them where they are with sacking or blanketing and heating them with steam from a pipe or hose. Then the amalgam can be scraped off. Or the plates may be lifted off their tables, placed on bricks or rocks built up a foot or so, coated with a solution of sal ammoniac, and heated by a wood fire under the plates. The amalgam can then be scaled off. (During this heating process some mercury vapor will be given off, so men engaged in this job should be well out of range of the vapor.

The amalgam and scale from such operations may be mixed and ground in a mortar or barrel with mercury and retorted or may be melted as is.

Sickening or Flouring and Reviving Mercury. Mercury is sickened, and perhaps floured, by all greasy materials, talcy minerals, acid water, soluble salts in ore, heavy iron pyrite, arsenopyrite, metallic oxides, mill water too cold, carbonaceous minerals as graphite in schist, and sulphides as antimony, bismuth, and copper.

It is important to keep mercury as clean and pure as possible; otherwise amalgamation will be poor and losses of mercury and gold follow. The metal may be purified by retorting it alone or with lime and fine iron. Sodium amalgam will revive sickened mercury. It is made by warming some mercury in a basin or flask and by some means dropping on to or holding under the mercury pea-size pieces of sodium. (There is some risk of burns while doing this, so one must be careful.) About 3 per cent sodium is enough to make the amalgam. It is then poured on to a flat surface to cool, broken up, and placed in a bottle under naphtha or kerosene. But as sodium amalgam is not used often, it should be made as required. If any mercury needs treatment to make it more active, stir in a few pieces of the sodium amalgam or dissolve it in some clean mercury and then add to the foul stuff. Sodium is obtainable from chemical supply firms and costs 20 cents per pound wholesale; sodium amalgam is also procurable.

While on the subject of amalgamating gold, we may suitably include something on platinum: Black sands or concentrates that contain platinum and have been re-concentrated with the iron minerals removed by magnet may be ground and analgamated in a barrel or other machines, as described. Amalgamation is promoted by the use of zinc amalgam, copper sulphate, and sulphuric acid. After being cleaned, the amalgam is squeezed and treated in earthernware jars with dilute sulphuric acid which dissolves zinc and iron. Then the amalgam is retorted. The retorted platinum may contain 70 per cent platinum metals.

Corduroy

Although blanketing, canvas, sacking, porous rubber matting, and skins with the hair on have saved much gold in the past, we will confine this section on gold-saving to corduroy. The author has seen this used in plants treating 50, 1000, and 1400 tons of ore a day, catching coarse and fine gold and sulphides. The process is described as world practice in *Engineering and Mining Journal,* New York, for February, 1935, and in *Information Circular* 7085 (1939), Federal Bureau of Mines.

Everyone knows corduroy by sight, even if he has not worn it, although the gold-saving material differs somewhat, the ribs and the space between them being wider. Instead of copper plates, the material is laid across the tables where the plates would be and is washed in a tub or barrel once, twice, or several times a shift. Corduroy is easier to handle than plates; it catches gold regardless of the rate of a stream of pulp and is excellent for recovering sulphides. Also, no chemical reactions affect the cloth as they do plates and cause loss of gold. Acid mine water has no effect; nor have antimony, arsenic, bismuth, clay, graphite, or lead minerals. Unclassified pulp may be flowed over the material.

If panning shows an ore to contain a fair amount of coarse gold and mineral, there should be no hesitancy in using corduroy, but only experience with it will show how to place it and how often to wash it.

The slope of corduroy or blanket tables depends upon the type of ore—steep for heavy sulphides and low for clean quartz containing a little mineral—for the latter, 1⅜ to 1½ inches per foot should be about right. Tables should be adjustable to 1 or 2 inches.

A table 4½ by 6 feet or 27 square feet, laid with three strips of corduroy or blanketing overlapping one another a couple of inches, is good for 100 tons or more of ore in 24 hours. A table 10 feet long and 28 to 30 inches wide will take care of the pulp from 5 stamps. One rule is 1 to 1½ square feet per ton per day.

As with the slope, the number of times that the cloth should be washed depends upon the gold content of the ore, also the amount of mineral. With $10 to $15 ore, carrying fine gold, once or twice a shift may be often enough; with ore of similar value, but carrying coarse gold, washing every hour or two is sometimes necessary. In general, it is advisable to wash the upper strips of corduroy more often than the lower ones.

Corduroy may be purchased in rolls or possibly in short lengths at $1 or 4 shillings or more a yard from the following firms:

American Cyanamid Company, New York.
Cottrell Engineering Company, Los Angeles, California.
Denver Equipment Company, Denver, Colorado.
James Johnson, Manchester, England.
National Equipment Company, Salt Lake City, Utah.
Peacock Brothers, Montreal, Quebec, Canada.
Plummer Bag Manufacturing Company, Los Angeles, California.
G. and R. Wills, Perth, Western Australia.

As a rule, machinery and supply houses in mining districts handle corduroy or will get it for anyone who wants it. Corduroy concentrates are ground and amalgamated in a barrel or Berdan pan.

Tabling and Floating

These operations are described under their own general heads, but many gold-silver ores are rendered more suitable to cyaniding if sulphides are first removed. As previously stated, concentrating machines do much better work if they are given a classified feed—coarse and fine. Of course, if a plant has only one table or cell, it must take the whole pulp.

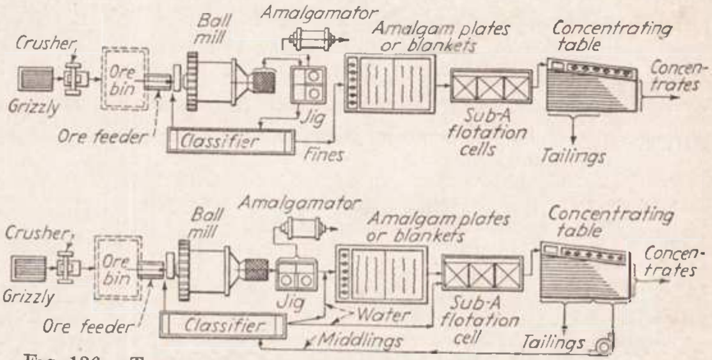


FIG. 136.—Two arrangements for catching gold and sulphides. Above, jig, amalgamation, flotation, concentration. Below, retreating middlings from concentrating table.

The addition of flotation brings recovery to the highest point as slimes are recovered as well as more granular minerals. Gold that can be amalgamated is in bullion form and the remainder is recovered in flotation concentrate, this flow-sheet is necessary where a minor percentage of gold is present as metallic, at general fineness of grinding and where the minerals are friable and easily slimed in fine grinding such as galena or the telluride minerals. A 5- to 10-ton plant costs $3650 to $3900.

As a rule, gold ores, if they carry sulphides, have chiefly iron pyrite or arsenopyrite, with minor amounts of pyrrhotite, chalcopyrite, and galena. These are generally easily separated from the quartz and other silica minerals by tabling or floating or by both (Fig. 136). The pulp, after more or less grinding, is then ready for cyanide treatment. Some pulps, after being concentrated, are run to waste because the precious-metals content is too low to pay for further handling. A great daily tonnage of gold-silver ores is being treated in this way. The residue is somewhat higher than if the ore had been fully treated, but the cost is much lower.

Grinding and Amalgamating Trapped, Tabled, or Clean-up Concentrates

Grinding and amalgamating are practical and satisfactory methods for treating gold-bearing concentrates or black sands or for cleaning up a mill. The gold is brightened and made more amalgamable. The tailings might be rich enough for cyaniding.

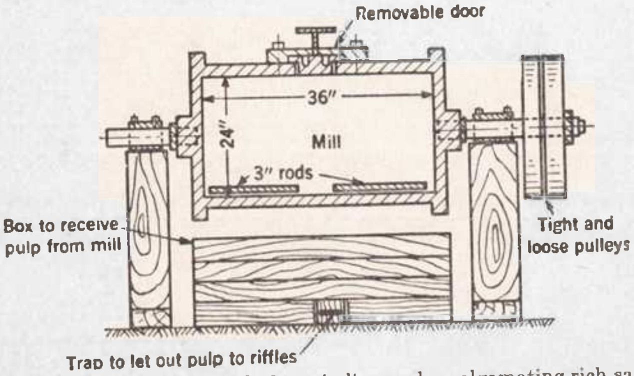


FIG. 137.—A ball mill suitable for grinding and amalgamating rich sands.

Figure 137 shows an amalgamation barrel. Laboratory ball-mills and the smaller of the ball-mills (amalgam gets behind liners in these) used in regular ore-grinding could be used; so could a small concrete mixer. Some firms make barrels for grinding and amalgamating. One can be made on the job from a pressed-steel oil-drum, but it should be scoured with hot water or by burning out the oil. Amalgamation barrels may run on rollers, or a shafting attached to the ends sits in regular bearings. The barrels have a cover which is clamped on, with a rubber gasket to prevent leakage.

A barrel is charged partly full with concentrate, water, mercury, a little lime or lye, and several steel balls or short pieces of shafting. The lid is set, and the machine started. It is run for an hour or several hours, depending on what is being ground. The pulp is then let out; the mercury and amalgam are washed clean and finally retorted. To prevent flowing of the mercury, it may be added to the charge after the grinding is finished.

Figure 138 shows a Berdan pan, whose use is spreading. It is an old type of machine, is as satisfactory as a barrel and causes less work, and is made by several firms. The pan is a cast-iron basin, lined or unlined, driven by gears above or beneath, the whole fitting into a wooden or iron frame. The pan is set at an angle of 15 degrees to the vertical and is driven at 20 to 30 revolutions per minute. It may be driven either right or left. Grinding is done by one or two large steel balls or preferably by a heavy drag cast to the shape of the pan. The pan's direction of travel is down from the drag, but either direction is suitable if balls are used.

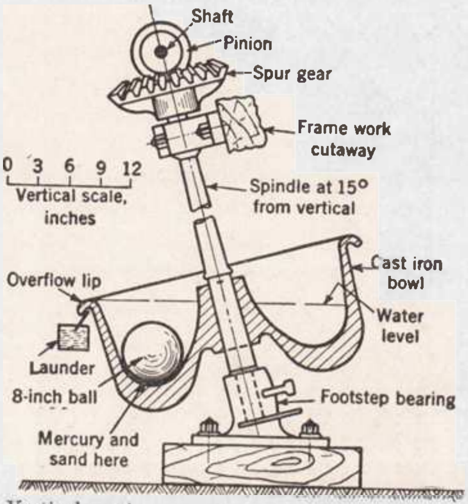


FIG. 138.—Vertical section of Berdan pan; supporting frame removed. Some Berdans are gear-driven beneath the pan, thus eliminating the spindle and top gear. (*After Henry Louis, with notations by the author.*)

In operation, grinding may be done in charges or with continuous feeding and overflow. When the process is carried on in charges, the feed is added; and when the latter is ground fine enough, water is turned on and the slime is washed out into a launder. In continuous work, the amount of water added determines the fineness of the tailing. Mercury, in amount to be determined by experience, is placed in the bowl of the pan. To clean up, when all the feed has been ground and the water becomes clear, the mercury and amalgam are scooped out and squeezed or retorted as is.

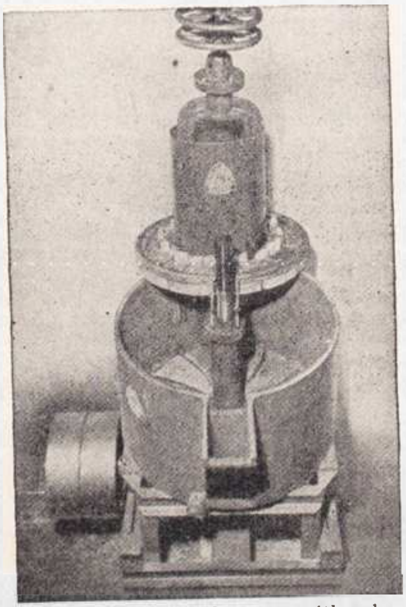


FIG. 139.—Grinding pan, as described in text, with yoke and muller lifted out to show dies and central spindle.

Wheeler Grinding Pan. A clean-up pan of the Wheeler type is made by the Denver Equipment Company. It is designed for batch or continuous grinding and amalgamation of high-grade ore and concentrates. By its use, free metallics can be removed before the concentrate is sent to a smelter, or the material being ground may be treated at the mine. A brief description follows: The pan, which sits on a low wood frame, is of 1-inch cast iron. In the center is cast a hollow tube through which passes a steel spindle that engages a yoke and grinding muller in the pan and is gear-driven beneath. The muller has shoes attached, and these grind on dies at the bottom of the pan. In operation, the batch of flow of pulp is run into the pan, mercury is added, and the muller lowered on to the dies while the pan is rotating, this being done by means of handwheels and a screw spindle working in the yoke. The slime produced overflows from a weir which is cast on to the pan's side. The amalgam accumulates between the dies and the point where their lugs engage the side of the pan and the central spindle tube. Operation and clean-up are simple, the writer having run a group of eight 60-inch pans on rich ore.

This pan is made in 4 sizes—12-, 24-, 36- (see Fig. 139), and 60-inch diameter. The 24-inch size is suitable for small plants. It is built up of welded plate, and the muller spindle is gear-driven from the top. This size requires 3 horsepower and weighs ½ ton.

Amalgamating Drum. Another suitable machine for treating small quantities of black sands or clean-up material is the Denver amalgamating drum. The 12-inch size has a capacity of 25 to 50 pounds per charge and sits on the same foundations as a ¾-horsepower gasoline engine or electric motor. The drum is belt-driven. Ordinarily, a single large ball grinds and amalgamates the pulp. A tilting device allows the slime to be drained out while the machine is rotating. The concentrate is removed through a drain outlet on the amalgam groove. This collects the mercury and holds the concentrate while the slime is being discharged.

Arrastre. A simple motor- or animal-driven arrastre is sometimes used for cleaning up. One with a 48-inch-diameter, cast-iron bowl, in which travel two iron shoes, is satisfactory for grinding and amalgamating the coarse and fine materials from sluices and corduroy. Lime or lye and mercury, of course, can be added to the charge. The ground pulp is drawn off and panned, and the amalgam is handled in the regular way.

Black Sand. What follows is abstracted from *Information Paper* 7000 by vonBernewitz, published by the Federal Bureau of Mines in 1938, itself partly compiled from scattered reports which are acknowledged therein.

During the past 50 years or more there has been a great waste of money, energy, and time in devising, building, and trying many machines to recover gold and platinum, also gemstones, from black sand. Volumes have been written on the subject, and many inquiries have been made by prospectors and others who thought that although they could not save the precious metals, which most likely were never there, some process must be suitable. Near Nome, Alaska, the black sand was rich, and some on the west coast of the South Island of New Zealand is being worked at a profit at the present time. A few spots along the California-Oregon coast were worth handling, as have several along the rivers in the western United States and Canada. The black sands from sluicing and dredging operations are worth careful treatment because they are from the concentration of thousands of yards of gravel daily. By-product black sand from inland placering is often richer than beach sand. But generally, black sand, unless a concentrate, is not worth much effort. In any case, it is worth spending a dollar or two to have an assay made for gold of a carefully taken sample, not selected sand. The Denver mechanical gold pan can be used for sampling test pits of sand.

Most placer gold is associated with black sand, which is composed largely of grains of magnetite (magnetic iron oxide) but may contain varying proportions of hematite (non-magnetic iron oxide, but rendered magnetic by heating), ilmenite (iron-titanium oxide), pyrite and marcasite (iron sulphides), monazite (cerium, lanthanum, thorium phosphate), rutile (titanium oxide), scheelite (calcium tungstate), tourmaline (boron and aluminum silicate), wolframite (iron-manganese tungstate), zircon (zirconium-silicate), chromite (iron oxide and chromium oxide), and other heavy minerals.

A cubic yard of gravel may yield up to 100 pounds of black sand. But more or less of this material does not indicate much or little gold. If too much is present, it is a nuisance in filling the riffles of a sluice-box. The specific gravity of the minerals that compose black sand ranges between 3 and 5. Crude gold's gravity is 15 to 19, and crude platinum 14 to 19. The gold and platinum particles exist generally as fine, thin scales which are difficult to save. They tend to float and thus be lost; therefore they should be wetted before being panned or washed in any way. The previous metals may be rusty or tarnished, therefore difficult to amalgamate without grinding. If crude platinum metals are present, they probably will not contain more than 65 per cent platinum, and buyers pay for this metal only on the market price for the pure metal. Therefore, transactions will be at several dollars an ounce under the market price.

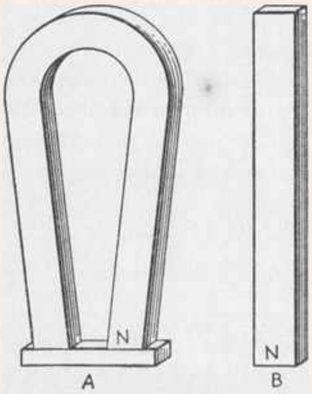


FIG. 140.—(*A*) Horseshoe magnet; (*B*) bar magnet.

When a black-sand concentrate has been collected, before it can be treated locally or sold it should be reduced to as small a bulk as possible. By repeated panning, rocking, long-tomming, jigging, tabling, magneting, or passing the sand over cloth of some kind, most of the more or less worthless material may be discarded.

Figure 140 shows a horseshoe magnet and a bar magnet. Care must be taken in using them because the precious metals may be somewhat coated with iron and the magnet might attract some of them with the real iron minerals. By this means some gold may be lost. Therefore the magnetings should be carefully examined before they are discarded. If a piece of cellophane or other material is held over the magnet, only iron minerals will be lifted out.

Figure 141 shows a hand-jig which is suitable for treating black sands. The feed may be sized or unsized. The sieve may be movable or fixed. If the former, the sieve constitutes the bottom of a frame or basket which works in a tank of standing water. The simplest jig is a hand-jig whose feed and discharge are intermittent. Jigs with fixed sieves are more common and are generally homemade. The motion of the water is actuated by a plunger, either at the side of the jig cell or under it. New water must be added to replace what passes over the tailboard and through the hutch.

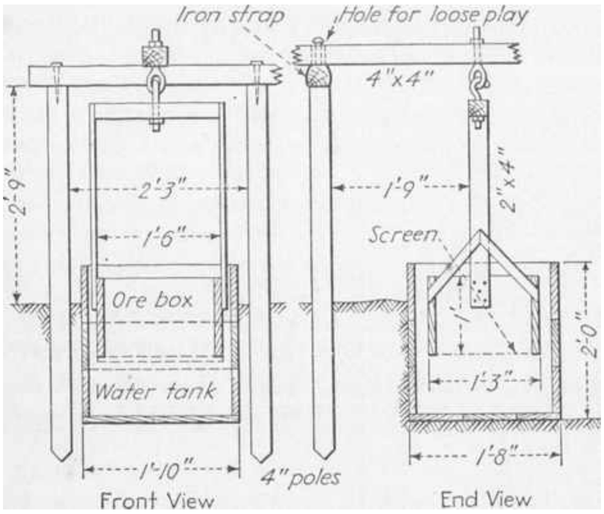


FIG. 141.—A simple hand jig. (*According to A. F. Taggart.*)

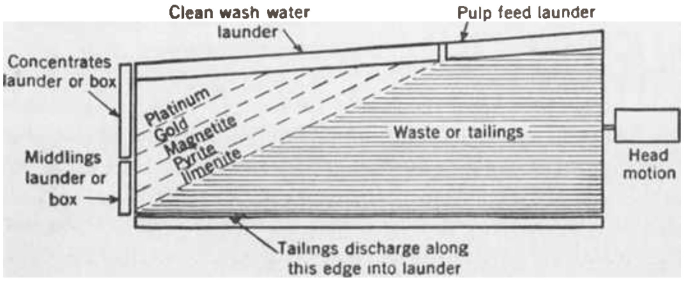


FIG. 142.—Top of a gravity table, showing approximate strata of minerals.

If a placer claim yields much black sand of value, it might pay to install a small shaking table. These machines are described under Concentration, but Fig. 142 shows the deck of a table while concentrating black sand. The iron minerals are saved as middlings and are returned to the table, while the precious metals are caught in a launder, box, or tub.

When the black sand has been re-concentrated into small bulk, it may be ground and amalgamated at the mine, as described earlier in this section on gold, or sent to a smelter. But first it should be assayed, because its value must be known before smelters will accept it. Some smelters and dealers do not pay for platinum; others make part payment; others make full payment. There is a smelter at Tacoma, Washington; Selby, California; El Paso, Texas; Garfield, Utah; East Helena, Montana; Carteret, New Jersey; a treatment works at Smartsville, Yuba County, California; and buyers are located in San Francisco, California; Newark, New Jersey; and Toronto, Ontario.

In cleaning up at the Rock Creek placer of E. T. Fisher Company, New Atlantic City, Wyoming, amalgam, liquid mercury, and 3 gallons of concentrate are removed from each 12-foot sluice-box which is fitted with riffles. Considerable black sand is washed over during the clean-up, and in the final treatment of the concentrate, when the liquid mercury is washed out and coalesced, most of the sand is wasted. The final riffle material is ground for a half hour in a barrel with mercury and old cast-iron bucket teeth. If grease is present, cyanide or lye is added. The sludge is riffled again, and the black sands discarded. The live mercury is strained; the amalgam is retorted; and the retort gold is shipped to the Mint. The gravel averages 24 cents a cubic yard, according to a report of the Federal Bureau of Mines.

Cyanidation

As coarse gold is not dissolved by cyanide, it must be removed from an ore by one of the methods already described. Weak solutions of sodium cyanide (or potassium cyanide, seldom used) will dissolve the fine, untarnished gold and silver in ores and tailings, provided the latter have been ground fine enough and do not contain any material, such as acid compounds or minerals, that would affect the cyanide. The gold and silver are recovered or precipitated from the solutions by means of zinc shavings or zinc dust. Melting of the dried precipitate with fluxes yields marketable bullion. An entire ore may be slimed and cyanided, or it may be divided into sand and slime and then cyanided. Tailings may be sand or slime or a mixture of such. Barren solutions, when strengthened with more cyanide salt, can be used again. The strength of solutions must be known, but this is easily determined, as described later.

Cyanide. Two types of cyanide are used in treating gold and silver ores and tailings, also in the flotation of ores: sodium cyanide, which contains 98 per cent NaCN, and calcium cyanide (Aero brand), which contains up to 50 per cent NaCN equivalent. The wholesale price for these cyanides has been steady around 16 to 18 cents or 8 to 9 pence a pound for the sodium salt and 13 to 15 cents or 6½ to 7½ pence for the calcium salt per pound of actual contained sodium cyanide equivalent. As a rule, one cyanide is as effective as the other, but more of the calcium salt must be used because of its lower strength.

Cyanides should be purchased from chemical supply firms. The sodium salt is made in the form of small cubes or in blocks or cakes packed in drums. The calcium salt is made in the form of black flakes and is packed in drums holding 100 and 200 pounds.

Both forms of cyanide adsorb moisture on exposure and become slippery. Both are easily soluble in water, the calcium salt leaving a little undissolved material in the dissolving tank.

(Cyanides in any form—as salts, as strong and weak solutions, and as vapors in enclosed places—are deadly; precautions are necessary at all times when handling these forms of cyanide.)

Cyanide may be added to water to form solutions or to strengthen weak solutions by dissolving part of a drum or several drums of it in a special stock or stronger-solution tank or by placing the salt at some point in a launder or in a basket at the discharge of a pipe where pulp or solutions are flowing. When a stock tank is used, the solution's strength must be known before any is mixed with weak solutions; and when the salts are dissolved by flowing material, the amount used must be calculated to give the proper strength.

Water. An important factor in cyanidation is the quality of the water used. At most places this does not occasion any trouble, but in others it may be brackish, salty, acid, or high in magnesia. The acidity or alkalinity of water is simply determined by means of litmus papers, as explained in another part of this book. Milling, cyaniding, and floating can be and is done satisfactorily in brackish or salty water. If acid, the water must be neutralized with lime, even before milling and especially before amalgamation. In parts of Australia and Rhodesia the water is high in magnesia. This increases the consumption of cyanide, but the addition of lime precipitates the magnesia and leaves the water slightly alkaline. For example, 8, 12, 15, 22, 28, and 40 pounds of lime have been added per ton of water to precipitate the magnesia; and at one mine, where 12 pounds was required, the cyanide used was cut from 2 pounds to ⅓ pound per ton of ore treated. Therefore, the quality of the water must be watched.

Solutions. Clean gold ores may be treated with first solutions having a strength of 0.05 per cent or less NaCN and with a consumption of 1 pound or less per ton treated. If silver occurs with the gold, the strength and consumption will be somewhat higher. Straight silver ores require a solution strength of 0.3 per cent or more NaCN and consume twice as much cyanide as do gold ores. Concentrates may need solutions as strong as 0.1 to 0.8 per cent NaCN, depending on the silver, and the consumption may reach several pounds per ton.

Cyanide solutions may become more or less fouled by the decomposition of minerals during treatment, this forming soluble sulphides. If this condition arises, they may be rendered harmless by adding lead salts in the form of lead acetate, lead nitrate, or lead oxide (litharge). These salts may be added at any point in the plant, but the proper time must be determined by trial. The quantity consumed is small.

Cyanide solutions must be kept alkaline, and lime is added at various points in a plant, including to the ore as fed to the mill.

The first solutions used in a plant are made up of fresh water (salt water will do if it is the only water available) and sodium or calcium cyanide, but all new strong solutions are made up of weak barren solutions and either the cyanide salt (98 per cent) or a strong solution from a stock tank containing a 10 to 20 per cent cyanide. A calculation involving the strength of the salt or stock solution, of the barren solution, and of the desired solution, also the quantity of the solution needed in tons, gives the amount of salt or stock solution to be added.

It will require 2 pounds of sodium cyanide for each ton of water to make a solution testing 0.1 per cent cyanide or half of that amount for an 0.05 per cent solution. If weak solutions are used in the make-up, the salt required will be less than these amounts.

How to Test Solutions of Cyanide. Solutions of cyanide are tested by the silver-nitrate method, as follows:

1. Dissolve 13.08 grams of silver nitrate in 1000 milliliters or 1 liter of distilled water. (If only occasional tests are to be made, take half or a quarter of these quantities or buy the solution ready made.) Keep the solution in a dark bottle because it decomposes in the light.
2. Dissolve 10 grams of potassium iodide in 100 cubic centimeters of distilled water.
3. Two 50-cubic centimeter burettes on one stand or two close together are required.
4. Fill the burettes—one with the cyanide solution to be tested and the other with the silver-nitrate solution.
5. Measure out 10 cubic centimeters of cyanide solution into a small beaker, add to it two or three drops of potassium iodide, and then slowly drop in silver nitrate. A whitish turbidity shows but re-dissolves as long as any free cyanide is present. The beaker should be shaken. The end-point is a permanent faint white to bluish turbidity.
6. Note the amount of silver nitrate used and calculate: 1 milliliter of silver nitrate = 0.1 per cent cyanide or 2 pounds of cyanide per ton of solution.

THICKENING

Thickening pulp means allowing the solids to settle to the density required so that they may be pumped from thickener to agitator or filter or elsewhere. While settling is taking place, the surplus water or weak cyanide solution is clearing of suspended slime and is allowed to flow over the side of the thickener and into a launder for re-use. The settled or thickened slime is drawn off at the bottom of the tank by gravity or by diaphragm pump. Filling, thickening, and drawing off is continuous. To prevent the slime from settling hard on the bottom of the tank, thickeners have, like agitators, a central gear-driven spindle with arms and rakes, but the speed is very slow so that the slime is not stirred up.

There are several types of thickeners (Fig. 143). In simple cyanidation, thickeners are placed ahead of agitators and filters.

They are also used in the countercurrent washing and decantation process and for thickening residues so that the surplus water may be saved.

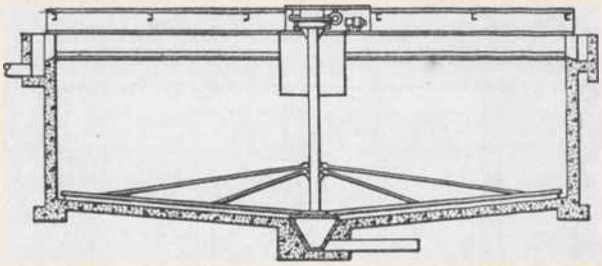


FIG. 143.—A Hardinge thickener. The pulp enters at the top center. The thickened slime settles to the bottom and is scraped to the bottom center by the revolving arms and is there discharged and piped where desired. The clear water or solution overflows in a launder which surrounds the tank.

Thickening can be done to a degree in classifying cones.

AGITATING

When slime is being cyanided, agitation is necessary to keep it from settling and to beat in air which supplies the oxygen needed for the dissolving action of the gold and silver. The period of agitation depends upon the fineness of the pulp, on whether the ore is gold- or silver-bearing, and on the type of machine used. Experience with an ore is the only way to determine this; it may be 12 to 24 hours for simple ores. Silver ore generally requires twice as much time as gold ore. Concentrates may need several days to a couple of weeks.

If an ore is crushed and ground in water or in weak solution, lump cyanide or a strong solution is added to the agitator to bring the pulp to the required strength.

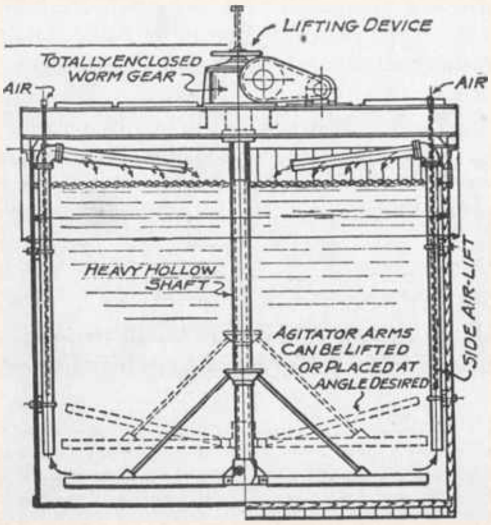


FIG. 144.—A Denver agitator with central spindle and rakes and side air shafts. In case of a shut-down, the entire shaft assembly can be raised to prevent slime from settling around the arms. There are 16 sizes of these agitators, the smallest being 10 feet in diameter and 10 feet high, with a volume of 555 cubic feet per foot of depth. A 2-horsepower motor will drive this size.

The simplest type of agitator is a tank in which is a central gear-driven spindle at whose bottom are two arms or rakes fixed thereon slightly above the vat bottom. The arms may have light plows attached to prevent slime from settling too hard. Agitation may be aided by means of compressed air freed from a fixed pipe at the bottom of a tank and at or near the side (Fig. 144). The Dorr agitator of the spindle-and-arm type has an air-lift in the spindle and thus circulates the pulp. The Denver type has an air-lift inside against the side. These agitators rotate at slow speed. In case of a shut-down, agitator spindles and arms may be lifted vertically or the arms may be lifted from the horizontal to an angle to prevent their becoming embedded in pulp.

Several agitators have short, high-speed impellers which operate high up in the pulp or within a central pipe of several feet diameter. Rapid circulation results, and the agitation period is much shorter, but power consumption is higher. Such machines are suitable for treating concentrates and beat much air into the pulp.

The air agitator, which consists of a tall, narrow tank with coned bottom in which is a central air-lift, is used in many places and is favorably regarded. Slime accumulating at the sides is troublesome, and high pumping is part of the transference of pulp.

FILTERING

In cyaniding, it is necessary to separate the gold- and silver-bearing solutions from the slime so that they are clear for precipitation of the precious metals on zinc. This is done by means of cotton filter-cloth of standard weaves and weights. The solutions pass through the cloth and leave thereon the cake of slime. (In leaching sand in a vat, the filter-frame on the bottom is covered with filter-cloth; and in clarifying "clear" solutions, sand makes a good filter in a vat bottom.)

As in all cyaniding equipment and that for dressing any kind of ore there are several makes of filters: the rotating disk, stationary or movable leaf, plate and frame, and rotary drum.

Figure 160, in the section on preparation of concentrates, shows a thickener-filter arrangement also suitable for cyanide pulp.

For small plants, the Oliver rotary filter (Fig. 145) (*a* and *b*) and Butters or Moore leaf filters are probably most suitable. The former is made by the Oliver United Filters Company, San Francisco and New York, and the other types are available from cyanide-equipment makers.

Briefly, the rotary filter consists of a drum covered with cloth which is held in place by wire wound around it. The drum, attached to horizontal shafting, revolves in a tank into which the

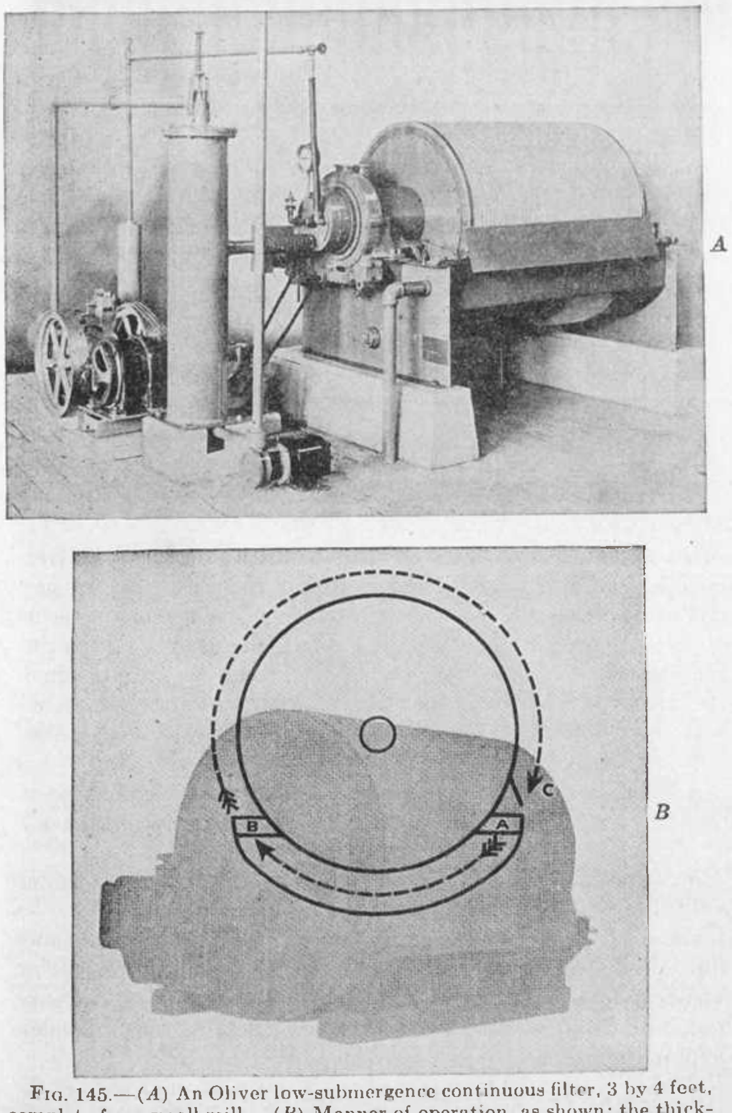


FIG. 145.—(*A*) An Oliver low-submergence continuous filter, 3 by 4 feet, complete for a small mill. (*B*) Manner of operation, as shown: the thickened or agitated slime is fed into the tank *A-B* where it is packed up by the rotating filter, washed and dried between *B* and *C*, and discharged at *C*.

treated pulp from agitators is continually flowing and kept agitated. A vacuum is maintained in the drum, and spray nozzles wash the cake formed thereon with weak barren solution or with water. At the opposite side of the drum, compressed air is admitted and a scraper lifts off the final more or less dry slime, which is wasted or re-treated. All these operations are automatic and continuous.

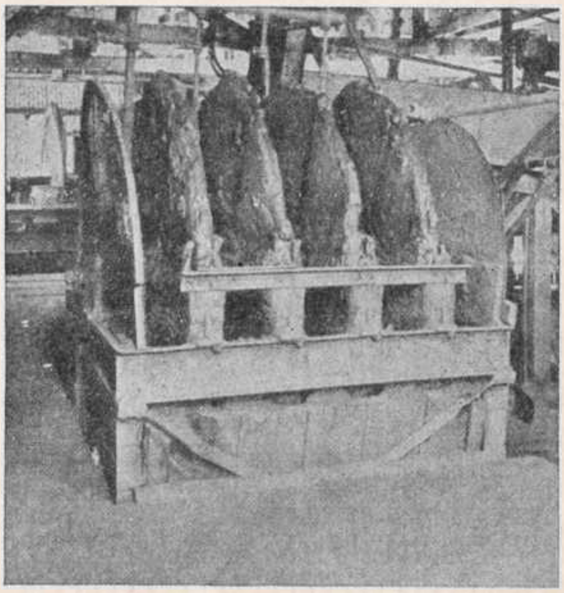


FIG. 146.—The disk or American filter, whose operation is clearly shown.

The life of a filter-cloth depends upon the care given it, the fineness of the pulp, the lime content of the ore, and occasional scrubbing of the cloth with dilute hydrochloric acid (say 2 per cent) and washing in water. Any period over 100 days is considered fair life. Makers of filters and dealers in equipment can supply cloth.

The disk filter, which consists of several disks on a horizontal shafting, operates in a similar manner to the rotary filter. It is simple and occupies small space, as seen in Fig. 146.

The Butters and Moore leaf filters are similar, except that in the former the basket of leaves always remains in the one tank in which the slime cake is formed, then washed, and finally discharged. The Moore leaves are first lowered into slime, then lowered into wash solution or water, and then discharged, each operation taking place in a different tank, which is V-shaped. Overhead gear is needed for the Moore filter. Leaf filters are intermittent in operation.

The baskets may consist of up to 150 leaves or filter-frames made of pipe and covered with canvas. The cake of ½ to ¾ inch is formed by vacuum, as is the washing done, and the treated cake is blown off with compressed air.

EXAMPLES OF CYANIDATION

As in the dressing of any type of ore, there are many different flow-sheets in which cyanidation is a part. The general scheme of treatment for several types of gold ore is given, but there is no space here for details of equipment which are well described in manufacturers' bulletins.

Figure 147 shows a simple treatment plant for soft oxidized ore without sulphides—a crusher, bin, Huntington mill with self-feeder, copper plate, and leaching vats for the sand which is separated from the slime in settling boxes. (Leaching is described under Tailings or Residues Treatment.)

Although some ores contain a minor amount of sulphides, these are insufficient to interfere with cyanide treatment and are ground with the other gangue minerals without further attention.

A quartz ore-pulp from which 1 to 5 per cent sulphides has been removed by tabling or flotation may be ground finer and then agitated in cyanide solution and filtered. The concentrates are treated separately or are ground and mixed with the mill pulp or are sold.

An ore may be crushed and the pulp divided into three products, each of which is cyanided separately—sand by leaching, slime by decantation or agitation and filtration, and concentrate by further grinding followed by long agitation and final filtration.

An ore in which the gold is very fine and associated with pyrrhotite can, with care, be amalgamated and divided into sand and slime which are cyanided separately.

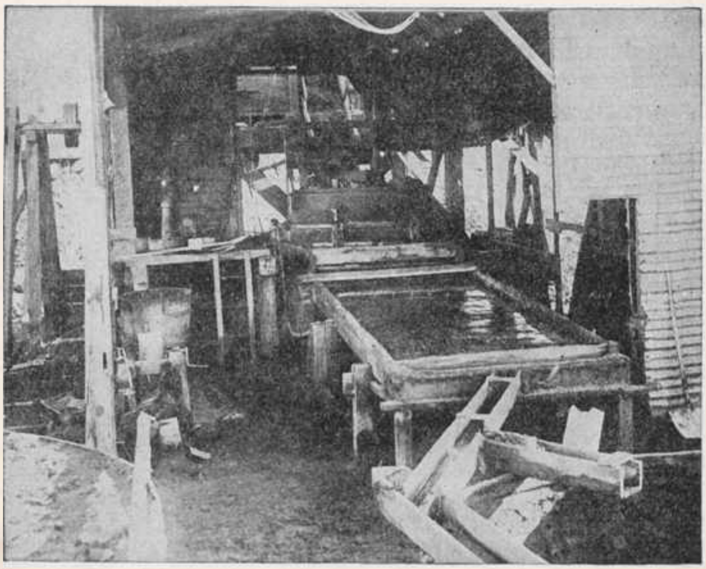


FIG. 147.—A prospector's complete milling and cyaniding plant, as described.

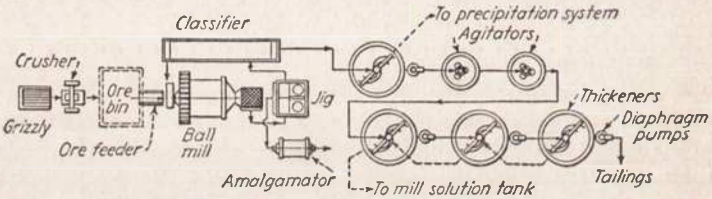


FIG. 148.—A counter-current decantation cyanide plant. A 16- to 20-ton plant costs $10,000 to $15,000.

A gold or silver or lead telluride ore can be cyanided fairly satisfactorily raw or roasted, but such ores require considerable attention.

Figure 148 shows a Denver countercurrent decantation plant whereby the pulp and cyanide solutions move in opposite directions, the pulp becoming poorer and the solution richer as they are transferred from tank to tank. The final pulp is sometimes discharged as is; but since it contains soluble gold and silver, in some plants it is filtered. The problem to determine is which is more profitable—to waste the pulp or to filter it, which means installing a filter?

In the flow-sheet of Figure 149, a jig is part of the mill-classifier circuit. It collects coarse gold and some sulphides which are ground and amalgamated in the barrel. All the classifier slime is thickened, agitated with cyanide, thickened again, and filtered.

EFFECT OF SULPHIDES ON CYANIDE

Freshly crushed and ground minerals of the pyrite group have little effect on cyanide solutions, except that these minerals slow the dissolution of the gold and silver in the solutions; but if the minerals are exposed to the air for any time, acid (a cyanicide) is formed which lowers the protective alkalinity of the solutions and thus lessens the action of cyanide on the precious metals; hence their recovery is not so satisfactory. Antimony, bismuth, and lead sulphides

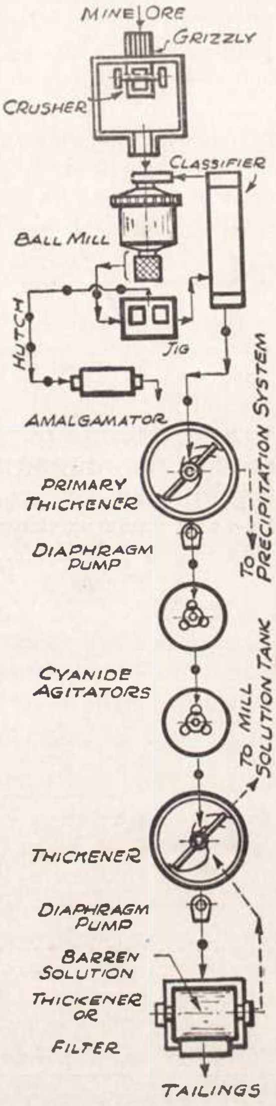


FIG. 149.—A Denver flow-sheet with jig in mill-classifier circuit, and thickening, agitation, and filtering of slime. The jig concentrate is ground in the barrel with mercury.

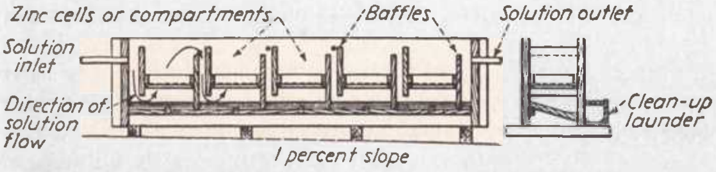
do not act like the pyrite minerals, although if solutions are high in lime, there is an undesirable reaction with antimony and with oxidized lead minerals. Some copper minerals are soluble in cyanide solutions, causing heavy consumption of cyanide; and the copper coats the zinc shavings in the precipitating boxes, thus preventing gold and silver from being deposited. Much trouble is encountered in precipitating gold with zinc dust if cyanide solution contains copper.

Precipitation of Gold and Silver

When gold- and silver-bearing or pregnant cyanide solutions are brought into contact with zinc shavings, filament or thread, or zinc dust, the precious metals are precipitated as a dark film on the zinc and some zinc is dissolved. The solutions must be clear and strong enough for proper precipitation. The zinc is procurable ready for use from chemical supply firms and from The Merrill Company, San Francisco, California, which controls the patents for precipitation by zinc dust. Shavings or filament and dust must be kept in a dry place until needed. The cost of precipitation varies from 1½ cents (¾ penny) to 3 cents (1½ pence) per ton of ore. In the treatment of a clean gold-bearing ore the consumption of filament may be 0.12 pound per ton, whereas that of dust is 0.04 pound or one-third.

Zinc-box. The simplest precipitation equipment for a small mine is what is known as a zinc-box (Fig. 150). This consists of a long, narrow, sloping, wood or painted sheet-iron box divided into wide compartments or cells which are separated by baffle-boards and narrow compartments. The bottom of the box slopes to one side to facilitate the clean-up through plug-holes which discharge into a small launder. Near the bottom of each large compartment is a ledge on which is supported a heavy wire screen-tray.. These compartments are filled firmly yet are springy with zinc shavings or filament. The gold- and silver-bearing solution is turned into the first narrow compartment, and the baffle, which does not reach the bottom, deflects the solution under the tray holding the zinc. The solution flows upward through the zinc, over the side of the compartment, down by the next baffle to the next lot of zinc, and so on, through 6 to 10 cells to the discharge, whence the solution flows to a sump or storage-tank. At this point it should be practically barren of precious metals. One cubic foot of filament will serve 6 to 10 tons of solution a day.

From time to time during a mill run the zinc falls in the compartments, but it should be kept to the surface. The supply of solution is shut off; the zinc is gently lifted out from one cell to another until full; and the last cell or two are filled with new zinc. Then the flow is re-started. If the last one or two cells do not collect any gold, they need not be filled.



Side view End view

FIG. 150.—A precipitation box for zinc shavings. This is made of plank, but painted flat iron that has been riveted together is suitable. This box is large enough for a small plant; a larger one may need up to ten cells or compartments. To save wood or iron, two boxes can be built back to back, the middle piece serving as a divider. The other box would slope the other way. The box should have a strong hinged and locked lid made of 2- by 4-inch timber and $\frac{1}{2}$-inch heavy wire screen.

At clean-up time the cells are siphoned out. The long filament is washed in the top cell or in a separate tub, and the gold-silver sludge is run out of the compartments and is mixed with that in the tub; the washed zinc is returned to the precipitating-box. Or all the zinc and the sludge are taken out and dissolved in weak sulphuric acid, and the residue is washed; filtered; partly dried; mixed with sand, borax, and soda ash; and melted in a graphite crucible.

Zinc shavings, which is $\frac{1}{16}$ inch wide and $\frac{1}{500}$ inch thick, costs little more than zinc sheet and is quoted at around 22 cents per pound in large lots and 24 cents for small lots—say 100 pounds.

Precipitation is aided by the following means:

1. Clarify the solutions by flowing them through a vat having a regular filter bottom atop of which are several inches of sand or

through sand or some porous material placed in the first compartment or two of a zinc-box or through vacuum leaves of Merrill design.

2. Maintain solution strength for good precipitation by regular feed of a drip of strong solution, say 10 per cent cyanide.

3. Improve precipitation by a regular drip of 10 per cent solution of lead acetate or lead nitrate.

4. Reduce the lime in the solutions as low as possible to prevent bulky precipitate resulting from the action of pyrrhotite.

5. Prevent deposition of copper by drips of strong cyanide and lead acetate or nitrate.

6. Prevent deposition of sulphate of lime by adding soda ash to the solutions.

7. Test the strength of the inflowing (0.02 to 0.05 per cent) and outgoing (effluent) solution regularly and assay the latter for gold and silver which should not exceed a trace.

8. Good precipitation is shown by numbers of bubbles of hydrogen gas rising to the surface of the cell or compartment.

Zinc Dust. This precipitant is mostly minus 200 mesh in size, consists mainly of zinc (95 per cent) with some oxide and lead, and costs around 8 cents per pound wholesale.

For the Merrill-Crowe clarification-de-aeration-precipitation process there are three types of equipment, the choice of which depends upon the size of a plant or the tonnage of solution handled daily. These are the bag-filter type, vacuum-leaf filter type, and filter-press type. The first is particularly suitable for precipitating small solution tonnages whether from the cyanidation of ore, concentrates, or tailings.

Briefly, a bag-filter precipitating unit (Fig. 151), which occupies small space, consists of a tank in which are vacuum-clarifying leaves, a vacuum receiver for the clarifier and for de-aerating (removing oxygen) cyanide solutions, a zinc-dust feeder for adding zinc to the de-aerated solution, and a bag-type filter through which the solution passes and leaves behind the precipitate of gold and silver. The barren solution is re-used in leaching or other operations. A single, liquid-sealed centrifugal pump is used to effect the passage of the pregnant solution through the successive steps of clarification, de-aeration, and precipitation.

The Merrill-Crowe process of precipitation of gold and silver on zinc dust has the following advantages over zinc shavings or filament:

(1) In the absence of oxygen in solutions, the formation of the troublesome white precipitate or hydrated zinc oxide is prevented; (2) as the filter-cloths are always coated with a layer of fine precipitant and precipitate, solution cannot escape coming in contact with the zinc dust; (3) the effective surface of zinc dust exposed is many times that of zinc filament; (4) the consumption of dust is much lower than that of filament; (5) precipitates are lower in unconsumed zinc and higher in gold and silver; (6) there is a decrease in cyanide consumption; (7) the effluent or solution leaving the precipitating system is lower in precious metals; (8) less labor is required in handling precipitates; (9) a complete clean-up is possible.

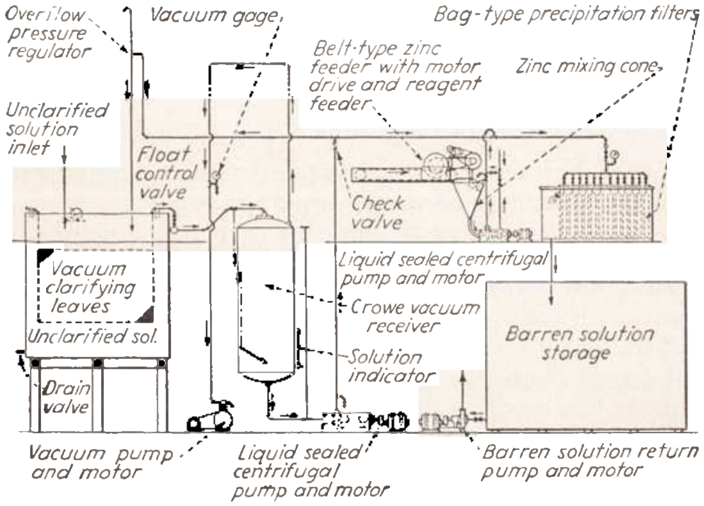


FIG. 151.—A clarifying and bag-type zinc-dust precipitation equipment.

Tailings or Residues Treatment

Many millions of tons of stamp-mill and other mill tailings have been and are being cyanided and recyanided throughout the world, and other enormous dumps await treatment. In general, such tailings are of low value and must be cheaply handled, say 50 cents or 2 shillings a ton; even less; also, the recovery of gold and silver is not high, 50 to 80 per cent being a range. During March, 1937, the author published in the *Mining Journal*, London, a review of world methods of tailings' cyanidation.

One of the most important jobs in deciding whether or not to arrange for the treatment of a dump is its sampling. Dumps may consist of clean sand, sand and slime, or slime. The general and easiest procedure is to take auger or pipe samples. The former is suitable for slimy material. A 1½- to 2-inch pipe, several feet long, with cap or welded solid at the top is "jumped" and hammered down through the tailings to near the bottom. The pipe, now full of material, is pulled out, and the core tapped out into any clean receptacle. As sand may run out while the pipe is being raised, special care is required. This is repeated at several spaced points on the dump, and all the samples are well mixed on a clean floor or large cloth, coned, flattened, and quartered until a few pounds remain for assays and tests. If these show that the tailings are treatable at a profit, a suitable plant should be erected.

In general, it may be said that the objective in treating old residues is: (1) to dissolve as quickly as possible with weak cyanide solutions any gold and silver that may have escaped the milling and concentrating processes and any that has been released by decomposition of iron pyrite and other sulphides; (2) to remove with weak solutions any soluble gold and silver from previous cyanidation. The first is a dissolving process, and the second is a washing process, although by the latter some of the metal will be dissolved.

Factors against the dissolving of gold and silver are as follows: They may be encased in grains of quartz or pyrite; they may occur as tellurides; they may be coated with sulphur of iron; copper may be present; graphite may precipitate some gold; or the residues may be too coarse. Some grinding might release and clean the precious metals, but the equipment required and the operation are expensive. Old mill tailings may be floated, and the concentrate sold or cyanided locally. Jigs may save the sulphides, if any.

Before treatment, tailings should be aerated or exposed to the air. As clean sand is porous, it needs little of this, but a mixture of sand and slime or slime alone should be plowed and harrowed or scarified to enable it to dry and break up. A layer of sand on the bottom of a leaching vat gives freer circulation of solutions through sand and slime. Slime, if not too clayey, may be dried, broken up, and mixed with sand before treatment. As many kinds of rubbish collect in dumps, this should be removed or avoided whenever it is seen, especially wood and ash.

If tailings are found to be acid, they may first be given a water wash or a lime wash, or lime may be broadcast while the vat is being filled or on top. A simple test of acidity is to shake a sample of tailings in water in a bottle and, when settled, dip in a slip of blue litmus paper. If the water is acid, the paper turns red; a slip of red litmus paper will turn blue if the water is alkaline.

EQUIPMENT

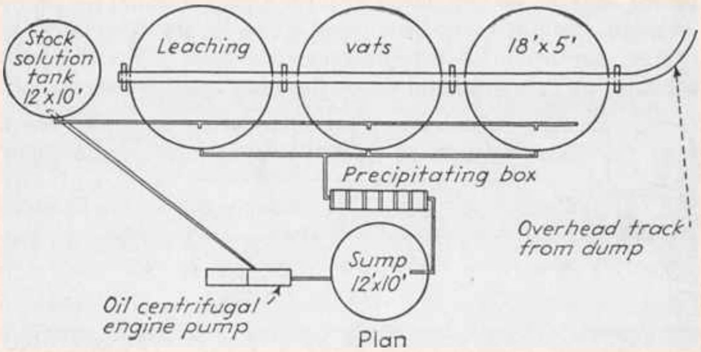
Used tanks and pumps might be procured from some near-by worked-out mine whose owners are willing to sell the material, but they are available from dealers in used equipment.

Tailings can be moved by wheelbarrow; by motor-truck; by scraper pulled by animal, by winch, or by motor-truck; and by scraper or bulldozer ahead of a motor-truck.

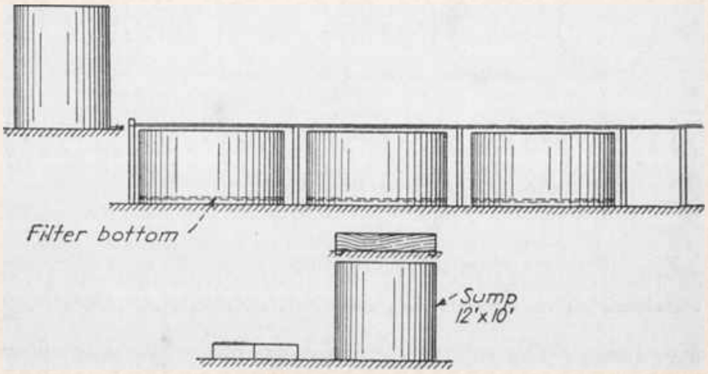
Plant for the treatment of sand is simple—several leaching vats with slat filter bottom and cloth or matting caulked around with rope or strips of cloth, solution tanks, and a pump or two.

The treatment of slime requires much more equipment than the simple handling of sand. The minimum requirements are agitators—air or mechanical—pumps, filters or decanting vats, and precipitators.

If it is desired to make round tanks on the job, the simplest method is the use of corrugated iron for the side and flat iron for the bottom, 16- or 18- to 20-gage thickness. The sheets are lapped several inches and double-riveted. To strengthen the side, the top sheet is turned over on a ½-inch rod for about 1 inch or slats are nailed or screwed to the top all around. When built, a tank is carefully painted all over with tar or pitch. Tanks should be laid on smooth ground or sand or on a number of boards.



Plan



Side Elevation

FIG. 152.—Simple tailings plant of wood tanks, costing about $2000. Piping is a general arrangement.

The capacity of vats varies from 35 to 100 tons. Figures 152 and 153 show simple sand-leaching plants.

Square tanks may be built entirely of flat iron riveted, and the sides strengthened by lengths of lumber, say, 2- by 4-inch, driven into the ground and against the tank to support it.

LEACHING SAND AND SAND-SLIME MIXTURE

Although it is common practice to charge the strong barren cyanide solution first, sometimes a weak gold-bearing solution is passed through the tailings first to enrich it before precipitation. The strong solution may be pumped or run by gravity atop of the charge, care being taken to prevent channeling or holing by the solution, or it may be run under the filter and thus up through the charge. The solution that remains under the filter after bottom-charging should be pumped on to the top.

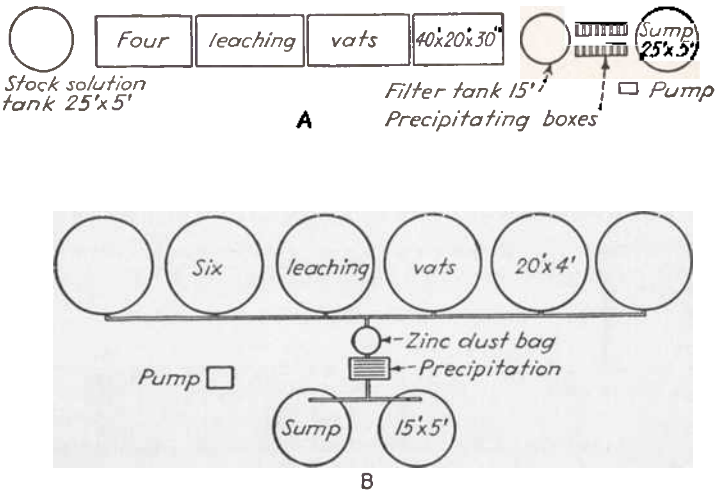


FIG. 153.—Two plans of simple tailing plants, the vats filled and emptied by trucks and shoveling: (*A*) flat iron riveted and tarred, (*B*) corrugated iron riveted and tarred.

Solutions should be circulated during the leaching (not washing) period to aerate them and make them more active in dissolving the gold and silver; they also become richer than if they flowed straight from the vats to the precipitators.

Treatment is completed with a final wash of weak solution or water. The cycle or total time of treatment may be 3 to 6 days.

Figure 154, taken with the following note from a report of the Federal Bureau of Mines, shows how to construct a "compressor" and air-lift, provided enough water is available. As the sketch is self-explanatory, little further need be said. The leaching tank is 18 feet in diameter and 5 feet high, of wood. The leaching cycle was 36 hours.

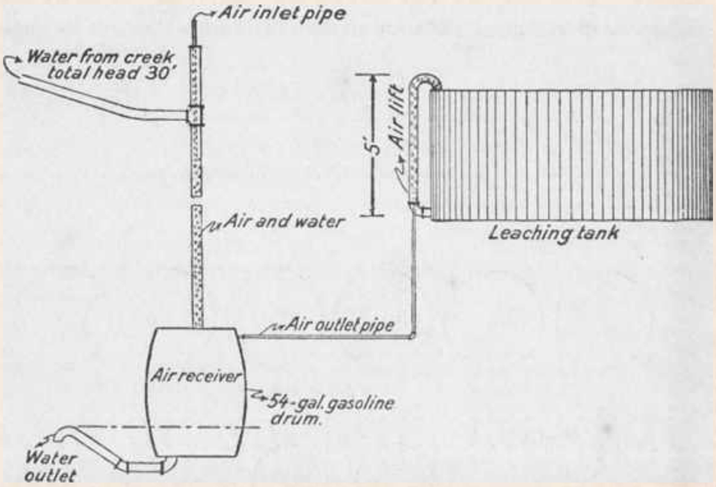


FIG. 154.—Hydraulic "compressor" and air-lift for circulating cyanide solutions.

Treating Slime. If a dump consists of slime that can not be leached in vats, it may be pulped preferably with weak cyanide solution in a small tank in which is a propeller-mixer or it may be sluiced. In both cases the pulp is then pumped to air or mechanical agitators where the solution is strengthened, and after the gold-bearing solution is separated from the slime by filtering or by settling and decanting. Air is introduced into the agitators by inside air-lifts or by compressed air freed in pipes or hose. The cycle of treatment may be 24 hours (see Fig. 155).

In Southern Rhodesia, the prospectors and owners of small mines milled the ores and cyanided the sands but left the slimes and moved on to other properties. The slime dumps ranged in size from several hundred to many thousand tons, but they could be treated only by simple and inexpensive cyanide plants.

In general, the slime wås not difficult to treat. A dump or dam was plowed to a depth of 6 inches, and the lumps were allowed to dry. No harrow was used. Before the wet season commenced, the dried slime was shoveled into conical heaps into which rain does not penetrate far. The slime was shoveled into vats 40 feet long, 20 feet wide, and 30 inches deep, of 20-gage, zinc-coated (galvanized), flat iron, well tarred and placed on the ground. From 9 to 18 inches could be leached. This is discharged by shoveling. The filter bottom consisted of 4 inches of coarse rock covered with clean, fine gravel, above which was laid cut grain sacks, 3 inches of sand divided into sections by floor boards. Such a tank can be built by natives in 6 days, and it will last for years. Every 4 feet the sides are supported by a vertical stick driven into the ground. If the plant is moved, these tanks are cut at the corners and rolled up, the angle iron at the top being first removed.

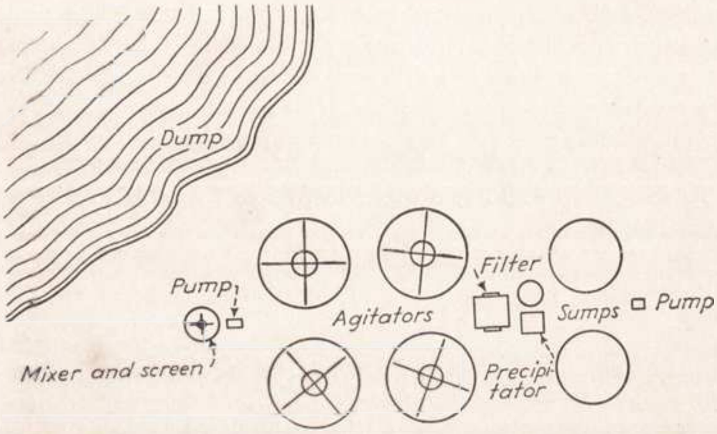


FIG. 155.—A simple slime-treatment plant. The dump may be sluiced or trucked to the mixer. The pulp can be thickened before or after agitating (thickener not shown).

All the solution tanks were built round with 22-gage corrugated-iron sides and 20-gage flat-iron bottoms, all tarred. To permit easy moving of these tanks to another site, they were made to nest—that is, one fitted into the other.

The precipitation boxes were of 20-gage flat iron, zinc filament being used.

Different types of pump were operated—hand and oil-engine or electric-motor driven.

Treatment ran from 3 to 6 days, and the residues rarely assayed more than 3 pence (6 cents) per ton in dissolved gold. On clean slime the cyanide consumption was ½ pound per ton. The labor was reliable, and one "boy" can shovel 10 tons of slime and 18 tons of sand a day. The cost of treating 4800 tons of slime a month at one property was 22 pence (44 cents) per ton. This included food for the natives, according to W. B. Blyth in the *Bulletin of the Institute of Mining and Metallurgy*, London, February, 1937.

Filling and Discharging. Sand vats are filled by trucks on an overhead trestle, which should not rest on the side of the vats, or by scrapers or by trucking and shoveling. The residue is discharged by shoveling or sluicing through holes (closed during treatment) in the bottom of the vat or by shoveling over the side for removal by trucks or horse-wagons.

Slime, as already stated, is sluiced from the dump to the agitators, using just the required amount of solution to make a thick pulp, or it is trucked to a mixer and then pumped to the agitators. The discharge is by gravity or by pumping.

Precipitation. Many small tailings plants use zinc shavings or filaments for precipitation of the gold and silver, this probably being preferable for such installations; yet the use of zinc dust is fairly simple and is generally as suitable as the filament. The flow of gold-bearing solution through the precipitation box or through a filter-press or bags may be by gravity, but generally for the latter the solution is pumped.

Gold Recovery. As stated before, the recovery of gold and silver from tailings ranges from 50 to 80 per cent. It depends upon the condition of the old residue and precious metals. Less silver is recovered than gold. Clean sand may yield 70 per cent or somewhat higher; mixed sand and slime, lower than this; and slime, 50 per cent or less. As a rule, it does not pay to install any grinding machine because this runs up the cost of treatment.

Chemical Consumption. The following amounts are per ton of dry tailings and depend upon their condition and pre-treatment: sodium cyanide—sand, ⅛ to ⅔ pound; slime, ½ to ¾ pound; lime—sand, ¾ pound to 20 pounds; slime, 1¼ pounds and more; zinc-shavings, ¼ pound; dust, 1/25 to 1/10 pound.

Cost. The cost of handling and treating tailings may be 33 to 80 cents (16 to 40 pence) per ton of sand and 50 to 100 cents (25 to 50 pence) per ton of slime.

Concentrates Treatment

Gold- and silver-bearing concentrates are treated locally or are sold. The factors involved are ease or difficulty in treatment, low freight, and fair terms with a smelter or custom plant. Some mines are so situated that local treatment is the only way; others have short haul by motor-truck or rail to a custom smelter, making the problem easily solved. Before dispatching concentrates they should be dried slowly to about 5 per cent moisture in the sun or on a large steel plate or tray heated by some means. Also, they should be carefully sampled.

The common sulphides saved by concentration are those of the pyrite group; but the only one treatable raw with ease is iron pyrite. Even this requires prompt treatment or storage under water to prevent decomposition until enough has accumulated. If an ore has not been crushed too coarsely, the pyrite may be leached as are old tailings, but much stronger cyanide solutions are required, up to 1 per cent, and the cyanide consumption may be as high as 5 pounds per ton. Also the period of treatment is as much as 2 weeks with continuous percolation. Silver makes for longer treatment and higher cyanide consumption. Any pyrrhotite present will probably affect these conditions more or less.

Raw pyrite alone or with argentite may be treated in batches by fine-milling and then air-agitation for a couple of weeks in strong cyanide solution or agitation by high-speed impellers for some hours, followed by filtering. Over 90 per cent of the gold and silver will be extracted in this manner. Before a concentrate is leached or agitated with cyanide, it is conditioned or rendered more treatable by aeration with lime solution for ½ hour to several hours.

Iron pyrite, pyrrhotite, and arsenopyrite are successfully roasted and cyanided. The calcine is mixed with water or weak solution and run over corduroy or onion sacking to recover coarse gold. Then it is ground finer, agitated with cyanide, and filtered. Much weaker solutions are used than on raw concentrates. Arsenopyrite is salable to smelters. It cannot be cyanided raw, and it is best roasted locally, even if the calcine is shipped to a smelter. Arsenic is caught in the flue-dust of regular furnaces, but one must be careful in roasting in the open.

Concentrates consisting mostly of chalcopyrite should be sold. If there is any free gold visible on panning, they may first be run over copper plates or corduroy. In fact, this could be done before any class of concentrate is treated or shipped.

Cyanidation or Flotation

It is well to warn mine operators not to install a cyanide plant or a flotation plant or one employing both processes until proper tests have been made on an ore. Some flotation enthusiasts would recommend flotation only, whereas cyanidation men are more open to consider a combination of these processes, if cyanidation alone is insufficient. The makers of equipment for small mines will make complete milling tests on gold ores for $50 upward and charge $10 or more for individual tests by amalgamation, tabling, flotation, or cyaniding. Assays are extra at $1 to $2 for gold and silver. Properly taken samples weighing 25 pounds should be sent prepaid, also money for the tests and assays.

A. M. Gaudin, professor of mineral dressing, Massachusetts Institute of Technology, Cambridge, Massachusetts, also author of the well-known book "Flotation" (McGraw-Hill Book Company, Inc., New York), said in a paper for The Electrochemical Society in 1931:

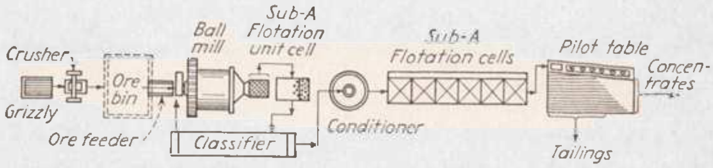
As to the choice between cyanidation and flotation, the first thing to consider is the form in which gold occurs. If it is associated with copper or lead sulphides, flotation is indicated. If the ore is straight oxidized, cyanidation will have much the best chance. Between these two ores are many intermediate types. The second thing to consider is mixed treatment—cyanidation and flotation; float the ore and cyanide the concentrates; or float the ore, cyanide the tailing but not the concentrate, which may be sold. A cyanide plant is more expensive than a flotation plant—about twice as much.

The Tobacco Root Mountains, Madison County, Montana, is a good example of a gold-silver district, from 1870 to 1900, the stamp-mills depended chiefly upon amalgamation for the recovery of gold; but when the upper, oxidized portions of the ore-shoots were exhausted, the recovery decreased. Also, costs were too high for profitable work, according to S. H. Lorain of the Federal Bureau of Mines. The higher price for gold revived lode, also placer, mining, and all plants are using bulk flotation, supplemented at some mines by plates, traps, blankets, or unit flotation cells for saving coarse gold or partly oxidized sulphides. No cyaniding is being done. Although gold and silver are the principal minerals, the district has yielded a fair quantity of lead, copper, and zinc, part of which was paid for at the smelters.

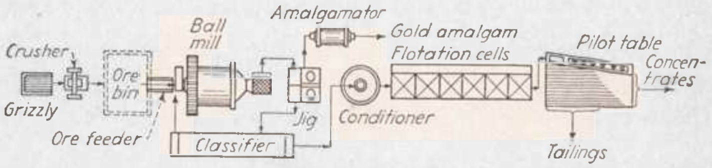
In general, the ore deposits are quartz veins occupying fractures in gneiss or quartz monzonite, dipping 30 to 60 degrees. No vein has yet been proved to persist below 800 feet. Electric power is available at 2.8 cents to 0.5 cents per kilowatt-hour, this range being based on 1 to 1000 horsepower. Trucking costs 10 to 33 cents per ton-mile or $1.50 to $3 per ton for 15 and 9 miles. Mining costs $3 per ton.

Some ore is shipped, as are all concentrates, to two smelters. Some sorting is done. Jaw-crushers are commonly used, also ball-mills (a few stamps), classifiers, flotation machines, thickeners, and filters. As already stated, plates, blankets, and traps are in the circuits. A few shaking tables are employed. Recoveries range from 81 to 93 per cent, but flotation of sulphides yields 90 to 93 per cent. The ratio of concentration is 10 to 1 to 40 to 1. Milling costs $1.65 per ton.

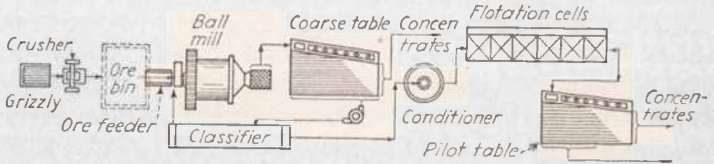
Figures 156*A*, *B*, and *C* show Denver flow-sheets of flotation plants for base-metal and non-metallic ores where most of the minerals are recoverable by flotation and where there is sufficient freed mineral in the ball-mill discharge to warrant recovery by means of a unit flotation cell, a concentrating table, or a jig, in the ball-mill-classifier circuit. Many gold and silver ores come under this same classification because not enough of the precious metals are present as free metallics to warrant the use of amalgamation. On lead-copper ores, the unit flotation cell is recommended, whereas with free gold ores containing coarse metallic gold, with sulphides, the mineral jig is recommended. No elevator or pump is necessary in this circuit when using the unit cell or jig, such as is the case when the table is placed between the ball-mill and classifier. Care must be taken when using a



A- Unit flotation cell in grinding circuit



B- Mineral jig placed in grinding circuit



C- Concentrating table in grinding circuit

FIG. 156.—Three arrangements for catching coarse minerals before floating, as described. The pilot table is a guide to the work of the other machines. Plants with a daily capacity of 16 to 20 tons cost $5500 each.

table not to permit the use of too much water in the circuit to interfere with subsequent treatment; therefore the unit flotation cell or mineral jig is economical to install and more efficient.

Metal and Mineral Losses

For a while after a plant starts work and during its lifetime, gold and rich heavy minerals will be caught and will collect in bins, in chutes, in mortar-boxes, on amalgamating plates and blanketing, behind mill liners, in launders and elevator boots, as spillage on floors, and through absorption of solutions by wood vats and other equipment. Eventually, the valuable material lost in this way will be recovered while repairs and cleaning are done; also, if a mine is to be abandoned, the whole place should be thoroughly cleaned. Wood launders and vats, also cloth of any kind, should be burned, and the ash smelted. Scrapings and sweepings should be ground with mercury which is retorted. The treatment of copper plates has already been described.

GRAPHITE ORE

Graphite is found in the flake form, disseminated as scales in schists and limestones, and in vein form in shales. The latter form may occur as pockets or as "ore" that can be hand-sorted and sold direct. The flake ore is high in waste rock which must be concentrated out, but its gravity (2.6) is only a little higher than that of graphite (2.2), and of mica (2.7), which often accompanies graphite; therefore jigging and tabling are not very effective. After crushing and grinding, the flake ore may be run through log-washers or floated, filtered, and dried.

IRON ORE

Because of the low price of iron ores at the mines ($2.70 a long ton in the Lake Superior district, $1.95 in the southeastern States, $2.78 in the northeastern States, and $2.82 in the Western States in 1940), it would be better for the discoverer of a body of iron ore to develop and sell it than to try to mine and dress the ore, if it needs such treatment.

About 17 per cent of the iron ores shipped in the United States during 1940 was improved in grade by crushing, screening, washing, jigging, and magnetic separation. The quantity dressed is increasing each year. Some of the ores are high in silica, and the purpose of dressing them by the method mentioned above is to rid them of as much of silica as possible. Fine hematite has been recovered by flotation but under present conditions is expensive.

Further reference to iron ore will be found under Log-washing.

LEAD ORE

A simple lead ore may easily be separated from its gangue and the galena recovered in a high-grade concentrate by classifying and tabling. By avoiding too fine grinding, the loss in slime will be reduced. If iron pyrite is present, its gravity is so much lower than that of galena that a clean separation is made. The pyrite may carry gold and silver, and the galena more or less silver. If the galena is finely crystalline and disseminated, it floats well.

Lead-zinc ore and zinc-lead ore are covered under those heads.

LEAD-ZINC ORE

As a rule, both the galena and sphalerite in lead-zinc ores carry silver, mostly in the former minerals. The waste rock may be quartz or quartzite (2.6) with siderite (3.8). The latter is close to the gravity of sphalerite (4.4), and makes gravity separation difficult. Such an ore may be handled by crushing, grinding, classifying, jigging, and tabling. The galena recovery should exceed 90 per cent; and if flotation is employed, the zinc recovery should be fairly high. Costs need not be over $1 a ton.

If the lead-zinc minerals occur with rhodonite (3.7) as the principal gangue mineral, gravity separation will save much of the galena but little of the sphalerite (4.4); therefore further grinding and flotation are essential.

MANGANESE ORE

Most manganese occurs as an oxide. The carbonate and silicate are not common in workable quality and quantity. Excepting chemical grades of ore, 70 to 85 per cent manganese dioxide, ores of medium grade and low grade may be improved for ferromanganese making by hand-sorting hard ore and by washing ore from clayey beds. Prices are quoted on the unit basis, a unit being 1 per cent of a long ton or 22.4 pounds of contained manganese. Battery grade manganese ore is quoted on a per ton basis. In 1940 the average value of domestic ores reported to the Federal Bureau of Mines was 50 cents per long ton unit for ore containing 35 per cent or more manganese. *E.&M.J. Metal and Mineral Markets* quotes nominal prices on imported ore: "Per long ton unit of Mn, dry basis, c.i.f. Atlantic ports, steamers paying for discharge, exclusive of duty (subject to usual penalties for objectionable impurities): Brazilian, 48 per cent, 65 cents; 46 per cent, 64 cents. Chilean, 48 per cent, 68 cents. Indian, 50 per cent, 66 cents; 48 per cent, 64 cents, nominal. South African, excluding war risk insurance, 45 per cent, 65 cents; 46 per cent, 63½ cents. Duty-free manganese ore: Cuban, 51 per cent, 81 cents; 48 per cent, 79 cents; 45 per cent, 75 cents. Philippine, 50 per cent, 81 cents, nominal. Domestic, 48 per cent, $1.00, f.o.b. mines."

Silicate ores give low results by concentration, and it may be found best to sort such ore and sell it. Manganiferous iron ores do not respond to dressing, but the silica may be removed thereby. Manganese dioxide or nodules in sandstone or shale are not concentratable. Some manganese ores can be freed from excess iron minerals by tabling classified feed to reduce the silica. The electrolytic process of the Federal Bureau of Mines treats ores as mined, but it is a method that requires chemical, metallurgical, and electrical knowledge.

Further attention to manganese ores will be found in the section of Log-washing.

MERCURY ORE

During 1937, the author's report on mercury at small mines (*Information Circular* 6966) was issued by the Federal Bureau of Mines.

Because of the simplicity and low cost of calcining or roasting or retorting cinnabar, most of the world's mercury is recovered by this means. Ores carrying as little as 5 pounds and as much as 100 pounds of mercury per ton are satisfactorily retorted. Some mercury ores may be sorted, and the worthless rock discarded, thus raising the grade of the ore. No fines should be thrown away. The ores of some deposits may be screened, and only the 2-inch and finer material need be retorted. Retorts are made for small mines and for large mines. As there are no custom plants and it will not pay to ship ore, the work must be done at the mine. If retorting is carefully done, the mercury will be fairly pure and marketable.

An important item to remember is that mercury poisoning develops from the handling of ore that contains free mercury, from dust and fumes that may escape during retorting the ore and condensing the vapors (likewise in the retorting of gold amalgam), and from the handling of liquid mercury. Ventilation of mine workings, tight joints and hoods in the calcining plant, and personal cleanliness (frequent washing) lessen the hazard.

Retorting

When heated to a temperature of 500 to 600°C. (932 to 1112°F.), depending on the texture of the ore, cinnabar will give up its mercury in the form of a vapor which, when condensed with water or air, yields liquid mercury.

Before a retort is charged, the ore should be broken or crushed to ¾ inch up to 2 inches. This depends upon its texture and the manner of mineralization.

The pipe retort or D retort is most suitable for prospects and small mines. Two retorts or multiples of two should be installed—right and left hand.

The pipe retort is 8 to 12 inches in diameter, generally 10 inches, and 9 feet long, holding several hundred pounds of ore. It is charged (not full) and discharged with a scoop on a long handle, also a hoe or flat disk on a handle for filling and emptying. A door is clamped on to the charging end. At the rear end is fitted a condenser pipe 3 inches in diameter and 8 feet long. The pipes are supported at each end in the furnace. To take care of the sulphur in the ore, some lime may be added before charging or air is admitted into the retort by a 1-inch pipe fitted into the door and extending to the rear. The air escapes outside through another pipe just behind the door. The mercury vapor from the retort passes through the water-cooled condenser to a trough of water.

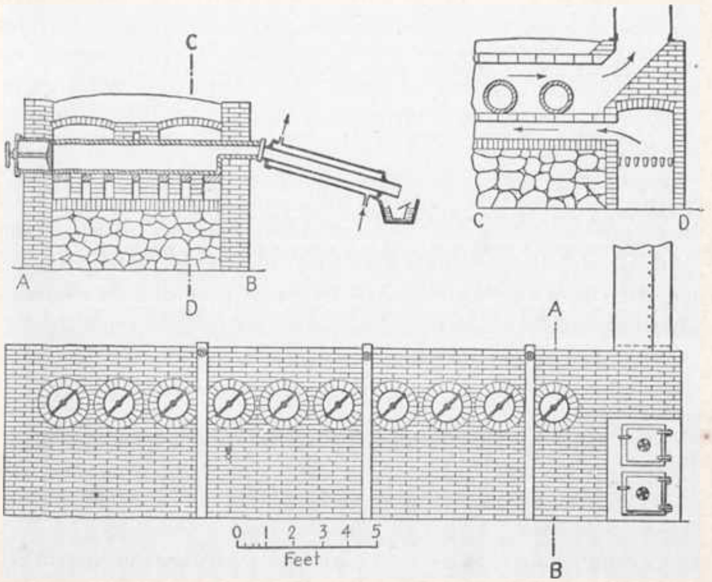


Fig. 157.—Sketch of setting pipe retorts and condenser. (*California Division of Mines, Bull.* 78.)

Pipe Retort. Although a pipe retort could be made at a mine, it is hardly likely that pipe of the size given and suitable tools would be available at a small operation. Therefore, it is best to purchase retorts and accessories from the makers previously listed.

The Johnson-McKay type is a common pipe retort. A 10-inch size is made, but the 12-inch is preferred. It is 6 feet long.

Batteries consist of 2, 4, 6, 8, 10, or 12 pipes. If enough ore is available, 12 pipes will treat 3 to 5 tons daily. Generally, one pipe would be discharged and re-charged every hour. Figure 157 shows a sketch of a retort furnace.

According to H. A. Franke, formerly of the State Division of Mines, California, Louis I. Rossi developed an inexpensive and efficient retort which is reported to be giving good results at a number of small mines. Figure 158 shows two pipes having a daily capacity of 1000 pounds of ore. They are of cast alloy $\frac{5}{8}$ inch thick, 74 inches long, and 10 inches in inside diameter. Discarded Johnson-McKay retorts are often used, opening one end for the lower discharge and the opposite upper side for the hopper by means of an oxy-acetylene torch. The pipes are set at a slope of about 30 degrees, and the ore is charged through a hopper at the upper end. The charge half fills the pipe which is closed at the lower open end by a plug of burned ore stacked in such a way as to let a little air draw through it. Two bricks are used to help stack the burned ore in plugging the lower end of the pipe. Damp ashes and clay are packed around the charging hole at the upper end. The pipes are directly exposed to the fire

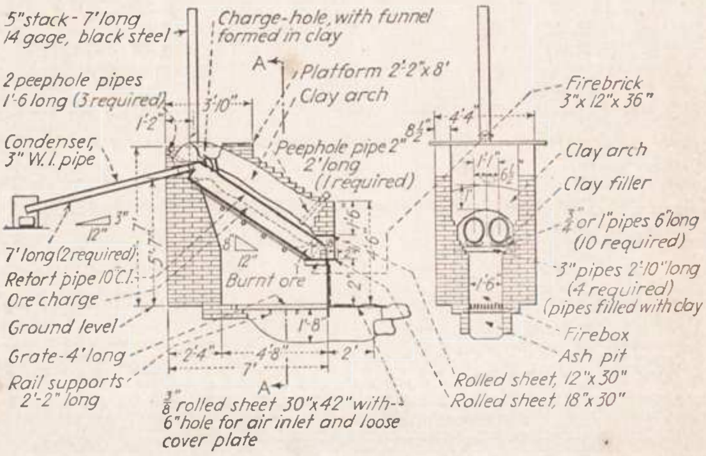


FIG. 158.—Side and front views of a pair of Rossi retorts.

in a box built so that they heat evenly. Mercury vapors are condensed in an 8-foot pipe with a hood at the lower end and an iron pot to collect the metal. This condenser pipe, 3 inches in inside diameter, set at a slope of 14 degrees, is connected to the retort pipe with a 10-inch nipple. Any kind of fuel may be burned, and consumption is low. Banks of more than two pipes may be built. Retorts can be partly built into the side of a hill to save masonry. They are charged and stoked every 6 hours, making four charges a day.

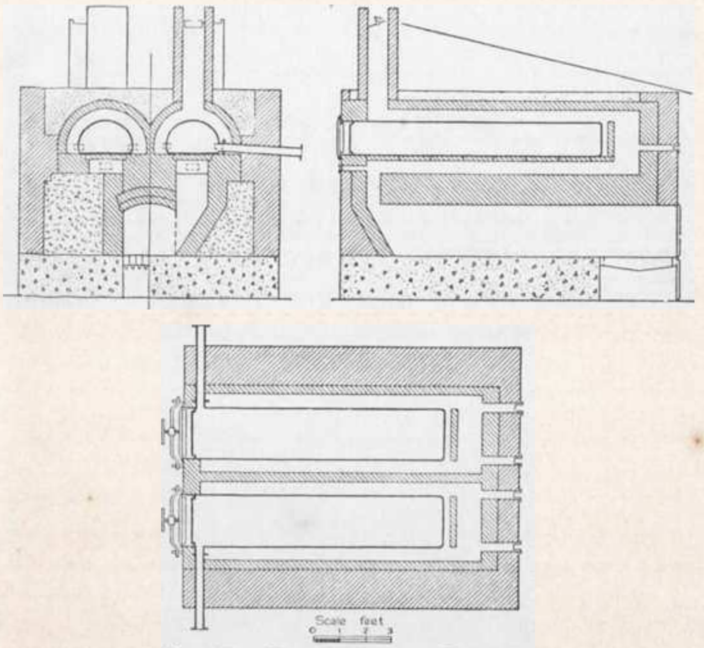


Fig. 159.—Details of setting D retorts.

D Retort. The D retort, which lies with its flat side down (⌓), is made of gray cast iron or of cast-iron alloy and costs $250 to $350. One make is 12 by 20 inches by 8 feet plus the charging end of 1 foot. It rests on fireclay tile. A stock stands above the charging end. The ore may be placed in pans, three holding 600 pounds, or it may be charged loose. One to three charges are calcined in 24 hours. The capacity of another make of D retort is about two 12-hour charges of 700 to 1000 pounds of ore or three charges of 400 to 500 pounds per 8 hours if the retort is run continuously. The throughput depends upon the type of ore. A two-tube D retort in Arkansas has calcined 3000 pounds in 24 hours, producing 40 to 60 pounds of practically pure mercury. The makers of these retorts furnish instructions for erection and operation (see Fig. 159).

Any type of fuel may be used for retorts—coal, coke, gas, oil, or wood—whichever is the easiest and cheapest available, but the furnace must be built to suit each different fuel.

For a mine capable of producing up to 20 tons of mercury ore in 24 hours, one of the Gould semi-portable rotary furnaces and condensers is suitable. This equipment is self-contained on a single bed-frame and costs $6859 to $7480 in San Francisco. Its furnace is 24 inches in diameter and 24 feet in length, and the daily capacity, depending on the ore, is 12 to 20 tons. It is fired with oil, requires little water, and is portable; erection costs are low; it makes a high recovery and may treat ore at 75 cents to $1 per ton. Power is supplied by a 15-horsepower gasoline engine.

Suitable similar furnaces for smaller or larger mines are the 18-inch by 16-foot size that treats 8 to 12 tons per day and the 36-inch by 40-foot size that handles 25 to 50 tons per day.

For large mines there are still larger sizes. The labor costs on the large furnaces naturally are lower than on the small ones.

The Nichols Herreshoff multiple-hearth furnace with one drying hearth at the top and several calcining hearths—fuel oil is used—has a capacity of 20 tons or more a day and will handle wet or dry ores in size from 200 mesh to 1¼-inch diameter. The ore passes from one hearth to another, being rabbled or stirred by air-cooled rotating arms to which rakes are attached. Dusting is reported to be low. The cost of furnacing varied from $1.53 to $2.75 per ton of ore.

Concentration

As cinnabar has a gravity of 8, there is no reason why it can not be separated from its enclosing rocks whose gravity is under 3. But crushing and grinding slime the cinnabar more or less, and concentrates and mud are not easy to retort, which must be done.

Following are examples of wet concentration in California:

At New Idria old, burned dump ore and furnace residues are trommeled, classified, jigged, and riffled, and the slime flows over carpet. Most of the mercury is free. A air recovery is made.

In Lake County the cinnabar at one mine is coarse and evenly distributed in soft sandstone, about 5 pounds per ton. A plant of 1 ton an hour capacity consists of jaw-crusher, rolls, vibrating screen, and shaking tables. Concentrates assay 50 per cent mercury, and the recovery is 85 per cent at a cost of $1.12 per ton for milling and retorting in pipe retorts.

In Sonoma County are two concentrators. At one mine a chert averaging 16 pounds of mercury per ton is simply washed and the ½-inch size is screened and tabled. The recovery is 50 per cent, and the cost $60 a flask. Concentrates are calcined in a D retort. At the other mine a soft sandstone contains native mercury and cinnabar averaging 9 pounds per ton. It is screened by the use of water, and half is discarded by sorting. Then follow crushing and rolling the $\frac{3}{16}$-inch material, which is further screened. The final undersize is run through a long ton, over a bumping table, and through carpet-lined troughs. The long-tom traps most of the metal. The recovery is 80 per cent, and concentrates, which assay 50 per cent, are pipe-retorted.

If an ore is high in pyrite, it is better to table or float the cinnabar. This lowers the sulphur content, and the concentrate may be retorted more easily.

Bottling Mercury

The mercury recovered from the condensing system should be clean and remain bright in contact with the air. A film or scum on it indicates contamination with a base metal, such as zinc, which oxidizes slowly on exposure to air. Bubbling air through or stirring the metal will remove much of the impurity, which will appear as a scum and can be skimmed off. At some mines the mercury is filtered through chamois skin. When the metal is quite clean, it is ready for bottling in the regular 76-pound flask. This container costs 70 to 80 cents retail and has a screw-plug which is dipped in red lead in oil to make a tight joint. Before filling the flask, the exact quantity should be carefully weighed. A special iron weighing bucket, with spout that fits into the flask top, should be used. Mercury cannot be carried around in ordinary buckets; also, it is not easy material to carry in an open container because of its weight and mobility. Bottles or jugs holding 1, 5, and 10 pounds of mercury are available from dealers.

Marketing

San Francisco is the principal market for mercury, and there are many buyers and dealers in California. New York is also an important market, as is London. Metal quotations, published daily, are much the same in both cities. Transactions are on the basis of flasks. As a result of the civil war in Spain in 1937, the price rose to $98 but averaged $75.47 in 1938 and, as a result of the Second World War averaged $103.94 in 1939, $176.87 in 1940, and $185.02 in 1941. Production of mercury in the United States in 1940 was sufficient for domestic consumption requirements for the first time since the First World War of 1914–1918.

Dealers in Mercury

Following is a list of dealers in mercury:

California

Atkins-Kroll and Co., 260 California St., San Francisco. Buyer of small quantities.

Mrs. J. Blackie, 722 Monterey St., Hollister. Buyer of small lots from local miners.

Braun-Knecht-Heimann Co., 584 Mission St., San Francisco. Buyer of metal, mostly from other jobbers.

Coast Chemical Distributors, V. R. Ghinsberg, 550 Sharon Bldg., San Francisco. A large buyer.

H. W. Gould and Co., 700 Mills Bldg., San Francisco.
Haas Bros. (J. Marx), 209 California St., San Francisco. A large buyer.
Justinian Caire Co., 573 Market St., San Francisco. Buy mostly from other jobbers.
Mefford Chemical Co. (Percy Chase), 1026 Santa Fe St., Los Angeles. A large buyer.
Quicksilver Producers Association (Irving Ballard), 560 Sacramento St., San Francisco. A large buyer.
Bernard T. Rocca, Pacific Vegetable Oil Co., 62 Townsend St., San Francisco. A large buyer.
Thalls and Co., San Miguel. Grocery store and buyer of small lots from local miners.

NEW YORK CITY

Charles Hardy, Inc., 415 Lexington Ave.
Goldsmith Bros. Smelting and Refining Co., 74 W. 46th St.
International Minerals and Metals Corporation, 11 Broadway.
Belmont Smelting and Refining Co., 336 Belmont Ave., Brooklyn.
Metal Traders, Inc., 67 Wall St.
Cuno Sievers, 101 Cedar St.
George Uhe Co., 80 Eighth Ave.

NEW JERSEY

Wood-Ridge Manufacturing Co., Inc., The, Wood-Ridge.

CHICAGO

Goldsmith Bros. Smelting and Refining Co., 58 East Washington St.

A list of dealers and buyers of the more uncommon ores and minerals is of interest to small miners. It is always wise when writing to any of these names to give complete information, such as assays, amount of ore available ready to ship and rate of production, and nearest shipping point.

ABRASIVES

Keystone Emery Mills, U-1669 Church St., Philadelphia.
American Abrasives Co., Westfield, Massachusetts.
Mid-West Abrasives Co., 2188 Beaufart, Detroit, Michigan.

Norton Co., Worcester, Massachusetts.
C. B. Chrystal & Co., 13 Park Place, New York.
Carborundum Co., Niagara Falls, New York.
Behr-Manning Corp., Troy, New York.
Abrasives Co., 5500 Tacony St., Philadelphia.
George F. Pettinos, 1200 Locust St., Philadelphia.

ALUMINUM ORES

Aluminum Co. of America, 1804 Gulf Bldg., Pittsburgh, Pa.
Arthur Seligman & Co. Inc., 30 Rockefeller Plaza, New York.

ANTIMONY ORE

Texas Mining & Smelting Co., Laredo, Texas.
Harshaw Chemical Co., Cleveland, Ohio.
Rare Metals Products Co., Belleville, New Jersey.
Antimony Products Co., New Brunswick, New Jersey.
Vitro Manufacturing Co., Pittsburgh, Pennsylvania.
Philipp Bros., 70 Pine St., New York.
Metal Traders Inc., 67 Wall St., New York.
Watson Geach & Co., 70 Pine St., New York.

ASBESTOS

Johns-Manville Corp., 22 E. 40th St., New York.
Raybestos-Manhattan Inc., North Charleston, South Carolina.
Allbestos Corp., Germantown, Philadelphia.
Norristown Magnesia & Asbestos Co., Norristown, Pennsylvania.
Philip Carey Co., Lockland, Cincinnati, Ohio.
Asbestos Fibre Spinning Co., North Wales, Pennsylvania.

BARYTES

Thompson, Weinman & Co., 52 Vanderbilt Ave., New York.
A. E. Stocking, DeSoto, Missouri.
National Pigments & Chemical Co., St. Louis, Missouri.

BERYLLIUM

Beryllium Corporation, 420 Lexington Ave., New York.
Renfrew Minerals, Ltd., 45 Richmond St., Toronto, Ontario, Canada.
David Taylor, 52 Broadway, New York.
Brush Beryllium Co., Cleveland, Ohio.

CHALKS, CLAYS, ETC.

Hammill & Gillespie, 225 Broadway, New York.
L. A. Salomon & Bros., 216 Pearl St., New York.
C. B. Chrystel Co., 7 Park Place, New York.
Wishnick-Tumpeer Inc., 295 Madison Ave., New York.
Harshaw Chemical Co., Cleveland, Ohio.
Whittaker, Clark & Daniels, 260 West Broadway, New York.

MOLYBDENUM

Climax Molybdenum Co., 500 Fifth Ave., New York.
Molybdenum Corp. of America, 500 Fifth Ave., New York.
Fansteel Company, North Chicago.
Charles Hardy, 415 Lexington Ave., New York.

PRECIOUS METALS

American Electro Metal Corp., 320 Yonkers Ave., Yonkers, New York.
American Platinum Works, New Jersey R. R. Ave. at Olive St., Newark, New Jersey.
Baker & Co., Murray and Austin Sts., Newark, New Jersey.
Bishop & Co., Platinum Works, 12 Channing Ave., Malvern, Pennsylvania.
Callite Tungsten Corp., 544 39th St., Union City, New Jersey.
Fansteel Metallurgical Corp., 2200 Sheridan Rd., North Chicago.
Handy & Harmon, 82 Fulton St., New York.
International Nickel Co., 67 Wall St., New York.
Mallory & Co., P. R., 3029 E. Washington St., Indianapolis, Indiana.
Wilson Co., H. A., 97 Chestnut St., Newark, New Jersey.

QUARTZ CRYSTALS

Bausch & Lomb Optical Co., Rochester, New York.
General Electric Co., Schenectady, New York.

RADIUM

Radium Chemical Co., Kearny, New Jersey.

TALC

Chas. B. Chrystal & Co., 7 Park Place, New York.
Hammill & Gillespie, 225 Broadway, New York.

Innis, Speiden & Co., 117 Liberty St., New York.
L. A. Salomon & Bros., 216 Pearl St., New York.
C. K. Williams & Co., Easton, Pennsylvania.

TITANIUM

Foote Mineral Co., Philadelphia.
Titanium Alloy Mfg. Co., Niagara Falls, New York.
American Rutile Corp. (Metal & Thermit), 120 Broadway, New York.
Titanium Pigment Co., 111 Broadway, New York.
Sicklick Ltd., 350 Madison Ave., New York.

TUNGSTEN

Fansteel Metallurgical Corp., North Chicago.
Electro Metallurgical Co., 30 E. 42 St., New York.
David Taylor Co., 52 Broadway, New York.
Metal & Ore Corp., 233 Broadway, New York.
Molybdenum Corp. of America, 500 Fifth Ave., New York.

COBALT

Deloro Smelting & Refining Co., Deloro, Ontario, Canada.
LaRose-Ronyor Mines Ltd., 112 Yonge St., Toronto, Ontario, Canada.
Central Trading Corp., 511 Fifth Ave., New York.

MANGANESE

Bethlehem Steel Corp., Bethlehem, Pennsylvania.
Jones & Laughlin Steel Co., Pittsburgh, Pennsylvania.
Carnegie-Illinois Steel Corp., Pittsburgh, Pennsylvania.
Colorado Fuel & Iron Co., Denver, Colorado.
Electro-Metallurgical Co., 30 E. 42d St., New York.
W. H. Muller & Co., 122 E. 42d St., New York.
Leonard J. Buck, Inc., 74 Trinity Place, New York.
Frank Samuel & Co., Harrison Bldg., Philadelphia.
E. J. Lavino Co., 1528 Walnut St., Philadelphia.
Harold P. Banks, 40 Exchange Place, New York.
W. R. Grace & Co., Hanover Square, New York.
International Selling Corp., 26 Beaver St., New York.
C. Tennant Sons & Co., 9 Rockefeller Plaza, New York.
David Taylor Co., 52 Broadway, New York.

Vanadium Corp. of America, 420 Lexington Ave., New York.
Republic Steel Corp., Cleveland, Ohio.

MANGANESE (BATTERY GRADE)

National Carbon Co., Long Island City, New York.
C. F. Burgess Laboratory, Madison, Wisconsin.
Ray-O-Vac Co., Madison, Wisconsin.
Bright Star Battery Co., Clifton, New Jersey.
General Dry Battery Inc., Cleveland, Ohio.
Acme Battery Co., 59 Pearl Street, Brooklyn.

MICA

Asheville Mica Co., 5 River Rd., Biltmore, North Carolina.
Brand & Co., 276 Fourth Ave., New York.
Continental-Diamond Fibre Co., 13 Chapel St., Newark, Delaware.
English Mica Co., 220 E. 42d St., New York.
General Electric Co., Appliance & Merchandise Dept., Bridgeport, Connecticut.
Hoje-Liberty Mica Co., 171 Camden St., Boston, Massachusetts.
Insulation Mfrs. Corp., 565 W. Washington Blvd., Chicago.
Mica Co. of Canada (N.Y.) Inc., Massena, New York.
Mica Insulator Co., 200 Varick St., New York.
Richardson Co., 27 & Lake Sts., Melrose Park, Illinois.
Spruce Pine Mica Co., Spruce Pine, North Carolina.
U. S. Mica Mfg. Co., 1521 Circle Ave., Forest Park, Illinois.
Westinghouse Electric & Mfg. Co., East Pittsburgh, Pennsylvania.

MINERAL COLLECTIONS

Peter Zodac, Peekskill, New York.
Wards Natural Science, 302 N. Goodman St., Rochester, New York.

MOLYBDENUM ORE

Molybdenite, if of good grade, may be sorted from the waste granitic rock; but if it is finely scattered through the matrix, as at Climax, Colorado, and as several places in Arizona, the ore must be concentrated. Although the specific gravity of molybdenite is 4.7 and some of it may be tabled, the recovery is not always satisfactory because part of it floats away, and in some ores it is admixed with wulfenite or lead-molybdenum oxides which slime or with copper and other minerals whose gravity is fairly close. Wulfenite may be tabled with fair results, especially if associated with lead carbonate. The flotation process is the most suitable for good recovery of molybdenite concentrates.

Molybdenite occurs with copper minerals in Arizona, Colorado, California, Idaho, Nevada, and Utah and in the large copper deposits in Chile, South America. In Arizona and Utah copper exists as chalcocite, whose gravity is 5.6; in the other States, with chalcopyrite, whose gravity is 4.2. Even with flotation there is difficulty in separating these minerals, and concentrates must be re-concentrated because the molybdenite must be free of or low in copper, and conversely. Unless a deposit is exceptional, it is better to develop one without chalcopyrite.

In New South Wales, molybdenite (4.7) occurs with bismuthinite (6.5) in quartz. A good separation is made by crushing and tabling—a molybdenite concentrate carrying some bismuthinite and a bismuthinite concentrate. (It may be added that smelters penalize bismuth in copper ores.)

PYRITE GROUP

Arsenopyrite (6), chalcopyrite (4.1), iron pyrite (5) as yellow pyrite and as white pyrite (marcasite), and pyrrhotite (4.6) form the pyrite group. They contain, in order, 46 per cent arsenic, 20 per cent sulphur, and 34 per cent iron; 35 per cent copper, 30 per cent iron, and 35 per cent sulphur; 46 per cent iron and 54 per cent sulphur; and 62 per cent iron and 38 per cent sulphur. As marcasite is not common in quantity, it may be disregarded.

Individually, the pyrite minerals may be separated from silicate minerals; but when the former occur intermixed, trouble starts from the closeness of their gravity, excepting arsenopyrite. Flotation will separate them as it does the chalcopyrite, pyrite, and pyrrhotite at Noranda, Quebec, and at Outokumpu, Finland, and the chalcopyrite and pyrite at Matahambre, Cuba. Noranda ore is massive and contains 7 per cent chalcopyrite, 22 per cent pyrite, and 52 per cent pyrrhotite; it yields considerable copper, gold, and silver by flotation. Outokumpu ore averages 11 per cent chalcopyrite, 30 per cent pyrite, 15 per cent pyrrhotite, and 42 per cent quartz. It is tabled and floated. Matahambre ore is massive, occurs as veinlets, and contains 12 per cent chalcopyrite (4¼ per cent copper) and 5 per cent pyrite; the copper recovery is 96 per cent at a cost of 48 cents per ton for milling and concentration.

As the market price for white arsenic is so low and has been for years, there is no encouragement to mine and mill arsenopyrite unless it carries gold, in which case the ore may be tabled, the concentrates sold, and the table tailings cyanided or wasted according to their value. In most cases they are run to waste.

The Hedley Mascot mine, British Columbia, yields arsenopyrite carrying gold, also some pyrite, pyrrhotite, and chalcopyrite. Simple, straight flotation makes a high recovery, and concentrates are sent to a smelter. There is no treatment of the flotation tailings. Neither is there at the Wiluna mine, Western Australia, where the gold is in pyrite and arsenopyrite. The concentrates are treated locally by roasting and smelting.

The Vaucluse mine, Virginia, produces quartz which carries iron pyrite and about $8 worth of gold per ton. Some barren quartz is discovered, and simple, straight flotation recovers 90 per cent of the gold content. The concentrates are railed to a smelter.

Some coals contain fine pyrite and lump pyrite. It is undesirable because of the sulphur, which produces problems in burning and in cooking. Little can be done about the fine pyrite, but the lump mineral is picked out underground and on the surface before and after the coal has been crushed. In the States of Illinois, Indiana, Kentucky, and Missouri some pyrite is saved and sold to acid-makers. In one washery in Illinois the pyrite is jigged out of the coal.

Nova Scotia ores contain gold which is free and with sulphides, chiefly arsenopyrite. If the gold is in quartz, it is coarse and crystalline, and when in slate it occurs as thin plates and scales, frequently coated and discolored. A. G. Roach of the Seal Harbor mine suggested a general flow-sheet to the Mining Society of Nova Scotia. He would sort the ore before it is crushed, grind it in a rod-mill, and save concentrates in a trap and Denver jig and on blankets; these would be ground and amalgamated in a barrel, and the barrel tailings dried and shipped or held. Between the jig and blankets would be a classifier whose sand is returned to the rod-mill. The blanket tailings are wasted.

GARNETS

Garnets for use as abrasives have been produced in New York, North Carolina, Vermont, and Idaho. In Benewah County, Idaho, a deposit in a creek bed was excavated in 1941 with a power shovel and screened in a portable screening plant where minus 2½ millimeter material was separated and transferred to the treatment plant. Designed by R. S. Handy, of Kellogg, Idaho, the plant consists of a hydraulic classifier which scalps off the slime and the lighter gangue of mica and quartz and delivers the spigot-product to a Z-compartment Harz jig. The first compartment products and the hutch of the second compartment are finished concentrate, while the second gate product is returned to the system for recleaning. The jig product is dried and screened into commercial products. The physical character of the garnet particles precludes the use of tables, as the particles have a tendency to roll in the dressing surface of the table. Extremely fine garnet particles have no known commercial importance.

SILVER ORES

The extraction of silver when associated with gold, which is the principal metal, is described under gold ores. This section deals with straight silver ore or with silver ore that has gold in low amount. Many silver ores are amenable to cyanidation; but as a flotation plant costs less, it may be economical to concentrate them. However, the cost of local treatment or shipment of concentrates must be carefully considered. For freight and custom treatment, the higher the value the higher the charges.

Although the silver minerals are dissolved by cyanide, the treatment period covers several days with fairly strong solutions, sometimes heated to 110°F. The cyanide consumption ranges from 2½ to 3½ pounds per ton of ore.

Cerargyrite or silver chloride and argentite give good results with cyanide. Stetefeldtite (a complex sulphide); polybasite, pyrargyrite, and stephanite (the sulphantimonites); proustite (the sulpharsenate); and tetrahedrite (the sulphantimonite of copper, with copper replaced by silver) are difficult to cyanide and should be floated.

In the Trinity district, Pershing County, Nevada, silver and gold occur in quartz in granite. The gold is free but associated with iron oxide. A 5-ton Gibson mill, copper plate, and shaking table gave 60 per cent recovery. Tailings were cyanided in 4- by 5-foot leaching tanks. Solutions were hand-pumped. Precipitation was on zinc shavings. This equipment cost $2000.

In the Rochester district, Nevada, the silver and gold occur in quartz and stockworks or a network of veinlets in rhyolite. In over 20 years the average was nearly 10 ounces of silver and $1.80 gold per ton. The principal mineral is argentite, the sulphide, also minor amounts of other sulphides. Stamping, amalgamation, and tabling were tried in small mills; cyaniding, in others; and now ball-milling and flotation are used.

At Waihi, New Zealand, the silver-gold table concentrates are tube-milled in batches and then cyanided for a couple of weeks in tall air agitators. A recovery of well over 90 per cent is made. The silver mineral is argentite.

In Mexico, at Fresnillo and Pachuca, for example, argentite is the principal silver mineral, with a little gold. The ore is all ground fine and cyanided during 3 to 4 days. The practice at Rosario, Honduras, is more or less similar and is satisfactory.

Freibergite, the silver-bearing variety of tetrahedrite, yields high in silver at several mines in the United States: The Sunshine mine, Crescent mine, and Polaris mine, Shoshone County, Idaho, and the Quartz Hill mine, Beaverhead County, Montana. The gangue minerals of the Sunshine are siderite and quartz, also some galena and pyrite; those of the Quartz Hill are quartz, calcite, and barite. The respective silver contents are 45 and 37 ounces per ton, also some copper. Sunshine ore is easily concentrated by rather coarse grinding and flotation. Concentrates assay up to around 1000 ounces per ton, with 12 per cent copper, 2½ per cent lead, and 9½ per cent antimony, also some bismuth. This product is sold to smelters. Crescent ore averages 25 ounces per ton, and flotation concentrates average 250 ounces, with some copper, lead, and antimony. Quartz Hill ore is sorted and sent to the smelter, but milling has been considered.

In Texas, near the Mexican border, the Presidio mine yields a quartz ore which in a recent year averaged 12 ounces of silver as argentite (the sulphide) and 8 ounces as cerargyrite (the chloride), also a little free gold, 1¼ per cent each of silver-bearing galena and cerussite, and nearly 5 per cent zinc. A recovery of over 90 per cent of the silver is made by breaking, screening and tabling, grinding and classifying to 70 per cent through 200-mesh screen, and agitating with cyanide with decanting of the solution. The table concentrates assay up to 285 ounces per ton. They are sun-dried, sacked, sampled, and trucked to a smelter.

TIN ORE

In the dressing of tin ore, the problem is to separate the cassiterite from the siliceous gangue, also from pyrite which is often present. Tin miners in Australia have built simple plants and get fair recoveries. As much waste as possible should be discarded. As cassiterite has a gravity of 7, it is relatively easy to separate from siliceous materials whose gravity is 2.6 and from pyrite which is 5. Any type of crusher is suitable for breaking ore, and stamps, ball- or rod-mills, or rolls will reduce it to suitable size for concentration in jigs and on shaking tables. If possible, table feed should first be classified, this giving higher results. An over-all saving of 80 to 85 per cent can be made by careful work, producing a concentrate carrying up to 50 per cent tin. As tin smelters penalize sulphur, the iron or other sulphides must be reduced as low as possible. Flotation will re-concentrate the gravity concentrates, but it is not likely that a small operator will try this.

TUNGSTEN ORE

As stated elsewhere, there are four ores of tungsten: ferberite (7.3), huebnerite (7.3), scheelite (6), and wolframite (7.5). These should be easily separated from their enclosing rocks, but other minerals are associated with them, and the tungsten minerals slime more or less. Stamps can be used, but a ball-mill or rolls are better. Plenty of water should be fed to a mill to wash out the tungsten quickly. The crushed ore should be classified in a rake or spiral trough or in a cone before it is jigged, and the sand and slime are run over separate shaking tables. As the slime carries tungsten, it should be further handled by running over canvas or by flotation. If pyrite (5) is present in quantity, it somewhat fouls the tungsten minerals when gravity concentration is employed.

As tungsten concentrates should assay 60 per cent tungstic trioxide and be practically free of sulphur, arsenic, antimony, bismuth, copper, tin, molybdenum, and phosphorus, milling and concentration should be carefully done.

At one mine in Nevada the scheelite ore was run through jaw-crushers and rolls and concentrated on tables. The concentrate was dried and cleaned by an electromagnet.

In the South Island of New Zealand, scheelite occurs irregularly in schist country at an altitude of 6000 to 7000 feet. The outcrop ore is hand-jigged three times on ½-inch, 8-mesh, and 32-mesh screens. The massive ore is broken, stamped, tabled, jigged, dried, and sacked. As some of the ore contains iron pyrite and arsenopyrite, it is first roasted in a crude kiln with wood and coal.

ZINC ORE

Seldom is zinc alone in an ore, but an example is the Mascot mine in Tennessee, where the sphalerite is in dolomitic limestone, itself the country rock. Milling is simple and consists of crushing, jigging, and floating. Possibly, if a small deposit of similar ore were developed, milling, jigging, and tabling would give fairly satisfactory results.

Zinc-lead Ore

The Tri-State or Joplin district of Missouri, Kansas, and Oklahoma and the Wisconsin field are representative of zinc-lead ore. In the former area the ore averages around 5½ per cent zinc and 1 per cent lead. The rock in the sheet-ground deposits is chert or dolomite (2.8). There is a large-capacity central or custom mills for lease ores, but there are also many small plants. Crushing to ½ inch size is done by jaw-crushers and rolls. Screening is followed by jigging and tabling. As there are losses in the slime, many plants dressing ores and tailings have grinding and flotation equipment. Costs are low.

An outline of the milling process is as follows, according to J. R. Reigart in *Information Circular* 6591 of the Federal Bureau of Mines:

1. Orebin.
2. Jaw-crusher.
3. Rolls, elevator ½-inch screens in circuit.
4. Undersize to desliming cone or to a drag, whose overflow goes to sand drag at head of tabling section; deslimed product fed to rougher jig.
5. Rougher and cleaner jigs.
6. Grinding and screening (about 10 mesh) sand.
7. Classifying and tabling.
8. Thickening and flotation; lead first, then zinc.
9. Filtering concentrate.

Tailings.—In the Tri-State district of Missouri-Kansas-Oklahoma there are estimated to be 50 million tons of workable zinc-lead tailings. About 15 tailings plants were busy in 1941. After careful sampling, the tailings are dressed by equipment that includes screening, rolling, ball-milling, jigging, tabling, and floating. The average tailings plant handles 60 to 80 tons an hour. The concentrate is of good grade, and the cost ranges from 20 to 45 cents per ton of heads treated.

Marketing Concentrates. The zinc concentrates and lead concentrates are sold locally each week to smelting and other companies. When the markets for zinc and lead are good, sales are active; when the markets are dull, a surplus of concentrates accumulates. The basis of sale is 60 per cent zinc in the zinc concentrate and 80 per cent lead in the lead concentrate. When zinc is around 8¼ cents a pound, the concentrate sells at $55.28 a ton; when lead is around 6 cents a pound, the concentrate sells at $77 a ton. At lower prices for zinc and lead, say, 5 cents a pound each, the settling prices are $33 and $56 per ton, respectively.

PREPARATION OF CONCENTRATES

The shipping of concentrates is covered elsewhere; but before they are bagged and dispatched, they should be more or less dried.

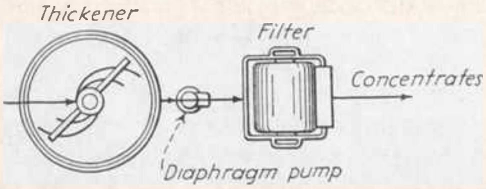


FIG. 160.—Filtering equipment for flotation concentrates. For a 16- to 20-ton plant, filtering 1½ to 2 tons, the cost is $2300; but for a flotation plant for two minerals, add $1750 to this amount.

Figure 160 shows filtering equipment for concentration. Then some form of dryer reduces the moisture from perhaps 20 to 5 per cent and also the loss from dusting, lowers the freight charges, and makes a better product for the smelter which may roast and sinter it before smelting. In a dry climate, concentrates may be

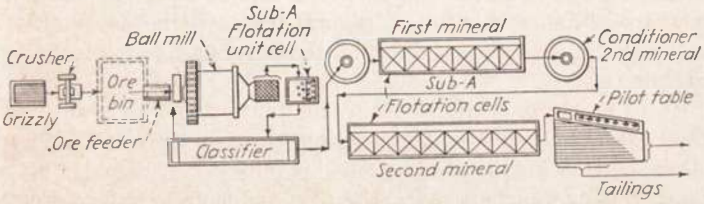


FIG. 161.—Recovering two minerals by selective flotation. This arrangement will treat, as a minimum, 16 to 20 tons in 24 hours and cost $9000. The pilot table is a guide to the work of the other machines.

dried by spreading and raking them on a cleared, hard space or on canvas or other material. A pan with a 3-inch upturned edge, 3 by 6 feet or more in area, set on rock or brick built up a foot or so, and under which a low log fire can burn, is suitable. As stirring creates dust and loss, this should be done sparingly and carefully; and for this reason it is better not to make the concentrates bone dry but to leave them in 3 to 5 per cent moisture. Roasting or smelting of sulphides should not be tried in homemade equipment.

COMPLEX ORES

If ore consisting of mixed sulphide minerals and quartz is developed, the prospector would be wise to sell it.

Figure 161 shows a Denver flow-sheet for dressing a complex ore.

One mine in Arizona yields ore containing galena, sphalerite, and pyrite, with some chalcopyrite and tetrahedrite. Silver occurs with the last-named, and gold is free. Only complicated flotation is suitable for such ore. Little sorting is possible. Lead concentrates and zinc concentrates are shipped, but each of these carries lead, zinc, copper, gold, and silver, a rather complex product for smelting. Excepting the lead, recoveries range from 80 to 86 per cent.

Another mine in Arizona produces a molybdenum-vanadium-lead-gold-silver ore, which required much skilled experimentation before a satisfactory concentration process was worked out.

Nickel-cobalt, gold-platinum, lead-zinc-gold-silver, oxidized lead-silver, manganese-silver, silver-cobalt, arsenic, and other combinations of ores are difficult to handle and require expert advice.

Graham Lamb of the Denver Equipment Company, in its *Bulletin* 3713-B, entitled "Marketing Concentrates," gives four possible methods of handling a complex sulphide ore assaying 0.45 ounce gold, 9.6 ounces silver, 6.7 per cent copper, 3.4 per cent lead, 5.1 per cent zinc, 18.5 per cent sulphur (in sulphides), and 38.4 per cent silica and other insoluble matter. If calculations are based on gold at $35 an ounce, silver at 77.6 cents an ounce (now 66.5 cents), copper at 12 cents a pound, lead and zinc at 6 cents a pound each, the following net returns would be made by handling the ore this way:

Four Methods of Handling a Complex Ore

Amount and class	How handled	Value	Net return per ton of ore
1 ton crude ore	To lead smelter	....	$14.10
1 ton crude ore	To copper smelter	....	20.05
1 ton crude ore concentrated	0.589 (say 0.6) ton concentrate to copper smelter	$42.35 per ton concentrate	24.95
1 ton crude ore amalgamated and concentrated	To mint	$8.98 bullion per ton ore	
	0.214 (say ⅕) ton copper concentrate to smelter	$12.20 per ton ore	
	0.065 ton lead concentrate	$7.97 per ton ore	30.80
	0.054 ton zinc concentrate	$1.65 per ton ore	

The net returns refer to cash received less hauling, freight, and treatment charges.

It proved much more profitable to catch as much gold and silver as possible and then make three flotation products, each of which goes to a different smelter. The copper concentrate assays 28 per cent copper and 14½ ounces silver; the lead concentrate, 45 per cent lead and 62 ounces silver; the zinc concentrate, 63 per cent zinc and 4½ ounces silver.

POWER SUPPLY

With regard to power, circumstances influence how much is required and what to use. Two to four horsepower per ton of ore may be needed. Steam boilers and engines are to be avoided if possible, as they need much fuel and good water. If enough water and pressure are available, a Pelton wheel can be used. A wheel for each machine has been operated in California and New Zealand. The simplest power is an oil engine using gasoline or one of the diesel type burning oil. Engines driven by producer gas made from wood, charcoal, coke, char, and several waste materials are suitable in isolated districts. Small diesel electric-generating units have found a growing market in the operation of small mines during the last few years. They are popular in Australia and Rhodesia. The motor of an automobile or truck may be arranged to drive a small plant. If electric power is available near by, use it, especially a motor for each machine. In level or slightly rolling country a transmission line will cost $1,000 a mile, in rough country several times this sum.

As to fuels, if they are to be used, the mine-owner may get free from the Federal Bureau of Mines, Washington, D.C., two 4- by 6-inch (34 pages and 17 pages) booklets, "Questions and Answers for the Home Fireman" and "Questions and Answers for the Coal Fireman." The first-mentioned describes and compares all types of fuels, including oil and gas, and tells how to burn them properly without waste and smoke. The second booklet fully covers coals and their burning.

PART V

CHAPTER XX

MEMORANDA

The prospector or other person who is searching for minerals or is mining and milling ores in the mountains, hills, plains, streams, or desert may be at a loss in making simple calculations because he has forgotten or is not sure of some weights and measures; therefore the necessary fundamental units and other aids to calculation are given here. They have been gathered from various sources, partly from *Miscellaneous Publication* 121 (1936) of the National (United States) Bureau of Standards, which makes the official recommendations and is custodian of the standard brass unit weights, containers, and measures. Excepting a few units, British weights and measures are the same as the American. The author's arrangement follows:

COMMON WEIGHTS AND MEASURES

Length

The yard, or 3 feet, is the unit of length. There are 1760 yards or 5280 feet in a mile. One foot is ⅓ yard or 12 inches, and 1 inch is $\frac{1}{36}$ yard or $\frac{1}{12}$ foot.

In surveying, the following units are used: 1 link is 7.92 (nearly 8) inches or $\frac{1}{100}$ chain, and 100 links or 66 feet or 22 yards or 4 rods is 1 chain; 1 rod is 5½ yards or 25 links; 1 furlong is ⅛ mile or 40 rods, and 8 furlongs makes 1 mile.

Other measures are: 4 inches equals 1 hand, 9 inches equals 1 span, and 6 feet equals 1 fathom.

Area

The square yard is a unit of area equal to the area of a square whose sides are 1 yard. Divisions of the square yard are 1 square foot, which is ⅑ square yard or 144 square inches. Multiples of the square yard are 1 square rod, which is 30¼ square yards; 1 acre, which is 4860 square yards or 43,560 square feet; and 1 square mile, which is 640 acres.

Volume

A cubic yard is a unit of volume equal to a cube whose edges are 1 yard. A cubic foot is 1/27 cubic yard, and a cubic inch is 1/1728 cubic foot or 1/46,656 cubic yard.

(The cubic yard was made legal volume in England in 1936, replacing the indefinite term "load.")

Capacity

A gallon, used only in the measurement of liquid commodities, is a unit of capacity equal to the volume of 231 cubic inches. One gallon of water weighs 8⅓ pounds. One cubic foot of water weighs 62.4 pounds and contains 7.48 gallons. A cubic foot of ice weighs 58.7 pounds, has a volume of 30 cubic inches and specific gravity of 0.92.

A bushel, used only in the measurement of dry commodities, is a unit of capacity equal to the volume of 2150 cubic inches.

(The British gallon contains 277 cubic inches and weighs 10 pounds or one-fifth larger, and the bushel has 2219 cubic inches or 3 per cent larger than the same American units.)

A quart is ¼ gallon; a pint, ⅛ gallon or ½ quart; a gill, 1/32 gallon or ¼ pint; and a fluid ounce, 1/128 gallon or 1/16 pint.

A peck is ¼ bushel, and a barrel for fruits, vegetables, and other dry commodities, except cranberries, contains 7056 cubic inches or nearly 3⅓ bushels.

Mass

The avoirdupois pound is the unit of mass for general weighing. It contains 16 ounces of 437½ grains each, or 7000 grains; 2000 pounds is a short ton, and 2240 pounds is a long ton. Excepting in countries that use the metric system only, the short ton is almost universally used in the mineral industry, and its relation to the long ton is 2000/2240 or, say, 9/10, or, conversely, 1.12.

The troy pound is the unit of mass for weighing precious metals. It contains 12 ounces of 480 grains each, or 5760 grains. In troy weight is the pennyweight of $1/20$ ounce or 24 grains, and 20 pennyweight are 480 grains or 1 ounce.

The relation of the troy pound to the avoirdupois pound is $5760/7000$ or 0.823. There are 14.58 troy ounces in 1 pound avoirdupois.

The apothecaries' pound is the unit of mass for weighing drugs and with the ounce is the same as the troy pound and ounce. A dram is 60 grains, and a scruple is 20 grains, respectively $1/8$ and $1/24$ of an apothecaries' ounce.

TEMPERATURE CALCULATIONS

There are two common systems of temperature measurement—Fahrenheit (F.), the more common, and centigrade (C.), less common, yet growing in use and employed in most scientific work. The Fahrenheit scale reads 32° (degrees) as freezing point and 212° as boiling point; the centigrade scale reads 0° for freezing and 100° for boiling. One system may be converted to the other as follows:

Fahrenheit to centigrade: $(212 - 32) \div 1.8 = 100$.

Centigrade to Fahrenheit: $(100 \times 1.8) + 32 = 212$.

If the temperatures to be converted are below 32°F. or 0°C. add the 32 for Fahrenheit and subtract the 32 for centigrade.

THE CARAT

The term carat refers to fineness of gold and silver and to weight of precious stones.

Twenty-four carat is 1000 fine or pure; 18 carat is $18/24$ or 750 fine. United States coins are 900 fine or $9/10 \times 24/1$ or 21.6 carat. British coins were 916 fine or 21.98 carat.

Since 1913 the United States has recognized the international metric carat of 200 milligrams or 0.2 gram or 3.086 grains (say 3) as the unit of weight for diamonds and other precious stones. There are 155 carats in 1 troy ounce. Special scales and weights are used.

THE METRIC SYSTEM

Although it is lawful throughout the United States to employ the weights and measures of the metric system, and they are used extensively in laboratories and works at mines, mills, and other industries and in government operations, the metric system, excepting electrical units, is not the legal standard of the United States or British Empire. Most other countries have adopted the system, and their peoples understand it—the common units, at least. In recent years news from Europe telling of the Olympic games gave distances run in the metric system, and chemists and metallurgists frequently speak of testing quantities and sieve sizes in metric terms.

Prospectors and others may be more or less puzzled when they hear or read of weights and measures in the metric system; therefore some of the units will be given. These are easily converted into our regular weights and measures, and tables are available for this purpose, the handiest being a 13-page, 3¾- by 5½-inch booklet, "Conversion Factors for Engineers," distributed free by The Dorr Company, engineers, 570 Lexington Ave., New York.

The metric units are as follows:

Meter. The meter is the unit of length. It is 39.37 inches, and its relation to the yard of 36 inches is 3600/3937. One thousand meters is a kilometer or 1094 yards or 0.62 mile. A square meter is a unit of area equal to the area of a square whose sides are 1 meter.

Gram. The gram is the unit of weight or mass. It is equal to 15.432 grains, say 15½. One thousand grams is a kilogram or 2.204 pounds, say 2⅕, and 1000 kilograms is a metric ton of 2204 pounds. A short ton contains 907 kilograms. In rounded numbers, there are 32 grams in 1 ounce, 32 ounces in 1 kilogram, and 32,000 ounces in 1 metric ton. In countries that use the metric system only, assays are given in grams per metric ton.

Liter. The liter is the unit of capacity. It is equal to the volume occupied by the mass of 1 kilogram of pure water at its maximum density of 4°C. or 39.2°F. The liter is equal to 33.8 fluid ounces or 2.1 pints or 0.26 gallon or 61 cubic inches.

The supplementary metric units are formed by combining the terms "meter," "gram," and "liter" with six numerical prefixes, as follows: *milli* or 1/1000, *centi* or 1/100, and *deci* or 1/10; *deka* or 10 times, *hecto* or 100 times, and *kilo* or 1000 times.

Following are the commonly used multiples and submultiples in addition to those given:

Millimeter—25.4 (say 25) equal 1 inch.

Centimeter—2.54 (say 2½) equal 1 inch.

Hectare—1 equals 2.47 acres (say 2½).

Milligram—1 equals 0.001 gram.

The term "cubic centimeter" (cc. or c. cm. or $cm.^3$), the unit of volume, is a sub-multiple of the meter and is frequently used in chemical work, but its use in this sense is incorrect because the "milliliter" (ml.), the unit of capacity, a sub-multiple of the liter, is the proper term to use. It is being written thus more and more, and most laboratory glassware is marked "ml."

ELECTRICAL UNITS

The man who buys or generates power for his mine and mill should understand the following terms:

Ampere or Amp. This is the unit of electric current or rate of flow, named after Ampère.

Ohm. This is the unit of electric resistance, named after Ohm.

Volt or Voltage. This is the unit of electric pressure, named after Volta.

Watt. The unit of electric power or 1 ampere × 1 volt is named after Watt; 746 watts equals 1 horsepower, and 1000 watts equals 1 kilowatt, and $^{1000}\!/_{746}$ equals 1.34 horsepower.

Kilowatt-hour. The unit of power sales equals 1.34 horsepower-hours or 1000 watt-hours or 1 kilowatt for 1 hour.

To crush and treat a ton of 200-mesh ore may use 20 to 30 or more kilowatt-hours, which may cost ¼ to 1 cent per kilowatt-hour. More than half of this power is absorbed in grinding. The more power consumed the less the charge per unit.

For transmitting power from a motor to any machine or line shafting, use the V-belt if possible. It grips better and pulleys may be closer than with flat belts. Special grooved pulleys are required, but available; yet the V-belt pulley may be run satisfactorily with one grooved pulley and one flat pulley.

GRAVITY OF OIL

Many persons speak of an oil as having a certain gravity, but not all of them know upon what this is based. The A.P.I. (American Petroleum Institute) scale is generally accepted in the United States. The following table compares gravity scales, specific gravity, and equivalent weights of oil:

GRAVITY SCALES AND EQUIVALENT WEIGHTS

Gravity		Specific gravity	Weight, pounds per gallon
A.P.I.	Baumé		
10	10.0	1.0000	8.328
20	19.9	0.9340	7.778
30	29.8	0.8762	7.296
40	39.7	0.8251	6.870
50	49.6	0.7796	6.490
60	59.5	0.7389	6.151
70	69.4	0.7022	5.845
80	79.3	0.6690	5.568
90	89.2	0.6388	5.316
100	99.1	0.6112	5.086

MISCELLANEOUS UNITS AND PRACTICE (ARRANGED ALPHABETICALLY)

Acidity and Alkalinity

Acidity and alkalinity are opposites, and one condition or the other is to be found in fresh water, sea water, brine, soils, mines, ores, tailings, and circulating solutions in mills. Acidity and alkalinity may be changed by adding an acid to an alkali, or conversely. But care must be taken not to overdo it. Tests for acidity or alkalinity follow:

1. Litmus papers, which are sold as books of slips of blue and red papers soaked in litmus solution, are the simplest means of testing fresh water, mine water, or mill circulating water. When

dipped in acid water, the blue paper turns red. If it is alkaline, the water turns the red paper blue.

2. A simple test for cyanide solutions is made with phenolphthalein. One gram of this is dissolved in a little alcohol, diluted to 100 milliliters with water, and kept in a stoppered bottle. Two or three drops added to the cyanide solution give a crimson coloration, indicating alkalinity.

For an ore, take 5 to 8 ounces of finely crushed material and shake with an equal amount of good water in a glass or china container. Filter the pulp. Add lime solution to clear the filtrate until slightly alkaline with phenolphthalein. Repeat this test with mill water to determine if there is any difference.

3. A more exact test for acidity or alkalinity of waters and solutions is the pH method. Its use is growing in mining and industry. On the pH scale, pH 7 represents a neutral condition; below 7 the liquid is acid, and above 7 it is alkaline. Reagents and a color chart are required for testing. The symbol pH is derived from "potential of hydrogen." The active acidity of a solution is often only a fraction of its total acidity. As active acidity falls off, the pH increases. The pH of pure water is practically 7. Tap water in towns ranges from 7½ to 9, because lime, aluminum salts, soda ash, and chlorine may be added for clarifying and purifying purposes.

pH papers, impregnated with a highly sensitized indicator and bearing a number of color bars each representing a different pH value, covering the range of 0.9 to 13.5, are now available in boxes of 200 strips from Paul Frank, 450 Fourth Ave., New York. When dipped in waters or solutions, the indicator will change color according to their pH. This color is then compared with the color bar, and the pH read from the measuring scale accompanying the papers.

The Atmosphere

Composition is 21 per cent oxygen and 79 per cent nitrogen, with 0.03 per cent carbon dioxide.

Pressure at sea-level is 14.7 pounds (say 15) per square inch or 29.9 inches (say 30) of mercury.

Pressure Drop at Altitude. Each 1000-foot rise reduces the pressure ½ pound and the boiling point of water 2°.

Weight of Air at Sea-level. One cubic foot at 62°F. weighs 0.076 pound (say 1⁄13).

Brickwork

17 brick are required for 1 cubic foot of brickwork, which weighs 125 to 140 pounds.

1000 brick closely stacked equal 56 cubic feet.

1000 brick loosely stacked equal 72 cubic feet.

400 to 600 pounds of fine fireclay will lay 1000 brick, which should be thinly coated by dipping them in the fireclay.

Prices of Building Materials in the United States

Year	Brick, common, per 1000	Building tile, hollow	Cement, per barrel (4 sacks = 1 barrel)	Lime, per short ton	Lumber, per 1000 board feet, common fir at mill
1940	$12.13	7.4 cents per block	*	$6.97	$21.26
1939	12.05	7.3	$1.56	7.10	19.34
1938	12.00	7.2	1.67	7.15	17.68
1937	12.05	7.0	1.49	7.31	20.87
1936	11.74	7.0	1.51	7.18	19.49
1935	11.77	7.0	1.51	7.28	16.00
1934	12.00	6.9	1.54	7.16	17.63
1933	10.53	5.2	1.33	6.28	14.12
1932	10.69	4.8	1.01	6.28	9.41
1931	12.40	$5.28 dollars per short ton	1.11	6.90	11.65
1930	11.14	6.04	1.44	7.56	14.70
1929	10.67	6.00	1.48	7.84	18.29
1928	10.81	6.49	1.57	8.18	19.02
1927	11.10	6.44	1.62	8.75	19.45
1926	11.74	6.79	1.71	9.11	20.17
1925	11.71	6.93	1.77	9.30	17.97
1924	12.11	7.07	1.80	9.72	

* Data not available.

Building-material Prices

The prices of building materials for mine plant vary according to where stocks are held and the cost of freight therefrom by rail, truck, or other means of transportation. If such materials are obtainable from a worked-out mine within reasonable distance and easy haulage, so much the better. The table on page 470 shows appropriate prices in recent years for the building materials needed at a mine, these prices being f. o. b. works shipping point; according to the Bureau of Labor Statistics.

Color Scale

In tempering drill-steel or bits or in welding, the following temperatures and colors are equivalent:

Color	Heat, °F.
Redness	980
Cherry red	1530+
Dark orange	1790+
Yellow	2050+
White	2280

Concrete

Concrete is either plain or re-inforced with rods or with wire and any suitable, clean, used iron or steel. As a rule, concrete consists of an intimate mixture of sand, crushed stone or gravel, cement, and water. Slag is used where available. These materials must be free of dirt and impurities. A general mixture is 1 part cement, 2 parts sand, and 4 parts stone. The concrete should not be too sloppy when poured; it should be well tamped; it should be kept wet with sacking for several days; the oiled forms should not be taken off too soon; the concrete should be protected from sun or freezing. If concrete is mixed in cold weather, the ingredients should be heated to at least 60° before they are mixed and placed and then should be covered.

Cement is mostly shipped in 3- to 5-ply paper sacks or in cloth sacks.

1 bag weighs 93 pounds net.

1 barrel (4 sacks) weighs 372 pounds.

1 long ton consists of 6 barrels or 24 sacks.

Cost of Ore-dressing and Treatment Plants

The General Engineering Company (Salt Lake City) in the *Metallurgical Bulletin* gives the following range of cost for milling plants:

COST PER TON-DAY CAPACITY

TYPE OF PLANT	COST
Stamps and amalgamation	\$400–\$700
Gravity concentration:	
Jigs	100– 150
Tables and other machines	300– 450
With flotation	600– 1000
All-slime cyanidation	700– 1200
All flotation:	
Straight	500– 800
2-product and 3-product	700– 1000

In chapter 4 will be found the cost of erecting certain types of plants, according to the Denver Equipment Company. Flowsheets accompany the information.

Cubic Content

Area of circle = diameter squared × 0.7854 or, say, 4/5.

Circumference of circle = diameter × 3.1416 or, say, 3 1/7 or 22/7.

Cubic content of round tanks = diameter squared × 4/5 × depth, in feet.

Cubic content of square or rectangular tanks = length × depth × width, in feet.

(Having the cubic content of tanks, multiply by 100 pounds per cubic foot for sand tailings or by 62½ pounds for water ÷ 2000 to find the total tonnage. Multiply the cubic content by 7½ to obtain the gallon capacity.)

Diameter of round tanks = circumference × 0.3183 or ⅓.

Paint required for a building = height of walls × length in feet ÷ 400 = gallons. (One gallon of good paint will cover 400 square feet.)

Custom Plants and Treatment Charges

If a prospector or operator of a small mine has ore and knows by panning or by assay and analysis that it is worth treating, and unless he is able to finance a small mill, it is best to study ways and means of shipping the ore to a custom plant. In most countries there are plants that either handle only custom ore or treat it with their own regular supply. This is so particularly in North America and Australia. These plants are managed by reliable men who have no reason to be unfair to prospectors and others. Their treatment charges, deductions, and penalties may seem unreasonable, but no plant recovers 100 per cent of the metals, and a number of minerals affect good recoveries of others. Frequently, the principal causes of dissatisfaction with returns from custom plants are the prospector's own faulty sampling method and panning estimates, assays made on samples incorrectly taken, neglect to discard barren rock, and an idea that assays do not reveal all the gold content of an ore. One result of this is discouragement, and another is attempts to smelt ore in crucibles or in some type of electric furnace; without prejudice, we say that such local treatment by a small miner is futile.

For the asking, while they last, the Federal Bureau of Mines, Washington, D.C., will send anyone a copy of each of its *Information Circulars* 6842 (1935) and 6926 (1936) entitled "Gold and Silver Custom Plants" and "Open Schedules for Gold and Silver Ores and Concentrates at Western Custom Smelters." These useful reports are by E. D. Gardner and by E. D. Gardner and Paul T. Allsman, who give details of milling and smelting and explain why the charges and deductions are made.

Custom Mills. The capacity of the individual gold and silver mills mentioned below is 5 to 2000 tons a day, and the charges range from $1.75 to $9.60 per ton of ore, depending on the type, but the medium range is $2.25 to $5. Clean-up charges on small lots are $5 to $15. The recovery is generally good, and payments are 80 to 96 per cent of the assay value. Flow-sheets are straight amalgamation, amalgamation with tabling or flotation, and straight cyanidation. Excepting the Golden Cycle mill, lead, copper, or other base metals which might be in gold and silver ore are not paid for. A part list of custom mills follows:

CUSTOM MILLS IN THE WEST

State	Place	Name of plant	Ore treated
Arizona	Oatman	Big Jim	Gold
	Oatman	Tom Reed	Gold
	Chloride	Katherine	Gold
	Morristown	Congress	Gold
	Octave	Octave	Gold, silver, lead, copper
	Salome	Forester	Gold
	Wickenburg	Wickenburg Ore Market	Gold, silver, lead, copper, sent to El Paso
California	Rosamond	Tropico	Gold, silver
	Mojave	Elephant and Eagle	Gold, silver
	Mojave	Golden Queen	Gold
	Nevada City	Queen Lil	Gold
	Nevada City	Hoge	Gold
	Hobo Springs	Hobo Springs	Gold
	Jackson	Amador Reduction (concentrates only)	Gold
	Randsburg	Big Butte	Gold
	Sonora	Sonora	Gold
	Victorville	Brand and Ellis	Gold
	Barstow	Baker and Bemard	Gold
	Sheep Ranch	Mar John	Gold
Colorado	Boulder	St. Joe	Gold, silver
	Colorado Springs	Golden Cycle	Gold, silver, and others
	Silver Plume	Watrous	Gold
	Blackhawk	War Dance	Gold
	Blackhawk	Farr	Gold
	Idaho Springs	Ruth	Gold
	Idaho Springs	Argo	Gold
	Idaho Springs	Gilpin	Gold
	Creede	Creede Mills	Clear Creek County
Kansas	Baxter Springs	Wade	Zinc, lead
Missouri	Chitwood	Zinc and Lead Producers	Zinc, lead
	Waco	Playter	Zinc, lead
	St. Louis	St. Louis Sampling & Testing Works	Zinc, lead
Nevada	Searchlight	Cyrus Noble	Gold
	Silver City	Trimble	Gold
	Silver City	Donovan	Gold
	Virginia City	Recovery	Gold, silver
	Sodaville	W. and M.	Gold
	Silver Peak	Black Monmouth	Gold
	Seven Troughs	Rodgers	Gold
New Mexico	Hillsboro	Hillsboro	Gold
Oklahoma	Miami	Bird Dog	Zinc, lead
	Miami	Indian	Zinc, lead
	Picher	Eagle-Picher	Zinc, lead
	Picher	United Zinc	Zinc, lead
Utah	Murray	United States Smelting	Zinc, lead, silver
	Murray	Utah Ore Sampling	All
	Tooele	International Smelting	Zinc, lead, silver

At several mills the shipper is given the amalgam and concentrate for his own disposal.

In Canada several mills in British Columbia and Ontario accept custom ore. The largest custom mill in Canada is that of the Consolidated Mining and Smelting Co. Ltd., Trail, British Columbia.

In Australia custom ores are received by several plants, and in most States are government-operated stamp-mills and cyanide plants suitably located.

Custom Smelters. Gold and silver ores are shipped to smelters only when milling facilities are not available; however, high tailing losses in milling a high-grade or refractory ore or low smelting rates because of the fluxing value of an ore may make direct smelting more economical.

An ore or concentrate that contains an appreciable amount of lead would probably be sent to a lead smelter, while ore high in copper and low in lead would go to a copper smelter. Some gold and silver concentrates contain a high percentage of zinc, and in general it is more economical to ship them to a copper or lead smelter and pay the penalty for the excess zinc.

Before making a smelting contract, a shipper should have complete knowledge of the approximate analysis and grade of his ore, the freight rates to competitive smelting plants, and the needs of these plants for his particular types of ore.

As the schedules for payments, deductions, and penalties at smelters are so variable, producers that propose to ship thereto should first procure a copy of the schedules. A list of the custom smelters is shown in the table on page 476.

Dump Measurement

Ore and tailing dumps, if more or less conical, may be estimated by multiplying the area of the base by one-third of the height. A good recent example of fair accuracy in measurement was the tailings dump on the Golden Horse Shoe mine, Kalgoorlie, Western Australia. The estimate was 2,850,000 tons, whereas 2,674,000 tons was actually treated. This was a fairly symmetrical dump, but most dumps are more or less scattered.

If tailings are built up more or less with square sides and a flat surface, they are fairly easy to measure and calculate from the cubic contents.

CUSTOM SMELTERS

State or Country	Place	Name	Products treated, ores and concentrates
Western United States:			
Arizona	Douglas	Copper Queen	Gold, silver, copper, lead
	Clarkdale	United Verde	Gold, silver, copper
	Hayden	A. S. & R.	Gold, silver, copper
	Superior	Magma	Gold, silver, copper
	Miami	International	Gold, silver, copper
California	Selby	Selby	Gold, silver, lead
	ElSegundo	Menardi Metals Co.	Antimony
Colorado	Leadville	Arkansas Valley (A. S. & R.)	Gold, silver, lead, copper
Idaho	Bradley	Bunker Hill	Gold, silver, lead
Illinois	Alton	Federal Plant A. S. & R.	Lead, gold, silver
Montana	Anaconda	Anaconda Reduction Works	Gold, silver, copper, zinc
	East Helena	A. S. & R.	Gold, silver, lead
Nevada	McGill	Nevada Con.	Gold, silver, copper
Texas	Amarillo	A. S. & R.	Zinc and others
	Dallas	National Lead	Lead, antimony
	El Paso	A. S. & R.	Gold, silver, copper, lead
	Corpus Christi	A. S. & R.	Electrolytic zinc
	Laredo	Texas M. & S.	Antimony
	Texas City	Tin Processing Corp.	Tin
Utah	Tooele	International	Gold, silver, copper, lead
	Murray	A. S. & R.	Gold, silver, lead
	Garfield	A. S. & R.	Gold, silver, copper
	Midvale	U.S.S.R. & M.	Gold, silver, lead, zinc
Washington	Tacoma	A. S. & R.	Gold, silver, copper
Canada:			
British Columbia	Trail	C. M. & S.	Gold, silver, lead, zinc
Quebec	Noranda	Noranda	Gold, silver, copper
Manitoba	Flin Flon	Hudson Bay Mining & Smelting Co.	Gold, silver, copper, lead, zinc
Mexico:			
Coahuila	Rosita	Mexican Zinc Co. (A. S. & R.)	Zinc
Chihuahua	Chihuahua	A. S. & R.	Lead, gold, silver
Nuevo Leon	Monterrey	American Metal Co.	Same
Nuevo Leon	Monterrey	A. S. & R.	Same
San Luis Potosi	Matehuala	Cia Minera Asarco S. A.	Copper, gold, silver
	San Luis Potosi	Cia Minera Asarco S. A.	Copper, gold, silver, lead
Sonora	Cananea	Cananea Cons. Copper Co.	Copper, gold, silver
Australia:			
New South Wales	Port Kembla	Electrolytic Refining Co.	Gold, silver, copper
	Sydney	O. T. Lempriere & Co.	Antimony, tin
South Australia	Port Pirie	Broken Hill Associated Smelters	Gold, silver, lead, zinc
Tasmania	Risdon	Electrolytic Zinc Company	Gold, silver, zinc
Victoria	Bendigo	Leggo & Co.	Concentrates—gold, arsenic
South America:			
Chile	Potrerillos	Andes Copper Co.	Copper, gold, silver
	Caletones	Braden Copper Co.	Same
Peru	Oroya	Cerro de Pasco Copper Corp.	Copper, gold, silver, zinc, lead

Calculate 160 pounds per cubic foot for broken ore and 100 pounds for tailings.

Gold

With gold at $20.67 an ounce, 1 pennyweight (dwt.) is worth slightly over $1 or 4 shillings, and 1 grain is worth 4 cents or 2 pence.

With gold at $35 an ounce, 1 dwt. is worth $1.75 or 7 shillings, and 1 grain is worth 7 cents or 3½ pence.

Gold colors or particles in panning vary greatly; and until a man is accustomed to a particular ore or gravel or has had considerable experience, estimates may be high or low. The counting of colors may be done with a hand lens, marking off a section of the "tail." Of the finest gold, it may require 300 colors to be worth 1 cent; minus 40-mesh gold may require 40,000 colors to make 1 ounce; minus 20-mesh gold, 12,000 colors; minus 10-mesh gold 2200 colors.

Gravel

One cubic yard of average gravel in place weighs 2800 to 3000 pounds and expands 15 to 20 per cent when dug.

One cubic foot of frozen (around 20°) gravel weighs 137 pounds. Of this, 120 pounds is gravel, the remainder ice.

One cubic foot of frozen (around 20 degrees) muck weighs 87 pounds.

One man can pan ½ to 1 cubic yard of gravel a day.

One man can shovel up to 7 cubic yards of gravel a day.

One cubic yard of gravel requires 3600 to 8300 gallons of water to sluice it away.

One cubic yard of sand weighs 2600 to 2800 pounds.

Metal Prices

Since the prospector, miner, and mine operator should know the current and past average prices of metals, the following table has been prepared from *Engineering and Mining Journal* and *American Metal Market,* recognized authorities. Those metals quoted in cents per pound are given only to the first place after the decimal point.

AVERAGE YEARLY PRICES FOR COMMON METALS IN AMERICA

Year	Aluminum, cents per pound	Antimony, cents per pound	Copper, cents per pound electrolytic refinery	Iron (Valley), dollars per ton	Lead, cents per pound	Mercury, dollars per flask	Nickel, cents per pound	Silver, cents per pound	Tin, cents per pound	Zinc, cents per pound
1941	16.5	14.0	11.8	23.50	5.8	185.02	35.0	34.8*	52.02	7.5
1940	18.7	14.0	11.3	22.50	5.2	176.80	35.0	34.8*	49.3	6.3
1939	20.0	12.5	10.9	21.10	5.0	107.00	35.0	39.1*	50.3	5.1
1938	20.0	12.3	10.0	21.71	4.7	75.47	35.0	43.2*	42.3	4.6
1937	19.9	15.4	13.2	22.99	6.0	90.18	35.0	44.9*	54.3	6.5
1936	20.0	12.2	9.5	19.10	4.7	79.92	35.0	45.1*	46.4	4.9
1935	20.5	14.1	8.6	18.17	4.0	72.17	35.0	64.3*	50.4	4.3
1934	23.3	8.9	8.4	17.70	3.9	74.25	35.0	47.9*	52.2	4.2
1933	23.3	6.5	7.0	15.44	3.9	59.48	35.0	34.7	39.1	4.0
1932	23.3	5.6	5.5	14.25	3.2	58.30	35.0	28.7	22.0	2.9
1931	23.3	6.7	8.1	15.88	4.2	91.91	35.0	28.7	24.4	3.6
1930	24.3	7.7	12.9	17.99	5.5	116.97	35.0	38.1	31.7	4.5
1929	23.9	8.9	18.1	18.20	6.8	122.94	35.0	52.9	45.1	6.5
1928	23.9	10.3	14.6	16.55	6.3	124.32	37.0	58.2	50.4	6.0
1927	26.4	12.3	12.9	17.71	6.7	118.51	35.6 average	56.4	64.3	6.2
1926	27.0	15.9	13.8	18.55	8.4	92.16		62.1	65.3	7.3
1925	27.0	17.5	14.0	19.59	9.0	83.53		69.0	57.9	7.6
1924	27.6	10.8	13.0	20.23	8.1	70.51		66.8	50.2	6.3

* Other than new-mined silver in the United States.

METAL CONTENT OF MINERALS

Mineral or metal	Formula	Metal in pure mineral, per cent
Aluminum:		
Bauxite	$Al_2O_32H_2O$	74 Aluminum
Corundum	Al_2O_3	53
Kaolinite	$H_4Al_2Si_2O_9$	39 alumina
Antimony:		
Jamesonite	$2PbS.Sb_2S_3$	29 antimony
Stibnite	Sb_2S_3	71
Arsenic:		
Arsenopyrite	$FeAsS$	31 arsenic
Orpiment	As_2S_3	61 arsenic
Realgar	AsS	70
Barite	$BaSO_4$	56 barium oxide
Beryl	$Be_3Al_2(SiO_3)6$	5 beryllium
Bismuthinite	Bi_2S_3	81 bismuth
Borax	$Na_2B_4O_7$	37 boric oxide
Chromite	$FeCr_2O_4$	46 chronium
Cobalt:		
Cobaltite	$CoAsS$	36
Linnaeite	Co_3S_4	48 cobalt
Smaltite	$CoAs_2$	28
Columbite-tantalite	$(Fe,Mn)O_6(Nb,Ta)_2$	83 niobium pentoxide 86 tantalum pentoxide
Copper:		
Azurite	$2CuCO_3.2H_2O$	55
Bornite	Cu_3FeS_3	63
Brochantite	$CuSO_4.2Cu(OH)_2$	—
Chalcocite	Cu_2S	80
Chalcopyrite	$CuFeS_2$	35 copper
Chrysocolla	$CuSiO_3.2H_2O$	36
Covellite	CuS	66
Cuprite	Cu_2O	89
Malachite	$CuCO_3.Cu(OH)_2$	57
Tetrahedrite	$3Cu_2S.Sb_2S_3$	52
Dolomite	$CaMg(CO_3)_2$	21 magnesia
Fluorine:		
Cryolite	$3NaF.AlF_3$	54 fluorine
Fluorite	CaF_2	49
Iron:		
Hematite	Fe_2O_3	70
Limonite	$2Fe_2O_3.2H_2O$	60
Magnetite	Fe_3C_4	72
Marcasite	FeS_2	46 iron
Pyrite	FeS_2	46
Pyrrhotite	$Fe_{11}S_{12}$	61
Siderite	$FeCO_3$	48
Lead:		
Cerussite	$PbCo_3$	77 lead
Galena	PbS	87
Lime:		
Calcite	$CaCO_3$	56 calcium oxide
Gypsum	$CaSO_4.2H_2O$	33
Magnesite	$MgCO_3$	29 magnesium
Manganese:		
Pyrolusite	MnO_2	63 manganese
Rhodochrosite	$MnCO_3$	62 manganese oxide
Rhodonite	$MnSiO_2$	48 manganese

METAL CONTENT OF MINERALS.—(*Continued*)

Mineral or metal	Formula	Metal in pure mineral, per cent
Mercury:		
Calomel	HgCl(white-gray)	85 mercury
Cinnabar	HgS(crimson)	86
Metacinnabarite	HgS(black)	86
Molybdenum:		
Molybdenite	MoS_2	60 molybdenum
Wulfenite	$PbMoO_4$	26
Nickel:		
Chloanthite	$NiAs_2$	28 nickel
Millerite	NiS	65
Niccolite	NiAs	44
Pentlandite	(Fe,Ni)S	22
Silver:		
Argentite	Ag_2S	87 silver
Cerargyrite	AgCl	75
Polybasite	$9Ag_2S.Sb_2S_3$	76
Proustite	$3Ag_2S.As_2S_3$	65
Pyrargyrite	$3Ag_2S.Sb_2S_3$	60
Stephanite	$5Ag_2S.Sb_2S_3$	68
Tin:		
Cassiterite	SnO_2	79 tin
Stannite	$Cu_2S.FeS.SnS_2$	28
Titanium:		
Ilmenite	$FeTiO_3$	32 titanium
Rutile	TiO_2	60
Tungsten:		
Ferberite	$FeWO_4$	64 tungsten
Huebnerite	$MnWO_4$	61
Scheelite	$CaWO_4$	64
Wolframite	$(Fe,Mn)WO_4$	51
Vanadinite	$(PbCl)Pb_4.(Va_4)_3$	19 vanadium pentoxide
Zinc:		
Calamine	H_2ZnSiO_5	54 zinc
Franklinite	$(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$	16
Smithsonite	$ZnCO_3$	52
Sphalerite	ZnS	67
Willemite	Zn_2SiO_4	59
Zincite	ZnO	80
Zirconium:		
Zircon	$ZrSiO_4$	67 zirconia

Metals in Minerals

No formulas or combining forms of one element with one or more elements to form minerals have been given in this book, only the symbols for the elements in the list of atomic weights. Sometimes the prospector is told that a mineral, when pure, will contain so much metal. If he knows what mineral he has, he can then tell how much metal is possible. For example: (1) The combining form of silver with sulphur to form argentite is Ag_2S, or two atoms of silver to one of sulphur; and as the atomic weight of silver is 108 and that of sulphur is 32, we have $108 \times 2 + 32 = 248$, and $^{216}\!/_{248} = 87$ per cent silver. (2) The combining form of zinc with oxygen to form zincite is ZnO; and as the atomic weight of zinc is 65 and that of oxygen 16, we have $65 + 16 = 81$, and

$^{65}/_{81}$ = 80 per cent zinc. In the table on page 479, the metal percentages are given to the nearest whole number and are close enough for the purpose. Only the common minerals are listed; the atomic weights will be found in the table on pages 494–496.

The formulas are mainly as given in "Dana's Textbook of Mineralogy," by W. E. Ford, 1932, published by John Wiley & Sons, Inc., New York. Two or more formulas were given for some of the complex minerals, because one element may replace another or the proportions vary or other elements may be present; in fact, analyses reveal considerable variations in these types of minerals.

Although marcasite, pyrite, and pyrrhotite are listed under iron, they are also a source of sulphur—53, 53, and 40 per cent, respectively.

Ore and Mineral Prices

AVERAGE PRICES FOR IRON ORE AND ALLOY ORES, PER TON IN NORTH AMERICA

Year	Iron	Chromite*	Manganese ore†	Molybdenum, cents§	Tungsten‖
1940		$25.00	0.48‡	40	$20.61
1939	Iron ores, excepting those in Alabama, are hauled long distances to furnaces. At Lake Superior mines, 51½ per cent ore averages around $2.50 per ton; at Alabama mines, about 40 per cent ore, $1.60; northeastern mines, over 50 per cent ore $2.50; and at Western mines, $1.40	22.50	0.36‡	45	20.00
1938		21.59	17.00	43	20.00
1937		22.55	15.00	42	18.50
1936		17.76	10.40	42	14.32
1935		17.70	12.00	42	13.37
1934		19.00	11.00	42	14.57
1933		17.00	9.00	42	9.58
1932		18.00	10.00	42	9.20
1931		18.50	10.10	31	11.02
1930		21.50	11.10	33	12.09
1929		22.00	12.70	..	13.13
1928		23.00	12.60	..	10.40
1927		22.88	13.60	..	10.37
1926		22.46	......	..	11.10
1925		21.95	......	..	10.57
1924		21.35	......	..	8.47

* At Atlantic ports for 47 per cent ore. Prices vary several dollars during the year.

† For around 48 per cent ore per long ton North Atlantic ports, exclusive of duty.

‡ Prices of manganese ore according to grade and origin are quoted on a unit basis. The Unit is 1 per cent of a long ton or 22.4 pound of contained manganese.

§ Per pound of contained MoS_2 in concentrates carrying 90 per cent sulphide.

‖ Per short ton unit of WO_3 65 to 70 per cent concentrates, for domestic product.

AVERAGE PRICE FOR SOME NON-METALLIC MINERALS AT NORTH AMERICAN MINES*

Year	Asbestos,† short ton	Barite (crude), short ton	Boron minerals (borax), short ton	Emery corundum, short ton	Feldspar (crude), long ton	Fluorspar, short ton	Gypsum,‡ short ton	Magnesite (crude), short ton	Mica-§ scrap, short ton	Phosphate rock, long ton	Pyrite, long ton, domestic	Talc,‖ short ton
1941	$ 40.00	$8.00	$43.00	$10.00	$11.00¶	$23.00	$11.50	$20.00	$16.00	$3.60	$3.50	$10.50
1940	33.62	7.00	23.00	9.00	4.37	22.00	11.25	7.50	14.05	3.08	3.06	10.69
1939	33.19	7.00	23.00	9.00	4.40	20.27	11.20	7.50	12.66	3.27	3.05	10.63
1938	32.00	6.47	20.80	9.00	4.50	19.90	10.90	7.40	12.66	3.46	3.00	10.82
1937	28.75	6.30	20.16	8.70	5.15	18.89	9.82	7.30	14.08	3.28	4.00	11.16
1936	28.15	5.91	19.62	8.92	5.32	17.65	9.67	6.82	12.44	3.40	3.23	10.71
1935	32.84	5.56	19.71	9.13	5.30	15.04	9.90	6.73	12.94	3.60	3.10	10.72
1934	31.13	5.29	19.88	9.52	5.53	16.22	8.95	7.24	12.93	3.54	2.81	10.39
1933	27.54	5.08	18.27	11.63	5.17	14.25	8.93	7.76	11.22	3.16	2.71	10.35
1932	29.58	5.74	16.62	11.12	4.60	15.54	9.11	7.37	11.90	3.36	2.63	11.00
1931	36.85	5.70	27.62	10.85	5.23	17.41	8.13	6.78	15.02	3.66	2.95	11.18
1930	68.20	6.55	30.18	10.80	5.54	18.22	7.70	7.99	16.21	3.56	2.96	11.31
1929	111.25	6.67	26.58	11.60	5.77	19.06	6.24	7.99	18.86	3.50	3.75	11.53
1928	156.85	6.51	30.53	12.52	6.01	18.91	6.28	8.64	17.06	3.55	3.46	12.36
1927	113.01	6.57	31.84	11.57	6.28	18.08	7.89	8.98	17.54	3.55	3.73	11.33
1926	99.21	7.45	26.97	9.43	6.83	18.20	8.29	8.99	19.40	3.39	3.70	11.23
1925	41.10	7.47	27.14	7.69	6.33	18.06	8.38	11.87	17.90	3.32	3.82	10.70
1924	141.75	7.85	27.42	9.00	6.58	19.61	8.47	8.67	18.53	3.57	4.03	12.21

* From Federal Bureau of Mines *Information Circular* 6794, September, 1934, by Paul M. Tyler, and other reports.

† For mixed grades.

‡ Crude and calcined average. Crude alone brings one-third to one-fourth of these prices.

§ Scrap sheets and splittings sell for about 14 cents a pound.

‖ Ground product.

¶ Semi-granular per short ton.

Average Yearly Prices for Common Metals in British Dominions Where the Pound Sterling Is Current*

Year†	Antimony, per long ton	Copper, per long ton	Lead, per long ton	Mercury, per flask	Silver, pence per ounce	Tin, per long ton	Zinc, per long ton
1939*							
1938	£76	£45	£15	£13	19½	£189	£14
1937	72–81	54	23	14–13	20	242	22
1936	77–72	38	18	12–14	20	205	15
1935	....	32	14	12	29	226	14
1934	....	30	11	11	21	230	14
1933	....	33	12	10	18	195	16
1932	....	32	12	14	18	136	14
1931	....	38	13	19	15	118	12
1930	....	55	18	22	18	142	17
1929	....	75	23	22	24	204	25
1928	....	64	21	23	27	227	25
1927	....	56	24	20	26	289	28
1926	....	58	31	16	29	291	34
1925	....	62	36	14	32	261	36
1924	....	63	34	12	34	249	34

* From Quin's "Metal Handbook and Statistics," London. Prices to nearest round number.

† Quotation of prices suspended September 1, 1939, because of Second World War.

Precious Metals

Gold, silver, and platinum and its associated metals are generally termed "precious metals." Although a fair tonnage of nickel and other metals is used in coinage, the principal metallic coins are of gold and silver. Little gold circulates now in the form of coins. Gold and silver form the backing of paper currency. The price of gold has been raised from its long-fixed value of $20.67 or £ 4.25 to $35 and its approximate equivalent in other countries. Within the British Empire the price changes slightly daily. The silver mined within the United States brings a higher price than silver in other countries, but outside the United States the price is approximately uniform. As silver is used so much in industries and will be more so, it is actually a common metal; there are industrial metals of higher price per pound than silver. Prices for recent years are tabulated elsewhere. Although platinum is used in jewelry, it is also an industrial metal. The average annual price per ounce for refined platinum has been $37.92 in 1940, $36.75 in 1939, $36 in 1938, $50 in 1937, $41 in 1936, $32 in 1935, $35 in 1934, $30 in 1933, $34 in 1932, $33 in 1931, $42 in 1930, $64 in 1929, $76 in 1928, $78 in 1927, $109 in 1926.

Transportation of Ore, Concentrates, Bullion, and Machinery

By what means and at what cost may ore, concentrates, and bullion be shipped from prospects and small mines is the subject of this section.

In the 17-page *Information Circular* 6898 (1936) of the Federal Bureau of Mines, E. D. Gardner has contributed useful costs of trucking and packing ore in Western gold mining districts. His summaries will be given briefly:

Trucking. The costs of trucking vary widely in different sections and depend mainly upon the condition of roads, length of haul, daily tonnage handled, and regularity of shipments. The roads to many small mines are unimproved, a condition that is directly reflected in the relatively higher costs. As production increases, more work is done on the roads, which, with more regular shipments, results in lower costs. The cost of trucking regular tonnages of ore over good dirt roads, with no shoveling, in northwestern Arizona and California were as follows in 1935: up to 1 mile, 35 cents a ton-mile; 1 to 2 miles, 22 cents; 2 to 5 miles, 12 cents; 5 to 10 miles, 9 cents; 10 to 20 miles, 6 cents; 20 to 100 miles, 5 cents. Each time the ore is shoveled, add 35 cents per ton divided by the miles hauled to the costs given. The average cost of intermittent trucking in Nevada is 15 cents per ton-mile; if steady, 10 cents.

The cost of trucking depends upon the condition of the road all the year round, the grades, and the distance covered.

The daily cost per truck ranges from 11 cents for level to 2 per cent grade per mile to 55 cents for 10 per cent for a 2-ton truck and 18 to 90 cents respectively for a 5-ton truck.

In southeast United States ore is hauled on company account at 12 cents per ton-mile; from mines around Salt Lake Valley, with supplies going in, contractors get about 25 cents per ton-mile for small lots on 20-mile haul; in Southern California gravel is hauled in 10-ton trucks on level pavements at 20 to 25 miles an hour for about 5 cents per ton-mile.

Packing. Generally, packing costs are considered to be about $1 per ton-mile for moderate distances. For short trips (½ mile or less), the cost is high, as most of the time is consumed in loading and unloading the animals. For longer trips, less time is taken for loading but the loads are lighter. A reasonable contract price for packing with burros over fair trails is $2 per ton-mile for ½ mile, $1.50 for 1 mile, $1 for 2 miles. The cost with mules will be 25 to 50 per cent higher.

The *Metallurgical Bulletin* of the General Engineering Company, Salt Lake City, gives the following items:

Wagon Haul. The charge is from 50 cents to $1 a ton-mile, using sleds in winter.

Aerial Tram. Loading and unloading cost 10 to 20 cents per ton plus 5 to 10 cents per ton-mile, the minimum charges being on 10 to 20 tons an hour. Fred C. Carstarphen points out in *Engineering and Mining Journal*, July 24, 1930, that, if a mine has a life of several years and requires more than 25,000 ton-miles per year, a properly designed and erected aerial tramway would be the most efficient method of transportation.

Incline Tram. Two cars, 3 to 10 cents per ton.

Average Freight Rates on Ores, per Ton

Smelter value of ore per ton	Miles				
	50	100	200	400	800
$ 10	$0.80	$1.25	$2.00	$3.60	$ 6.00
20	0.95	1.50	2.30	4.10	6.70
30	1.10	1.75	2.65	4.60	7.40
40	1.25	2.00	3.00	5.10	8.10
50	1.40	2.25	3.40	5.60	8.80
60	1.50	2.50	3.90	6.10	9.50
80	1.75	3.00	4.70	7.30	11.50
100	2.00	3.60	5.50	8.80	13.50

Rail Haul. As the Salt Lake Valley is an important smelting and custom milling center, tariffs are available from and to points of shipment of ore and concentrates. The table on page 485 gives average freight rates for various distances on various ores. These are for preliminary purposes, and the regular tariffs should be used when available.

In all cases the percentage of moisture in the ore or concentrates must be taken into account in calculating freight rate. For freight purposes the value of an ore is the net amount per ton paid by the smelter to the shipper, less the freight per ton, but not deducting the smelter-treatment charge. The higher the grade of an ore or concentrate the higher the freight, with a maximum.

The railroads will supply the actual rates on ore and concentrates and copper, lead, and zinc as bullion or refined.

In *Information Circular* 6926 (1936) of the Federal Bureau of Mines, E. D. Gardner and Paul T. Allsman say regarding rail haul:

> Commodity rates on carload lots are established by the railroads when regular shipments of ore are to be made. A base rate for low-grade ore is quoted; an increase is made for regular increments in the value of the ore. The average base rate on western railroads is about 1 cent per ton-mile. Rates for large tonnages of low-grade ore may be as low as ½ cent per ton-mile; rates on branch roads may be 2 cents or more per ton-mile.

Machinery rail freight rates per ton from Denver to other points are as shown in the table on page 487 according to the *Denver Equipment Index*, 1936.

These are rates for machines knocked down, the customary way for shipment.

Parcel Post. Dry ores and concentrates and common metals, securely packed so that nothing can sift out, may be sent as fourth-class matter by parcel post to assay offices, dealers, or custom plants; in fact, anywhere. The limit of weight is 70 pounds for all zones, with a minimum of 8 ounces. The limit of size is 100 inches in length and girth combined; for example, a package 43 inches long, 14 inches wide, and 12 inches high measures 95 inches in length and girth combined. If star-route or rural haul is involved, only 200 pounds may be sent to the same person or firm on one day. The name and address of the sender must be written on the parcel. Identifying marks may be placed on the wrapper. A letter, bearing full postage, may also be attached to the package. Parcel-post rates are obtainable at all post offices. They range from 7 to 15 cents for 1 pound for local delivery and to the eighth zone to 42 cents to $7.74 for 70 pounds for similar deliveries.

MACHINERY FREIGHT BY RAIL

FROM DENVER TO	COST PER TON
Kingman, Arizona	$2.84
Prescott Arizona	2.52
Grass Valley, California (add 17 cents per ton for transfer at Colfax)	3.41½
Cripple Creek, Colorado	0.78
Idaho Springs, Colorado	0.49
Wallace, Idaho	2.92½
Joplin, Missouri	1.82
Neihart, Montana	2.41
Pioche, Nevada	2.71
Tonopah, Nevada	3.25
Eureka, Utah	2.09½
Nelson, British Columbia	4.07
Chihuahua, Mexico	2.77½

As to precious metals—gold, silver, and platinum—all gold must be sent to the Mint at San Francisco, Denver, or Philadelphia. The Mints will receive placer gold, bar gold, sponge gold from retorted amalgam, gold specimens, and scrap gold. The Mints also buy silver in these forms.

The gold and silver may be sent to the Mints and platinum to dealers by parcel post or by registered mail.

If the precious metals are sent by parcel post, they should be insured, but the limit in the post office is $200 for each package. Outside insurance may be arranged by the sender, the post office not having anything to do with this.

If the precious metals are sent by registered mail, the fees for indemnity, in addition to regular postage, run up to $1 for $1000 value for any distance; but if the value is higher, zone rates apply. Outside insurance may be arranged as with parcel post.

Paragraph 47 of the "United States Postal Guide" reads as follows regarding Alaska:

> The rate of postage on gold coin, gold bullion, and gold dust offered for mailing between any two points in Alaska, or between any point in Alaska and any point in the United States or its possessions, costs 2 cents an ounce or fraction thereof, regardless of distance. Such gold coin, gold bullion, or gold dust must be inclosed in sealed packages not exceeding 50 pounds in weight and sent by registered mail.

Because of the high charges, unless a mine product is bullion or rich specimen ore, the use of air mail or express on airplanes is too expensive.

Express. The Railway Express Agency ships gold and other precious metals insured at full value. It also will handle dry ores and concentrates and common metals.

Water

Cubic feet per second × 449 = gallons per minute.

Gallons per minute × 6 = tons of water per day.

Hydraulic pressure = head in feet × 0.43 = pounds per square inch; a head of 100 feet = 43 pounds.

Specific gravity = 1 (sea water, which contains 3 per cent sodium chloride, is 1.028).

Rain: 1 inch an acre = 100 long tons = 27,000 gallons.
1 acre-foot = 1 acre × 1 foot depth = 43,560 cubic feet = 325,850 gallons.

Miner's Inch. This varies with the head and locality but is equivalent to $\frac{1}{40}$ to $\frac{1}{50}$ cubic foot per second or $1\frac{1}{2}$ cubic feet per minute or 11 gallons. In Arizona, 1 second-foot = 40 miner's inches; in California, 50.

Snow (fresh): 1 cubic foot = 8 pounds and has a specific gravity of 0.125.

Ice: 1 cubic foot = $57\frac{1}{2}$ pounds and has a specific gravity of 0.92.
Floating ice has about one-ninth as much of its mass above the water as below it.

Water under a 4-inch head will flow at 3 gallons a minute through $\frac{1}{2}$-inch pipe.

Pipe capacity is increased four times by doubling its diameter.

Requirements for milling (General Engineering Company) follow:

Individual machine	Quantity, tons per ton of ore	Complete plants	Quantity, tons per ton of ore
Stamps	3–8	Stamps	3–15
Tables	2–4	Tables	8–15
Mills	⅓–1	Tabling and flotation	3–7
Flotation	2–3½	Flotation	3–5
Filters	¼–½	All-slime cyanidation	0.7–1½
Sluicing tanks	1½		

Water recovered from ponds = 25 to 75 per cent of total mill water.

Water recovered from thickeners and clarifiers = 40 to 90 per cent of total mill water.

Water high in magnesia may be made suitable for cyanidation by adding lime which, by precipitating the magnesia, reduces the consumption of cyanide.

Water from the sea or dense salt water from mines or wells in arid country is more or less suitable for milling, cyanidation, and flotation.

Water from the sea does not contain enough gold or other metals to be treated therefor. The treatment of millions of tons of sea water for bromine in North Carolina proves this to be so; the gold content (not recovered) ran from 0.025 to 0.08 cent per ton of water.

PART VI

GLOSSARY OF TERMS USED IN MINING[1]

A

Abrasion. The act of wearing away, such as abrasion of rock by glaciers or polishing stones or metals with quartz and tripoli.

Absorb. To suck up, as a liquid by a solid, such as a sponge, fuller's earth or bentonite. To *adsorb* means to be attached to the surface of anything, as cyanide gold on charcoal.

Accident prevention. This means the exercise of caution while at work or elsewhere, alone or with others. It includes safety, first aid, and rescue work. Organized safety work, such as by companies, reduces accidents; individual responsibility does not lessen them, largely because of a lack of supervision.

Accretion. The process by which inorganic bodies grow larger, by the addition of fresh particles to the outside.

Acicular. Needle-shaped, such as the crystals of antimony.

Acid. A salt of hydrogen, or a compound of hydrogen, containing one or more atoms of hydrogen which may be displaced by a metal. An acid rock is one in which the silica predominates in excess of the bases. Acidic is the opposite of basic.

Acre. An area of land equal to 43,560 square feet.

Acre-foot. The quantity of water required to cover 1 acre to a depth of 1 foot, or 43,560 cubic feet.

Adamantine. Like a diamond in hardness or luster.

Adhesion. Sticking together.

Adit. A tunnel or drainage drift open to the surface.

Adobe. Dobie; clayey.

Adsorb. Adhesion of gases or dissolved substances to surface of solid bodies.

Aerial. In the air, such as an aerial tram or aerial photography and surveying.

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[1] Compiled partly from *Bulletin* 95 of Federal Bureau of Mines, by the late A. H. Fay, 1920, but amplified by the author of this Handbook.

Afterdamp. The gas remaining in a mine after explosions of firedamp and coal dust or after a fire; it contains carbon monoxide, carbon dioxide, nitrogen, and some oxygen. It is irrespirable.

Agate. A variegated waxy quartz in which the colors are in bands.

Agglomerate. A breccia composed largely or wholly of fragments of volcanic rocks. Calcined ore may agglomerate.

Aggregate. A collection; to bring together; to mix into a mass, such as concrete.

Alaskite. An igneous rock consisting essentially of quartz and alkali feldspar.

Albite. Sodium feldspar.

Alignment or **alinement.** A laying-out or adjusting to a line.

Alkali. Any substance having marked basic qualities, particularly calcium, potassium, and sodium.

Alkali flat. A plain or basin in an arid region in which the salts have become concentrated by evaporation and no drainage.

Alkaline. Applied to minerals having the taste of soda.

Allegheny formation. One of the formations comprised in the Pennsylvania series of strata in the bituminous coal districts of the northern Appalachian field.

Alliaceous. Minerals having the odor of garlic—arsenical pyrite, for instance.

Alligator wrench. A tool having a fixed V-shaped opening, one jaw having teeth; useful about mines for holding or turning pipe or rod.

Allotropy. The capacity of some minerals to exist in two or more conditions, such as carbon as the crystalline diamond and amorphous charcoal.

Alloy. A solid solution of two or more metals. It must be homogeneous or uniform.

Alloy steel. A product containing alloy metals, such as beryllium, chromium, columbium, manganese, molybdenum, titanium, tungsten, or vanadium or certain mixtures of these metals.

Alluvial. Pertaining to alluvium, which may be loose gravel, soil, or mud, deposited by water.

Altaite. Telluride of lead, found in Colorado and Ontario.

Altered rock or **mineral.** One that has undergone chemical changes since its original deposition.

Altitude. Vertical distance or elevation above any given point; usually sea-level is the base.

Alumina. Oxide of aluminum. Corundum, ruby, and sapphire are pure crystalline alumina.

Aluminum minerals. Alunite, amblygonite, andalusite, bauxite, and cryolite. As a source of aluminum, bauxite is the only mineral in the United States.

Alunite. A hydrous sulphate of aluminum and potash found in Utah and Arizona.

Amalgam. Usually a physical alloy of mercury with another metal, such as gold and silver. Such alloys are found in native state. When mercury and gold are so mixed, it is called amalgamation.

Amber. A hard, yellowish-brownish, fossilized vegetal resin.

Ambergris. A wax from the sperm whale.

Amblygonite. A fluo-phosphate of aluminum and lithium.

Amethyst. A purple or bluish-violet quartz, used as a gem.

Amianthus. A fine and silky variety of asbestos.

Ammonia. A colorless gaseous compound of hydrogen and nitrogen, with pungent odor. Useful in first-aid kits as a solution.

Amorphous. Without form; applied to rocks and minerals having no definite crystalline structure.

Amparo (Mexican term). Continued possession of claims, by keeping a certain number of men employed, to secure title. Similar to the labor requirement in Australia and analogous to assessment work in the United States.

Ampere. The unit of electric current flow.

Amphibolite. Hornblende schist.

Amygdaloid. A cellular igneous rock, ordinarily basaltic, in which the cavities have been partly or wholly filled with a secondary deposit of calcite, quartz, epidote, or native copper (as in Michigan).

Analogous. One argument that fits the case of another.

Analysis. The determination, by chemical methods, of the contents of any compound substance. A quantitative analysis refers to the amount of the various constituents, while a qualitative analysis deals with what the substance contains. Both may be conducted at the same time.

Andalusite. Silicate of alumina, sometimes used as a precious stone.

Andesite. A volcanic rock resembling trachyte, with porphyritic or felsitic texture.

Anemometer. An instrument for measuring the velocity of air currents.

Anglesite. Lead sulphate.

Anhydrous. Without water.

Anneal. To heat and gradually cool metals to toughen them and remove brittleness.

Annual labor. Assessment work on claims; $100 for each year ending noon, July 1.

Anthracite. Hard coal containing up to 95 per cent carbon.

Anticline. A fold or arch in rock strata, a term frequently used in oil fields.

Antigua (Spanish). An old working in Mexico.

Antimonite. Native sulphide of antimony; stibnite.

Antiseptic. A drug or chemical used to destroy bacteria with little or no harmful effect on the living tissue. Carbolic acid is useful in a first-aid kit, also iodine, listerine, and zonite.

Apatite. A lime phosphate and chloride; a common mineral in igneous rocks.

Apex. The top, point, or summit of anything, such as a vein or mountain. The apex of a blind lode is not an outcrop. The exact meaning is very controversial, as in the law of the apex in claims.

Aphrodite. A hydrous silicate of magnesium, resembling meerschaum.

Aplite. Finely crystalline muscovite-granite which occurs in dikes.

Apparatus. Any device, tool, or machine used for a particular purpose about mines or other works.

Apron. A canvas-covered frame used in a miner's rocker. In hydraulics, where the water from a dam flows away; usually of concrete.

Aqua regia. Mixture of 3 parts hydrochloric and 1 part nitric acid. Dissolves gold and platinum.

Aqueous rocks. Sedimentary rocks.

Arborescent. Minerals of tree-like form.

Archean. Ancient. A geologic period.

Areal geology. Pertaining to the distribution, position, and form of the areas of the earth's surface.

Argentiferous. Silver-bearing.

Argentite. Silver sulphide containing 87 per cent metal.

Argillaceous. Of a clayey nature—also shale and slate.

Argillite. A clay-slate, with true slaty cleavage.

Argol. Potassium bitartrate; used in assaying.

Arid. Very dry, barren, parched with heat.

Arrastre. A crude machine for grinding ore and amalgamating gold Consists of a heavy stone dragged around in a circular bed. Prospectors occasionally construct and use them.

Arroyo (Spanish). A small stream, or deep, dry gully.

Arsenious. Containing arsenic; compounds of such.

Arsenopyrite or mispickel. A sulphide of arsenic and iron.

Artesian well. A well bored to such a depth that the water is forced to the surface owing to the conformation of the strata.

Asphalt. A complex compound of various hydrocarbons; related in origin to petroleum.

Assay. The determination of precious or base metals in ores. The method may be either the wet or dry assay; the former by chemicals, the latter by fire.

Assay-foot. The assay-value multiplied by the number of feet across which the sample is taken. (See section under Sampling.)

Assay-inch. The assay-value multiplied by the number of inches over which the sample is taken.

Assay-ton. A weight of 29.166 grams used in assaying.

Assay-value. The calculated value of metals in an ore, obtained by multiplying the quantity by the market price.

Assessment work. Annual labor upon an unpatented claim in the United States, equal to $100 per year ending noon, July 1.

Astringent. Taste that puckers the mouth; certain minerals, such as alum, have this characteristic.

Atmosphere. The air surrounding the earth, having a pressure of nearly 15 pounds per square inch.

Atomic weight. The weight of an atom of a chemical element as compared with that of an atom of hydrogen. A table of the atomic weights follows, as determined by the Committee on Atomic Weights of the International Union of Chemistry in 1932:

INTERNATIONAL ATOMIC WEIGHTS*
(1938)

Element	Symbol	Atomic number	Atomic weight
Aluminum	Al	13	26.97
Antimony	Sb	51	121.76
Argon	A	18	39.944
Arsenic	As	33	74.91
Barium	Ba	56	137.36
Beryllium	Be	4	9.02
Bismuth	Bi	83	209.00
Boron	B	5	10.82
Bromine	Br	35	79.916
Cadmium	Cd	48	112.41

International Atomic Weights.*—(*Continued*)

Element	Symbol	Atomic number	Atomic weight
Calcium	Ca	20	40.08
Carbon	C	6	12.010
Cerium	Ce	58	140.13
Cesium	Cs	55	132.91
Chlorine	Cl	17	35.457
Chromium	Cr	24	52.01
Cobalt	Co	27	58.94
Columbium	Cb	41	92.91
Copper	Cu	29	63.57
Dysprosium	Dy	66	162.46
Erbium	Er	68	167.2
Europium	Eu	63	152.0
Fluorine	F	9	19.00
Gadolinium	Gd	64	156.9
Gallium	Ga	31	69.72
Germanium	Ge	32	72.60
Gold	Au	79	197.2
Hafnium	Hf	72	178.6
Helium	He	2	4.003
Holmium	Ho	67	163.5
Hydrogen	H	1	1.0081
Indium	In	49	114.76
Iodine	I	53	126.92
Iridium	Ir	77	193.1
Iron	Fe	26	55.84
Krypton	Kr	36	83.7
Lanthanum	La	57	138.92
Lead	Pb	82	207.21
Lithium	Li	3	6.940
Lutecium	Lu	71	175.0
Magnesium	Mg	12	24.32
Manganese	Mn	25	54.93
Mercury	Hg	80	200.61
Molybdenum	Mo	42	95.95
Neodymium	Nd	60	144.27
Neon	Ne	10	20.183
Nickel	Ni	28	58.69
Nitrogen	N	7	14.008
Osmium	Os	76	190.2

INTERNATIONAL ATOMIC WEIGHTS.*—(*Continued*)

Element	Symbol	Atomic number	Atomic weight
Oxygen	O	8	16.0000
Palladium	Pd	46	106.7
Phosphorus	P	15	31.02
Platinum	Pt	78	195.23
Potassium	K	19	39.096
Praseodymium	Pr	59	140.92
Protactinium	Pa	91	231
Radium	Ra	88	226.05
Radon	Rn	86	222
Rhenium	Re	75	186.31
Rhodium	Rh	45	102.91
Rubidium	Rb	37	85.48
Ruthenium	Ru	44	101.7
Samarium	Sm	62	150.43
Scandium	Sc	21	45.10
Selenium	Se	34	78.96
Silicon	Si	14	28.06
Silver	Ag	47	107.880
Sodium	Na	11	22.997
Strontium	Sr	38	87.63
Sulphur	S	16	32.06
Tantalum	Ta	73	180.88
Tellurium	Te	52	127.61
Terbium	Tb	65	159.2
Thallium	Tl	81	204.39
Thorium	Th	90	232.12
Thulium	Tm	69	169.4
Tin	Sn	50	118.70
Titanium	Ti	22	47.90
Tungsten	W	74	183.92
Uranium	U	92	238.07
Vanadium	V	23	50.95
Xenon	Xe	54	131.3
Ytterbium	Yb	70	173.04
Yttrium	Y	39	88.92
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.22

* Journal American Chemical Society, April 1938.

Attrition. The act of rubbing together; friction; abrasion.

Augite. The commonest rock-making pyroxene (calcium and magnesium principally).

Auriferous. Containing gold.

Avoirdupois. The common system of weights used in the United States and in the British Empire.

Axis. A straight line, real or imaginary, passing through a body.

B

Back-sight. In surveying, any sight or bearing taken in a backward direction.

Bad lands. A region nearly devoid of vegetation and water, where erosion has cut the land into a maze of narrow ravines with sharp ridges, making travel almost impossible. The building of rock and brush and wire dams in these ravines will lessen such effect by their gradual filling with soil.

Baffle. Something that deflects, as in a launder or zinc precipitation box in cyaniding gold and silver ores.

Bailer. A cylindrical vessel used for dipping water out of a mine or oil from a well or in sampling gravels. Usually fitted with a self-closing valve.

Ball-ironstone. Strata containing large argillaceous nodules of ironstone.

Ball-porphyry. A variety of quartz-porphyry in which balls of felsite are developed.

Band. Slate or other rock interstratified with coal; or oil-shale with sandstone.

Banded structure. Term applied to veins having distinct layers or bands.

Banket. A conglomerate containing gold, as on the Rand. Somewhat similar to the copper conglomerate of Michigan.

Bar. A bank of sand, gravel, or other material at the mouth of a river; or similar gold-bearing material in the slack portion of a stream.

Barium. One of the rarer heavy metals. Only the chemical compounds are used. Any mineral containing barium gives a greenish color to a hot flame.

Barricade. Asphyxiating gases are formed when there has been a fire in any mine or an explosion in a coal mine. If men are unable to escape, they should retreat as far as possible, select some working place with plenty of space and with no connections, short-circuit the air from this place, build a light barricade or stopping, and remain behind it until rescued. Seven hundred lives had been saved by barricades to the end of 1940.

Barrilla (Spanish). South American term for tin concentrate or native copper disseminated in ore.

Basalt. An igneous rock; all dark volcanic rocks.

Base. A compound capable of reacting with acids to form salts. The opposite of an acid.

Base metals. All the useful metals, except the precious metals.

Basic. Igneous rocks low in silica, under 55 per cent.

Batholith. An irregular mass of granitoid rocks, which have crystallized in depth and have been exposed by erosion.

Battery. A set of stamps in a mortar-box, usually five; also, a battery of boilers or other equipment.

Beach placers. Deposits on either a present or ancient beach, such as at Nome or along the Pacific Coast. The former were payable; the latter are not, except in spots.

Bedded formation. One that shows successive beds, layers, or strata, resulting from its manner of formation.

Bedrock. Any solid rock underlying auriferous gravel and upon which the gold rests.

Benches. Ledges of all kinds of rock or gravel shaped like steps or terraces. Bench placers are usually 50 to 300 feet above the present streams. Oil-shale occurs as ledges or benches. Open-cut mining is often by benches.

Bit. Drill-bits may be part of the steel or detachable—screwed on to or into. The latter form is becoming increasingly popular and requires less drill-shanks.

Bituminous. Containing much carbonaceous matter. Such coal contains up to 75 per cent fixed carbon. There are three ranks depending on the carbon and volatile contents.

Black alta. A clay-schist.

Black copper. A furnace product.

Black powder. A granular explosive made in several sizes used in blasting in open pits. It should not be used in coal mines.

Black sand. Heavy grains of magnetite, chromite, ilmenite, cassiterite, and tourmaline found in rivers, beaches, and sluice-boxes. It sometimes carries gold and platinum. Read the section on this.

Blackband. An earthy carbonate of iron, accompanying coal beds.

Blackdamp. A gas formed by mine fires and explosion of firedamp; a mixture of carbon dioxide and nitrogen, greatly lacking in oxygen.

Blackjack. A dark variety of zinc blende or sulphide of zinc. Common in Oklahoma. It has a resinous luster and yields a light-colored streak or powder.

Blanket deposit. A flat ore-deposit much larger and wider than it is thick. A blanket vein is a horizontal or sheet deposit.

Blende. Zinc blende or blackjack, a sulphide of zinc, sphalerite; a term little used now.

Blind shaft. One that is not open to the surface.

Blind vein. One without outcrop; covered with alluvium.

Blockholing. Drilling into large rocks or boulders for blasting.

Blow-out. A large outcrop, beneath which the vein is smaller. A blast that does not shatter the rock is called a blow-out.

Blow-out shot. Improperly placed or overcharged shots of black blasting powder in coal which frequently result in mine explosions.

Blue vitriol. Copper sulphate.

Blue-sky law. A law to regulate promoters and investment companies.

Bluejohn. A columnar variety of fluorspar.

Bluestone. Copper sulphate; also a bluish-gray feldspathic sandstone.

Bog iron ore. A spongy variety of iron oxide or limonite, found in lumps or layers in sandy soils covered with swamp or bog.

Bog manganese. Same as wad.

Boghead coal. A variety of cannel coal valuable as a source of oil and gas.

Bogie. A small truck upon which a bucket is carried from shaft to dump.

Boiling point. 212°F. or 100°C.

Boleo (Mexican). Float mineral; a kidney of ore.

Bone. The bituminous slate in coal mines.

Booming. Accumulation and sudden discharge of water for washing gravel. Used where water is not plentiful. The operation is intermittent.

Borehole. An exploratory or prospecting hole made by drilling with churn or diamond-drill.

Bort. An impure diamond used for drilling boreholes.

Boss. A dome-like mass of igneous rock congealed beneath the surface and laid bare by erosion.

Bostonite. A dike rock somewhat similar in composition to trachyte and porphyry. Feldspar is abundant, but the dark silicates are few or lacking.

Botryoidal. Minerals occurring in bunch-like (grapes) form, iron, for instance.

Brattice.	Any partition in a mine which confines air and forces it into the working places.
Break.	A fault or fracture.
Breaker.	The plant where coal is washed, crushed, and sized for market. A rock-crusher.
Breaking strain.	The least load that will break a rope or chain.
Breast-and-pillar.	A system of mining anthracite coal by boards 10 yards wide, with pillars 5 yards wide between them, holed through at certain intervals.
Breasting.	In drift mining, breaking down the gravel underground and retreating toward the crosscut from which the drifts were driven.
Breccia.	Fragmental and angular rock, caused by faults and eruptions. The rocks are frequently cemented and are very hard.
B. t. u.	Abbreviation for British thermal unit; a heat unit; 100,000 B. t. u. = 1 therm, a term used in gas technology.
Brittle.	Easily broken; lacking toughness.
Broken.	A dislocation of a vein by faulting.
Bromine.	An element which does not occur native but is derived from brines. At ordinary temperature it is a deep reddish-brown caustic liquor with overpowering odor.
Brown spar.	Any light carbonate such as ankerite, dolomite, and magnesite, colored by iron oxide.
Bucking.	Pulverizing ore by means of a muller (an oval-faced piece of iron with handle) on a flat, cast-iron plate.
Buckwheat.	A prepared size of anthracite coal.
Bulkhead.	A partition of wood, rock, and mud or concrete in mines for protection against gas, fire, and water. Many miners have saved their lives by erecting bulkheads to prevent gas from reaching them.
Bull-pup.	A worthless mining claim, analogous to wild-cat.
Bull-wheel.	A sheave-wheel, particularly in oil-well drilling.
Bulldozing.	Blasting large pieces of rock underground.
Bullion.	Gold and silver mixture, also pig lead containing these metals.
Bunchy.	An orebody containing small scattered masses of ore.
Buried placers.	Gravel covered with lava or other strata.
Burnt ore.	Roasted or calcined ore, concentrates, or limestone.
Burrstone.	A cellular but very compact siliceous rock from which millstones are made.

Butte. An isolated hill or small mountain, especially one with steep sides.

Button. The globule of metal remaining on an assay-cupel or in a crucible, at the end of a fusion.

By-product. A secondary product; something recovered after the main product has been saved, such as gold and silver from base metals, gas from coke-ovens, arsenic from smelter fumes.

By-wash. An overflow at a certain point from a reservoir or ditch; a sort of regulator for the quantity of water required.

C

Cache. A place where supplies are hidden.

Caisson. A water-tight box or chamber, in which submarine work is carried on under pressure or open to keep the water out.

Calc-schist. A schistose rock containing much calcite or dolomite.

Calc-spar. Calcite.

Calcareous. Consisting of or containing carbonate of calcium (lime).

Calcine. To roast or expose to heat.

Calcium carbide. A furnace product—calcium and carbon—used in miners' lamps for making acetylene gas.

Caliche. Crude nitrate of soda, as in Chile.

Calorie. The quantity of heat required to raise the temperature of 1 gram of water 1°C.; analogous to the British thermal unit, in which it is the heat required to raise the temperature of 1 pound of water 1°F.

Calyx. A drilling machine, in which the cutter is provided with teeth that chip the rock.

Cam. A rotating tool, either non-circular or eccentric, such as is used for lifting stamps or for the piston valves on an automobile. Stamp cams are keyed to a cam-shaft; automobile cams are part of the shaft.

Cannel coal. A massive, non-coking, tough coal of even and compact grain, of low-fuel ratio, easy to light, with more or less quantities of woody or peaty material.

Cañon. A gorge or precipitous valley.

Canvas table. A sloping floor on which canvas is laid to catch concentrates in a stamp-mill.

Cap-rock. A hard layer of rock, usually sandstone, above the shale above a coal bed; on the layer of rock next overlying ore, generally of barren material.

Capillarity. The action of liquids rising through a solid.

Carat. A unit used in weighing diamonds, equal to 3.2 grains, also the equivalent of fineness of precious metals, 24 carat being fine.

Carbolic acid. A caustic poison and a powerful antiseptic.

Carbon dioxide, or carbonic acid gas. A heavy, colorless, irrespirable gas, which puts out fire or a miner's candle or lamp. It is formed in mine explosions and mine fires and is part of the afterdamp. It is also used as an explosive and in solid form for cooling foods.

Carbon monoxide. A colorless, odorless, and very asphyxial gas, the product of incomplete combustion of carbon. It burns with a pale-blue flame, forming carbon dioxide. Four parts carbon monoxide in 10,000 parts air is about the limit a man can stand for 1 hour. This gas is formed during mine fires and after explosions, in automobile exhaust, and in gas stoves.

Carbon steel. A steel deriving its qualities mainly from carbon and having no alloy-metals in it.

Carbonaceous. Containing carbon or coal.

Carbonate. A chemical compound of carbon, oxygen, and a metal.

Carboniferous. A geologic period; also a system into which certain stratified rocks are divided.

Carborundum. An artificial abrasive or grinding material; useful for sharpening tools.

Casing-head. A fitting attached to the top of the casing of an oil well to regulate the flow of oil and gas; also, in well-boring, a heavy mass of iron screwed into the top of a string of casing to take the blows produced when driving the pipe—a drive-head.

Caustic. Capable of eating away a substance by chemical action, corrosive; burning.

Caustic lime. Slaked lime.

Caustic potash. Potassium hydroxide.

Caustic silver. Silver nitrate.

Caustic soda. Sodium hydroxide.

Cave-in. Partial or complete collapse of mine workings.

Caving system. A method of mining whereby the ore is purposely caved, the roof falling later on as the ore is withdrawn.

Cellular. Cell-like.

Center cut. The drill-holes put in a face to include a wedge-shaped piece of rock and fired first.

Centigrade. One hundred divisions on a scale, such as the thermometer whose freezing point is 0 and boiling point 100.

Ceramics. Pertaining to clays and their many products. A ceramist is one who understands clays and their uses.

Cerium metals. A group of related rare-earth metals including cerium, lanthanum, praseodymium, and neodymium.

Cerro. A hill or mountain.

Chaffee work. A Colorado term denoting assessment work.

Chain. In surveying, 66 feet or 100 links. The men who use the chain or tape are called chainmen.

Chain-tongs. A pipe-fitter's tool.

Chairs. Movable supports for the cage or bucket in a shaft.

Chalcedony. A hard and transparent or, more generally, translucent crystalline quartz.

Chamber deposit. A cave filled with mineral.

Channel. Gravel either in a river-bed or covered with lava.

Chats. Term used in Missouri for tailing or waste product from the concentration of lead-zinc ore.

Check-off. A method of collecting union dues, fees, and fines, by withholding them from the miner's wages.

Check-valve. An automatic non-return valve, which permits a liquid to pass one way but closes when the fluid attempts to go the reverse way.

Chekako. Alaskan term for a tenderfoot; equivalent to **new chum** in Australia.

Chemistry. The science of the composition and changes of substances.

Chert. A compact, siliceous rock of chalcedonic or opaline silica, one or both. It occurs in limestone, as flint. The lead-zinc deposits of the Tri-State region of Kansas-Missouri-Oklahoma are in cherty limestone.

Chilean mill. A useful type of grinding mill composed of vertical rollers running in a circular enclosure with an iron base or die. These are used at both small and large mines and do good work.

Chimney. An ore-shoot of unusual occurrence.

China clay or kaolin. Clay derived from decomposition of feldspar and suitable for manufacture of china or porcelain.

Chloride. A compound of chlorine with another element or radical; a salt of hydrochloric acid.

Chlorides. A common term for ores containing chloride of silver.

Chloridize. By adding salt to a silver ore and roasting it the minerals are changed to chlorides.

Chlorine. An element; a greenish-yellow gas, of a suffocating odor and exceedingly poisonous.

Chlorite. A green mineral, a silicate of aluminum with iron and magnesium and chemically combined water.

Chloritic schist. A schist containing chlorite.

Chrome-steel. An iron-chromium alloy which hardens intensely on sudden cooling. One well-known brand of mine shovels is of chrome-nickel steel. Steel containing around 13 per cent chromium is stainless.

Chuck. That part of a rock-drill which grips or holds the drill.

Churn-drill. The drill-head is attached to a rope or cable and allowed to drop into the hole, thus cutting the rock.

Chute (not shoot). A pass, box, or trough down which ore is shoveled or allowed to fall to another level.

Cincho. A belt or girdle; a cinch.

Claim. Lode, 600 by 1500 feet; placer, 660 by 1320 feet or 20 acres. A claim in Transvaal is 155 by 413 feet or 1½ acres; in Australia (a lease), 24 acres.

Clastic. Fragmental; rock formed from the fragments of other rocks.

Clay. A hydrous silicate of alumina.

Clay gouge. A thin seam of clay separating ore or rock and ore.

Clay parting. Clayey material bound between a vein and its wall. Also called casing and parting.

Clay-ironstone. Clayey carbonate of iron.

Clay-rock. A clay that must be ground before using.

Clay-shale. Shale composed wholly or chiefly of clayey material, which again becomes clay on weathering.

Clay-slate. A clayey rock having a slaty structure. It is different from clay-shale in that it has been altered.

Cleavage. The definite way in which a mineral breaks.

Clinker. The product of the fusion of earthy impurities (ash) of coal during its combustion or burning in a furnace or forge.

Clinometer. An instrument useful for measuring angles, especially dips of veins. It is handy to have on a prospecting trip.

Coal cleaning or preparation. This means the hand sorting and screening of coal to remove lumps of slate and sulphur or the wet washing or air cleaning and screening of coal to remove slate and other impurities and so reduce the ash content. It is an important development in the marketing of coal.

Coal dust. Finely divided coal, the cause of many explosions in coal mines and sometimes in plants using pulverized coal. Application of a certain amount of fine limestone or shale dust to mine workings will stop or limit an explosion.

Coalition. An association of persons for joint operation.

Cohesion. The force by which molecules of the same kind or of the same body are held together, so that the body resists being pulled to pieces.

Collar. The timbering around the top of a shaft.

Color. The shade or tint of the earth or rock that indicates ores. A particle of gold in the prospector's pan after a sample of rock has been crushed and panned. "So many colors to the pan" is a way of estimating values. Some gold is so fine that it takes 2000 colors to equal a cent.

Combustible. Capable of undergoing combustion; flammable.

Comminute. To pulverize to powder.

Compact. Close; firm; solid; dense, as in rocks.

Complex. Containing many minerals; compound or composite. An ore is complex when it carries several metals difficult to extract.

Compound. A substance formed by the chemical union of two or more substances in definite proportions by weight.

Compound vein. One consisting of a number of parallel fissures united by cross fissures, usually diagonally.

Concentrate. The valuable minerals separated from the gangue or containing rock by any process of concentration.

Conchoidal. Shell-shaped. Rocks such as flint break with concave and convex surfaces and have a conchoidal fracture.

Concretion. A spheroidal aggregate formed by the segregation and precipitation of some soluble mineral like quartz or calcite around a nucleus, which is often a fossil.

Conduit. A pipe, canal, or tube.

Confluence. A junction of streams.

Conformable. Strata that lie upon one another in regular order are conformable; but if one set of beds rests upon the eroded or upturned edges of another, showing a change of conditions, they are said to be unconformable.

Conglomerate. An aggregate of rounded and water-worn pebbles and boulders cemented together.

Contact. The joint-plane where two different formations meet. Orebodies frequently occur along contacts.

Contact deposit. One between two unlike rocks, usually applied to an orebody at the contact between a sedimentary rock and an igneous rock.

Contiguous. Either in actual contact or near though not in actual contact, as mining claims.

Contorted. Bent or twisted together, such as folded strata.

Contour. The outline of the surface of the ground with respect to its undulation. Topographic maps of the United States Geological Survey show contour lines and are useful in this respect.

Contraction. Shrinking.

Copper plate. Sheets laid down in front of a stamp-mill, cleaned, and amalgamated with mercury, so that when the crushed ore and water flow over them the gold is arrested and amalgamated.

Cord. A measure for wood cut for fuel; a pile 8 by 4 by 4 feet, equal to 128 cubic feet.

Corduroy. A specially made and effective gold-saving cloth.

Correlate. To put in relation with each other, as two geologic formations.

Corrosion. The process of eating or wearing away.

Corrosive sublimate. A poison; a bichloride of mercury.

Coyote hole. Same as gopher hole, used in blasting large masses of rock or ore.

Creek claim. One that includes the bed of a creek, as, under the law of Oregon, the land extends to the middle of the stream.

Creosote. An oily antiseptic liquor obtained by distilling wood or coal tar. It is extensively used in preservation of mine timbers and railway ties or sleepers.

Cretaceous. Of the nature of chalk. A geologic period.

Crib. A system of timbering in which logs are laid horizontally upon one another, like a number of sets.

Cross-bedded. Cross-stratified.

Crosscut. A level driven across the course of a vein or at right angles from a main level.

Crude. In a natural state.

Crushed vein. One composed of crushed material, resulting from folding, faulting, or shearing.

Crust. A hard outside covering; an incrustation.

Culm. The waste or slack of anthracite mines.

Cupola. A small blast-furnace.

Cusec. One thousand cubic feet of water per second.

D

Dacite. An igneous rock containing quartz and feldspar; quartz-andesite.

Damp. A general term for gaseous products in coal mines, such as afterdamp, blackdamp, firedamp, whitedamp.

Danger signal. Take note of what it says.

Dead. Such as dead-end, an unventilated end of a drift; dead work; driving in country rock; development.

Deadman. A buried log or the like serving as an anchor for tackle.

Débris. Rock fragments, sand, earth collected at the bottom of a cliff, or tailings from hydraulicking.

Decomposition. Breaking up or decaying.

Decrepitate. Crackling; flying to pieces.

Deflagrate. To burst into flame.

Dendritic. Branching like a tree; said of minerals.

Denudation. Erosion of surface by water and wind.

Deposit. Enough mineral in rock to make it ore.

Detonate. To cause to explode.

Detritus. Rocks, gravel, sand collected in one place but not hard or cemented.

Develop. To open a mine and ore; more or less to search, prospect, explore.

Diabase. A basic igneous rock usually occurring as dikes or intrusive sheets and composed of feldspar and an iron-magnesian mineral.

Diaphanous. Allowing objects to be seen through; more or less transparent, as some dress materials.

Diesel engine. An engine that uses crude or low-gravity oils. The oil does not explode in the cylinder like gasoline but burns, creating great heat and pressure, thus forcing the pistons to work.

Dike. Any mass of igneous rock, which, while in a state of fusion, has entered a fissure in other rocks and has there become chilled and solidified. Dikes are mostly vertical; sills are horizontal.

Dilute. To weaken by adding water, as dilute sulphuric acid.

Diorite. A common rock of the granite family composed mainly of hornblende and feldspar. Quartz is often present.

Disintegrate. Breaking asunder or crumbling of rock caused by weathering and chemical changes set up therefrom.

Dislocation. More or less a fault.

Disruptive. A shattering force.

Disseminated. Scattered; such as chalcocite in porphyry and chromite in serpentine.

Distortion. Twisting out of place or shape.

Disturbed. Unsettled country rock.

Divining rod. Keep clear of such frauds.

Dobie. Adobe; clayey; muddy.

Dolerite. Coarsely crystalline basalt.

Dome. An uplift in which the beds dip outward in all directions from a center; more or less an anticline. Gold veins in Nova Scotia are in this type of formation. Oil occurs in salt domes of Texas and Louisiana.

Downcast. The shaft through which air is drawn into a mine; intake.

Drift. Any horizontal passage underground; although a drift follows a vein, and a crosscut intersects or goes through it.

Drift-gravel. Gold or tin-bearing gravel lying on slate or granite and covered with basalt.

Drusy. A crust; many minute crystals; leached and soft ore.

Ductile. Capable of being drawn or hammered thin.

Dull. Blunt; sluggish.

Dunite. An iron-magnesian rock of the serpentine family.

E

Economic geology. The practical application of geologic theories to mining; really mining geology.

Effervesce. Bubbling and hissing; such as the action of hydrochloric acid on limestone.

Efflorescent. Incrustation on rocks, as nitrate.

Egg coal. Any coal lumps about 3 inches in size.

Electrum. A natural alloy of gold and silver; but rare.

Element. There are 92 elements in the earth, each of which is of definite composition and can not be split up into any substance different from itself.

Eluvium. Sand and gravel accumulated by wind. Alluvium is similar matter moved by water.

Emulsion. A mixture of water and oily material, generally the result of agitation or beating the oil into the water.

End-lines. The lines of a mining claim that cross a vein are the end-lines.

Enhydrous. Containing water, such as opal-silica and water. The opposite of anhydrous.

Entry. In coal mining, a haulage road, gangway, or airway to the surface.

Epidiorite. Dikes of diabase, whose igneous matter is partly altered to hornblende.

Epidote. A basic silicate of calcium, aluminum, and iron. It often indicates rock alteration.

Erosion. Briefly the weathering and movement of rocks and debris.

Eruptive. Igneous. Rocks that have been forced through others when in a molten state are eruptive, as andesite, basalt, rhyolite.

Etching. Pitting, as hydrofluoric acid attacks glass.

Evaporate. To boil a liquor until all has disappeared. In arid regions the heat evaporates water and leaves various salts behind.

Exploit. To make the best use of a mining property.

Explore. To search, develop, or prospect.

Exposure. Any part of a rock formation easily seen; an outcrop.

Extralateral right. The law of the apex concerning veins and claims.

Extrusive. Igneous rocks that cooled after reaching the surface are extrusive.

Exude. To ooze out, as oil from sandstone strata.

F

Face. Any part of a mine where work is under way.

Fahrenheit. The scale used on the ordinary thermometer; 0 is zero; 32 is freezing; 212 is boiling.

Fake opal. A variety of opalized quartz.

False set. A temporary set of timber used to hold up bad ground until there is space for the permanent set.

False topaz. A yellow variety of quartz resembling topaz.

Fascine. Bunches of branches and twigs laid on bad roads.

Fathom. Six feet.

Fault. See discussion under Geology.

Feldspar. A general name for a group of abundant rock-forming minerals containing alumina, silica, and potash, soda, or lime, existing in all igneous rocks.

Felsite. Finely crystalline quartz-porphyry.

Ferro-alloy. A mixture of iron and any one of the following: aluminum, boron, chromium, cobalt, manganese, molybdenum, tungsten, titanium, silicon, vanadium, and zirconium. One or more are added to steel to make it hard or tough.

Ferruginous. Iron-carrying or -bearing.

Firedamp. An explosive gas given off by coal beds; a mixture of methane and air.

First aid. What everybody should learn and what the Federal Bureau of Mines teaches free by publicity and in its Mine Rescue-cars. In 26 years 800,000 miners and others have been trained in this country, resulting in a great reduction of accidents. As soon as possible after any accident, the victim should get first aid. (See section under First Aid.)

Fissile. Capable of being split, as mica, slate, schist.

Fissure. A crack or opening in rocks. Fissure veins are those formed by mineral matter being deposited in the cracks.

Flammable. Easily set on fire; combustible; inflammable.

Float. The loose or scattered pieces of ore broken off from a vein outcrop. When prospecting is thoroughly done, the float may be traced to its source or outcrop. Also, fine gold and minerals float in panning and other operations, causing losses.

Floor. In other words the footwall of a flat orebody or coal bed.

Flotation. A process of concentration much used everywhere. When crushed ore is mixed with water and oil or chemicals, the minerals float while the worthless material sinks. Gold and silver ores are floatable.

Floured. Mercury sometimes becomes broken up into very small globules and will not amalgamate with gold or join together, probably owing to some scum on the surface of the mercury. Beware of amalgamating machines, as these invariably flour mercury, causing loss of gold.

Flume. A wood or sheet-iron trough used for the conveyance of water. Those of wood are of square section, and those of iron semi-circular. Flumes constitute part of a ditch for water power or for transporting lumber and coal.

Fluvial. Sand and gravel deposits laid down by rivers are of fluvial origin.

Flux. Any chemical or rock added to an ore to assist in its reduction by heat, as limestone with iron ore in a blast-furnace. A solid or liquid for soldering.

Fold. A roll or bending in rocks or veins.

Foliated. Leaf-like, such as mica or schistose rocks.

Footwall. The lower enclosing wall of an inclined vein.

Forfeiture. Mining claims are forfeitable when the owner neglects to comply with the regulations. They may then be entered or "jumped" by another man.

Formation. Generally the common local rock in which an orebody is found. Several formations in a region make a system of rocks.

Fossil. Any plant or animal impressions or remains in a rock such as limestone, sandstone, or shale. The eruptive rocks do not contain fossils.

Fracture. The appearance of a freshly broken rock surface.

Fragments. Pieces of rocks, more or less broken by volcanic action. A breccia is a fragmental and angular rock caused by eruptions and faults.

Fumarole. A spot in a volcanic or other region, from which fumes issue, such as sulphur and other gases.

Fusion. Melting.

G

Gabbro. A fine to coarse crystalline igneous rock composed mainly of lime-soda feldspar, with predominant iron-magnesian mineral, which may contain lime.

Gallon. 231 cubic inches or 8⅓ pounds of water. The British gallon weighs 10 pounds.

Gallows-frame. Incorrect for head-frame.

Gangue. The valueless part of an orebody in a vein. For instance, in a gold-quartz vein the quartz is of no value and is the gangue.

Gash vein. A vein of small size in every direction; one that does not persist at depth.

Geode. A hollow nodule lined with crystals.

Geography. A useful and interesting study of the surface of the earth.

Geology. A practical and theoretical science dealing with the formation of the earth and ore deposits.

Geophysics. Briefly, geophysics is the physics of the earth, and prospecting is done by means of waves induced by explosives or by electrical devices. Petroleum, metallic mineral, and water-bearing areas have been detected by geophysical prospecting.

Glacial. Pertaining to glaciers, which once covered part of North America.

Glance. A term applied to minerals with a resplendent luster, such as copper glance, iron glance, lead glance, silver glance.

Glistening. Minerals that give a general reflection, but not images, from their surfaces glisten.

Glossary. A collection of explanations of certain terms and words. This section of the Handbook is a glossary.

Gneiss. A layered crystalline rock with a more or less well-developed cleavage but without the fissility (splitting capacity) of schist.

Gold brick. A suspicious and incorrect term for gold bar. Avoid promoters who talk of gold bricks.

Gophering. Prospecting in any and every way, without any apparent definite object, or searching for float in surface soil or for ore underground.

Gossan. The iron-bearing deposit filling the upper parts of veins or covering masses of pyrite.

Gouge. A layer of soft material along the wall of a vein.

Graduate. A glass flask marked with lines indicating its contents in cubic centimeters or milliliters, one of which of water is a gram or 15½ grains nearly; 1000 grams is the weight of 1 liter or 1.7 pints. Graduates are of all sizes, from 25 to 2000 cubic centimeters or millimeters, and are marked cc. or ml., but mainly the latter, which is preferred.

Gram. A unit of weight in the metric system, equal to 15½ grains nearly.

Granite. A granular igneous rock composed mainly of quartz, mica, alumina, and potash, the last two as a feldspar.

Granite-porphyry. A coarsely crystalline quartz-porphyry with large, conspicuous crystals.

Grano-diorite. A rock type between granite and quartz-diorite.

Granular. Composed of almost equal grains, as in igneous rocks. Many ore deposits are related to granular rocks—that is, in rocks in or near intruding granite.

Graphitic. Containing graphite or carbon.

Gravity. The force by which substances are attracted or fall to the earth. (See Specific gravity.)

Graywacke. A shaly sandstone.

Greensands. A green silicate of iron and potassium, a future possible source of potash.

Greenstone. Diabases and diorites.

Greisen. An igneous rock, such as granite, composed of quartz, mica, and fluorine; the source of the tin ore cassiterite.

Grit. A sandstone composed of coarse, angular grains and very small pebbles.

Grizzly (not grizzley). An iron grating set on a slope for screening rock and ore.

Gulch. A narrow ravine or small cañon.

Gully. More or less a gulch.

Gumbo. A sticky or clayey mud; adobe.

Gunite. Cement sprayed on to mine timbers to make them fire-resisting or on to rock in drifts to strengthen them.

Gyratory. More or less eccentric, as in certain rock-crushers.

H

Halite. Rock salt.

Hanging wall. The upper enclosing side or wall of an inclined vein.

Hardpan. Boulder clay or layers of cemented gravel.

Head-frame. A structure erected over shafts for hoisting purposes. Once called gallows-frame.

Heads. The value or metal content of an ore before being milled. The residue after treatment is the tails.

High-grading. Work that generally results in jail.

Hitch. A hole cut in rock to hold up timbers, such as stulls.

Homogeneous. Consisting of similar parts.

Hornblende. A variety of the mineral amphibole, partly a silicate of calcium and magnesium, with iron and manganese. The color is black, blackish green, and dark brown.

Hornfels. A dense, compact rock resulting from the contact of a granite intrusion with slate.

Horse. A mass of country rock in ore. Some mines are full of horses. **Horsebacks** occur in coal beds.

Horseplay. Never indulge in this in mines or works, as many accidents result therefrom. Safety men frown on it.

Hungry. Hard, barren vein matter, such as white quartz.

Hydrated. Containing water in chemical combination, as lime and water in gypsum; hydrous.

Hydraulic. Water in motion, more or less in a ditch or pipe. Hydraulicking is the process of washing down gravel with water under pressure.

Hydrochloric acid. Muriatic acid.

I

Igneous. Rocks of eruptive or volcanic origin which have solidified from the molten state are igneous.

Impregnated. Metallic minerals scattered through a vein or country rock.

Incline. Sloping; underlay; on the dip.

Incrustation. A crust or coating on a rock, such as carnotite on sandstone.

Interbedded. Occurring between beds; interstratified, such as coal between shale and fireclay.

Intrusion. A mass of igneous rock which, while molten, was forced into or between other rocks.

Iodine. Useful in first-aid work.

Iridescence. A play of colors in the interior or surface of anything.

J

Jack. Zinc blende; sphalerite.

Jackhammer. A hand-held hammer type of rock-drill using hollow steel.

Jade. A hard and tough silicate of sodium and aluminum, with iron, calcium, magnesium, and potash. It is used for making ornaments.

Jet. A dense black lignite which can be polished and used for jewelry.

Joggle. A notch cut near the end of round timber to prevent rolling when placed on another round piece.

Jumping a claim. Taking possession of an abandoned claim or one on which the labor requirements have not been performed.

K

Keweenawan. A body of igneous rocks of great thickness, conglomerates, and sandstones, such as contain the copper deposits of Michigan and the silver veins of Ontario.

Kindly. Rock that is likely to or appears as if it would carry ore.

Knob. A round, isolated hill; knoll; butte; *kopje* (South Africa).

Kyack. A pack-sack swung on either side of a pack-saddle.

Kyanite. An aluminum silicate, similar to sillimanite.

L

Labor. The annual assessment work required on claims calls for $100 of labor and improvements. In Australia claims have continuous labor or are manned throughout the year.

Ladder. See that ladders in mines are in good order and that ladderways are kept clear of débris.

Lagging. Planks, slabs, or small timbers—split or sawn—placed around sets of timber; laths; spiling.

Latite. A rock type between trachyte and dacite.

Lava. A general name for the molten material poured out from volcanoes. Basalt is a lava flow.

Lay. The direction of twist of wire and strands in a rope.

Lay operations. When a miner in Alaska leases a placer claim and pays the owner up to 50 per cent of the gross output.

Leach. To dissolve metals from ore by draining the liquors downward. Gossan is the result of nature's leaching.

Lead (leed). Lode or vein or gravel channel.

Ledge. The only true ledges are deposits of oil-shale, slate, or the like. A ledge is a horizontal layer; therefore a vein or lode is not a ledge.

Leg. The prop of timber supporting a cap-piece or roof of a drive.

Lens. An orebody thick in the center and thin at the ends; lenticular.

Lessee. One who leases mining land; incorrectly leaser. A tributer.

Level. A horizontal passage or drift in a mine. They are generally at 100-foot intervals. Drifts and crosscuts are driven from them.

Lick. A swamp area surrounding a salt spring the soil of which is licked by animals.

Linear. Along a length of; such as linear inch or feet. Do not use "lineal" in this sense, as this means family descent.

Litmus paper. Slips of prepared paper about ½ inch wide and 3 inches long and purchased as books, used to test acid and alkaline solutions. Acid turns the blue paper red, and alkali the red paper blue.

Loam. Earthy matter composed of clay and sand.

Location. Staking out or marking a mining claim.

Lode. A more or less irregular vein—that is, one which has no well-defined walls, its actual width determined only by frequent sampling.

Log-washer. See description under Ore-dressing and Treatment.

Longwall. A system of working a bed of coal in which the whole bed is mined and no pillars are left, excepting the shaft pillars and sometimes the main-road ones.

Luster. The character of the light reflected by minerals. If a mineral has no luster, it is dull; if it has the luster of metals, it is metallic; if of the diamond, it is adamantine; if of broken glass, it is vitreous; if of yellow resin, it is resinous; if like pearl, it is pearly.

Lute. Clay or other matter used to make joints between two flat surfaces. The top and bowl of a retort may be luted with clay.

M

Macroscopic. Visual, or recognizing minerals with the unaided eye; the opposite of microscopic, which is identifying by means of a microscope.

Magma. Liquid molten rock from which igneous rocks are formed by solidification.

Magmatic water. Water derived from cooling igneous magma. (See Meteoric water.)

Malleable. Easily hammered when cold, such as lead, gold, silver; the opposite of brittle.

Marsh gas. Methane, found in coal mines and natural gas.

Mass copper. Large pieces of native copper, such as found in Michigan mines.

Matrix. Gangue or the rock that contains minerals or ore.

Mesh. One of the openings in a sieve or screen. A screen with 20 holes to the linear inch is termed 20 mesh and has 400 holes to the square inch. Some grinding is now done through 325 mesh.

Metallurgy. The science or art of treating ores and extracting metals therefrom.

Metamorphism. Any change in texture or composition of a rock by such agencies as heat, moisture, and pressure. Metasomatism is the chemical alteration of minerals or rocks or their replacement by another mineral.

Meteoric water. Atmospheric moisture or surface water which enters the earth through cracks and the like. Meteoric and magmatic waters are responsible for the formation of veins and their enrichment.

Meter. Basis or unit of the metric system; equals 3⅓ feet or nearly 40 inches; 1000 meters is 1 kilometer or about ⅔ mile. Used in most foreign countries.

Methane. Marsh gas, found in coal mines and in old shafts and explosive when 5 to 15 per cent is mixed with air.

Metric system. The French method of weights and measures, used more or less throughout the world, including the United States, although not in force in this country. The *meter* is the unit of length; the *are*, of surface; the *liter*, of capacity; and the *gram*, of weight. The multiples or divisions are simply ten times or tenths, hundreds, and thousands.

Metric ton. Used in most foreign countries, Mexico, and Central and South America, equals 2204 pounds. Compare with the long ton of 2240 pounds and short ton of 2000 pounds.

Mill. One-thousandth part. A mill of a dollar is 1/10 cent, so if an assessment of, say, 5 mills per share is levied, the amount payable is ½ cent.

Milligram. One-thousandth of a gram or 0.0154 grain.

Millimeter. One-thousandth of a meter or 0.039 inch.

Mineral. Any rock substance of regular and definite chemical composition.

Mine rescue-car. As used by the United States Bureau of Mines, which has eleven at various points in the United States; they are fully equipped with a trained crew and first-aid and safety apparatus with which to instruct miners and use in case of accident. The cars are moved from place to place for instruction and in case of accidents at any mine in the country.

Mineralogist. One who is well versed in the science of minerals.

Miners' inch. A measure of water equal to 1½ cubic feet a minute or 12½ gallons, equal to 18,000 gallons a day.

Miner's Right. A permit to prospect in Australia or other British territory.

Misfire. Failure of a charge to explode. Do not approach a misfire in less than 3 hours; rather drill a hole near it and then shoot.

Molecule. The smallest combination of atoms that will form a given chemical compound.

Monadnock. A rock, hill, or mountain standing above a surface of low relief; generally the result of erosion of the surrounding country.

Monitor. A giant or pipe and nozzle, as used in hydraulicking.

Monolith. A single stone or block of stone of large size.

Monument. A permanent object indicating the boundary of a claim or any boundary. Many claim-owners do not keep their monuments in good order, so that others may see them.

Mother lode. The mineralized formation that passes through any district, not rich enough to be worked as a whole but containing numerous workable veins. The Mother Lode of California is an example; it is over 100 miles long.

Muck. A common term in Alaska for the surface soil and sand lying above placer deposits.

Mucker. A shoveler.

N

Native. A mineral that occurs in nature as a pure metal is termed native, as copper, gold, silver, platinum.

Neutral. Neither acid nor alkali.

Niggerhead. A very hard, round stone, found in gravel deposits and coal beds.

Nodule. A small roundish lump of mineral, such as bauxite and ironstone.

Non-metallic. Not metallic, containing no metal, such as borax.

Norite. A rock of the gabbro family which carries nickel veins in Ontario and platinum in Transvaal.

Normal. Standard; regular; not affected by anything abnormal.

Nugget. A lump of metallic copper, gold, silver, or platinum, or of chromite, more or less water-worn.

Nystagmus. A weakness of the eyes affecting miners.

O

Obsidian. Volcanic glass. Extrusive volcanic rocks that have cooled without crystallizing, or only partly so, are obsidians.

Occurrence. Existence; how an orebody is found.

Oölite. Egg-stone, or round grains, such as oölitic limestones.

Option. An arrangement whereby one man secures a property from another. Generally a small cash payment is made; the purchaser is allowed to develop the mine and, if satisfied, either buys outright or gives the owner a share interest in any company that may be organized later.

Ore. Any rock that contains enough mineral to be mined profitably is an ore.

Orebody. Those parts of a vein that carry ore may be considered orebodies or shoots.

Organic. Of animal or plant origin, as oil and coal.

Orthoclase. A potash feldspar.

Oxide. A compound of oxygen with any metal.

Oxidize. To unite with oxygen or to burn.

Oxidized zone. The upper portion of an orebody that has been altered by water, carbon dioxide, and oxygen to oxides and carbonates.

Oxygen. The ordinary air contains 21 per cent of this gas. Men can exist for several hours in air containing only 13 per cent oxygen.

Ozokerite. A mineral wax of green to yellow-brown color, with light to brown streak, greasy feel; it floats on water. It belongs to the petroleum family. In Utah it occurs as narrow seams in sandstone, near shale.

P

Parting. A layer of clay or rock in a coal bed or the gouge between a vein and one of its walls.

Pass. An opening in a mine through which ore is delivered from a higher to a lower level; an ore-chute.

Patent. When a mining claim has had $500 of work done upon it, the holder may apply for and obtain a patent. The owner is then relieved of further annual assessment work, which results in many claims being idle.

Pay-ore, pay-streak. The payable parts of a vein or gravel channel.

Pegmatite. Giant granite, a coarse-grained igneous rock, the source of many non-metallic ores.

Penstock. A floodgate or regulating box or chamber from which water flows into pipes going to water-wheels or monitor.

Penthouse. A strong Λ-shaped wooden covering built in shafts, to protect men who are sinking from being injured by falling débris.

Peon. A Mexican laborer.

Permissible explosives, lamps, motors, and rescue apparatus. Those that have passed certain tests by the Federal Bureau of Mines and considered safe for use in mines, if maintained in the condition required.

Persistent. Continuous; orebodies are often persistent in depth and metal contents but are never permanent.

Phenocryst. A porphyritic crystal.

Phonolite. A very fine-grained igneous rock consisting of potash, feldspar, silica, sodium, potassium, aluminum, calcium, magnesium, and iron. It is an uncommon rock but is an important ore carrier at Cripple Creek, Colorado.

Phthisis (thī-sĭs). Miners' lung disease.

Picric acid. A lemon-yellow crystalline powder composed of carbon, hydrogen, nitrogen, and oxygen. Sterilized gauze, soaked in a weak solution of the acid, is used at mines in the first-aid treatment of burns and scalds. The gauze may be procured ready for use. It should be moistened before use. Picric acid may be used as an explosive. A no. 8 detonator will explode loosely packed picric acid, provided the detonator is so inserted in the charge that it is in close contact with the picric acid and that the latter is perfectly dry.

Pig. An ingot or cast bar of any metal, particularly iron or lead.

Pinched. A narrowing or squeezing of a vein. When the walls meet, the vein is said to be pinched out.

Pipe. An elongated orebody or formation. A famous pipe in Western Australia yielded over $30,000,000 in gold, in tellurides and iron pyrite. It pitched sharply from surface to a depth of below 1000 feet, through five mining properties, and there ended. Its thickness was about 200 feet. The famous diamond deposit at Kimberly, South Africa, is a vertical pipe.

Pitch. The inclination of an orebody in the direction of its strike.

Placer. Any gravel deposits or minerals, particularly gold, not in place are placers. A placer claim is 1320 feet square and contains 10 acres.

Plumbago. Graphite.

Porosity. The state or quality of being porous or open; pumice and oil-sand, for instance.

Porphyry. See under Copper.

Precipitate. When any substance is held in solution in a liquid—such as silver in nitric acid—and is thrown down as a sediment from that solution by the addition of some other substance in solution—as common salt added to the nitric acid solution throwing down the silver as white cloudy chloride—the deposited matter or sediment is called precipitate. Several field tests for metals depend on this reaction.

Primary. Original. In the case of metals, virgin.

Promoter. Be careful of mine promoters with glib speech, polished manners, and convincing arguments.

Prop. Timber used in a mine, vertical or raking.

Prospectus. A report describing a prospect; or even a big mine when further capital is required or shares are to be listed on an exchange. Some prospectuses are of a suspicious character and are written by unscrupulous promoters and untrained mining men.

Pseudo. False.

Pulverize. To grind to powder.

Pumice. A cellular or porous lava which floats on water. It is used as an abrasive.

Q

Qualitative. In testing ores, how many and what metals are present.

Quantitative. In testing ores, how much of each metal is present.

Quartering. See under Sampling.

Quartzite. A changed quartz sandstone. Secondary silica has been deposited between the original grains, so that the rock is more firmly cemented and less porous than before and tends to break across the grains.

Quartzose. Containing mainly quartz.

Quintal (kin-tle). About 100 pounds. The Spanish quintal is 101½ pounds.

R

Rabble. A scraper or stirrer.

Radiate. Emission and diffusion of light or heat.

Raise. A shaft driven upward to connect two levels.

Rake. The inclination of a vein.

Reagent. A substance—solid or liquid—used in testing anything or in treating ore.

Reaming. Enlarging the diameter of a bore-hole.

Reconnaissance. A preliminary examination or survey of a district.

Reef. A British term for vein.

Refining. Purifying by heat.

Refraction. A change of direction when a ray of light passes from one medium to another of different density.

Refractory. In ores, a complex mixture difficult to treat, such as a copper-zinc-lead-silver ore or arsenical pyrite and gold.

Replacement. The process by which one mineral or chemical substance takes the place of some earlier different substance, often preserving its structure or crystalline form; for instance, lead deposits in limestone.

Rescue-car. See Mine rescue-car.

Residual. A remnant, such as a large rock remaining after the once surrounding country has been eroded by weathering agencies.

Respirator. A screen of fine wire or gauze worn, but not liked, by men working in dusty places.

Reticulate. To form a network.

Retreating. Robbing pillars in coal mines and working back toward the shaft.

Rhyolite. An igneous rock composed mostly of quartz and feldspar.

Rib. A pillar of coal left as a support for the roof or the side of a working.

Riffle. A groove or channel or slat laid crosswise in a sluice-box rocker, long-tom, to catch gold or other minerals.

Roast. To heat to the point where sulphur, arsenic, and other minerals are driven off from ores but not to the point of sintering or clinkering.

Room and pillar. A system of mining coal whereby it is extracted in rooms separated by narrow ribs or pillars.

Royalty. The sum of money paid by a lessee or operator to the owner of a claim or mine. The amount is generally based on so much per ton of ore mined or so much per cent of the output. For example, in the Oatman district, Arizona, ore assaying up to $10 a ton pays 5 per cent royalty, $15 to $20 a ton pays 15 per cent, $25 to $30 a ton pays 25 per cent, $40 to $45 a ton pays 40 per cent, $50 and over pays 50 per cent.

Rubble. Small broken stones.

Run of mine. Coal or ore just as mined; without sorting or preparation.

Rusty gold. Free gold coated with a thin coating of iron oxide or silica, needing grinding before it will amalgamate.

S

Saddle. A formation shaped like a saddle or anticline, in which the strata dip away each side from the crest or ridge. A famous example of gold-bearing quartz saddles is Bendigo, Australia, which has yielded about $400,000,000 of gold.

Safety first. Whether underground or on the surface, have this thought foremost. Safety first applies to prevention of accidents, first aid, and rescue work.

Safety-lamp. A lamp whose flame is so protected that it will not immediately ignite firedamp in coal mines. The flame is generally surrounded by a wire gauze or screen. An electric cap-lamp is also a safety-lamp.

Saline. Salty.

Saller, soller. A boarded floor or stage on which to work or shovel in a mine.

Salting. A dishonest practice. But in sampling ores and gravels a man may unintentionally salt them.

Sandstone. A sedimentary rock formed of cemented sand.

Schist. A crystalline rock that can be readily split or cleaved because of its foliated or parallel structure.

Schistose. Of the nature of schist.

Scintillation. Burning with brilliant sparks.

Secondary. Formed by alteration since the original formation of the rock, as secondary enrichment, explained in this work.

Sectile. Easily cut.

Sedimentary. Formed by deposition of grains or fragments of rock-making material; one of the three great classes of rocks—igneous, metamorphic, sedimentary.

Seepage. Oozing of water, oil, or bitumen from rocks; a spring.

Selvage. A layer of clay or decomposed rock along a vein-wall; gouge.

Semi-. Half, somewhat, or partly.

Sericite. A talc-like mica occurring in small scales and forming sericitic schist.

Shale-oil. The product of distillation of oil-shale.

Shalene. A term proposed in place of gasoline for that product distilled from oil-shale.

Shear-zone. One in which the rock is crushed and shattered.

Shoot of ore. Ore-shoot or orebody.

Shot-firer. A man whose duty it is to set off all shots in coal mines.

Sierra. A mountain chain, such as Sierra Nevada (white mountains).

Silicate. Pertaining to silica or a salt of silicic acid; siliceous.

Silicosis. Miner's lung trouble or phthisis, caused by silica or quartz dust. Frequently termed pneumoconiosis. Coal dust gives asthma. Asbestos dust is also harmful.

Sill. An intrusive sheet of igneous rock. A member of a set of mine timber or sole piece in building.

Single-jack. A light single-hand hammer used in drilling.

Slack. Small coal or coal dirt.

Slake (not slak). As when water is added to lime. Lignite slakes when exposed.

Slickenside. Polished surface on the walls of a vein the result of rubbing during faulting.

Slip. A fault.

Slope. An inclined entry or drift in a coal mine.

Sluice-box. A trough, lined with riffles, through which gravel from hydraulicking flows and in which the gold or tinstone is caught.

Sluicing. Hydraulicking gravel.

Sourdough. A miner who has lived in Alaska more than one season.

Spall. To break lumps of ore with a heavy hammer.

Specific gravity. The ratio of the weight of any substance to that of an equal volume of water. If a piece of quartz is weighed in air and then in water, its specific gravity is obtained by dividing its weight in air by its loss of weight when weighed in water.

Specimen. A hand sample or selected piece of ore.

Specular. Mirror-like, such as specular iron ore.

Spelter. Slab zinc; it is a term now in disuse.

Spiegeleisen. Mirror-iron or iron and manganese, a white metal low in manganese used in certain steels.

Spiling. Lagging; laths.

Split-check. A system of leasing practiced at Cripple Creek, Colorado, and Kalgoorlie, Western Australia, whereby the men and company divide the profits.

Spodumene. A silicate of lithium and aluminum, used as a source of lithia for medicinal purposes. The clear green and lilac varieties are used as gems. Mined in South Dakota.

Stalactite. Hanging columns of limestone formed by the dripping of water containing it.

Stalagmite. Uprising columns of limestone formed in a similar way to stalactites.

Starter. The first drill used in boring a hole, usually 18 to 24 inches long.

Steatite. Soapstone; a massive variety of talc.

Stemming. The material tamped on top of a charge of dynamite.

Stockwork. Generally an ore formation consisting of a number of small veins in country rock, too small to be mined singly but may be mined as a whole.

Stope. A drift above a drift or level in which ore is mined to the level above. There are no tracks or cars in stopes, the ore building up on the timber above the main drift and then passing to the level through chutes.

Straits tin. Tin from Malaya and Netherlands India. These countries up to 1942 supplied half of the world's tin.

Stratified. Formed or lying in beds, layers, or strata.

Striated. Marked with fine parallel grooves or scratches, as rock marked by glaciers, as visible in Ontario and New York.

Stringer. A narrow vein or veinlet.

Stripping. Removing overburden from ore or gravel.

Structure. The general occurrence or nature of rocks.

Sublimate. A coating or deposit formed in a glass tube or on charcoal as a result of heating certain minerals, as in blowpipe tests.

Sublime. To pass from a solid to a gaseous or smoky state and condense to solid form or sublimate, as zinc dust.

Sulphate. A salt of sulphuric acid, such as copper and acid making the blue copper sulphate.

Sulphide. A compound of sulphur and any metal.

Sulphuret. Sulphides; concentrates.

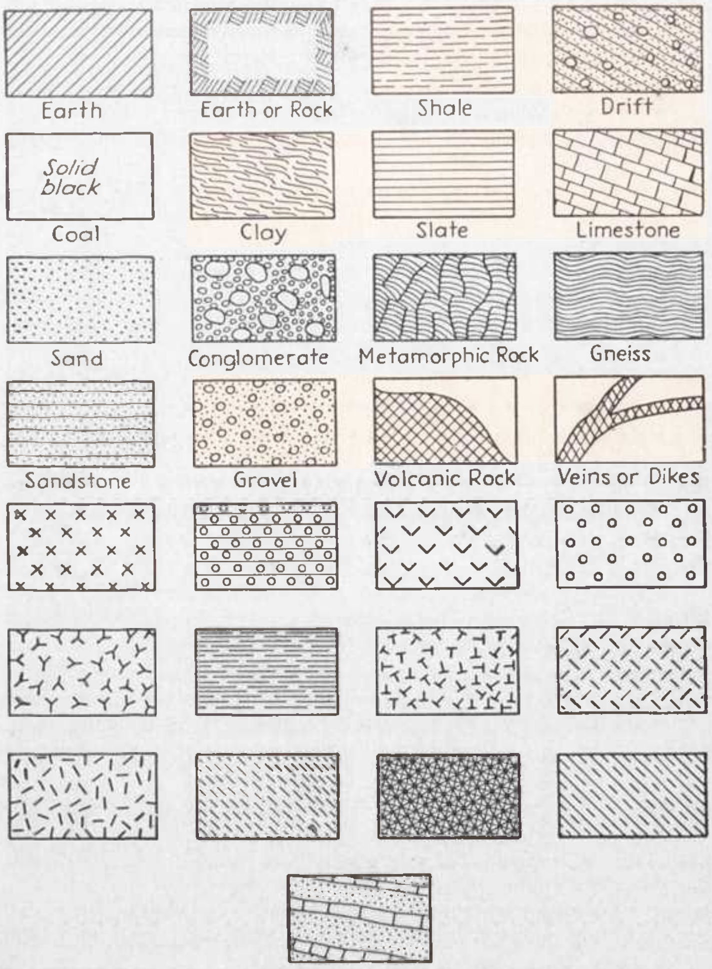
Sump. A hole sunk below a shaft or drift to catch water.

Surficial. On the surface of the earth; not superficial, which means general or excessive or even unnecessary.

Syenite. An uncommon granite-like rock with little quartz but with feldspar and mica.

Symmetry. Regular arrangement.

Symbols. See under atomic weight and page 525 as used by students in the University of California.



Geological conventions. The unnamed symbols may be used for any rock.

Syncline. A fold in rocks in which the strata dip inward from both sides toward the axis; the opposite to an anticline.

System. It is a good plan to cultivate system and be systematic in working.

T

Tabular. Platy; a tendency in certain igneous or crystalline rocks.

Talc-schist. Schistose rocks consisting mainly of talc and quartz.

Tally. A mark or number made for each car of coal, ore, or other material.

Talus. A heap of coarse broken rock at the foot of a cliff.

Tamping. Forcing gently but firmly the stemming or material on top of a blasting charge in a hole.

Tamping bar. A piece of wood the size of a broom handle for tamping or forcing the stemming in a drill-hole. Never use a metal tamping bar.

Tarnish. The change of color of a mineral caused by atmospheric action, such as dampness or fumes.

Technologist. One skilled in industrial science, such as metallurgy and manufacturing.

Temper. To give drill-steel the desired degree of hardness by heating and cooling, which requires considerable practice. Cooling is done in water and/or oil, according to the class of steel.

Tenderfoot. A newcomer in a rough mining camp; analogous to a **chekako** in Alaska and **new chum** in Australia.

Tenor. Percentage or average metal content or value of an ore.

Tension. A tendency to pull apart or strain, as on a wire rope when hauling ore or on a tightly strained bolt.

Termite. An insect which eats out the heart of timber in houses and structures and whose presence is not known until the material collapses or shows signs of dry rot.

Texture. The character, arrangement, and mode of aggregation of the fragments, particles, or crystals that make a rock. Somewhat structural.

Theodolite. An instrument used in surveying, consisting of a tripod or stand, compass, level, graduated scale or vernier, and telescope.

Thermal. Hot or warm.

Thermite. A mixture of aluminum dust and iron oxide, which, when lighted, will weld two pieces of iron or steel. Large broken castings may be repaired quickly and thoroughly by this means.

Throw. A fault or dislocation.

Tierra. Earth, land, or ground.

Tin-plate. Sheet iron dipped in molten tin, which amounts to 2 or 3 per cent of the finished plate.

Tinstone. Cassiterite, tin oxide, black tin.

Tipple. A place where coal cars are tipped or dumped into a washery, screening plant, or railroad cars.

Tool-steel. A steel containing tungsten used in making tools for lathe work, etc. The tool may become red hot yet do its work.

Topography. The physical features of a region, such as the hills and valleys. The United States Geological Survey has nearly 3000 topographic maps for distribution at 10 cents apiece, or they may be bought at 25 cents at most stationers in towns of any size. These maps are very useful and should be carried on prospecting expeditions.

Tough. Flexible without brittleness. Oil-shale is tough.

Tourniquet (tur-ne-ket). A bandage or strap tied tightly around a person's limb between the heart and the wound to prevent profuse bleeding. Usually a little pad or compress is placed over the blood vessel or artery at this point. The bandage should be slackened every 15 minutes to prevent mortification setting in.

Translucent. Admitting the passage of light but not capable of being seen through.

Transparent. Capable of being seen through; diaphanous.

Transverse. Across.

Trap rock. A general name for dark, fine-grained igneous rocks, such as lavas and dikes; basalt, dacite, diabase.

Travertine. Carbonate of lime or limestone. The travertine type of marble is somewhat cellular and in demand for building purposes.

Trend. Direction or bearing of any rock formation; more or less the strike.

Triboluminescence. Some zinc sulphide and other minerals emit sparks when scratched, but they will not set fire to flammable gases.

Tribute. A lease. A tributer is a lessee.

Trommel. A revolving screen or sieve.

Troy. A system of weights for precious metals. One pound equals 5760 grains, compared with 7000 grains in the avoirdupois pound. To convert avoirdupois pounds into troy ounces multiply by 14½.

Tuff. Volcanic dust, ash, that may or may not be deposited in water, heterogeneous or well sorted, loose or hard. It is classed as a sedimentary rock or formation.

Tugger hoist. A useful little air-hoist for small or big mines.

Tundra. A level or undulating treeless plain in the Arctic regions. The soil is black and mucky, with a frozen sub-soil, on which moss thrives. In Alaska there are tundra or gravel-plain placers along the coastal plain of Seward Peninsula.

Tuyère (tweer). The pipe or blowpipe of a forge bellows or blast-furnace which is in contact with the fire. Water is circulated to prevent the iron or copper from burning.

U

Ultra-basic. Igneous rocks containing less than 35 per cent silica.

Umiak. A large Eskimo boat made of skins.

Umpire assay. When a dispute arises over the results of two assays on the sample, a third or umpire assay is made by an independent man upon whose result the settlement is made.

Unconformable. When one rock formation is in a different position to that of the one below it the structure is said to be unconformable. For instance, the higher formation may be horizontal and the lower, vertical.

Unctuous. Having a greasy feel, such as talc.

Undercut. To undermine, as a coal bed.

Underhand stoping. Mining downward or below the level.

Underlay. Dip or slope.

Undulating. Wave-like.

Unit. Any standard amount or quantity. In ores, a unit is 1 per cent of a short ton or 20 pounds.

Unpatented claims. Those which require $100 of work to be done each year. Claims cannot be patented until $500 has been spent on them.

Upcast. A mine opening through which the air goes to the surface.

Upper. A drill-hole driven in an upward direction.

V

Vacuum. Space mechanically made.

Vanner. A concentrator or shaking table.

Vapor. A substance in a gaseous state. Steam is water vapor.

Vegetal. Of vegetable or plant origin.

Vein. Any well-defined mineralized zone, with or without payable orebodies or shoots.

Vent. A small aperture or hole through which gas may escape.

Verdigris. A green "rust" on copper.

Vermilion. A bright-red pigment made from cinnabar.

Vesicle. A small cavity in an eruptive rock.

Viscosity. Gumminess; not properly fluid; as thick oils, tar, or slag; the opposite of fluidity.

Vitreous. Having the luster of broken glass.

Vitriol. A sulphate of any metal, such as blue vitriol (copper), green vitriol (iron), white vitriol (zinc). Oil of vitriol is sulphuric acid.

Volatile. Easily evaporated or converted into fume.

Volcanism. Volcanic activity.

Volt. The unit of electric pressure.

Vug. A cavity in a rock.

W

Wad. A soft bog manganese.

Wall. The country rock on either side of a vein. That on the top side is the hanging wall, and that on the lower side is the footwall.

Warning signals. See Danger signals.

Wash. Auriferous gravel.

Washery. A place where coal is cleaned.

Waste. Barren rock.

Water-right. The right to use water for mining or other purposes.

Weathering. Rocks that are affected by air, rain, plants, bacteria, and temperature decay and finally crumble into soil are weathered.

White damp. Carbon monoxide, a deadly gas existing in coal mines in afterdamp or in gases given off by mine fires.

Wild-cat. Any risky venture in mining, sometimes crooked. In oil parlance, wild-catting means drilling holes on chance.

Windy shot. A blast that blows out without breaking any coal.

Winze. An interior shaft sunk from one level to another for development and ventilation purposes.

Wyomingite. An igneous rock containing leucite and other minerals.

Z

Zinc-coated. Formerly galvanized, as zinc-coated iron; analogous to tin-plated.

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