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BLOWPIPING
MINERALOGY
GEOLOGY
PROSPECTING

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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice —together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one to select the proper formula, method, or process and in teaching him how and when it should be used.

This volume contains papers on the following subjects of particular interest to the metal miner and prospector: blowpiping, mineralogy, geology, and prospecting. These subjects are covered in sufficient detail to enable the prospector to properly locate mining claims, to determine the value of minerals, and to recognize likely regions for prospecting and thus avoid working in wholly unproductive fields. The text has been so prepared that the only preliminary knowledge required is a little arithmetic and how to read and write the English language.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 37, page 26, will be readily found by looking along the inside edges of the headlines until § 37 is found, and then through § 37 until page 26 is found.

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Note.—All items in this index refer first to the section and then to the page of the section. Thus, "Analysis of drill cores, §42, p49," means that analysis of drill cores will be found on page 49 of section 42.

BLOWPIPING

INTRODUCTION

1. Object of Blowpiping.—The purpose of **blowpiping** is to furnish a rapid method for the determination of the approximate composition of minerals and ores. In general, blowpipe determinations are merely *qualitative*—that is, they indicate the presence of the different constituents, but not the proportions. In the cases of a few of the metallic elements that can be completely reduced from their minerals before the blowpipe, by methods to be described later, a rough idea of the proportions may be gained; but these results are not at all accurate, on account of the roughness of the method and the losses through volatilization. To determine with any accuracy the percentage composition of a chemical compound, the more elaborate methods of quantitative analysis must be followed.

It is not sufficient that a student has such a knowledge of the subject as will enable him to give all the tests for the different metals or minerals as they are printed, but he should obtain a practical knowledge by actual experiments that will enable him to recognize minerals, either by their physical characteristics or by their blowpipe reactions. This knowledge can be obtained only by practical work. When taking up the subject, the student should first carefully read the instructions and then, and not until then, begin work with the blowpipe outfit.

2. Symbols and Abbreviations.—In blowpiping and mineralogy, to avoid tedious repetition, the following symbols and abbreviations are used. The symbols give the chemical composition of the minerals and reagents, while the abbreviations stand for blowpipe manipulations and physical characteristics.

B. B., before the blowpipe. *Infus.*, infusible. *F.* or *Fus.*, fusible. *R. F.*, reducing flame. *O. F.*, oxidizing flame. *Fib.*, fibrous. *Sp. Gr.* or *G.*, specific gravity. *Amorph.*, amorphous. *Gran.*, granular. *H.*, hardness. *Mass.*, massive.

REAGENTS

INTRODUCTION

3. Acids.—An acid is a compound of hydrogen with one or more other elements, in which the hydrogen is replaceable, wholly or in part, by a metallic element or a group of elements equivalent to a metal. As a class, acids have a sour (*acid*) taste, and most of them turn blue litmus red—thus giving a very delicate test for the presence of an excess of acid.

Certain oxides, when dissolved in water, combine with it chemically and form acids; these are called **anhydrides**, which means containing no water. The following equation illustrates the reaction between sulphuric anhydride and water:

$$SO_3 + H_2O = H_2SO_4 \text{ (sulphuric acid)}$$

In this equation sulphur trioxide containing no hydrogen is added to water to make sulphuric acid.

The term *acid* is sometimes used in reference to anhydrides, as carbon dioxide CO_2, but this usage is being abandoned.

Acids containing oxygen are called *oxy-acids*, or *oxacids*, to distinguish them from a group of acids containing no oxygen, which are known as *hydracids*—such as hydrochloric acid, HCl, hydriodic acid, HI, hydrofluoric acid, HF, etc.

When an element forms more than one oxacid, the termination *-ous* is applied to the name of the acid in which the

TABLE I

NAMES, SYMBOLS, AND ATOMIC WEIGHTS OF ELEMENTS

Elements	Symbol	Atomic Weight	Elements	Symbol	Atomic Weight
Aluminum	*Al*	26.9	Molybdenum	*Mo*	95.3
Antimony (stibium)	*Sb*	119.3	Neodymium	*Nd*	142.5
Argon	*A*	39.6	Neon	*Ne*	19.9
Arsenic	*As*	74.4	Nickel	*Ni*	58.3
Barium	*Ba*	136.4	*Nitrogen*	*N*	13.93
Bismuth	*Bi*	206.9	Osmium	*Os*	189.6
Boron	*B*	10.9	*Oxygen*	*O*	15.88
Bromine	*Br*	79.36	Palladium	*Pd*	105.7
Cadmium	*Cd*	111.6	*Phosphorus*	*P*	30.77
Cæsium	*Cs*	131.9	Platinum	*Pt*	193.3
Calcium	*Ca*	39.7	Potassium (kalium)	*K*	38.85
Carbon	*C*	11.91	Praseodymium	*Pr*	139.4
Cerium	*Ce*	139.2	Radium	*Ra*	223.3
Chlorine	*Cl*	35.18	Rhodium	*Rh*	102.2
Chromium	*Cr*	51.7	Rubidium	*Rb*	84.9
Cobalt	*Co*	58.55	Ruthenium	*Ru*	100.9
Columbium	*Cb*	93.3	Samarium	*Sm*	149.2
Copper (cuprum)	*Cu*	63.1	Scandium	*Sc*	43.8
Erbium	*Er* or *E*	164.8	*Selenium*	*Se*	78.6
			Silicon	*Si*	28.2
Fluorine	*F* or *Fl*	18.9	Silver (argentum)	*Ag*	107.11
			Sodium (natrium)	*Na*	22.88
Gadolinium	*Gd*	154.8	Strontium	*Sr*	86.94
Gallium	*Ga*	69.5	*Sulphur*	*S*	31.82
Germanium	*Ge*	72.	Tantalum	*Ta*	181.6
Glucinum (beryllium)	*Gl*	9.03	*Tellurium*	*Te*	126.6
			Terbium	*Tb*	158.8
Gold (aurum)	*Au*	195.7	Thallium	*Tl*	202.6
Helium	*He*	4.	Thorium	*Th*	230.8
Hydrogen	*H*	1.	Thulium	*Tm*	169.7
Indium	*In*	114.1	Tin (stannum)	*Sn*	118.1
Iodine	*I*	126.01	Titanium	*Ti*	47.7
Iridium	*Ir*	191.5	Tungsten(wolfram)	*W*	182.6
Iron (ferrum)	*Fe*	55.5	Uranium	*U*	236.7
Krypton	*Kr*	81.2	Vanadium	*V*	50.8
Lanthanum	*La*	137.9	Xenon	*Xe*	127.
Lead (plumbum)	*Pb*	205.35	Ytterbium	*Yb*	171.7
Lithium	*Li*	6.98	Yttrium	*Yt*	88.3
Magnesium	*Mg*	24.18	Zinc	*Zn*	64.9
Manganese	*Mn*	54.6	Zirconium	*Zr*	89.9
Mercury (hydrargyrum)	*Hg*	198.5			

NOTE.—The elements neodymium and praseodymium always occur together, and so they are called didymium in the tables on blowpipe reactions. The italic type in the table represents non-metallic elements, the metallic elements being printed in roman type.

proportion of the oxygen to the characteristic element is smaller and *-ic* to the more highly oxidized acid.

4. Bases.—A **base** is a compound—usually an oxide or a hydrate of a metallic element, or of a radical equivalent to a metal—which is chemically opposed to acids in all its reactions and characteristics. Certain bases in which the distinctive chemical characteristics are very marked are called **alkalies.** They neutralize acids, restore the blue color to litmus reddened by acids, and turn yellow turmeric paper to a reddish-brown color. The most familiar alkalies are caustic soda and caustic potash (sodium and potassium hydroxides or hydrates—$NaOH$ and KOH) and ammonia (ammonium hydroxide or hydrate—NH_4OH). The metallic constituents of these compounds belong to a group known as the *alkali metals*, consisting of lithium, sodium, potassium, rubidium, cæsium, and the metallic radical ammonium, NH_4. The metals of this group and their oxides combine with great readiness with water, forming strongly alkaline hydroxides—all except lithium bursting into flame on being wet or thrown into water—and ammonia gas, NH_3, dissolves with remarkable rapidity in twice its weight of water, forming a hydroxide. The gas may be completely expelled from the water by heating, and is liberated to a considerable degree at ordinary temperatures. The alkalies impart a peculiar soapy taste and feel to water.

The *alkaline earth metals*, barium, strontium, calcium, and magnesium, have many characteristics in common with the alkali metals. The basic compounds of this group are less soluble, however, and their alkaline reactions are less pronounced.

5. Salts are compounds produced by the replacement of part or all of the hydrogen of an acid by a metallic element or an equivalent group of elements. Many metals are directly soluble in acid, the reaction giving a salt of the metal and liberating hydrogen gas, thus:

$$Fe + H_2SO_4 = FeSO_4 + 2H$$

Bases (metallic oxides and hydroxides) react with acids, the metal of the base interchanging with the hydrogen of the acid, forming a metallic salt and water, thus:

$$FeO + 2HCl = FeCl_2 + H_2O$$

or

$$2NH_4OH + H_2SO_4 = (NH_4)_2SO_4 + 2H_2O$$

The salts of the alkali metals are all soluble, hence they do not form precipitates, except in very highly saturated solutions.

The salts of the hydracids take the termination *-ide*—chloride, fluoride, sulphide, etc. The salts of the lower or *-ous* oxacids take the termination *-ite*, thus:

$$\underset{\text{(sulphurous acid)}}{H_2SO_3} + 2NaOH = \underset{\text{(sodium sulph\textit{ite})}}{Na_2SO_3} + 2H_2O$$

The salts of the higher, or *-ic*, oxacids take the termination *-ate*, thus:

$$\underset{\text{(nitric acid)}}{2HNO_3} + PbO = \underset{\text{(lead nitr\textit{ate})}}{Pb(NO_3)_2} + H_2O$$

OXIDATION AND REDUCTION

6. Oxidation is a reaction by which a substance takes up oxygen, or is *oxidized*, by the proportion of oxygen to the metallic constituent being increased. In the chemical sense, oxidation applies to reactions in which there is an actual increase in the proportion of oxygen, and also to analogous reactions in which there is an increase in the proportion of the non-metallic constituent. Thus, any reaction by which ferrous chloride, $FeCl_2$, is converted into ferric chloride, Fe_2Cl_6, or ferrous sulphate, $FeSO_4$, is converted into ferric sulphate, $Fe_2(SO_4)_3$, is just as truly oxidation as the reaction by which ferrous oxide, FeO, is converted into ferric oxide, Fe_2O_3. In blowpiping, however, oxidizing reactions are usually attended by actual oxidation, or an increase in the proportion of oxygen.

7. Reduction is the inverse of oxidation; that is, a reducing reaction is one by which the proportion of the non-metallic constituent to the metallic constituent is decreased.

Oxidation and reduction always occur simultaneously; that is, an oxidizing reaction is at the same time reducing, for what one reagent gains it must take from another, either directly or indirectly, and the second reagent is therefore reduced. The reaction is termed oxidizing or reducing, according as the principal product is the result of oxidation or reduction.

DRY-TEST REAGENTS

8. Reagents.—In order to produce changes in minerals, so as to test their composition, **reagents** are used. They are known as *dry*, *wet*, and *gaseous*, according as they are used in the solid, liquid, or gaseous form. Most of the reagents can be obtained sufficiently pure at drug stores or from dealers in chemicals.

9. Borax, $Na_2B_4O_7 + 10H_2O$.—The most important blowpipe flux is **borax,** which makes fusible double borates of soda and most of the metals. As most metals give different-colored borax beads, this sometimes serves to distinguish them, though other tests should be made to confirm the metal that the color of the borax bead indicates. The colors from the same metal are usually different in the outer and inner lamp flame, and should therefore be tried in both, and the colors noted while hot, while cooling, and when cold.

Ordinary borax, on heating, at first puffs up and swells greatly from the slow expulsion of the water of crystallization that it contains; this should be driven off, and the borax heated until perfectly quiet, clear, and colorless before adding the substance to be tested. *Borax glass* (borax that has been fused and then ground up) or *calcined borax* (borax from which the water has been driven off by slowly heating to a temperature slightly above the boiling point of water) may be used. Care should be taken that the borax bead on the platinum wire is perfectly colorless, as dirt left upon the wire from a previous assay may discolor it and so indicate the presence of metals not contained in the substance to be tested. In case the wire is dirty, boiling in acid will clean it; or, if that is not convenient, making several beads, heating highly, and throwing off the dirty beads, will wash, or rather flux, the wire clean.

10. Salt of Phosphorus, Microcosmic Salt.—Salt of phosphorus, *S.Ph.*, makes easily fusible double phosphates of soda that usually give different-colored beads with the various metals. In most cases the bead colors are the same as with borax, but in some cases they are not. Salt of phosphorus boils up and is apt to drop off the wire loop on first heating, from the expulsion of a large amount of water of crystallization, but it soon quiets down to a perfectly clear, colorless bead. As with borax, the substance to be tested should be added only after the salt has fused down to a clear, colorless bead, carefully observing that it shows no color from a dirty wire or other impurities.

11. Soda.—In testing for sulphur, reducing metals, etc. the bicarbonate of soda, $NaHCO_3$, or the carbonate of soda, Na_2CO_3, may be used, the former being preferable on account of its containing less water. The name in either case is usually shortened to **soda.** The pure soda must be used, otherwise it will be apt to give a sulphur reaction; and every new lot should be tested to insure its freedom from sulphur (in the form of sulphate of soda). On account of the lightness of sodium bicarbonate, it is apt to trouble the beginner by blowing off of the charcoal; but if a gentle flame is blown until it is fused, the strong blast can then be used without any trouble. A gas flame should not be used in testing for sulphur, as it always contains enough sulphur to give a reaction.

12. Cobalt-Nitrate Solution. — For certain tests, a dilute solution of **nitrate of cobalt,** $Co(NO_3)_2$, is employed. The substance is moistened with the solution (preferably with a dropping tube), strongly heated on charcoal in O. F. for about 5 minutes, and then allowed to cool, when different colors result. The colors of certain minerals under this test are very characteristic.

13. Niter. — For a few special tests, niter (sodium nitrate, $NaNO_3$, or potassium nitrate, KNO_3) is employed on account of its powerful oxidizing effect. While either potash or soda niter can be employed, the former is better.

14. Cupric oxide, CuO, in the form of a powder, is used in testing for the haloids (chlorine, bromine, and iodine).

15. Bismuth Flux.—To test for lead and bismuth, a special flux is made of 1 part each of iodide of potassium, KI, and potassium acid sulphate, $KHSO_4$, and 2 parts of sulphur, which are ground together. Two to four parts (by volume) of this flux are mixed with one of the substance, and heated on charcoal, when bismuth gives a brick-red coat, and lead a coat yellow close to the assay, and greenish beyond. The flux itself gives a white coat, but does not interfere with the above.

16. Test Lead.—For the silver-cupellation assay, finely granulated lead, known as **test lead,** is employed to collect the silver into a button preparatory to cupelling. It usually contains more or less silver, and should be tested by cupellation for this metal before using.

17. Bone ash is employed for making the cupels; it is made of calcined bones, hoofs, and horns, ground to a fine powder.

18. Tin.—For obtaining a strong reducing action, finely ground pure metallic tin or tin shavings are sometimes used.

19. Potassium-acid sulphate, $KHSO_4$, in the form of crystals, is used in testing for certain acids and as an acid flux.

20. Acids. — Hydrochloric acid, HCl, sulphuric acid, H_2SO_4, and nitric acid, HNO_3, are necessary in blowpiping. As a rule, the strongest sulphuric acid should be used, while the hydrochloric and nitric acids should be of only medium strength. All these acids should be kept in glass-stoppered bottles, as they corrode and destroy corks.

21. Hydriodic Acid.—For obtaining a very characteristic series of bright-colored coats with the volatile metals, hydriodic acid, HI, is employed on white tablets of plaster of Paris. The substance to be assayed is placed on the end of a tablet, moistened well with hydriodic acid (preferably with a dropping tube), and then heated with a pure blue flame, as a yellowish flame would smoke the white tablet. The acid itself gives a brownish coat of iodine, but this quickly evaporates and leaves the bright iodide coats. If the acid cannot be made (by passing sulphureted hydrogen through water containing iodine crystals until a clear solution is obtained) or purchased, a substitute that will answer, though not so well, is to dissolve iodine in alcohol, or else fuse equal parts of iodine and sulphur together and grind to a powder; the latter is a solid, and much more convenient in traveling than the liquid acid or spirits of iodine.

22. Litmus paper is necessary to test for alkalies and acids, the blue turning red for acids, and the red turning blue for alkalies. It will be found convenient to use it cut up in the form of strips.

23. Turmeric paper has a fine yellow tint, and is used to detect boron and zirconium, and the alkalies. The test for boron is very delicate. If a piece of the paper be moistened with a dilute solution of a boron mineral in hydrochloric acid and then dried at boiling temperature by wrapping around a test tube of boiling water, it assumes a reddish-brown color, becoming inky-black if moistened with ammonia. Moistened with a solution of any zirconium mineral in hydrochloric acid it turns orange-red. Alkalies turn it brownish-red.

24. Brazil-wood paper is used to detect fluorine, which gives it a straw-yellow color; also to detect the alkalies, which color it violet.

25. Reagent Box.—The dry or solid reagents can be conveniently kept in a block of wood, say 2″ × 2″ × 8″ in size, in which ½-inch holes have been bored. Common corks can be used for stoppers, and the name of the flux written on top of them or on the box. Such a reagent box can be purchased for about one dollar, but it is easily made. Small pill boxes or vials may be used instead of the block of wood.

WET TESTS

26. Introduction.—In ordinary chemical analysis the substance to be tested must first be brought into a liquid form by dissolving in acids, and the different constituents then precipitated by means of proper reagents; but by the use of the blowpipe for qualitative analysis, the reactions by which the different constituents are recognized are gotten directly from the substance tested, without previous solution. There are certain simple **wet tests,** however, which are universally used in conjunction with the blowpipe tests, and have come to be considered a part of blowpipe practice. These tests are mainly of the solubility of the substances in the common mineral acids—hydrochloric, HCl, nitric, HNO_3, and sulphuric, H_2SO_4—and the phenomena attending the complete or partial solution, and precipitation.

For testing with acids, a mineral should first be powdered; a little of it is then placed in the bottom of a test tube, and well covered with the acid. The most important points to be observed are, first, whether the substance dissolves slowly or rapidly, completely or incompletely, or is insoluble either when the solution is cold, or when heat is applied; and second, whether a gas is evolved, producing bubbling or effervescence, or a solution is formed without effervescence, or whether a precipitate is formed or an insoluble constituent separated.

Hydrochloric acid is most frequently used in testing the solubility of a mineral, though in the case of lead, silver, and mercury compounds, nitric acid is required, as these metals form insoluble chlorides. Sulphuric acid is least used as a solvent. Dilute acids are generally used. Minerals that are insoluble or only partially soluble in either hydrochloric acid or nitric acid alone, are usually soluble in aqua regia, which is a mixture of 3 parts of hydrochloric acid with 1 part of nitric acid.

REACTIONS OF DIFFERENT MINERALS IN ACIDS

27. Carbonates.—All **carbonates** dissolve in acids, liberating carbon-dioxide gas, CO_2, with lively effervescence. Some carbonates will dissolve in cold acid, but others require the acid to be heated, as in the case of magnesite (magnesium carbonate), dolomite, and siderite. Dilute hydrochloric acid is generally used for these tests but nitric acid gives the best results with lead, copper, and zinc carbonates.

28. Sulphides.— When **metallic sulphides** are dissolved in hydrochloric or sulphuric acid, hydrogen sulphide, H_2S, is liberated. This is a colorless, highly poisonous gas, very readily recognized by its characteristic odor, which is that of rotten eggs.

Some sulphides, when treated with boiling nitric acid, decompose, forming a metallic nitrate or oxide, and liberating sulphur, which separates as a white or yellowish precipitate.

29. Silicates.—Some **silicates**, when finely powdered and treated with boiling concentrated hydrochloric or nitric acid, are decomposed, the silica separating as a gelatinous precipitate or as a fine powder. Other silicates are unaffected by acids.

Besides the insoluble silicates, there are a number of minerals that are insoluble in acids; mostly, however, of rather unusual occurrence, as titanates, tantalates, columbates, etc. Among the commoner insoluble minerals are barite, celestite, and anglesite—the sulphates of barium, strontium, and lead, respectively—and many phosphates.

30. Oxides.—The majority of the **mineral oxides** are soluble in acids. Hydrochloric acid alone will dissolve most of them, while several more are soluble in nitric acid or in aqua regia. There are a number of mineral oxides, however, which refuse to yield to the solvent powers of acids, such as corundum, Al_2O_3, spinel, $MgAl_2O_4$, chromite, $FeCr_2O_4$, rutile, TiO_2, cassiterite, SnO_2, quartz, SiO_2, etc.

REAGENTS SOMETIMES USED FOR WET TESTS

31. The following list contains the reagents, solutions of which are sometimes used for wet tests:

Acetic acid, $HC_2H_3O_2$
Ammonium hydrate or ammonia, NH_4OH
Ammonium chloride, NH_4Cl
Ammonium sulphocyanide, NH_4CNS
Ammonium sulphide, $(NH_4)_2S$
Ammonium molybdate, $(NH_4)_2MoO_4$
Ammonium carbonate, $(NH_4)_2CO_3$
Ammonium oxalate, $(NH_4)_2C_2O_4$, $2H_2O$
Antimony trioxide, Sb_2O_3
Antimony pentoxide, Sb_2O_5
Aqua regia 1 part HNO_3 + 3 parts HCl
Barium chloride, $BaCl_2.2H_2O$
Barium hydroxide, $Ba(OH)_2$
Copper sulphate, $CuSO_4$
Copper, Cu
Cyanide of potassium, KCN
Calcium chloride, $CaCl_2$
Citric acid, $H_3C_6H_5O_7.H_2O$
Ferrous oxide, FeO
Ferric oxide, Fe_2O_3
Ferrous sulphate, Fe_2SO_4
Gold trichloride or auric chloride, $AuCl_3$
Hydrochloric acid, HCl
Hydrogen peroxide, H_2O_2
Hydrogen sulphide, H_2S
Iron, Fe
Litharge, lead oxide, PbO
Lead peroxide, PbO_2
Manganese dioxide, MnO_2
Magnesia mixture = $MgSO_4$ 1 gm., NH_4Cl 1 gm., and NH_4OH 4 cubic centimeters + 8 cubic centimeters H_2O. Dissolve thoroughly.
Molybdate solution = 1 gm. MoO_3 dissolved in 4 cubic centimeters NH_4OH, and poured into 15 cubic centimeters HNO_3 (G 1.2)
Microcosmic salt, $HNaNH_4PO_4.4H_2O$, phosphorous salt, or hydrogen sodium ammonium phosphate
Magnesium sulphate, $MgSO_4$
Mercuric chloride, $HgCl_2$
Mercurous chloride, $HgCl$
Neutral oxalate of potassium, $K_2C_2O_4$
Nitric acid, HNO_3
Phosphorous salt = microcosmic salt
Potassium iodide, KI
Potassium hydroxide, KOH
Potassium ferrocyanide, $K_4Fe(CN)_6$
Potassium ferricyanide, $K_6Fe_2(CN)_{12}$
Potassium chlorate, $KClO_3$
Potassium oxalate (neutral), $K_2C_2O_4$
Platinic chloride, $PtCl_4$
Potassium acid sulphate, $KHSO_4$
Sodium acetate, $NaC_2H_3O_2$
Sodium hydroxide, $NaOH$
Sodium carbonate, Na_2CO_3
Sodium chlorate, $NaClO_3$
Sodium nitrate, $NaNO_3$
Sodium chloride, $NaCl$
Silver nitrate, $AgNO_3$
Stannous chloride, $SnCl_2.2H_2O$
Stannic oxide, SnO_2
Sulphuric acid, H_2SO_4
Salt of phosphorus, $S.Ph.$ = microcosmic salt
Tartaric acid, $H_2C_4H_4O_6$
Zinc, Zn

APPARATUS

THE BLOWPIPE

32. The **blowpipe** has been employed a very long time for producing an intense heat, and has been used by such eminent men as Gahn and Berzelius in the determination of minerals and in the preliminary examination of substances before analyzing them quantitatively.

The most improved form is shown in Fig. 1. It consists of the mouthpiece *1*, made of hard rubber which is pressed against the lips, and is so large as not to tire the operator; the tube *2*, which fits by a ground joint into the moisture reservoir *3*; and the tip holder *4*, fitting by a ground joint into the reservoir; the tip is a small disk of platinum foil, pierced in the center by a very fine hole and soldered in the free end of *4*. Some blowpipes have detachable conical tips of platinum, fitting into the tip holder with ground joints; these are considerably more expensive than the form described, and no better; besides the tips are small and apt to get lost. A plain brass blowpipe of the form illustrated in Fig. 1 (the Plattner pattern) costs about $1.50. The pipe can be taken to pieces for packing.

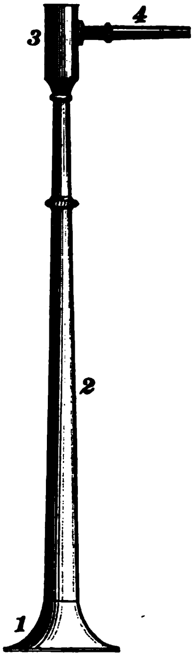


FIG. 1

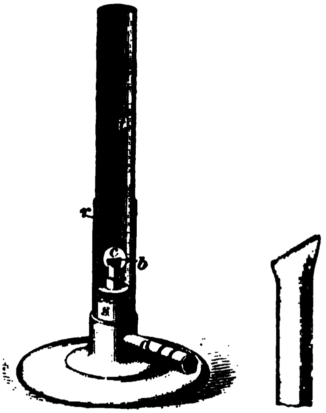
33. The Blast.—The success of the blowpipe as a means of making qualitative analyses depends on its proper manipulation. It is necessary that the operator be able at will to produce an oxidizing or reducing flame for an indefinite period of time. Considerable practice is usually necessary to attain proficiency in this, and no determinations should be undertaken until a fair degree of skill in blowing has been acquired.

The blowpipe may be held in any convenient position, usually between the index finger and the thumb, as a pen or pencil, with the arms resting on the edge of the table. The operator should choose any position satisfactory to himself.

In order to blow a steady and continuous blast, the mouthpiece of the blowpipe should be pressed firmly against the lips and the cheeks distended with air. The proper pressure is obtained by contracting the cheek muscles and not by blowing directly from the lungs. Breathing should be continued through the nose. As soon as the cheeks are nearly empty they are filled again from the lungs without interrupting the blast. In order that these operations may be performed properly the tongue should be drawn back so as to close the connection between the throat and the mouth. Care should be taken not to blow too hard. A gentle blast is all that is required.

BLOWPIPE LAMPS AND FUELS

34. Bunsen Burner.—The most convenient fuel for blowpipe operations is illuminating gas, and the burner best suited for the purpose is the Bunsen burner shown in section, Fig. 2 (*a*), with a flattened removable tip shown in Fig. 2 (*b*) as a cap piece to flatten the flame. There are various forms of these burners, the essential feature being the mixture of air with the gas before combustion, but the one shown is the most commonly used.



(*a*) (*b*)

FIG. 2

The neck *a* is connected to the gas fixture by rubber tubing. The tube *t* screws on to the body of the lamp and the gas flows up into it through a small tube, or tip, *b*, which is flattened at the top so that the gas issues from a mere slit about ½ inch long. Near the bottom of the tube *t* are two holes *c*, and there are corresponding holes in a short sleeve *s*, around the base of *t*. A small guard ring *r* keeps the sleeve *s* in position. By turning the sleeve, the quantity of air passing into *t* and mixing with the gas can be regulated. When the openings in the sleeve are between the openings in the tube, the blank spaces in the sleeve cover the openings in the tube and exclude all air, and the gas burns at the top of the tube *t* with the ordinary yellow, luminous flame; but if the sleeve be turned a little, the openings in the tube will be partly uncovered and air will rush in and mix with the gas, the flame will then become hotter and less luminous; and by opening the air holes the proper amount a clear, blue, non-luminous flame is obtained, which is very hot. If there is very little dust in the air, this flame can sometimes be gotten so clear as to be invisible against a dark background. If too much air is admitted, it is apt to blow the flame out, or off the burner. This colorless gas flame is very convenient for making flame tests. For blowpiping, however, a yellow flame about 1½ inches high is used, the blowpipe furnishing the necessary oxygen for perfect combustion.

In some forms of burners the regulating sleeve is not provided, and in order to get a yellow flame a second tube, whose outside diameter corresponds to the bore of the tube *t*, is slipped inside of *t*, shutting off the air. By flattening this tube at the top into a narrow slit, and cutting it at a slight angle, lengthwise of the slit, instead of horizontally, a flat flame like that of an oil lamp is obtained. Flattened tips, Fig. 2 (*b*), are also made to set on the top of the ordinary Bunsen burners to get a flat flame for blowpiping, and specially designed blowpipe burners with flat-tipped tubes are also made, as they afford a much better flame than straight Bunsen burners.

35. Oil and Spirit Lamps, Etc.—The oil and spirit lamps for blowpiping are of various patterns. They are made of both metal and glass, and with single and double wicks. The oils used in blowpipe lamps should be rich in carbon. Kerosene, refined rapeseed oil, olive oils, and mixtures of alcohol and benzene are variously used in lamps, but none of these is as satisfactory as illuminating gas, with a Bunsen burner.

Spirit lamps can be used for some blowpipe tests, but alcohol is comparatively poor in carbon, making it almost impossible to obtain a strong reducing flame. Common wood alcohol makes a good fuel, but does not give a good reducing flame. If this is mixed with benzole, or, as it is commonly called, benzene, C_6H_6, in the proportion of ten parts benzole and 90 parts alcohol, the flame will contain a greater per cent. of carbon and become a good reducing flame. The *ordinary benzene* used for cleaning purposes is simply a gasolene and *is too volatile for this work.*

Candles are sometimes used for blowpiping when no better flame is obtainable, but they are rather unsatisfactory, as the water in the tallow or wax cools the flame and makes it sooty.

THE FLAME

36. An ordinary luminous flame, like the flame of a candle, lamp, or gas burner, consists of three parts: an inner zone, just above the wick or burner, of gas or volatilized oil or tallow that has not yet caught fire; immediately outside of this is a zone of burning gas, rendered yellow and luminous by innumerable minute particles of incandescent carbon, resulting from the decomposition of some of the hydrocarbons under the influence of heat. This zone is the luminous portion of the flame; and outside of this again an invisible envelope of carbon dioxide gas and water vapor, H_2O—the products of the complete combustion of the hydrocarbons of the fuel.

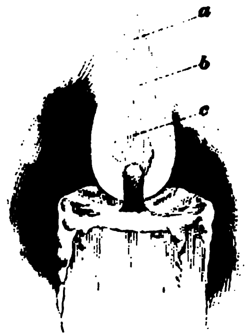


FIG. 3

The flame of a candle, Fig. 3, for instance, is a typical luminous flame. The inmost cone *c* consists of volatilized wax or tallow not yet ignited, and is blue and transparent; the middle cone *b* is the luminous portion of the flame, and outside of *b* is a third cone *a*, of a faint blue color and hardly visible, consisting almost entirely of carbon dioxide, gas, and water vapor.

37. Reducing Flame.—If the tip of the blowpipe is held about ⅛ inch above the top of the wick or burner of a blowpipe lamp, and just outside of the flame, as shown in Fig. 4, and a strong, steady blast blown, the flame is thrown into a horizontal cone. The amount of air used should be just sufficient to keep a steady, horizontal flame, free from soot, but still yellow. The entire flame will be diminished in size, but the temperature will be greatly increased, and if a reducible substance is held just inside of the tip of the yellow cone *b* it will be rapidly deoxidized or reduced. This reducing action of the flame gives it the name of **reducing flame** (R. F.). It is due to the partially burned gas and incandescent carbon of the luminous portion of the flame, which seek to oxidize themselves at the expense of any substance heated in the flame. The reaction of the flame on the mineral cuprite, Cu_2O, may be taken as an example of this. The reaction between the mineral and incandescent carbon is

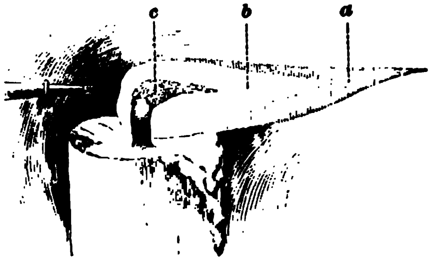


FIG. 4

$$Cu_2O + C = 2Cu + CO$$

a reduction of the cuprite to metallic copper, and a partial oxidation of the carbon; and the reaction between the mineral and the partially oxidized carbon (CO—carbon monoxide) of the flame is

$$Cu_2O + CO = 2Cu + CO_2$$

the carbon monoxide, CO, oxidizing, at the expense of the cuprite, to carbon dioxide, CO_2, the highest oxide of carbon. Sulphates are similarly reduced to sulphides, and carbonates first to oxides and then to metals.

NOTE.—If the student wishes to test the reducing flame, it can be done as follows: Place a small piece of metallic tin on charcoal and melt it with the reducing flame. As long as a pure reducing flame is blown the metal will be bright. But if it comes into the oxidizing flame a white coat of the oxide will be formed. The student should practice until he can blow a pure reducing flame.

38. Oxidizing Flame.—If the tip of the blowpipe be introduced into the flame, as shown in Fig. 5, and a strong, steady current of air be blown, the flame will be elongated into a narrow cone; the luminous portion, if sufficient air is supplied, will disappear entirely, the air from the pipe affecting the combustion of the volatilized tallow at *c* in the same way as the air through the ports of a Bunsen burner affects that of the gas. The mixture of gas and air burns with a pale-blue, non-luminous flame, to carbon monoxide, carbon dioxide, and water vapor. The outside cone *a*, in which all the carbon has burned to carbon dioxide, is unaltered. This flame is called the **oxidizing flame** (O. F.), and a substance held at the tip of the outer cone, where the air can get at it, but away from any possible reducing action of the carbon monoxide in the cone *b*, will be rapidly oxidized.

FIG. 5

The oxidizing flame is also used for flame tests, on account of being colorless, and for fusing, as it is the hottest flame obtainable with the blowpipe. The hottest point of the flame is just beyond the tip of the inside cone *b*.

NOTE.—To test the oxidizing flame the student can prepare a borax bead and add a little manganese mineral to the same. As long as the bead is kept in the oxidizing flame it will remain violet when hot and reddish-violet when cold. But the reducing flame will clear the bead and render it colorless both when hot and when cold.

SUPPORTS

39. Charcoal.—The materials to be examined before the blowpipe are supported by certain substances that are either infusible or are capable of withstanding a high heat without appreciably changing their form.

For roasting, obtaining coats, reducing metals, and making sulphur tests, **charcoal** is the support used. It is made from wood that gives a dense coal with very little ash, and can be bought in specially prepared blocks or sticks, of convenient size for blowpiping, for 50 cents a dozen, and in this form is much more satisfactory than lump charcoal. Artificial charcoal, made of charcoal dust compressed into sticks, is also used. If the artificial charcoal gets damp, it is liable to explode with considerable violence on heating, from the impossibility of the steam escaping fast enough; if such charcoal is slowly dried out for several hours over a stove, it will no longer cause trouble. A small hole is bored with a knife blade into the charcoal, Fig. 6, to hold the assay, which is moistened if it tends to blow away. Old coats on the coal are scraped off with a knife before reusing.

FIG. 6

40. Platinum Wire.—For holding the borax beads, **platinum wire**—No. 27 (or jeweler's hole 12¼)—is used, as platinum withstands the high heat and is unaffected by the reagents or flame. Pieces about 2 or 3 inches long are used, held, preferably, in special wire holders that are made for the purpose (costing about one dollar), or else one end is fused into a short piece of glass tubing for a handle, or held in the forceps. To make a bead, the wire is heated and dipped into the flux.

41. Platinum Foil.—For testing for manganese and chromium, a small piece of **platinum foil** is employed. Care must be taken not to fuse metals like lead, zinc, tin, nickel, copper, or silver on it, nor should compounds of these metals be treated on platinum foil in the R. F., as the metals reduce and form a fusible alloy with the platinum.

42. Forceps.—For testing the fusibility of minerals, the **platinum-pointed goose-neck forceps** shown in Fig. 7 are used; they have also pointed steel tips at the other end that will be found very convenient. Such forceps cost about $2.25 a pair.

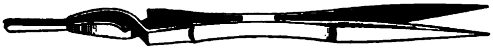


FIG. 7

FIG. 8

For trimming the flame and for rough work, the iron forceps shown in Fig. 8 are used; they cost only 10 or 15 cents.

43. Glass Tubes.—*Open tubes* of hard glass, free from lead, from $\frac{1}{16}$ to $\frac{1}{4}$ inch inside diameter, and from 4 to 6 inches long and open at both ends, are used in the examination of substances to be ignited in a current of air. The tube is sometimes bent slightly an inch or two from one end, Fig. 9, to keep the body *a*, under examination, which is placed in the bend, from falling out. Usually the material to be tested is pulverized, inserted by means of a bent paper, and then pushed down with a match or piece of paper rolled up for the purpose.

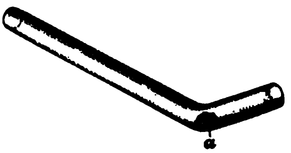


FIG. 9

Closed tubes are used for the ignition of bodies in a limited supply of air. They are made of the smaller sizes of tubing, $\frac{1}{8}$ to $\frac{3}{16}$ inch inside diameter, and closed at one end. They are usually made by heating in the middle a tube of twice the desired length, turning it slowly in the flame so that it will be uniformly heated all the way around, and when it is soft and pasty, pulling it out at both ends, into two closed tubes. The filament of glass on the bottom of each tube can be melted up into the tube by directing the flame on it for a moment, giving a smooth bottom. Small lumps of material are better suited for closed-tube tests than powder.

A clean tube should be used at each new operation. Tubes may sometimes be cleaned by swabbing with soft paper wrapped around a wire.

44. Glass matrasses are used for testing for acids by fusion with potassium-acid sulphate, etc., and are also frequently used for the same purposes as closed tubes. They are of the form shown in Fig. 10—practically only a closed tube with the closed end blown into a bulb. An ordinary, straight, closed tube, about 4 inches long and $\frac{1}{4}$ inch inside diameter, is a satisfactory substitute for a matrass, or the student can blow a bulb on the end of such a tube and have a bulb tube that will answer his purpose fully as well as the matrasses he might buy. For holding matrasses, special wooden handles are made, but a strip of paper, folded lengthwise several times and held around the neck of the matrass, with the ends serving as a handle, will answer the purpose.


FIG. 10

45. Test tubes are used in making wet tests, boiling in acids, etc. They are straight glass tubes, closed at one end and with a lip on the open end. They are made of thin, hard glass, that will stand considerable heat without cracking. A test-tube rack, in which the tubes can be stood upright, is also necessary. A holder, for holding tubes while heating, is convenient, but a paper holder will answer.

ACCESSORY APPARATUS

46. Mortars.—A small agate **mortar** and **pestle** are used for reducing materials to a very fine powder. The substance should be powdered by grinding, and never pounded in this mortar, as the mortar is liable to be damaged.

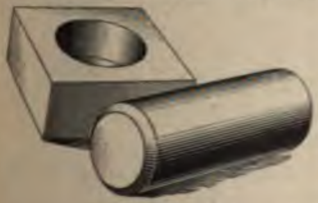


FIG. 11

A diamond mortar and pestle, made of the very best tool steel and very hard, are used for crushing minerals and for flattening beads. One form is shown in Fig. 11. The bottom of the mortar is used as an anvil, while the mortar and pestle are used for crushing hard and brittle minerals, as they prevent the loss of pieces by flying out. Such a combined anvil and mortar cost from two to four dollars.

47. Hammer. — For knocking chips off of minerals, flattening beads, stamping cupels, etc., a small **hammer** is necessary. Any small, square-headed hammer, with sharp corners and made of good steel, will do.

48. Cutting pliers are useful in detaching fragments from mineral specimens.

49. File.—A small three-edged **file** is necessary for cutting glass tubes.

50. Cupel Mold and Stand.—For making the cupellation assay, special iron or steel molds, (*a*), (*a*), Fig. 12, are used. After filling these loosely with finely ground bone ash, moistened with a little water in which a little carbonate of soda has been dissolved, the die (*b*) is placed on top, and then given two or three sharp blows with a hammer, producing a nice, smooth cupel. Cupels should be thoroughly dried before using. The mold with its cupel is set on a stand (*c*) with a wooden base while cupelling. After the cupellation is completed, the old, lead-soaked bone ash is scraped out, the mold is refilled with fresh bone ash, and a new cupel is struck. The holder, die, and set of two molds cost about $1.50.

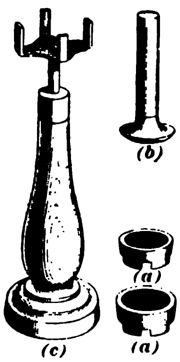


FIG. 12

51. Magnifying Glass.—An indispensable adjunct to the blowpipe outfit is a good **magnifying glass**, and the most serviceable kind for this purpose is the pocket type shown in Fig. 13, which has three lenses of different powers that, combined, make a very strong magnifier. It costs about 60 or 75 cents.

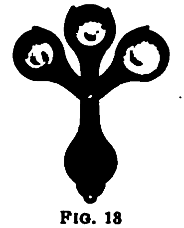


FIG. 13

52. Magnet.—For detecting magnetic metals, it is necessary to have a **magnet.** A small horseshoe or bar magnet is best, but a very convenient one for this purpose, and also for the field mineralogist, is a magnetized blade of a pocket knife, which is easily made by stroking the blade a few times, from handle to point, with a strong magnet, or holding the point against one of the poles of an electric dynamo.

53. Watch glasses and **porcelain capsules** are used for testing the solubility of minerals, and are supported on rings carried by the lamp rod, or else on a wire tripod. The capsules are better than watch glasses, as they do not crack so readily in heating. The substance should be finely ground, and should be stirred with a glass rod while heating. The acid should be completely driven off, as sometimes it cannot be told whether the substance has been affected by the acid until it has been evaporated and redissolved in water.

54. Streak Plate.—A small plate of unglazed porcelain is very convenient for obtaining the streak of minerals. These plates are 2¼ by 3¼ inches and cost 35 cents.

EXAMINATION OF A SUBSTANCE BEFORE THE BLOWPIPE

55. Plattner has recommended the following order of examination:

(*a*) *Examination Without Reagents:* (1) Heating in a small matrass or in a closed tube, to observe whether the substance is hydrous or anhydrous; whether it gives off volatile products; whether it decrepitates, or is phosphorescent, or changes color, etc. (2) Heating in an open tube, to observe whether any constituent is present that oxidizes on ignition in a current of air; and if vapors are given off, attention should be paid to their odor and to the sublimates they form on the inner surface of the tube, etc. (3) Heating on charcoal, to observe the characteristic alterations that substances undergo in both the oxidizing and reducing flames; whether metallic constituents are present that volatilize and form coats on the coal; and to observe the odor after a short exposure to heat, etc. (4) Heating in platinum forceps, to test the fusibility, and to observe the colorations of the flame, etc.

(*b*) *Examination With the Aid of Reagents:* (1) Treatment with a weak solution of nitrate of cobalt of infusible or nearly infusible substances of a light color, to observe what color is imparted to them. (2) Fusion with borax, to observe the colors imparted to the bead, etc. (3) Fusion with salt of phosphorus, to observe the colors imparted to the bead, etc. (4) Treatment with carbonate of soda on charcoal, to effect the reduction of any metallic oxides present, which can thus be more easily accomplished than by the use of the reducing flame alone.

In all these operations the smallest possible amount of the substance to be examined, consistent with the success of the reactions, should be used. The substance should, in most cases, be finely powdered. The blowpipe lamp should be set on a piece of stout wrapping paper, or glazed paper, if convenient, so that the assay may not be lost if, through carelessness, it is allowed to fall. The operations in blowpiping should be conducted in the daytime and in a good light if possible, if not the cold beads should be kept and examined in daylight.

The closest observation will be found necessary for the detection of the various reactions, and the student is advised to begin with simple substances whose exact composition is known, so that he may fix in his mind their characteristic behavior when treated with and without reagents.

EXAMINATION WITHOUT REAGENTS

HEATING IN A CLOSED TUBE

56. The substance in a finely powdered state is placed in the bottom of a tube sealed at one end, care being taken that none of it adheres to the inner surface of the tube. It may be introduced by placing it first in a paper trough, holding the tube horizontal, then pushing the trough in the tube clear to the bottom, and finally bringing the tube to a vertical position and carefully withdrawing the trough. The tube is now held in a slightly inclined position over the flame and heated, gently at first, and then, if necessary, more intensely. The successive phenomena are closely observed and noted; thus:

1. The substance decrepitates, as fluorite, barite, etc.
2. The substance is phosphorescent, as fluorite, apatite, etc.
3. The substance changes color, and nothing volatilizes except, perhaps, a little water, as zincite and cerussite, which turn yellow, and malachite and siderite, which turn black.
4. The substance fuses, as stibnite, etc.

5. The substance gives off oxygen, as psilomelane; told by placing a bit of charcoal in the tube, heating it first and then heating the assay, whereupon the charcoal will glow brightly.

6. The substance yields water, which condenses in the upper and cooler portions of the tube, as limonite, etc.

7. The residue is magnetic, as in the case of siderite, $FeCO_3$, pyrite, FeS_2, etc.

8. The substance gives sublimates which condense on the cold part of the tube.

Sulphur.—A sublimate, dark yellow to reddish-brown while warm, pure sulphur-yellow when cold; this indicates the presence of sulphur either originally free or in combination as a sulphide, as in the case of metallic sulphides, like pyrite, FeS_2, and chalcopyrite, $CuFeS_2$.

Arsenic.—A sublimate, dark brownish-red to almost black while warm, orange-red or reddish-yellow to red when cold; this indicates the presence of sulphide of arsenic, as in the case of realgar, AsS, and orpiment, As_2S_3, or in combinations of metallic sulphides and arsenides, like arsenopyrite, $FeS_2 + FeAs_2$, or $FeAsS$. A sublimate of a black, brilliant luster, having a garlic odor; this indicates metallic arsenic, as in the case of native arsenic, arsenious and arsenic oxides, and various arsenides. The test may be made very delicate by placing a splinter of charcoal in the tube above the assay, and first heating this red hot and then heating the assay. The volatilized arsenious oxide will be reduced in passing over the glowing carbon, and will deposit a black mirror of metallic arsenic just above the charcoal. This test will distinguish arsenic when combined with antimony, as the latter gives no mirror under these circumstances.

Antimony.—A sublimate when the substance is strongly heated, condensing just above the assay, black when hot, cherry-red to brownish-red when cold; this indicates the presence of sulphide of antimony, as in the case of stibnite, Sb_2S_3, or of compound sulphides of antimony and some other metal or metals, like pyrargyrite or ruby silver ore, Ag_3SbS_3, or $3Ag_2S + Sb_2S_3$.

Mercury.— A sublimate, dull black when cold, which becomes red when rubbed with a splinter of wood; this indicates the presence of sulphide of mercury, as in cinnabar, HgS, or where other metallic sulphides are combined with sulphide of mercury, as in mercuriferous tetrahedrite. A sublimate of a lustrous gray color, consisting of metallic globules (use a lens) that can be rubbed together with a splinter; this indicates metallic mercury, as in case of amalgams.

Selenium.—A sublimate of a dark-red to an almost black color, having the odor of decaying horseradish; this indicates the presence of selenium, as in the case of various selenides.

Tellurium.—A sublimate of metallic luster that condenses in small drops in the upper end of the tube; this indicates tellurium, as in the case of various tellurides.

(The reactions in the closed tube for non-volatile metallic sulphides and those that contain a low proportion of sulphur, for non-volatile arsenides and those containing only 1 atom of arsenic for 2 atoms of the metal, and also for tellurides and antimonides, are very uncertain, and sometimes there are none at all.)

HEATING IN THE OPEN TUBE

57. In the open tube the substance is heated in a current of air, and hence is subjected to an oxidizing or roasting action; whereas in the closed tube the substance was heated in a very limited supply of air and volatilized without oxidation. This constitutes the difference between the two chemical reactions.

In **heating in the open tube,** care must be taken to proceed by gently heating the substance at first, and gradually increasing the heat, otherwise some substances will volatilize at once without oxidation, and will give reactions similar to those in the closed tube. Straight tubes are generally used, as they are easier cleaned, but the beginner may make a slight bend in the tube about an inch from the end, at which point the assay is to be placed. The current of air is started up through the tube by warming it just above the assay first, afterwards bringing the flame immediately under it.

When examining a substance, it is advisable to have a moistened piece of litmus paper in the top of the tube, and the effect of the vapors upon it should be noted.

The effects of the heating should be observed exactly as in the closed tube, and many of the phenomena will be found identical. Many substances that were not volatile in the closed tube, however, here become oxidized, and escape, some as gases, recognized by their characteristic odor and their action on litmus paper; others as sublimates that condense in the cool part of the tube at varying distances from the assay.

58. The following are the most important open-tube tests:

Sulphur.—Metallic sulphides and substances containing even trifling amounts of sulphur yield sulphurous anhydride, which is recognized by its sulphurous odor and by reddening moistened blue litmus paper.

Selenium.—Selenides and substances containing even small amounts of selenium yield a gaseous oxide of selenium having the characteristic odor of decaying horseradish. If there be much selenium present, a steel-gray sublimate is formed near the assay, the sublimate becoming red at a greater distance from it.

Arsenic.—Metallic arsenic and arsenides containing much arsenic yield a white crystalline sublimate of arsenious acid, which is very volatile, and hence is at quite a distance from the assay. This reaction requires only a moderate heat.

Antimony.—Most compounds of antimony yield, at first, a dense white smoke, consisting mostly of pure oxide of antimony, which passes through the whole length of the tube, partly condensing on the upper side of the tube and partly escaping. This coat is volatile and may be driven off by again heating to redness. Afterwards a white, non-volatile, infusible sublimate, which consists of a combination of oxide of antimony and antimonic acid, gathers on the lower side of the tube. This sublimate is yellowish while hot.

Tellurium.—Most compounds of tellurium yield tellurous acid, which passes through the tube and condenses into a sublimate; this sublimate can be fused into colorless drops, which solidify on cooling, distinguishing it from the corresponding antimony coat.

Mercury.—Most compounds of mercury yield a bright metallic sublimate consisting of small globules of metallic mercury, which can be rubbed into a big drop with a splinter of wood. A moderate heat is sufficient for this reaction.

Lead.—Sulphide of lead yields, in addition to sulphurous acid, a white sublimate of sulphate of lead, which condenses on the bottom of the tube.

Bismuth.—Most compounds of bismuth yield a sublimate of oxide of bismuth, which condenses near the assay, and is fusible to drops that are brown when hot and dark-yellow when cold.

Molybdenum.—Sulphide of molybdenum yields, in addition to sulphurous acid, a thin, white, crystalline sublimate, fusible to drops which are yellowish while hot and nearly colorless when cold. When the R. F. is directed upon them, they become blue, or even copper red, from reduction. High heating is necessary for this reaction.

HEATING ON CHARCOAL

59. A fragment of the substance to be examined is placed in a shallow cavity in the charcoal and the flame directed downwards upon it. Its behavior in both flames is observed. If the mineral decrepitates, it will be found necessary to powder it and make it into a paste with water; this is placed on the charcoal and heated, slightly at first, and then more intensely. If any difficulty is encountered, when infusible and non-volatile substances are treated, in keeping the assay in its place sufficiently long to observe its behavior fully, it will be found advantageous to heat the fragment to redness and then touch it to a grain of borax.

The borax attaches itself to the fragment, and both are put on the charcoal and heated. The borax melts and adheres to the charcoal, keeping the assay in place.

The characteristic phenomena to be observed are the odor after short exposure to the heat, the fusibility of the substance, the character of the residue, and the sublimates, or coats, formed at a distance from the assay. The color of the coats must be closely observed, both while hot and when cold; it should be noted at what distance from the assay they condense, whether they disappear when either O. F. or R. F. is directed against them, and how they color the flame.

60. The following are the most important elements giving characteristic reactions on charcoal:

Selenium melts easily; yields brown fumes in both O. F. and R. F., which deposit near the assay as a steel-gray coat with a feeble metallic luster, and at a somewhat greater distance as a dark-gray, dull coat. The coat is volatile in both flames, and when treated with the R. F., it disappears with a fine azure-blue flame. The odor of decaying horseradish is strongly perceptible throughout the entire operation.

Tellurium melts easily; volatilizes in fumes in both flames; and coats the coal at no great distance from the assay. The coat is white, with a red or dark-yellow border, and is volatile in both flames. Under the R. F. the coat disappears with a green flame. In the presence of selenium, the flame is bluish-green.

Arsenic volatilizes without fusing, and coats the coal in both flames. The coat is white, appearing grayish when thin, and forms at a distance from the assay. It can be easily driven off by simply warming with either flame, and if rapidly treated in the R. F., it disappears, coloring the flame a pale blue. During the volatilization of arsenic in the R. F., a strong garlic odor is evolved.

Antimony melts easily, and forms a coat with both flames. The coat is white, bluish when in thin layers, and is not as distant from the assay as the arsenic coat. It is volatile in both flames, and disappears when treated with the R. F., tinging the flame pale green.

Lead melts easily, coating the coal with oxide in both flames. The coat is dark lemon-yellow while warm, sulphur-yellow when cold, and bluish-white when in thin layers. The coat is volatile in both flames, and disappears in the R. F., coloring the flame azure blue.

Bismuth melts easily, coating the coal with oxide in both flames. The coat is dark orange-yellow while hot and lemon-yellow when cold, being yellowish white in thin layers. It is volatile in both flames, but does not color the reducing flame.

Cadmium volatilizes very easily, and burns in the O. F. with a dark yellow flame and brown fumes that coat the coal rather near the assay. Next to the assay the coat is thick, crystalline, and of a very dark, almost black, color; farther off it is reddish-brown; and when in thin layers, it is of an orange-yellow color. In appearance, the coat is iridescent, like a peacock's feather. It is volatile in both flames, but gives no coloration to them.

Zinc melts easily, and burns in the O. F. with a strongly luminous, greenish-white flame, and forms a coat near the assay that is yellow while hot and white when cold. In the O. F. this coat is luminous, but not volatile. It is volatilized very slowly in the R. F.

Tin melts easily, and forms in the O. F. an oxide that covers the assay, and can be blown away. In the R. F. the metal becomes lustrous, and forms a coat that is pale yellow while warm and white when cold, and is so close to the assay that it borders upon it. It cannot be driven off by either flame.

Molybdenum is infusible. In the O. F. it gradually oxidizes and forms a coat near the assay, yellowish and sometimes crystalline while hot and white when cold. When touched for an instant with the R. F., a dark blue color is given to the coat. The flame in this case must not be too hot. In the O. F. the coat is volatile, but leaves a red stain on the coal which is not further affected.

Silver melts easily. In a powerful O. F., it gives a slight reddish-brown coat of oxide. If a little lead is present, the yellow coat of oxide of lead is formed, and then the reddish-brown silver coat is formed just outside of this. With antimony the white coat of oxide of antimony is first formed, which becomes red on continued blowing. With a little of both antimony and lead present, a copious carmine-red coat is formed after the antimony and lead are mostly volatilized.

The sulphides, chlorides, iodides, and bromides of potassium, sodium, rubidium, cæsium, and lithium give less copious white sublimates, similar to those of many of the foregoing metals, while the salts fuse and are absorbed by the coal. In every case these coats disappear before the R. F., coloring it with their characteristic colors.

TEST OF FUSIBILITY

61. Scale of Fusibility.—For arriving at the comparative or relative fusibility of minerals, the following scale, arranged by Von Kobell, is employed:

1. *Stibnite;* fuses easily in a candle flame in coarse splinters.
2. *Natrolite;* fuses in the candle flame only in fine splinters.
3. *Garnet* (the red almandite variety); fuses easily before the blowpipe in coarse splinters.
4. *Actinolite;* fuses with slight difficulty B. B. in coarse splinters.
5. *Orthoclase;* fuses B. B. only in fine splinters.
6. *Serpentine;* almost infusible; rounded on the edges in very fine splinters (use a lens).
7. *Quartz;* infusible, even on thinnest edges.

In using this scale, the hottest, or oxidizing, flame should be employed, and the thinnest possible splinters of the mineral tested. The splinter should be held in the tip of the platinum-pointed forceps, which are best ground to a sharp, thin point, so as to conduct away as little heat as possible. If the substance decrepitates so that a splinter of it cannot be used, it should be ground to a powder and mixed with water into a paste. It is then spread out in a thin layer on the coal, and heated, slowly and gently at first, and finally more strongly, until the mass forms a thin, coherent plate, which can be held in the forceps and tested in a pure O. F.

The various gradations of fusibility are expressed in decimals, thus: B. B. beryl becomes clouded, and fuses at 5.5; which means that in fusibility it is midway between orthoclase and serpentine.

EXAMINATIONS WITH THE AID OF REAGENTS

COLORATION OF THE FLAME

62. Many substances give characteristic colorations to the flame. A pure O. F. that is entirely free from yellow streaks should be used. Either take a thin splinter of the mineral, as in testing for fusibility, or the powder for this test. In the latter case make a platinum wire loop and dip it into pure water or hydrochloric acid, then touch it to the powder and introduce it into the flame. Often a mere trace of mineral, such as will adhere to a dry wire, will give much better results than a larger fragment, which is difficult to get hot enough to volatilize.

The greatest care should be observed in these tests, that no foreign material adheres to the forceps or platinum wire. They should be clean, and when heated alone in the flame should give no coloration. This cleaning is effected by dipping, while hot, into hydrochloric acid, and then rinsing with distilled water. Drawing the wire through the fingers or wetting with saliva is to be avoided, and likewise too much handling of the specimen to be tested. If the specimen is to be powdered, the mortar and pestle should both be thoroughly washed before using.

Some substances when heated alone in the flame give only slight colorations, or none at all, in which case they are moistened with sulphuric acid and heated again. By this means the colorations of the flame, as in the case of phosphoric and boric acids, become evident.

EXAMINATION WITH COBALT SOLUTION

63. The **cobalt test** is applicable only to those substances that are of a light color, either before or after ignition, and are infusible, or nearly so.

If the substance will absorb the solution, a splinter or fragment of it is moistened with the solution, and then strongly ignited in the O. F. Friable substances and crystalline substances that are too dense to absorb the solution, are powdered, made into a paste with water, and spread upon the charcoal. They are then gradually heated until a coherent crust is formed, which is moistened with the solution and ignited in the O. F. The colorations imparted to the assay are then closely observed in a good light. The various coats on charcoal may likewise be tested in this way by moistening with a drop of the solution and gently igniting in the O. F.

The colors thus obtained are:

1. From magnesia, flesh-red.
2. From baryta, brownish-red.
3. From alumina and silica, blue.
4. From the oxides of zinc, green (yellowish-green); from tin (bluish-green); titanic acid (yellowish-green); antimonic acid (dirty, dark green).
5. From strontia and lime, gray.

Various other elements give more or less peculiar colorations with the cobalt solution, but only the colorations for alumina, magnesia, zinc, and tin are to be at all relied on. This test for alumina and magnesia is infallible when they are in the pure state, and also in many of their combinations. Silicates of zinc, on strong heating, give an ultramarine blue, from the silica, instead of the zinc green. The blue of alumina is not to be confounded with the blue of silica. The blue of the silica almost always appears fused on careful examination, while the blue of alumina is dull. The blue of the silica also appears only after intense ignition, and it is therefore well if, after moderate heating, the substance shows no blue, to discontinue the heating before fusion.

ROASTING

64. When borax and salt of phosphorus are fused with certain metallic oxides, they exert a powerful solvent action upon them, and highly colored glasses are formed which are exceedingly characteristic.

It is essential, in the bead tests, when the preliminary examination of the substance has shown the presence of sulphur or arsenic, that these elements be removed, as they interfere with the reactions. This is effected by **roasting,** which is conducted in the following manner:

The finely pulverized material is placed in a shallow cavity on charcoal and pressed flat with a knife blade, forming a thin layer. The assay is then treated with a feeble O. F. so that only the tip of the flame touches it. It is thus heated and kept for some time at a low, red heat, during which operation most of the sulphur is volatilized as sulphur dioxide, SO_2, and the metals are oxidized. This sulphur dioxide has a tendency to change into sulphuric oxide at the expense of the already forming metallic oxides, and these are converted into sulphates, and if arsenic be present, into arsenates. When, therefore, the odor of sulphur dioxide has disappeared, the assay is treated to a feeble R. F., which, for the most part, reduces the sulphates and arsenates thus formed, and the arsenic is more or less completely volatilized. When the arsenical odor is no longer apparent, a feeble O. F. is again used, which generally causes a slight odor of sulphur dioxide. The assay that is thus baked together, but not fused, is turned with a knife blade, and the other side treated alternately to the O. F. and R. F. in the same way. The coherent mass, after this treatment, is removed and powdered in a mortar, and since it is not entirely free from sulphates and arsenates, and, if it has not been carefully roasted, may even contain slight quantities of sulphides and arsenides, it is replaced on the charcoal, and subjected to still further roasting.

If the assay fuses, it must be removed from the coal, powdered in a mortar, and then replaced on the coal and roasted.

Substances containing selenium, tellurium, and antimony, if free from sulphur and arsenic, usually need not be roasted, since these elements do not interfere with the reactions.

FUSION WITH BORAX

65. In the O. F.—A clean platinum wire, in one end of which a small loop has been made, is heated to redness and the loop dipped in borax powder. The borax that will adhere is then heated until it fuses to a transparent, colorless bead. This bead, while still hot, is brought in contact with a very small quantity of the substance to be tested, and heated before the blowpipe in the O. F.

The phenomena attending the solution of the substance in the borax must be closely observed, whether it dissolves slowly or rapidly, quietly or with effervescence; and when the solution is effected, the color of the bead must be carefully noted while hot (not red hot, but still soft and pasty), while cooling, and when cold, as well as whether its transparency is disturbed on cooling. The bead is held before the eyes against the light. A lamp light will not do, as the colors are greatly modified, and the experiments must be conducted in the daytime.

The intensity of the colors depends on the degree of saturation of the bead. It is well at first to use the smallest possible quantities of the substances to be tested, and afterwards increase them by successive additions until a satisfactory degree of saturation is obtained. If too much of the substance has been used, and the bead is so deeply colored that it is difficult to decide what color it has, it may be flattened, while still hot or pasty, on an anvil with the butt end of the blowpipe; or a portion of the bead may be thrown off the wire by a sudden jerk, and the remaining portion diluted with more borax. If the operator is in doubt as to the color, the bead should be viewed through a lens, and compared with beads of known color. In fact, this is the only resource for those who are at all color blind.

66. In the R. F.—After the phenomena in the O. F. are carefully noted, the bead is brought into the R. F. and observed as before. The flame should be so managed that no soot is deposited upon the bead. Sometimes it is found necessary to add a little more of the substance to the assay. When metallic oxides and acids that are not easily reduced with borax, as the oxides of manganese, iron, uranium, chromium, cobalt, and titanic and tungstic acids are present, the bead may be treated on platinum wire; but when easily reducible oxides are present, as those of zinc, nickel, cadmium, lead, etc., the wire would be injured, therefore the bead must be shaken off after treatment in the O. F. on platinum, and treated in the R. F. on charcoal. After blowing 1 or 2 minutes, the bead is pinched with the forceps, and drawn out so that its color can be distinctly observed.

The reductions in the borax bead on charcoal are sometimes more easily obtained by placing in contact with the bead a piece of metallic tin, about as large as a pin head. The tin has a great affinity for oxygen and partly absorbs the oxygen from the metallic oxides in the glass, dissolving itself to a colorless bead, while the oxides in the glass are reduced and produce their characteristic colors.

67. Flaming.—The alkaline earths (oxides of barium, strontium, calcium, magnesium) and some other substances dissolve in borax and form beads that, when almost saturated, are colorless while hot and when cold, but when heated slowly and gently, especially with an intermittent reducing flame, or alternately with the O. F. and R. F., become opaque and enamel-like. This operation is called **flaming.**

Most substances that, at a certain degree of saturation, become opaque by flaming, do so without flaming when the saturation is carried a little further.

FUSION WITH SALT OF PHOSPHORUS

68. The general rules for fusion with borax are applicable to **fusion with the salt of phosphorus.** It is difficult to make a good bead with salt of phosphorus, owing to the fact that it boils violently while its water of crystallization and ammonia are passing off. It is advisable to melt salt of phosphorus on the platinum wire very gradually, using a small quantity at first and making successive additions until a good bead has been formed.

Silica can be easily recognized in this bead, since silicates are but very slightly soluble in salt of phosphorus. The silica separates from the metals with which it is combined and which are themselves dissolved in the bead, and floats about in the fused glass in the form of a white gelatinous skeleton.

The colors produced in the salt of phosphorus beads are generally about the same as those produced in borax by the same substances, but in some cases there are characteristic differences.

69. Importance of Bead Tests.—The bead tests for iron, manganese, chromium, copper, cobalt, nickel, titanium, tungsten, molybdenum, uranium, vanadium, cerium, and didymium are of themselves distinctive and characteristic of the elements, but the other bead tests are of little importance, except occasionally as confirmatory tests.

REDUCTION OF METALLIC OXIDES WITH SODA

70. Reducible Oxides.—Many oxides can be reduced to the metallic state on coal with the aid of soda, which could not be reduced without it.

The best way to conduct the experiment is to powder the substance in a mortar and mix with moistened soda. The coherent mass is then put into a cavity in the coal and treated to the R. F.

The metals that are reducible from their compounds with soda as above are gold, silver, molybdenum, tungsten, antimony, tellurium, copper, bismuth, tin, lead, zinc, indium, cadmium, nickel, cobalt, and iron. Arsenic and mercury are also reduced, but are immediately volatilized.

Neutral oxalate of potassium, $K_2C_2O_4$, or cyanide of potassium, KCN, may be advantageously substituted for soda when treating oxides that are reduced with great difficulty. The cyanide has the disadvantage of spreading over the coal and scattering the metallic particles. These fluxes are both serviceable when the reduction is conducted in a matrass.

71. Non-Reducible Oxides.—Many oxides cannot be reduced to the metallic state by soda, but form with it more or less fusible compounds. Silicon dioxide, titanium dioxide, tungsten trioxide, molybdenum trioxide, etc., form fusible compounds, and so do salts of barium and strontium. The compounds formed by barium and strontium sink into the coal. Calcium salts are decomposed, and the soda sinks into the coal, leaving the calcium oxide behind.

72. The Halogens.—A few elements that are of decided interest, as they form a very important set of compounds, are the **halogens**—bromine, chlorine, fluorine, and iodine.

Bromine.—When bromides are added to a salt of phosphorus bead that has previously been saturated with oxide of copper, and then ignited, the bead is surrounded with a beautiful halo of blue flame, inclining to green on the edges, and this continues as long as the bromine remains.

As this reaction may be confounded with those given for chlorine, another test is recommended. The substance is fused with dry potassium-acid sulphate in a glass matrass, when bromine and sulphur dioxide are liberated, and the matrass becomes filled with heavy brown fumes. The bromine is recognized by the extremely suffocating odor, or by exposing moistened starched paper to these vapors, which turn it yellow.

Chlorine.—Chlorides, like bromides, may be detected, by adding them to a salt-of-phosphorus bead previously saturated with oxide of copper, and igniting. The bead is instantly surrounded by an intense azure-blue flame without any tinge of green.

Fluorine.—Substances containing fluorine, when heated in a glass tube with potassium-acid sulphate, give off hydrofluoric acid, which etches the tube immediately above the assay, and imparts to a strip of moistened Brazil-wood paper, placed on the end of the tube, a straw-yellow color.

Iodine.—Iodides added to a salt-of-phosphorus bead, previously saturated with oxide of copper, tinge the outer flame an intense emerald-green. Like bromides, they also are decomposed by fusion with potassium-acid sulphate, free iodine being liberated, which may be distinguished by its violet color and disagreeable odor.

73. Nitrates.—When nitrates are fused in a glass tube with potassium-acid sulphate, dark reddish-yellow fumes of oxides of nitrogen are liberated. The color is best observed by looking into the tube.

74. Sulphuric Acid.—The presence of sulphates may be detected by fusing the substance with pure soda, then placing the fused assay on a silver coin and moistening with pure water. If sulphuric acid was present in the substance, it was converted in the fusion to sulphide of sodium, and this substance leaves a dark-brownish or black stain on the bright surface of the silver.

75. Water.—The presence of moisture (either hygroscopic moisture or water of crystallization) may be detected by heating the assay in a matrass or closed tube. The water given off condenses in the cooler portions of the tube.

DETERMINATION OF GOLD AND SILVER IN ORES

76. Occasionally ores are rich in gold and silver, and these metals can be determined by the blowpipe, but as a rule the ores are of comparatively low grade, and the amount that could ordinarily be treated before the blowpipe would not be sufficient for the isolation of the precious metals. On this account, one of two methods must be followed. If the ore is free milling it may be amalgamated, while if it is a concentrating ore it may be concentrated in the gold pan. In either case, the sample, which may weigh several pounds, should be crushed fine in a mortar, so as to set the valuable materials free.

77. In the **amalgamation test** the sample is placed in the gold pan with sufficient water to saturate and cover the ore. After this a small amount of mercury is added, and the material vanned or panned in such a manner as to carry the pulp around and around over the mercury, or in some cases the pulp is worked comparatively stiff and the mercury worked back and forth through the mass, either with a spatula or by hand. After the ore has been thoroughly exposed to the amalgam, the waste material or gangue is washed away and the amalgam collected.

The excess of mercury is squeezed from the amalgam by passing it through buckskin. The small piece of the amalgam so obtained can be placed on charcoal, heated before the blowpipe, thus volatilizing the mercury and leaving a small piece of the precious metals, which can be melted down to a bead or button.

78. In the **concentration test** the ore is washed as in ordinary panning, and the rich mineral collected as concentrates.

It is best to employ two pans, and to wash from one to the other, each time obtaining a small amount of concentrates, which are laid to one side. After the concentration has been carried as far as it is considered necessary, the concentrates may be dried, placed on charcoal, and any arsenic or antimony driven off by roasting them before the blowpipe. The roasted concentrates are mixed with soda and metallic lead. The soda acts as a flux in melting the minerals and the lead takes up any gold or silver they may contain. The lead button obtained in this manner must be cupelled in order to separate the lead from the gold or silver. As has already been stated, cupels are made from bone ash, but in case the prospector has neither bone ash nor a cupel mold, he may accomplish the desired results by burning a few bones in his camp fire, then pounding them to a fine powder, adding a little water, and pressing the mass into a small cupel on a block of dry wood or in a spoon or thimble. When cupelling the lead button, it must be heated with an oxidizing flame, which action results in the formation of lead oxide, part of which is absorbed by the bone ash and part of which is volatilized. When all the lead has been oxidized, the precious metals will remain as a small bead. Just before the last of the lead is driven out, the bead will appear as though it were spinning rapidly, and be covered with a thin film of oxide. At the moment the last of the oxide disappears, the bead will appear to brighten, and after this will not appear to be spinning.

79. Parting.—If it is desired to separate the gold and silver in the bead, it may be accomplished by dissolving out the silver with nitric acid (providing there is 2¼ times as much silver present as there is gold). Strong nitric acid diluted with an equal amount of water answers this purpose very well. The bead is dropped into the acid, and after the first evolution of gas ceases the acid is boiled. The acid is then poured off and a fresh supply added, and the bead once more boiled. Any gold will remain behind as black specks, or as a black skeleton of the bead. In case there is more gold than silver, it will be necessary to add some silver to the bead before it can be parted. After the silver has all been dissolved, the gold that remains should be washed with clean water (preferably distilled water) and then heated to a red heat, which will restore the ordinary yellow color to the metal. If there is enough gold present, it may be melted down into a bead before the blowpipe. If the water or the acid used gives a white precipitate with silver nitrate solution, chlorine is present, and they are not fit for parting.

QUALITATIVE TESTS FOR ELEMENTS OCCURRING IN MINERALS

80. Introduction.—With the exception of very rare elements, the qualitative tests are given in the following pages so that the student can refer to them while making mineral determinations. The elements are taken up in alphabetical order, and the common tests both by dry and wet methods described.

ALUMINUM

81. Blowpipe Tests. — With soda, **aluminum**, *Al*, swells and forms an infusible compound.

With borax or salt of phosphorus, *S. Ph.*, it gives a clear or cloudy bead that is never opaque.

With cobalt solution, a fine blue color is obtained when the mineral becomes cold. (Some phosphates, borates, and fusible silicates become blue in the absence of alumina, for instance silicates of zinc, and cobalt oxide may impart to any fused material a blue color.)

82. Wet Test.—Ammonia, when added in slight excess to an acid solution containing aluminum, precipitates gelatinous aluminum hydroxide. but other substances give gelatinous precipitates, hence collect the precipitate on filter paper, transfer some of it to a test tube, and add potassium hydroxide, which should completely dissolve the precipitate if it is aluminum hydroxide.

Basic acetate of aluminum is precipitated by the addition of sodium acetate to warm and slightly acid solutions.

Confirm wet tests by blowpipe tests.

ANTIMONY

83. Blowpipe Tests.—On charcoal in the R. F., **antimony**, *Sb*, gives a volatile white coat, bluish in thin layers, that continues to form after cessation of blast. This coat may be further tested by *S. Ph.* or flame.

With bismuth flux on plaster, a somewhat mottled peach-red coat, which may be made orange by ammonium sulphide, is obtained. On charcoal with bismuth flux, antimony gives a faint yellow or red coat.

In the open tube, a dense, white, non-volatile, amorphous sublimate is formed; the sulphide stibnite if too rapidly heated will yield spots of red.

In the closed tube, the oxide will yield a white fusible sublimate of needlelike crystals; the sulphide yields a black sublimate while hot, red when cold.

The flame should be pale yellow-green.

With *S. Ph.*, antimony dissolved in the O. F. and treated on charcoal with tin in R. F. becomes gray to black.

84. Interfering Elements.—*Arsenic*, which may be removed by gentle O. F. on coal. *Arsenic with sulphur* is removed by gently heating in closed tube. *Copper* in *S. Ph.* bead with tin in R. F. may be momentarily red but will blacken. *Lead and bismuth* retard the formation of antimony coats, but this may be overcome by intermittent blowing or by the addition of boracic acid. Confirm this coat by flame and not by *S. Ph.*

85. Wet Tests.—Hydrogen sulphide precipitates orange-red antimonous sulphide from acid solutions containing antimony. The precipitate is soluble in strong hydrochloric acid, in alkalies, and in alkaline sulphides.

Hydrogen sulphide precipitates orange antimonic sulphide from acid solutions containing antimony. The precipitate is soluble in hydrochloric acid, in alkalies, and alkaline sulphides.

To distinguish between antimonous and antimonic sulphides, add a solution of silver nitrate in the presence of potassium hydroxide or sodium hydroxide. If antimonous sulphide is present, a black precipitate will be formed that is insoluble in ammonia; on the other hand, if antimonic sulphide is present a white precipitate will be deposited on the addition of silver nitrate, and this is not soluble in ammonia.

Stibnite effervesces with HCl and when water is added gives an orange precipitate.

ARSENIC

86. Dry Tests.—On smoked plaster, a white coat of octahedral crystals is obtained from **arsenic,** As.

On charcoal, a very volatile white coat and strong garlic odor is produced. The oxide should be mixed with soda to reduce it before the garlic odor will be prominent. The sublimate will deposit at an appreciable distance from the assay.

With bismuth flux, on plaster, a reddish-orange coat forms that may be made yellow by ammonium sulphide.

In the open tube, white sublimate of octahedral crystals is obtained; too high a heat may form brown suboxide or red or yellow sulphide of arsenic.

In the closed tube one may obtain white oxide, yellow or red sulphide, or a black mirror of metal. If a piece of charcoal is placed above the assay the oxide will be reduced in passing the hot coal and an arsenical mirror will be formed. This mirror will dissolve in sodium hypochlorite solution. The flame is a pale azure-blue.

87. Interfering Elements.—*Antimony:* Heat the substance in a closed tube with soda and charcoal; treat resulting mirror in oxidizing flame for garlic odor. *Cobalt or Nickel:* Fuse in O. F. with lead and recognize arsenic by garlic odor. *Sulphur:* (*a*) Red or yellow sublimate of arsenic in closed tube. (*b*) Odor of arsenic when fused with soda on coal.

88. Wet Tests.—Hydrogen sulphide precipitates yellow arsenious sulphide from HCl solutions. This is soluble in alkalies and alkaline sulphides.

Hydrogen sulphide gas precipitates arsenic sulphide from acid solutions after heating the solution and passing the gas through it for some time.

Silver nitrate precipitates yellow silver arsenite, or reddish-brown silver arsenate soluble in dilute acids, ammonia, and ammonia salts.

Copper sulphate precipitates yellowish-green copper arsenite, $Cu_3(AsO_3)_2$, or greenish-blue copper acid arsenate, $CuHAsO_4$, soluble in ammonia, or ammonium chloride.

Ammonium magnesia mixture precipitates white ammonium magnesium arsenate, $MgNH_4AsO_4$.

BARIUM

89. Blowpipe Tests.—On charcoal with soda, **barium,** *Ba*, fuses and sinks into the coal. The flame is yellowish-green, improved by moistening with hydrochloric acid.

With borax or *S. Ph.*, clear and colorless beads that can be flamed opaque white are obtained.

With the exception of silicates and phosphates, barium minerals become alkaline upon intense ignition before the blowpipe; if then they are placed upon moistened turmeric paper they will turn it brown. Other alkaline earths also give the same reaction.

90. Wet Tests.—Alkali carbonates precipitate from barium solutions white barium carbonate soluble in hydrochloric and nitric acids.

Soluble sulphates and sulphuric acid precipitate white barium sulphate from barium solutions, which is practically insoluble in water or dilute acids.

BISMUTH

91. Dry Tests.—On charcoal in either flame, **bismuth,** *Bi*, is reduced to a brittle metal and yields a volatile coat; dark orange-yellow while hot; lemon-yellow when cold, with yellowish-white border.

With bismuth flux on plaster, a bright scarlet coat surrounded by chocolate-brown with sometimes a reddish border is obtained. The brown may be made red by ammonia.

With bismuth flux on charcoal, a bright red coat is formed, with sometimes an inner fringe of yellow.

With *S. Ph.* dissolved in O. F. and treated on coal with tin in R. F. a bismuth assay is colorless while hot, but blackish-gray and opaque when cold.

The reactions on coal are quite similar to those of lead but may be distinguished from the latter by mixing the powdered mineral with 3 or 4 times its volume of potassium iodide and sulphur, when with a small oxidizing flame a yellow coat is produced near the assay with a brilliant red at its outer edges.

92. Interfering Elements. — *Antimony:* Treat the mineral on coal with boracic acid, and the resulting slag on plaster with bismuth flux. *Lead:* Dissolve coat in *S. Ph.*

93. Wet Tests. — Hydrogen sulphide or ammonium sulphide precipitates brownish-black bismuth sulphide insoluble in dilute acids but soluble in strong nitric acid.

Water precipitates white bismuth oxychloride from a solution of bismuth chloride. This may be collected on a filter and tested with bismuth flux. It is soluble in HCl and HNO_3.

Stannous chloride in the presence of sodium or potassium hydroxides will precipitate black bismuth oxide from solutions. Confirm these tests by the blowpipe.

BORON

94. Dry Tests.—All borates intumesce and fuse to a bead. A yellowish-green flame is obtained from boron, *B*, minerals that may be intensified by moistening with sulphuric acid, or by mixing to a paste with sulphuric acid and ammonium fluoride. Boracic acid flux (4½ parts of potassium-acid sulphate and 1 part calcium fluoride) made into a paste with the mineral will intensify the flame.

95. Turmeric Paper Tests.—If this paper is moistened with a dilute HCl solution containing boron and then dried at 212° F., it assumes a reddish-brown color, which is changed to inky black by moistening with ammonia.

96. Wet Tests.—Barium chloride and calcium chloride precipitate white barium borate and calcium borate from solutions.

Silver nitrate precipitates white silver borate.

BROMINE

97. Blowpipe Tests. — With *S. Ph.* saturated with cupric oxide, CuO, treated at the tip of the blue flame, the bead will be surrounded by a greenish-blue flame if **bromine,** *Br*, is present.

In matrass with acid potassium sulphate, $KHSO_4$, a brown choking vapor is evolved.

98. Wet Tests. — Bromine sometimes occurs in salt brine, and after the salt has been crystallized out, the bittern, as the mother liquor is called, contains magnesium bromide. Bromine salts are mostly soluble in water.

Silver nitrate precipitates yellowish-white silver bromide.

Silver bromide when heated in a closed tube with galena yields a sublimate of lead bromide, sulphur-yellow when hot, and white when cold.

99. Interfering Elements.—*Silver:* The bromide melts in $KHSO_4$ and forms a blood-red globule, which cools yellow and becomes green in the sunlight.

CADMIUM

100. Dry Tests.—On charcoal in the R. F., **cadmium,** Cd, produces a dark-brown coat, greenish-yellow in thin layers. Beyond the coat, at first part of operation, the coal has a variegated appearance.

On smoked plaster with bismuth flux, a white coat is obtained that may be made orange by ammonium sulphide.

Borax or *S. Ph.* O. F. gives a clear yellow bead while hot, colorless when cold, but the bead can be flamed milk-white. The hot bead touched to thiosulphate, $Na_2S_2O_3$, becomes yellow. R. F. becomes slowly colorless.

101. Interfering Elements.—*Lead, Zinc, Bismuth:* Collect the coat of the cadmium mineral, mix with charcoal dust, and heat gently in a closed tube. Cadmium will yield either a reddish-brown ring or a metallic mirror. Before collecting the coat, treat it with O. F. to remove arsenic.

102. Wet Tests.—Dissolve the mineral in nitric acid, add a little sulphuric acid, and heat until the dark-brown nitric fumes disappear. Dilute with water.

Hydrogen sulphide will precipitate yellow cadmium sulphide that is insoluble in dilute acids, alkalies, alkaline sulphides, or cyanides, but soluble in strong hot HCl, HNO_3, and H_2SO_4. The precipitate mixed with soda and heated on charcoal will give the cadmium coat for confirmation.

Zinc will precipitate gray cadmium from acid and ammoniacal solutions.

Potassium hydroxide and sodium hydroxide will precipitate cadmium hydroxide, $Cd(OH)_2$, insoluble in excess; while ammonia gives a similar white precipitate that is soluble in excess.

CALCIUM

103. Dry Tests.—On charcoal with soda; **Calcium carbonate,** $CaCO_3$, is insoluble and not absorbed by the coal. The flame is yellowish-red and is increased in intensity by moistening with HCl. Borax or *S. Ph.* gives a clear and colorless bead that can be flamed opaque.

Calcium minerals, with the exception of silicates, phosphates, and borates, become alkaline upon ignition. If then placed on moistened turmeric paper, they will give an alkaline reaction. Other alkaline earths will give a similar reaction.

104. Wet Tests. — *Sulphuric acid* precipitates white calcium sulphate soluble in a concentrated solution of ammonium sulphate, thus distinguishing it from barium and strontium.

Alkaline arsenites precipitate calcium acid arsenites soluble in acids and ammonia water. Barium, strontium, and magnesium give this precipitate only in concentrated solutions when ammonium salts must be absent. This precipitate may be confirmed by the blowpipe test.

CARBON DIOXIDE

105. Heat a carbonate with dilute nitric acid, and **carbon dioxide,** CO_2, will be given off with effervescence. Pass the gas through lime water. A white precipitate indicates carbon dioxide. After borax or *S. Ph.* has been fused to a clear bead, the addition of a carbonate will cause effervescence during further fusion.

CHLORINE

106. Dry Tests.—Chlorine minerals treated with *S. Ph.* saturated with cupric oxide, CuO, and the bead then placed in the tip of the blue-lamp flame, will give it an intense azure blue color.

To test on charcoal, grind the mineral with cupric oxide, CuO, and with a drop of H_2SO_4 spread the paste on coal, dry gently in O. F., and treat with blue flame, which will be colored greenish-blue, then azure-blue.

Mix with the mineral 4 times its volume of potassium-acid sulphate and a little manganese dioxide; heat the mixture in a small test tube, when chlorine gas will be given off, which will bleach litmus paper. Silver chloride or a silicate should be fused with sodium carbonate and then treated.

107. Wet Tests.—Silver chloride is quite insoluble in water and dilute nitric acid. Dissolve a chloride in dilute HNO_3, add silver nitrate, and white silver chloride will be precipitated. This precipitate is soluble in ammonium hydrate and may be reprecipitated by neutralizing with nitric acid.

CHROMIUM

108. Dry Tests.—With borax or *S. Ph.* in the O. F., **chromium,** *Cr*, gives a reddish bead hot, fine yellow-green to green when cold.

With soda in the O. F., a dark-yellow bead when hot is obtained, opaque and light-yellow when cold.

With borax in the R. F., a green bead is given when hot and cold.

With soda in the R. F., an opaque and yellowish-green bead is given when cold.

With *S. Ph.* in the R. F., the bead is red when hot and green when cold.

109. Interfering Elements.—Manganese with soda bead in O. F. will be bright yellowish-green.

110. Wet Tests.—Ammonia precipitates bluish-green chromium hydroxide slightly soluble in excess of ammonia.

From solutions of chromium trioxide, lead salts precipitate yellow lead chromate soluble in nitric acid and insoluble in acetic acid. It is difficultly soluble in potassium hydroxide.

A very delicate test for chromium as chromium trioxide is by means of hydrogen peroxide and ether, which gives a fine blue color.

COBALT

111. Dry Tests.—On charcoal in the R. F., the oxide of **cobalt**, *Co*, reduces to a magnetic substance. This dissolved in HCl will be rose-red, but on evaporation will be blue.

With borax or *S. Ph.*, the bead will be blue in either flame.

112. Interfering Elements.—*Arsenic:* Roast and scorify with successive additions of borax. The bead may have colors in the order given: Yellow (iron), green (iron or cobalt), blue (cobalt), reddish-brown (nickel), green (nickel and copper), blue (copper). *Copper and Elements That Color Strongly:* Fuse the mineral with borax and lead on coal in R. F. The borax bead on platinum wire in O. F. will show the cobalt except when obscured by much iron or chromium. Iron, nickel, or chromium are to be fused in R. F. with a little metallic arsenic, then treated as an arsenide. Sulphur or selenium are to be roasted and scorified with borax as before described.

113. Wet Tests.—Fixed alkalies precipitate blue basic salts. This precipitate absorbs oxygen and becomes an olive-green hydroxide. If boiled before oxidation in the air, it becomes rose-red. Cobaltous hydroxide, $Co(OH)_2$, does not dissolve in excess. Ammonia, HN_4OH, produces the same precipitate, which is soluble in excess.

Potassium ferricyanide, $K_3Fe(CN)_6$, precipitates dark-brown cobalt ferricyanide insoluble in hydrochloric acid. If to a solution of cobalt or nickel an excess of ammonium chloride and ammonia is added and then potassium ferricyanide, a blood-red color indicates cobalt. If nickel is present and the solution is boiled, a copper-red precipitate forms; if any cobalt is present, a dirty green precipitate is formed on boiling.

To a dilute solution of cobaltous nitrate add tartaric or citric acid, then an excess of ammonia and a few drops of potassium ferricyanide; a deep-red color appears even if largely diluted. Confirm by blowpipe tests.

COPPER

114. Blowpipe Tests.—On charcoal in the R. F., **copper,** *Cu*, minerals are reduced to red metallic globules. The flame is emerald-green or azure-blue, according to the compound. The azure-blue flame may be obtained by roasting sulphur, selenium, and arsenic from the copper ores; lead in copper minerals necessitates a gentle heat; then by moistening the assay with hydrochloric acid or aqua regia, drying gently with O. F., and heating strongly in R. F., an azure-blue flame reaction may be obtained (see flame test for chlorine). Also by saturating *S. Ph.* bead with the substance, adding common salt and treating with the blue flame of the lamp, the azure-blue flame may be obtained.

With borax or *S. Ph.* in the O. F., a green bead is obtained while hot, but blue or greenish-blue when cold. By repeated slow oxidation and reduction a borax bead becomes ruby-red. In a R. F. a greenish or colorless bead is obtained when hot, and an opaque and brownish-red when cold. With tin on coal, this reaction is more delicate.

115. Interfering Elements.—Roast thoroughly, treat with borax on coal in strong R. F. (the oxides, sulphides, and sulphates are best reduced by a mixture of soda and borax), and if the button forms separate from the button from the slag, remove any lead from it by O. F. and make either a *S. Ph.* or a flame test on residual button. If no visible button forms, add test lead to the borax fusion, continue the reduction, separate the button, and treat as in next test.

116. Lead or Bismuth Alloys.—Treat with frequently changed boracic acid in strong R. F., noting the appearance of slag and residual button. If there is a trace of copper, a red spot will appear in the slag. If there is over 1 per cent. of copper, the residual button will be bluish-green; when melted it will dissolve in the slag and color it red on application of O. F., or may be removed from the slag and be submitted to either *S. Ph.* or the flame test.

117. Wet Tests.—Ammonia produces a deep-blue solution; this will not occur if there is carbon present and may not at first appear in case there is a large quantity of iron.

Sodium hydroxide and potassium hydroxide when added to saturation precipitates blue copper hydroxide insoluble in excess. When boiled, the precipitate changes to black copper hydroxide. Organic substances generally prevent the formation of this precipitate.

Iron and zinc precipitate metallic copper from cupric solutions.

IRON

118. Dry Tests.—On charcoal in the R. F., many **iron,** *Fe*, compounds become magnetic when cool. Soda will assist the reaction. With borax in O. F., the bead is yellow to red when hot, and colorless to yellow when cold; in R. F. it is bottle-green. With tin on coal, the bead is violet-green. With *S. Ph.* in O. F., the bead is yellow to red while hot, greenish when cooling, colorless to yellow when cold; in R. F., the bead is red both when hot and cold, but greenish while cooling. A borax blue bead from cupric oxide is made red by ferrous oxide, FeO, and greenish by ferric oxide, Fe_2O_3.

119. Interfering Elements.—*Chromium:* Fuse with niter and sodium carbonate on platinum, dissolve in water, and test residue for iron. *Cobalt:* By dilution with borax the cobalt-blue bead may be often lost before the yellow of iron. *Copper* may be removed from borax bead by treatment with lead on charcoal in R. F. *Manganese* may be faded from a borax bead by treatment with tin on coal in R. F., or from a *S. Ph.* bead by R. F. *Nickel* may be faded from borax bead by R. F. *Tungsten* or *titanium* will color a *S. Ph.* bead in R. F. a reddish-brown instead of blue or violet. *Uranium* has the same effect as chromium. *Alloys, sulphides, arsenides, etc.:* Roast, treat with borax on coal in R. F., then treat borax bead in R. F. to remove reducible metals.

120. Wet Tests.—*Ferrous Compounds in Solution:* Ammonia throws down ferrous hydroxide as a white or dirty green precipitate that gradually takes oxygen from the air and turns brown. Potassium ferricyanide added to cold dilute solutions of ferrous salts will give a deep-blue precipitate of ferrous ferricyanide. Ammonium sulphocyanate, NH_4CNS, produces no coloration with ferrous solutions. Ferrous iron may be changed to ferric by boiling HCl solution with a few drops of nitric acid to furnish oxygen.

Ferric Compounds in Solution.—Ammonia precipitates brownish flocculent ferric hydroxide. Potassium ferrocyanide added to cold dilute ferric solutions will throw down ferric ferrocyanide or Prussian blue. Ammonium sulphocyanate, NH_4CNS, produces a blood-red solution with ferric solutions. Ferric iron may be changed to ferrous by boiling the hydrochloric-acid solution with metallic tin or zinc until the yellow color entirely disappears.

Detection of Ferrous and Ferric Iron in Silicates.—Make a large sodium-carbonate bead on platinum wire. Dip the button while red hot into the finely powdered mineral. The bead must not be further heated, but is to be removed from the wire, crushed in a diamond mortar, and dissolved in a test tube in hot dilute HCl, and separate portions of the solution tested with potassium ferri and ferrocyanides.

LEAD

121. Dry Tests.—On charcoal, in either flame, **lead**, *Pb*, compounds are reduced to malleable metal that yields near the assay a dark lemon-yellow coat, which becomes sulphur-yellow when cold, and bluish-white at the border. Lead phosphate yields no coat without the aid of a flux.

With bismuth flux on plaster, a chrome-yellow coat, blackened by ammonium sulphide, is obtained; on charcoal, a volatile yellow coat, darker while hot. The flame is azure-blue.

With borax or *S. Ph.* O. F., a yellow bead while hot, colorless when cold, is obtained. Can be flamed opaque yellow in R. F. The borax bead becomes clear, the *S. Ph.* bead becomes cloudy.

122. Interfering Elements.—Galena, when roasted alone on charcoal at a high temperature, an abundant white sublimate is formed, resembling oxide of antimony; roasted at a low heat, a yellow coating is formed and a metallic button. *Antimony:* Treat on coal with boracic acid and reduce the slag on plaster with bismuth flux. *Arsenic Sulphide:* Remove by gentle O. F. *Cadmium:* Remove by R. F. *Bismuth:* Usually the bismuth-flux tests on plaster are sufficient. In addition the lead coat should color the R. F. blue.

123. Wet Test.—Zinc precipitates crystals of lead from solutions.

Sulphuric acid precipitates white lead sulphate, $PbSO_4$, slightly soluble in excess, insoluble in alcohol, but soluble in ammonium acetate or citrate.

Hydrogen sulphide or ammonium sulphide precipitates black lead sulphide, soluble in nitric acid, with the formation of lead sulphate.

Ferrocyanide of potassium precipitates white lead ferrocyanide. To obtain a solution from lead minerals use 1 part nitric acid and 2 parts water. Sulphuric acid will throw down white lead sulphate which is insoluble in water. Hydrochloric acid will give a heavy white precipitate of lead chloride soluble to a large extent in hot water.

LITHIUM

124. Dry Test.—A **lithium**, Li, mineral colors the flame crimson by heating it near the wick. If the mineral contains sodium, the crimson flame will appear before the yellow of the sodium.

125. Interfering Elements.—*Sodium:* Fuse on platinum wire with barium chloride in O. F. The flame will be first strong yellow, then green, and lastly crimson. *Calcium or Strontium:* These elements will not color the flame crimson in the presence of barium chloride. *Silicon:* Make into a paste with boracic acid flux and water and fuse in the blue flame. Just after the flux fuses the crimson flame will appear.

126. Wet Test.—Sodium carbonate, Na_2CO_3, precipitates white lithium carbonate slightly soluble in water.

MAGNESIUM

127. Dry Tests.—**Magnesium**, Mg, minerals fluxed with soda and ignited on charcoal are insoluble and are not absorbed by the coal. With borax or *S. Ph.*, a clear colorless bead may be obtained, that can be flamed opaque white. With cobalt solution and strongly heated it becomes a pale flesh color. With silicates this action is of use only in the absence of coloring oxides. The phosphate, arsenate, and borate become violet-red. The dry tests are not as satisfactory as the wet tests for magnesium.

128. Wet Tests.—Sodium phosphate, Na_2HPO_4, precipitates in the presence of ammonia and ammonium chloride, white ammonium magnesium phosphate in fine crystals. Before making the test, it must be ascertained that substances precipitated by ammonia, ammonium sulphide, and ammonium carbonate or oxalate have been removed from solution, as otherwise a phosphate of some other element might be thrown down and mistaken for magnesium. Magnesium will not be precipitated by the above reagents if the solution is sufficiently dilute, contains a free mineral acid, such as hydrochloric or nitric, or an acid with which magnesium forms an insoluble compound.

MANGANESE

129. Dry Test.—With borax or *S. Ph.* in the O. F., amethystine while hot, reddens on cooling; with much mineral it is black and opaque. The colors are more intense with borax than with *S. Ph.* If a hot bead is touched to a crystal of niter, an amethystine, or rose-colored, froth is formed; in a R. F. it is colorless or with black spots. With soda in O. F. it is a bluish-green bead, becoming opaque when cold. Niter assists this reaction. The powdered mineral fused on platinum with sodium carbonate to which a little potassium nitrate has been added, to bring about oxidation, gives a bluish-green coloration. By this means a very small quantity of oxide of manganese (.1 per cent.) may be detected.

130. Interfering Elements.—*Chromium:* The soda bead in O. F. will be bright yellowish-green instead of bluish-green when cold. *Silicon:* Dissolve in borax bead and then fuse with soda.

131. Wet Test.—Boil the powdered mineral with nitric acid and add peroxide of lead, PbO_2. A reddish-violet solution indicates manganese. There are a number of manganese minerals that, dissolved in hydrochloric acid, will cause an evolution of chlorine gas.

MERCURY

132. Blowpipe Tests.—With bismuth flux on plaster, a volatile yellow and scarlet coat will be formed; if too strongly heated the coat is black and yellow. On charcoal, a faint yellow coat is shown at a distance from the assay.

In a matrass with dry soda or litharge, mirrorlike sublimate, which may be collected in globules, is obtained. Gold leaf is whitened by the faintest trace of mercury.

In the open tube, a crystal of iodine just above the assay will form a bright red sublimate of iodide of mercury, if any **mercury**, *Hg*, is present. Sulphide of mercury will give a gray sublimate after sulphur dioxide is driven off gradually by heat. The gray sublimate is metallic mercury.

133. Wet Tests.—A piece of bright metallic copper will be coated with mercury if inserted in a solution of mercury.

Stannous chloride will precipitate white mercurous chloride and then gray mercury.

To distinguish between mercuric and mercurous compounds, hydrochloric acid precipitates white mercurous chloride (calomel) from mercurous solutions, soluble in aqua regia, nitric acid, and ammonium chloride, and blackened by ammonia. There is no precipitate from mercuric compounds on the addition of HCl.

MOLYBDENUM

134. Dry Tests.—On charcoal in an O. F., **molybdenum,** *Mo*, minerals give when hot a yellowish coat, which becomes white when cold; crystalline near assay. In the R. F. the coat is turned in part deep blue, in part dark-copper red. The flame is yellowish-green color.

With borax in an O. F., it is yellow when hot, colorless when cold. In the R. F. the bead becomes brown to black and opaque.

With *S. Ph.* in the O. F., it is yellowish-green when hot, colorless when cold. The bead crushed between damp, unglazed paper becomes red, brown, purple, or blue, according to the amount present. In R. F. it is emerald-green.

With dilute $\frac{1}{4}$ HCl solutions. Fuse the substance with *S. Ph.* in O. F. and dissolve in the acid and heat with tin, zinc, or copper. The solution will turn blue, green, and brown. If the *S. Ph.* bead has been treated in R. F. the solution will become brown.

If thin pieces of molybdenite are highly heated in the open tube, a yellow sublimate deposits above the assay, sometimes becoming a mass of delicate crystals.

135. Wet Test.—Upon heating an acid solution with zinc, it will turn successively blue, green, and brown.

NICKEL

136. Blowpipe Tests.—On charcoal in the R. F., the oxide becomes magnetic.

With borax in the O. F., it forms a violet bead while hot, pale reddish-brown when cold. In the R. F. it forms a cloudy bead, which finally becomes colorless.

With *S. Ph.* in the O. F., the bead is red while hot, yellow when cold. In the R. F. it is red while hot, yellow when cold. On coal with tin it becomes colorless.

137. Interfering Elements.—Saturate 3 borax beads with the roasted mineral, and treat on coal with strong R. F. If a visible button results, separate it from the borax and treat with *S. Ph.* in the O. F., replacing the *S. Ph.* until a nickel bead is obtained. If no visible button results, add a few grains of test lead. Continue the reduction; scorify the button with boracic acid to small size, complete the removal of lead in O. F. on coal and treat residual button with *S. Ph.* in O. F. *Arsenic:* Roast thoroughly, treat with borax in R. F. as long as color shows, treat residual button with *S. Ph.* in O. F. *Alloys:* Roast and melt with frequently changed borax in R. F., adding a little lead if infusible. When the borax is no longer colored, treat residual button with *S. Ph.* in O. F.

PHOSPHORUS

138. Dry Tests.—The flame is a momentary greenish-blue, which is improved by concentrated sulphuric acid. In a closed tube, when soda is mixed with the mineral in equal parts and dried, and the mixture is covered over dry magnesium, there will be on heating a vivid incandescence, and the resulting mass when crushed and moistened will yield the odor of phosphureted hydrogen, which is somewhat like the garlic odor of arsenic.

139. Wet Tests.—*Orthophosphate Solutions:* Magnesia mixture precipitates white magnesium-ammonium phosphate, $MgNH_4PO_4$, from ammoniacal solutions. Silver nitrate precipitates light-yellow silver phosphate, Ag_3PO_4, soluble in nitric acid and ammonia. Ammonium molybdate with nitric acid precipitates yellow ammonium phosphomolybdate. The precipitate is soluble in ammonia provided no organic substances are present.

Pyrophosphate Solutions: Magnesium sulphate precipitates white magnesium pyrophosphate, $Mg_2P_2O_7$, soluble in an excess in either solution. On boiling it separates again. By this reaction pyrophosphates can be detected in the presence of phosphoric acid. Ammonia fails to precipitate it from these solutions.

Ammonium molybdate with nitric acid (molybdate solution) does not give a precipitate until orthophosphate is formed. Most of the pyrophosphates of the heavy metals (*Ag* an exception) are soluble in alkali pyrophosphates, which will distinguish them from orthophosphates.

Silver nitrate precipitates white silver pyrophosphates soluble in nitric acid and ammonia. The addition of an alkali aids the precipitation.

Metaphosphate Solutions: Magnesia mixture gives no precipitate. Molybdate solution gives no precipitate. Silver nitrate precipitates white silver metaphosphate, $AgPO_3$, soluble in alkali metaphosphate solutions, but not in pyrophosphate solutions.

Albumen gives a precipitate with metaphosphate, but not with ortho- or pyrophosphate solutions. Fusion with sodium carbonate converts meta- and pyro- into orthophosphates.

POTASSIUM

140. Blowpipe Tests.—Volatile **potassium,** *K*, compounds color the flame violet. The substance is held in the forceps or in a loop on platinum wire and placed in the hottest part of the flame. The color is not very strong but by viewing it through blue glass, the potash flame will be distinctly seen. Potassium compounds, with a few exceptions, such as silicates, phosphates, and borates, when ignited give a slight alkaline reaction.

141. Interfering Elements. — *Sodium:* The flame through blue glass will be violet or blue. A borax bead containing a little boracic acid, made brown by nickel, will become blue on addition of a potassium compound. *Lithium:* The flame through green-glass will be bluish-green.

142. Wet Test.—Platinic chloride, $PtCl_4$, added to a neutral or slightly acid potassium solution, will precipitate yellow crystalline potassium platinic chloride, $(KCl)_2 PtCl_4$. The precipitate is slightly soluble in water, but insoluble in alcohol.

SELENIUM

143. Dry Tests.—On charcoal in the R. F., **selenium,** Se, gives a disagreeable horseradish odor, brown fumes, and a volatile steel-gray coat with a red border. If the coating is touched with the reducing flame, the selenium volatilizes and imparts an azure-blue color to the flame.

In the open tube, selenium yields a white oxide, SeO_2, which usually crystallizes in radiating prisms on the sides of the glass. This may be reddened by finely divided selenium. The sublimate is volatile.

In the closed tube, a dark-red sublimate and a decaying horseradish odor is obtained.

On charcoal with soda, thoroughly fuse in the R. F.; place on bright silver, moisten, crush, and let stand. The silver will be blackened.

144. Wet Tests.—Hydrogen sulphide precipitates yellow sulphide of selenium from acid solutions. The precipitate is soluble in ammonium sulphide. Upon heating, the precipitate turns reddish-yellow.

Stannous chloride and hydrochloric acid produce a red precipitate of selenium, which turns gray at a high temperature.

Metallic copper when placed in a warm solution of selenious acid, containing hydrochloric acid, becomes black; if the fluid remains long in contact with the copper it turns red from the separation of selenium. Confirm the wet tests by blowpipe.

A mixture of selenium and alkali metal treated with ammonia produces an insoluble sodium or potassium selenide when the metal is in excess, while if selenium predominates a polyselenide is formed.

SILICON

145. Blowpipe Tests.—On charcoal with soda, silica, SiO_2, with its own volume of soda dissolves with effervescence to a clear bead; with more soda the bead is opaque.

With borax, a clear and colorless bead is obtained.

With *S. Ph.*, silica is insoluble. The test made upon a small fragment will usually show a translucent mass of undissolved matter of the shape of the original fragment. When the substance is not decomposed by *S. Ph.*, dissolve in borax nearly to saturation, add *S. Ph.*, and reheat for a moment. The bead will become milky or opaque white.

Moistened with cobalt nitrate solution and ignited, the color becomes blue.

146. Wet Tests.—Silicates are determined by the separation of silica either as gelatinous silicic acid or as a white powder. The surest way to detect a silicate is to get the mineral in an acid solution. Fuse a silicate with sodium carbonate and sodium nitrate, dissolve the mass in hydrochloric acid, and evaporate to a point where the solution becomes gelatinous. If evaporation is continued to dryness and the residue dissolved with hydrochloric acid and digested with water the bases will go into solution and the insoluble silica, SiO_2, will remain. Gelatinization will be more readily obtained with nitric acid than with hydrochloric, although in many cases either will answer. Confirm by the blowpipe test.

Some silicates are completely decomposed by boiling with acids, the bases going into solution while the silica is left in an insoluble condition without the formation of a jelly. Filter the soluble material and test with the blowpipe.

SILVER

147. Dry Tests.—On charcoal, **silver,** *Ag*, is reduced to a malleable white metal. On long treatment in the O. F. a faint reddish-brown coat of silver oxide is obtained.

With borax or *S. Ph.* in the O. F., the bead is opalescent.

Fuse on coal with 1 volume of borax glass and 2 volumes of test lead in the R. F. for about 2 minutes. Remove the button, scorify it on the coal in the R. F. with fresh borax, then place the button on the cupel and blow the O. F. across it, using as strong a blast and as little flame as is consistent with keeping the button melted. If the litharge is dark or if the button freezes before brightening, or if it brightens but is not spherical, rescorify it on coal with borax, add more test lead, and again cupel, until there remains only a white spherical button of silver.

148. Wet Tests.—*Precipitation of Silver as Silver Chloride:* Digest the mineral in hot nitric acid and precipitate white silver chloride with a few drops of hydrochloric acid. The precipitate is soluble in ammonia and is reprecipitated by nitric acid. It darkens on exposure to light. Collect on filter and confirm with the blowpipe.

Copper precipitates metallic silver.

Potassium iodide precipitates yellow silver iodide insoluble in ammonia.

SODIUM

149. Dry Tests.—**Sodium,** *Na*, is usually detected by flame coloration and alkaline reaction. Volatile sodium compounds color the flame intensely yellow and the test is exceedingly delicate. With the exception of the silicates, borates, phosphates, and the salts of a few rare acids, sodium salts on ignition give an alkaline reaction. Some other alkalies and alkaline earths give the same reactions.

150. Wet Tests.—If platinic chloride is added to a concentrated neutral or slightly acid solution of sodium chloride, red prisms of sodium platinic chloride, $(NaCl)_2PtCl_4$, will form.

STRONTIUM

151. Dry Tests.—**Strontium,** *Sr*, may be detected in minerals by flame coloration and by alkaline reaction after heating.

The flame is an intense crimson, improved by moistening with hydrochloric acid.

With borax or *S. Ph.*, a clear and colorless bead that can be flamed opaque is formed.

On charcoal with soda, it is insoluble, but is absorbed by the coal. When ignited and moistened, strontium minerals with the exception of silicates and phosphates give alkaline reaction.

152. Wet Tests.—Strontium sulphate is very insoluble in water and dilute acids, hence may be precipitated from solutions by a few drops of dilute sulphuric acid. Sodium hydroxide, ammonia, sodium carbonate, and ammonium carbonate produce precipitates from strontium solutions that closely resemble those produced by these reagents from barium salts. Confirm by blowpipe tests.

SULPHUR

153. Blowpipe Tests.—Sulphides can be most conveniently detected by roasting the mineral in the open tube or on charcoal, when the odor of burning **sulphur,** *S*, will be readily noticed; or an acid test may be made by holding moistened blue litmus paper in the fumes. Some sulphides oxidize so readily that when heated before the blowpipe they will take fire and burn; pyrite, FeS_2, and chalcopyrite, $CuFeS_2$, can be tested in this way.

In the open tube, suffocating fumes of burning sulphur are driven off; some sulphates are unaffected.

In the closed tube, there may be a red sublimate while hot, yellow when cold, or a sublimate of undecomposed sulphide, or the substance may be unaffected.

With soda and silica in equal parts, a yellow or red bead may be formed.

154. Silver-Coin Test.—Thoroughly fuse the mineral with soda and a little borax on charcoal in the R. F. flame and place on a bright silver coin, moisten, crush, and let stand. The silver will become brown or black.

To determine whether a mineral is a sulphide or sulphate, fuse with soda on platinum foil; the sulphide only will stain silver, as the sulphate is already oxidized.

If the sulphate is reduced to a sulphide the test on silver may be applied. To do this, make a paste of equal parts of sulphate and powdered charcoal, add 4 volumes of sodium carbonate; fuse on charcoal before blowpipe, and sodium sulphide will be formed.

155. Wet Test.—Barium chloride gives a white precipitate of barium sulphate when added to solutions containing sulphuric acid.

On the addition of hot nitric acid to sulphides, hydrogen sulphide gas is given off which is decomposed by nitric acid and sulphur is precipitated.

Most sulphides are either insoluble or difficultly soluble in hydrochloric acid, but those that are soluble emit hydrogen sulphide gas.

TELLURIUM

156. Dry Tests.—On charcoal, **tellurium,** *Te*, minerals give a volatile white coat with a brown or yellow border. If the fumes are caught on porcelain the resulting gray or brown film may be turned crimson when moistened with concentrated sulphuric acid, and gently heated.

On charcoal with soda, thoroughly fuse in the R. F., place the fused mass on a bright silver coin, moisten, crush, and let stand. The silver will be blackened.

Tellurium colors flame green. In an open tube, a gray sublimate forms, which is fusible to clear drops. Heat a mixture of finely powdered mineral with sodium carbonate and a little charcoal dust in a test tube. After cooling and the addition of water the solution will assume a violet-reddish color. This color gradually disappears and a gray precipitate forms if a drop is transferred to a porcelain plate. This may be hastened by blowing on the drop.

157. Wet Tests.—Hydrogen sulphide precipitates brown tellurium sulphide from acid solutions. This is soluble in ammonium sulphide.

Boiled with concentrated sulphuric acid, there results a purple-violet solution that fades upon further heating or dilution.

TIN

158. Blowpipe Tests.—**Tin,** *Sn*, is usually detected by the formation of metallic globules by reduction on charcoal.

Sodium carbonate and oxide of tin, without the addition of charcoal powder, usually form an infusible mass that is very difficult to reduce.

On charcoal in the O. F., the oxide becomes yellow and luminous. In the R. F., a slight coat is formed, assisted by additions of sulphur or soda.

Moisten the coal in front of the assay with the cobalt solution, and blow a strong R. F. upon the assay. The coat will be bluish-green when cold.

With copper oxide, CuO, in the borax bead, a faint blue bead is made reddish-brown or ruby-red by heating a moment in R. F. with a tin compound.

159. Interfering Elements.—*Lead or Bismuth Alloys:* It is a fair proof of tin if such an alloy oxidizes rapidly with sprouting and cannot be kept fused. Sprouting is blowing out from the center of the fused alloys. *Zinc:* On coal with soda, borax, and charcoal in R. F., the tin will be reduced, the zinc volatilized. The tin may then be washed from the fused mass.

160. Wet Tests.—*Stannous Solutions:* Hydrogen sulphide precipitates dark-brown stannous sulphide soluble in hydrochloric acid, in alkalies, and moderately soluble in yellow ammonium sulphide.

Mercuric chloride precipitates white mercurous chloride with excess of black mercury (distinction from stannic compounds).

Gold trichloride, $AuCl_3$, with HCl or HNO_3 in solution gives a purple precipitate.

Zinc precipitates spongy tin.

Stannic Solutions: Hydrogen sulphide precipitates yellow stannic sulphide, SnS_2, which is soluble in hydrochloric acid, alkalies, and alkaline sulphides.

Mercuric chloride gives no precipitate.

Auric chloride, $AuCl_3$, gives no precipitate.

Zinc precipitates spongy tin.

TITANIUM

161. Blowpipe Tests.—**Titanium,** *Ti*, may be detected by *S. Ph.* bead; reduction with metallic tin, or by oxidation with hydrogen peroxide.

With *S. Ph.* in the O. F., it forms a yellow bead while hot, colorless when cold. In a R. F., it forms a yellow bead while hot, a delicate violet when cold, never very intense.

With borax in the O. F., the bead is colorless to yellow while hot, colorless when cold, and can be made opalescent or opaque white by flaming. In the R. F. the bead is yellow to brown, and becomes enamel-blue by flaming.

162. Wet Tests.—Titanium minerals are very insoluble in acids, but after fusion with sodium carbonate, they go into solution with hydrochloric acid. If this acid solution is boiled with a little granulated zinc or tin, a pale-violet or blue solution is obtained after a while, and subsequently a blue precipitate that gradually turns white. Other substances do not seem to interfere with this reaction.

Ammonia gives a bulky white precipitate of titanium hydroxide insoluble in excess.

Hydrogen peroxide gives an exceedingly delicate test used for substances supposed to contain less than 3 per cent. of titanium dioxide, TiO_2. First fuse with sodium carbonate and then dissolve in sulphuric acid, heating until the solution becomes clear. Dilute with cold water, add some hydrogen peroxide, and if titanium is present the solution becomes reddish-yellow to deep amber, depending upon the quantity of titanium in the solution.

TUNGSTEN

163. Dry Tests.—With borax in the O. F., the **tungsten,** W, bead is colorless to yellow when hot, colorless when cold; it can be flamed opaque white. In the R. F. the bead is colorless to yellow when hot, yellowish-brown when cold These reactions are not very satisfactory.

With *S. Ph.* in the O. F., a clear and colorless bead is formed. In the R. F. the bead is greenish when hot, blue when cold. On long blowing, or with tin on coal, the bead becomes dark green.

164. Wet Tests.—If insoluble, fuse the substance with *S. Ph.* Dissolve in hydrochloric acid, and heat the solution with granulated tin, when it will become dark blue. Heated with zinc, the solution becomes purple and then reddish-brown.

When a tungstate is decomposed by boiling with acid, an insoluble canary-yellow tungstic oxide is obtained. On adding granulated tin and boiling, the color first becomes blue and finally brown.

Stannous chloride, $SnCl_2$, produces a yellow precipitate, which on acidifying with hydrochloric acid and boiling acquires a beautiful blue color.

Heated with hydrochloric acid and zinc the solution becomes purple, then reddish-brown.

Potassium ferrocyanide with hydrochloric acid gives a brownish-red color, and upon standing, a precipitate of the same color.

URANIUM

165. Blowpipe Tests.—Reactions with a salt-of-phosphorus bead usually serve for the detection of **uranium,** *U*.

With borax in the O. F., the bead, which is yellow while hot, colorless when cold, can be flamed enamel-yellow. In the R. F. the bead is bottle-green; it can be flamed black, but not enameled.

With *S. Ph.* in the O. F., the bead is yellow while hot, yellowish-green when cold. In the R. F. the bead becomes emerald-green.

166. Interfering Elements.—*Iron:* With *S. Ph.* in the R. F., the bead is green while hot, red when cold. With other elements that impart color to the fluxes, and for the detection of small quantities of uranium in minerals, the wet tests are more satisfactory.

167. Wet Tests.—Fuse with sodium carbonate, dissolve in hydrochloric acid, nearly neutralize the solution with ammonia, add solid ammonium carbonate, shake, and allow liquid to stand. The uranium is precipitated but is soluble in excess of ammonium carbonate, and by filtering may be separated from other elements precipitated by the same reagent. Make the filtrate acid, add ammonia in excess, collect precipitate on filter, and test with *S. Ph.* bead.

Ammonia, potassium, or sodium hydroxide produces a yellow precipitate of uranium hydroxide and alkali.

Potassium ferrocyanide produces a reddish-brown precipitate.

VANADIUM

168. Dry Tests.—Vanadium, *V*, is usually detected by the color it imparts to fluxes, but it should be given a wet test for confirmation.

With borax in the O. F., the bead is colorless or yellow while hot, greenish-yellow when cold. In the R. F. it is brownish while hot, emerald-green when cold.

With *S. Ph.* in the O. F., the bead is dark yellow while hot, light yellow when cold. In the R. F. it is brown while hot, emerald-green when cold.

169. Wet Tests.—Dissolved in sulphuric acid and reduced by zinc, the color becomes successively yellow, green, bluish-green, blue, greenish-blue, bluish-violet, and lavender.

When in solution, potassium ferrocyanide produces a flocculent green precipitate insoluble in acids.

An acidified solution of vanadates upon being shaken with hydrogen peroxide acquires a red tint; if ether is then added, and the solution is shaken, it retains its color, the ether remaining colorless.

To detect small quantities of vanadium, in cases where other substances are present, which color the fluxes: Fuse the powdered mineral on platinum foil with 4 parts sodium carbonate and 2 parts potassium niter; digest the fused mass with warm water. Filter, acidify with acetic acid, and add a little lead acetate, which will precipitate pale-yellow lead vanadate. Collect precipitate on filter paper and test with *S. Ph.* bead.

ZINC

170. Blowpipe Tests.—Zinc, *Zn*, volatilizes when heated before the blowpipe, giving a coating of oxide on charcoal. It may be detected also by cobalt nitrate and flame coloration.

Flame Test: Hold in forceps in a strong reducing flame; as the metal volatilizes, it burns with a vivid, pale, bluish-green light, appearing as streaks in the outer part of the flame.

On charcoal in the O. F., the oxide becomes yellow and luminous. In the R. F. the bead forms a yellow coat while hot, white when cold; the formation of the coat is assisted by fusion with soda and a little borax.

With cobalt solutions, moisten the coat in front of the assay with the solution, and blow a strong O. F. upon it. The coat will become bright yellowish-green when cold.

171. Interfering Elements.—*Antimony:* Remove by strong O. F. or by heating with sulphur in closed tube. *Cadmium, Lead, or Bismuth:* The combined coats will not prevent the cobalt solution test. *Tin:* The coats heated in the open tube, with charcoal dust by O. F., may yield white sublimate of zinc.

172. Wet Tests.—Alkali hydroxides precipitate white zinc hydroxide, which is soluble in excess of precipitant.

Hydrogen sulphide precipitates white zinc sulphide from alkaline neutral or acetic acid solutions.

Potassium ferrocyanide precipitates zinc ferrocyanide, which is insoluble in very dilute hydrochloric acid solutions.

Ammonium sulphide precipitates white zinc sulphide, which is insoluble in potassium hydroxide and acetic acid.

Confirm the wet tests by blowpipe tests.

TESTS FOR GASES

173. The gases that collect in the closed tube may be identified in the following ways:

1. *Carbon dioxide*, CO_2, is colorless and odorless. It may be identified by introducing a drop of barium hydroxide, $Ba(OH)_2$, into a test tube on the end of a glass rod and holding it above the surface of the liquid in which the mineral is being dissolved. The drop will be turned white by the precipitation of barium carbonate. Carbon dioxide is obtained from most carbonates by means of acids.

2. *Sulphur Dioxide*, SO_2.—Colorless, with strong, pungent odor. It imparts an acid reaction to blue litmus paper. Formed from decomposition of some sulphates, and in small quantities from some sulphides when air is in the closed tube.

3. *Oxygen*, O.—Colorless and odorless. Formed in the closed tube when higher oxides, such as manganese dioxide, are heated. It may be detected by its causing a piece of charcoal just above the assay to burn brightly, which it will not do if oxygen is not present.

4. *Ammonia*, NH_3.—Colorless with characteristic odor. Gives alkaline reaction.

5. *Hydrofluoric Acid*, HF.—Colorless with pungent odor, etches glass and gives a strong acid reaction, and colors Brazil-wood paper straw yellow.

6. *Nitrogen Dioxide*, NO_2.—Red vapors, with pungent odor.

7. *Bromine*, Br.—Red vapors with characteristic pungent odor.

8. *Iodine*, I.—Violet vapors, often accompanied by crystals of iodine.

9. *Brown smoke*, accompanied by dark distillation products and empyreumatic odor. Organic material.

TEST FOR ODORS

174. Some minerals when heated give off characteristic odors that are a guide to their identification.

1. The odor of burning sulphur is well known and can be obtained from a burning sulphur match.

2. Arsenic driven off rapidly from its compounds gives a garlic odor.

3. Selenium gives a peculiar odor, learned only by experience. It is usually described as resembling that of decayed horseradish.

TABLE II

FLAME COLORATIONS

Color	Shade	Element	Remarks
Red	Crimson	Lithium	Silicates or phosphates of lithium do not become alkaline after ignition like strontium minerals.
Red	Crimson	Strontium	Carbonates and sulphates become alkaline after reaction. Silicates and phosphates do not give crimson flame.
Red	Yellowish to orange	Calcium	This color is best brought out by moistening assay with hydrochloric acid, although this is not always necessary.
Yellow	Intense	Sodium	A delicate test. Flame color cannot be seen through moderately dark-blue glass.
Green	Yellowish	Barium	Carbonates and sulphates show the reaction and become alkaline. Silicates and phosphates do not give barium flame.
Green	Yellowish	Molybdenum	In the form of oxide or sulphide.
Green	Bright, somewhat yellowish	Boron	Rarely show alkaline reaction after ignition. The test with turmeric paper dipped in hydrochloric acid is decisive.
Green	Emerald	Copper oxide, iodide, and bromide	After moistening assay with hydrochloric acid, the flame becomes azure-blue, with green tinge.
Green	Pale bluish	Phosphorus	Not very decisive. Merely a guide for the identification of phosphorus.
Green	Bluish	Zinc	Appears as bright streaks in the flame.
Green	Pale	Tellurium, Antimony, Lead	
Blue	Azure	Copper chloride	The outer darts of the flame are tinged with emerald-green.

TABLE II—(*Continued*)

Color	Shade	Element	Remarks
Blue	Azure	Selenium	Accompanied by a characteristic odor.
Blue	Pale azure	Lead	Perceptibly tinged with green in the outer parts.
Blue	Pale	Arsenic	
Blue	Greenish	Phosphorous antimony	
Violet	Pale	Potassium	Can be detected when sodium is present by means of blue glass.

TABLE III

COLOR CHANGE, HEATED IN CLOSED TUBE

Original Color	Color After Heating		Substance	Remarks
	Hot	Cold		
Green *or* blue	Black	Black	Copper minerals	These changes usually occur when the oxides of metals are produced by heating.
Green or brown	Black	Black	Iron minerals	
Pink	Black	Black	Manganese and cobalt minerals	
red	Black	Dark red	Ferric oxide	
[illegible]	**Dark yellow to brown**	Pale yellow to white	Lead and bismuth minerals	
	Pale canary yellow	White	Zinc minerals	

TABLE IV

SUBLIMATES PRODUCED IN THE CLOSED TUBE

Color and Condition		Substance	Remarks
Hot	Cold		
Colorless liquid; easily volatile.	Colorless liquid,	Water, H_2O	From minerals containi of crystallization. May be acid, and rarely alkaline.
Pale yellow to colorless liquid; difficultly volatile.	Colorless to white globules.	Tellurous oxide, TeO_2	From tellurium and a fe compounds.
Red to dark yellow liquid; readily volatile.	Yellow and crystalline solid; nearly white when in small quantity.	Sulphur, S	From native sulphur a sulphides. Many sulphide decomposed in a closed tu
Deep-red, almost black liquid; readily volatile.	Reddish-yellow, solid.	Sulphides of arsenic	Realgar, AsS, orpiment and some compounds co sulphur and arsenic.
Black; difficultly volatile, solid.	Reddish-brown.	Oxysulphide of antimony	From sulphides of antim some of its compounds wit antimonites.
Brilliant black, solid; often gray and crystalline near the heated end.		Arsenic, As	If the tube is broken o the deposit and the sublim tilized the characteristic ga may be obtained.
Brilliant black, solid		Mercury sulphide, HgS	If the sublimate is remo rubbed fine it yields a red
Black fusible globules. The smallest ones transmit a reddish light.		Selenium, Se	From selenium and so ides. Usually there are also of selenious dioxide, SeO_2.
Black fusible globules		Tellurium, Te	From tellurium and so rides. Fused tellurous oxi ules, TeO_2, often present.
Gray metallic globules, which may be united.		Mercury, Hg	From native mercury a gams.
White, solid		Chlorides of lead and antimony. Oxides of arsenic and antimony. Ammonia salts.	

TABLE V

SUBLIMATES PRODUCED IN THE OPEN TUBE

Color and Character	Substance	Remarks
Black; volatile	Arsenic and sulphide of Hg.	These sublimates frequently result from too rapid heating, but they will not form if the open-tube test is made properly with sufficient draft for complete oxidation of the minerals.
Brown	Antimony oxysulphide.	
Yellow or orange, easily volatile.	Sulphur and sulphides of arsenic.	
Red; volatile	Selenium, Se	
Pale yellow while hot, white when cold.	Molybdenum trioxide, MoO_3	Forms slowly when molybdenum oxide or sulphide is heated, and collects as a network of fine crystals.
White; readily volatile and crystalline.	Arsenious oxide, As_2O_3	Sublimate forms as a crystalline ring.
White; readily volatile and crystalline.	Selenious dioxide, SeO_2	Sublimate appears as radiating prismatic crystals, often accompanied by a little finely divided selenium, which is red.
White to pale-yellow globules; slowly volatile.	Tellurous oxide, TeO_2	
White; slowly volatile and crystalline.	Antimonous oxide, Sb_2O_3	Obtained from antimony and its compounds, which do not contain sulphur.
Pale straw-yellow while hot; white when cold; infusible, non-volatile, and amorphous.	Antimony tetroxide, Sb_2O_4	Obtained from sulphide of antimony as a dense white smoke.
White; non-volatile and infusible.	Sulphite and sulphate of lead.	Obtained from sulphide of lead as a slight deposit.
Gray metallic globules; volatile.	Mercury, Hg	By rubbing the minute globules with a strip of paper they may be made to unite.

TABLE VI

SUBLIMATES ON CHARCOAL

Color and Character		Substance	Remarks
Near the Assay	Distant from the Assay		
White; very volatile and mostly away from assay.	White to grayish.	Arsenious oxide, As_2O_3	Obtained when arsenic or its sulphides and arsenides are roasted in the oxidizing flame. Often a garlic odor.
Steel-gray; faint metallic lustre, very volatile.	White, frequently tinged with red.	Selenious oxide, SeO_2. The red is selenium.	Obtained by roasting selenides in the oxidizing flame. A peculiar odor is emitted belonging to selenium.
White; very volatile and mostly distant from assay.	White and not very pronounced.	Oxide of thallium, Tl_2O	The sublimate heated in the reducing flame volatilizes, and imparts a green color to flame.
Dense white; volatile.	Gray, sometimes slightly brownish.	The white is tellurous oxide, TeO_2. The gray is tellurium.	The sublimate volatilizes in the reducing flame, and imparts a green color to it.
Dense white; volatile near assay.	Bluish	Oxides of antimony	Obtained when the oxides and sulphides of antimony are roasted in the oxidizing flame.
Canary-yellow when hot; white when cold. Not volatile in the oxidizing flame.	Faint white	Zinc oxide, ZnO	Some zinc minerals give a zinc oxide coating, which if moistened with cobalt nitrate becomes green.
Faint yellow to white when hot; white when cold. Not volatile in the oxidizing flame.	Faint white	Tin dioxide, SnO_2	The coating moistened with cobalt nitrate and ignited assumes a bluish-green color.
Pale yellow while hot; white when cold, sometimes distinctly crystalline. Volatile in O. F.	Bluish	Molybdenum trioxide, MoO_3	A copper-red sublimate of MoO_2 deposits nearer the assay than MoO_3. Coating touched for an instant with R. F. becomes azure-blue color.
Yellow while hot; straw color when cold. Volatile in both flames.	Dense white with bluish-white border.	A mixture of oxide, sulphite and sulphate of lead.	This sublimate resembles that of antimony; forms when galena and other lead sulphides are heated.

TABLE VI—(*Continued*)

olor and Character		Substance	Remarks
e Assay	Distant from the Assay		
llow when ur-yellow l. Volatile ames.	Bluish-white	Lead oxide, PbO	The coating when moistened with hydriodic acid and heated is changed to volatile yellowish-green lead iodide.
range-yel- ile hot; llow cold. in both	Greenish-white	Bismuth oxide, Bi_2O_3	The coating is changed to volatile chocolate-brown bismuth iodide when moistened with hydriodic acid and heated.
, almost anging in listance to rown. Vol- th flames.	Yellow	Cadmium oxide, CdO	Forms in thin deposit; the coating shows an iridescence like peacock feathers.
h to deep		Silver when accompanied by lead and antimony.	Pure silver when heated alone on charcoal for a long time gives a slight brownish coat.

TABLE VII

REACTIONS WITH COBALT NITRATE

or	Substance	Remarks
ink or r.	Magnesia, MgO, and salts containing Mg.	The color is only distinct when pure compounds are tested.
seen n cold.	Zinc oxide, ZnO, and compounds containing Zn.	Test may be applied to fragments of mineral or to the coating on charcoal.
green	Oxide of tin, SnO_2	Observed on testing a coat on charcoal.
arine- ae	Aluminum oxide, Al_2O_3, and compounds containing it.	The best test for aluminum, but must not be taken for silicate of zinc.
arine- ae	Silicates of zinc	Due to fusible silicate of cobalt.
green	Oxide of antimony	These colors are rather indistinct and not very satisfactory.
h-green	Oxide of titanium	
let	Oxide of silicon (quartz)	
nder	Oxide of beryllium	

TABLE VIII

REACTIONS OBTAINED WITH BORAX

Oxidizing Flame		Produced by Oxides of	Reducing Flame	
Hot	Cold		Hot	Cold
Colorless	Colorless	Silicon, tin, aluminum.	Colorless	Colorle
Colorless	Colorless to opaque white, depending on the degree of saturation.	Calcium, barium, magnesium, strontium, zinc, beryllium, etc.	Colorless	Colorless opaque w
Pale yellow	Colorless or white	Lead, antimony, or cadmium.	Pale yellow	Colorle
		Bismuth	Gray	Gray
		Molybdenum	Brown	Brown
		Tungsten	Yellow	Yellowish
		Titanium	Grayish	Brownish
Yellow	Nearly colorless	Iron and uranium	Pale green	Nearly colo
	Pale yellow	Cerium	Colorless	Colorles
	Yellowish-green	Chromium	Green	Green
	Yellowish-green, almost colorless	Vanadium	Dirty green	Fine gre
Deep yellow to orange red	Yellow	Cerium	Colorless	Colorles
	Yellow	Iron	Bottle-green	Pale bottle-
	Yellow	Uranium	Pale green	Pale green, ly colorle
	Yellowish-green	Chromium	Green	Green
Green	Blue	Copper	Colorless to green	Opaque red, much oxi
	Various shades yellow, green, and blue.	Iron, copper, nickel, cobalt.		
Blue	Blue	Cobalt	Blue	Blue
Violet	Reddish-brown	Nickel	Opaque gray	Opaque G
Violet	Reddish-violet	Manganese	Colorless	Colorles
Pale rose	Pale rose	Didymium	Pale rose	Pale ros

TABLE IX

REACTIONS OBTAINED WITH PHOSPHOROUS SALT

Oxidizing Flame		Produced by Oxides of	Reducing Flame	
Hot	Cold		Hot	Cold
lorless	Colorless to opaque white	Calcium, strontium, barium, magnesium, tin, silicon, zinc, aluminum	Colorless	Colorless to opaque white
ry pale yellow	Colorless	Tantalum, cadmium	Very pale yellow	Colorless
		Antimony, lead, bismuth	Gray	Gray
		Columbium	Brown	Brown
e yellow	Colorless	Tungsten	Dirty blue	Fine blue
		Titanium	Yellow	Violet
Yellow	Colorless	Uranium	Pale dirty green	Fine green
		Iron	Very pale yellowish-green	Colorless
llowish-green	Colorless	Molybdenum	Dirty green	Fine green
p yellow rownish-red	Yellow to almost colorless	Iron	Red, yellow to yellowish-green	Almost colorless to very pale violet
ellow to ep yellow	Yellow	Vanadium	Dirty green	Fine green
eddish to wnish-red	Yellow to reddish-yellow	Nickel	Reddish to brownish-red	Yellow to reddish-yellow
Green	Rather pale blue	Copper	Pale yellowish-green	Pale blue, colorless and ruby red
	Yellow, green or blue of various shades	Mixtures of iron, copper, cobalt, nickel		
ark green	Blue	Copper	Brownish-green	Opaque red
irty green	Fine green	Chromium	Dirty green	Fine green
Blue	Blue	Cobalt	Blue	Blue
Grayish-violet	Violet	Manganese	Colorless	Colorless
Pale rose	Pale rose	Didymium	Pale rose	Pale rose

MINERALOGY

(PART 1)

MINERALS AND THEIR PROPERTIES

INTRODUCTION

1. A **mineral** is any substance, either elementary or compound, of definite or approximately definite composition, making up the lithosphere, exclusive of living animal and vegetable matter. Although usually solid, minerals may exist in a gaseous, liquid, or viscid state. Water is a mineral that solidifies at 32° F. and is converted into a gas at a temperature somewhat exceeding 212° F. Petroleum, asphalt, and coal are minerals, although coal is of undoubted vegetable origin. Some fossils are minerals. Hence, minerals are either the uncombined elements in a native state or compounds of these elements formed in accordance with chemical laws, but without vegetable or animal life.

Most rocks are mixtures of more than one mineral, usually so blended that the composition may be difficult to name and classify; for instance, granite, which is composed of three minerals—orthoclase, mica, and quartz. There are a few rocks—like obsidian, limestone, and coal—that consist so nearly of a single mineral that they may be said to be composed of one mineral. In addition to the regular mineral combinations in rocks, accessory minerals are usually encountered here and there through their texture. In some cases the original minerals have been decomposed and the elements replaced by a process called *metasomatosis*, so that they have formed quite large masses—such as some of the iron, zinc, and copper ore deposits. However, these minerals usually contain some of the elements in the original mineral.

It is the object of mineralogy to learn how to distinguish the various minerals when they are presented for identification. Many rare minerals have no commercial importance; these are not mentioned, as it is the object in general to confine the subject to those minerals that have some commercial value.

2. Identification of Minerals.—To determine a mineral definitely one must test it to ascertain its chemical composition and its physical characteristics. In the careful preliminary examinations of a mineral specimen, the examiner will naturally first notice the *physical characteristics*, such as crystalline form, structure, color, streak, transparency, luster, tenacity, feel, cleavage, fracture, hardness, specific gravity, and taste. If the specimen be of sufficient size, the weight will give some idea of the specific gravity. These different physical characteristics vary greatly in minerals; thus the luster and color, which are characteristic of some, are absent in others. Consequently these properties are important for their identification.

3. Nomenclature.—The termination *ites* or *itis* was first originated as a suffix for the names of stones by the Romans. In English, the *s* has been dropped and *ite* used as a suffix for the singular; for instance, hematite, chlorite, cryolite, etc. In recent years it has been customary to introduce into mineralogy the names of those people who have discovered a new mineral; for instance, torbernite, named after the discoverer, Torbern. There are, however, minerals that do not have the termination *ite;* for instance, quartz, garnet, gypsum, etc.; while the names of metals, gems, etc., that are a part of general literature remain unaltered. Mica and feldspar, names equally old with quartz, refer to groups of minerals and are no longer applied to particular species. The termination *ine* has been adopted for a few minerals, such as tourmaline and serpentine, but most of the names are systematically terminated in *ite*.

PHYSICAL CHARACTERISTICS OF MINERALS

4. Transparency.—The property of transmitting light that is possessed by most mineral substances to a greater or less degree, is termed **transparency.** Minerals are *transparent* when the outlines of objects viewed through them are distinct; *subtransparent*, when objects are seen but have indistinct outlines; *translucent* when light is transmitted but objects cannot be seen; *subtranslucent* when merely the edges transmit light; and *opaque* when no light is transmitted at all.

5. Color and Streak.—In distinguishing minerals, both the external color and the color of a surface that has been scratched with a knife or file or the color of the powdered mineral are observed. The latter is called the **streak** and is best obtained for most minerals by the use of a *streak plate*, which is a piece of unglazed porcelain. The colors are either *metallic* or *non-metallic*; the metallic are named after some familiar metal as copper-red, bronze-yellow, brass-yellow, steel-gray, lead-gray, iron-black, etc.

6. The **luster** of minerals depends on their power of reflecting light, and consequently the nature of their surfaces. The kind of luster is usually designated by one of the following terms:

Metallic is the ordinary luster of metals. An imperfect metallic luster is described as *submetallic.*

Vitreous is the luster of broken glass. Imperfectly vitreous luster is called *subvitreous.* This is the characteristic luster of quartz.

Resinous is the luster of ordinary rosin. It gives the name "Rosin Jack" to some varieties of zinc blende.

Greasy, looking as if smeared with oil or grease; this luster is occasionally observed in quartz, and in some varieties of serpentine and steatite.

Pearly, like pearl; it is frequently found in such minerals as mica, talc, and gypsum, which are made up of very thin leaves, or layers. Pearly luster combined with submetallic luster forms *metallic-pearly* luster.

Silky, like silk, is the result of a fibrous structure, like that of asbestos, or of fibrous gypsum.

Adamantine, the luster of the diamond. Minerals having this luster may also be submetallic; in such cases the luster is called *metallic-adamantine*. Cerussite and pyrargyrite have such a luster.

Besides the different kinds of luster, there are different degrees of *intensity* of luster, depending on the clearness of the reflection. These are:

Splendent, when the surface is a perfect mirror, reflecting light with great brilliancy, and giving well-defined images.

Shining, when an image is produced, but not a clearly defined image.

Glistening, or *sheeny*, when there is a general reflection of light from the whole surface, but no image.

Glimmering, when the reflection is very imperfect, and the reflected light comes to the eye not from the entire surface, but from a number of separate points scattered over the surface.

Where there is a total absence of luster the mineral is said to be *dull*, or *earthy*. Chalk is a good example of this condition.

7. The **feel** (or feeling) of a substance is of importance in the case of a few minerals, such as talc and the talcose minerals. It will be readily recognized from the terms used to define it, as *greasy*, *smooth*, *harsh*, *gritty*, etc.

8. Structure.—Among minerals will be found a variety of **structure.** Most mineral specimens are aggregations of imperfect crystals. Even those whose structure to the naked eye appears destitute of crystallization are probably composed of impalpable crystalline grains. The structure of a mineral is said to be:

Columnar, when it is made up of slender columns or fibers. The several varieties of columnar structure are classified as follows: (*a*) *Fibrous*, when the columns or fibers are parallel, as in asbestos; (*b*) *reticulated*, when the fibers cross in various directions, and assume a net-like appearance; (*c*) *stellated*, when the fibers radiate from the center and produce star-like forms; (*d*) *radiated*, when the fibers radiate from a center without producing star-like forms, as sometimes in stibnite.

Lamellar, when it consists of plates, or leaves. These leaves may be curved or straight; in either case the structure is so described; and they may also be very thin and easily separable—a *micaceous* structure.

Granular, when it is composed of crystalline grains. If the grains are not to be distinguished by the naked eye, the structure is said to be *impalpable*.

Drusy, when covered with fine crystals so that the surface is rough like sandpaper.

Different minerals also assume many imitative forms; these are: *Reniform*, kidney-shaped; *botryoidal*, like a bunch of grapes; *mammillary*, breast-shaped, resembling botryoidal, but composed of larger prominences; *dendritic*, branching, tree-like; *filiform* or *capillary*, very long and slender crystals, like a thread or hair; *acicular*, slender and rigid, like a needle; *stalactitic* and *stalagmitic*, like the stalactites and stalagmites found on the roofs and floors, respectively, of caves.

9. Cleavage.—Most minerals have certain directions in which they yield most readily to a blow; this tendency to break in the direction of certain planes is called **cleavage.** The different degrees of cleavage are classified as follows:

Perfect, or *eminent*, when obtained with great ease, affording smooth, lustrous faces, as in calcite, mica, and galena. Eminent is used only in reference to the most perfect and pronounced cleavage.

Distinct, when obtained with tolerable ease, and with fairly good cleavage faces, but neither so easy nor so complete as perfect cleavage.

Indistinct, when obtained with some difficulty, and the cleavage faces and angles are not well defined.

Difficult, when obtained only with considerable difficulty, and barely discernible. Cleavage of this sort is very apt to be only in *traces;* that is, with a bit of cleavage face showing here and there.

Interrupted, when the cleavage face discontinues abruptly, only to be continued in another cleavage plane parallel to the first. This condition may occur in minerals having perfect or distinct cleavage.

The inferior degrees of cleavage are of themselves of no value in identifying minerals; but the absence of cleavage, or very poor cleavage, will sometimes serve to distinguish a mineral from minerals similar to it in appearance, but having more pronounced cleavage.

10. Fracture.—The term **fracture** is used to define the surface obtained by breaking a specimen in any direction except along a cleavage plane. The different kinds of fracture have been classified as follows:

Conchoidal, when the mineral breaks so as to give a curved or shell-like surface.

Even, when the fractured surface is approximately regular, though perhaps somewhat rough.

Uneven, when the fractured surface is irregular and rough.

Fracture is characteristic of a few minerals only, and then, like the inferior degrees of cleavage, is valuable to distinguish minerals from others having a similar appearance but a different fracture.

11. By **hardness** is meant the resistance that a mineral offers to abrasion. Thus, talc can be scratched by the finger nail, while the diamond is the hardest substance known. As minerals differ in this characteristic, and as each has usually a more or less constant hardness, Moh arranged a scale to measure the different degrees of resistance to abrasion offered by minerals as follows:

1. *Talc*, easily scratched by the finger nail.
2. *Gypsum*, scratched with difficulty by the finger nail; does not scratch a copper coin.

3. *Calcite*, scratches pure copper; not scratched by the finger nail.

4. *Fluorite*, not scratched by a copper coin; does not scratch glass.

5. *Apatite*, scratches glass with difficulty; easily scratched by a knife.

6. *Feldspar* (*orthoclase*, *etc.*), scratched with difficulty by a knife; scratches glass easily.

7. *Quartz*, not scratched by a knife; yields with difficulty to a file.

8. *Topaz*, harder than quartz; very few substances are as hard as this.

9. *Corundum*, hardest substance known except the diamond.

10. *Diamond*, the hardest substance known.

The hardness of any mineral is determined by ascertaining a point in the scale such that the given mineral will scratch any mineral in the scale below that point, and will be scratched by any mineral above the point. If no set of minerals comprising the scale of hardness is available, a mineral may be tested very well by the finger nail, copper coin, and knife. In case a mineral will scratch the mineral in the scale below, but is scratched by the mineral in the scale next above, its hardness is said to be half way between the two, and is written, for instance, as 3.5, 4.5, etc.

12. The **tenacity** of a substance is the persistency with which its particles cling together. This is different in different substances, but, like hardness, is more or less constant for any one substance. The different degrees of tenacity have been classified as follows:

Brittle, when the substance flies to pieces under a sharp blow, and powders under the edge of a knife in the attempt to cut it, like galena.

Sectile, when pieces may be cut off with a knife without falling to powder, but the substance still goes to pieces under the hammer. This is really a condition intermediate between brittle and malleable.

Malleable, when the substance can be beaten out under the hammer without flying to pieces, like gold.

Ductile, when the substance can be extended or drawn out by tension, as in wire drawing. Ductility is only another phase of the same property as malleability, and is possessed to a remarkable degree by gold, silver, iron, and copper, and some of the rarer metals.

Flexible, when the substance can be bent. Substances which are malleable and ductile are usually also flexible.

Elastic, when the substance can be bent or otherwise distorted, but returns to its original form as soon as the distorting force is removed. Steel is remarkably elastic. Highly elastic substances are usually more or less brittle.

13. The **specific gravity** of a substance is the ratio of the weight of a given volume of that substance to the weight of an equal volume of another substance, whose specific gravity is assumed to be unity (1). Water is the accepted standard, and its specific gravity is consequently considered as 1 (or unity). The specific gravity of a mineral may be determined thus:

Find the weight of the fragment out of water, just as you would weigh anything else; this weight = w. Then suspend the fragment by a fine, silk thread to the balance beam, submerge it in water and weigh again; this weight = w_1. Since the loss of weight of a solid submerged in water is equal to the weight of the volume of water displaced, $w - w_1$ = the weight of a volume of water equal to the volume of the mineral, and the specific gravity of the mineral = $\frac{w}{w - w_1}$.

The weights should be accurately taken on a good chemical balance, and the water should be distilled; and as the density of water varies with its temperature, in order to obtain uniform results 60° F. has been adopted as a convenient temperature.

EXAMINATION OF MINERAL SPECIMENS

CRYSTALLOGRAPHY

14. Introduction.—In the preliminary **examination of mineral specimens,** the student must note clearly all striking physical characteristics; the hardness should be determined, and the specific gravity, as nearly as possible, with the appliances at hand. These results will, of course, suggest to the student more or less about the specimen, according to his familiarity with minerals. Finally, the specimen should be thoroughly examined before the blowpipe, when it can be determined with reasonable certainty.

15. Crystals.—When chemical compounds solidify from a state of fusion, solution, or vapor they have a tendency to assume regular geometrical (*polyhedral*) forms bounded by plane faces; such forms are called **crystals.** The process of assuming this crystalline form is called **crystallization.** Different substances crystallize with greater or less ease according to their composition and physical condition; while the forms of crystals differ with different substances and with the same substance under different conditions, but usually each mineral has a definite crystallization, by which it may often be distinguished.

Crystallography is the science that treats of the forms and structure of crystals, and as minerals often occur in crystalline form, a knowledge of crystallography is of great importance in their identification.

16. Crystal Structure.—The most noticeable characteristic of all crystals is their superficial appearance. It is true that mineral crystals are rarely perfect, but even whe greatly distorted and some of the faces entirely obliterate it can be seen that they were developed from perfect form

The regular external form of crystals results from regular internal structure in which the particles of matte making up the body are similarly grouped along parall lines or planes. This structure can be shown to exist i crystalline bodies, even when distinct crystals are wanting by the cleavage; by the power of transmitting light and con ducting heat and electricity, which are always the same i parallel directions but may or may not be the same in direc tions not parallel; and by the corresponding luster an color of parallel surfaces. In homogeneous bodies, in whic there is no regularity of structure, these properties are no exhibited. For example, a piece of glass shows none c these properties regularly in one direction to a differen degree than in another. Such substances are said to b *amorphous;* that is, without form. The same substance may occur under differing conditions in either the crysta line or amorphous state. Sometimes substances are foun in crystals of a form belonging to another substance; suc crystals are called *pseudomorphs*, or false forms. Pseudo morphs are formed by the chemical change of a crystal b which it becomes converted into some other mineral. Suc crystals are said to be pseudomorphous after the origin substance.

17. Properties of Crystals.—The growth of crystals i due to additions of successive layers of the substance com posing them, on the outside, in such a manner as to develo the plane faces of the crystals. The number of faces tha occur on a crystal is always fewer than the number c mathematically possible planes for that system. It is nc uncommon to find substances of exactly the same chemic composition and physical properties crystallized in polyhedr bounded by entirely different sets of planes. This propert that some substances have of crystallizing in different form is called **crystal habit.**

The plane faces of crystals, with very few exceptions, always occur in pairs, parallel to one another and on opposite sides of the crystal. When two adjacent faces intersect one another, they make an angle called an *interfacial angle;* the solid angle formed by the intersection of three or more faces is called a *crystal angle.* The line of intersection of the faces is called an *edge.*

LAWS OF CRYSTALS

18. In studying crystals the following three laws are of importance:

(1) *The law of constancy of interfacial angles;* (2) *the law of symmetry;* (3) *the law of simple mathematical ratio.*

19. Law of Constancy of Interfacial Angles.—*The angles between corresponding faces of different crystals of the same substance are constant, no matter how much the crystal faces may be developed or what the habit may be.*

20. Law of Symmetry.—*The faces of all crystals are symmetrically grouped with reference to a central point or to certain planes or lines passing through the center of the crystal.*

The planes, or lines, to which the crystal faces are symmetrical are called, respectively, *symmetry planes* and *symmetry axes.*

A symmetry plane is an imaginary plane passing through the center of a crystal and dividing it in such a way that every point on the surface of the crystal on one side of the dividing plane has a corresponding point directly opposite, and at the same distance from the plane, on the other side. There are two kinds of planes of symmetry, *principal*, and *secondary*. **Principal planes** of symmetry are those planes that contain two or more equivalent or interchangeable lines or directions; that is, if the crystal is rotated around an axis at right angles to the plane of symmetry at its center until these equivalent lines exchange positions, the appearance of the crystal remains unchanged. **Secondary planes** of symmetry can contain no equivalent lines or directions.

A **symmetry axis**, is an imaginary line through the center of a crystal, perpendicular to a symmetry plane and connecting either the centers of opposite crystal faces or the vertices of opposite crystal angles. Axes of symmetry are also called *principal* and *secondary*, according as they are perpendicular to a principal or a secondary plane of symmetry. The difference between principal and secondary planes and axes of symmetry can be understood by reference to Fig. 1, which represents a tetragonal octahedron. The lateral axes $a - a$ and $a' - a'$ are of equal length while the vertical axis $c - c$ is longer. The planes $a a' - a - a'$ and $c a - c - a$ are both planes of symmetry. If the crystal be revolved about the axes $c - c$ 90°, the axes, or lines, $a - a$ and $a' - a'$ are found to be equivalent and interchangeable; hence, $a a' - a - a'$ is a principal plane of symmetry. If, however, the crystal be revolved about the axis $a - a$, the axes $a' - a$ and $c - c$ do not coincide, as they are of unequal length and are not equivalent and interchangeable; hence, $c a - c - a$ is a secondary plane of symmetry, and $c - c$ is a principal axis and $a' - a'$ is a secondary axis.

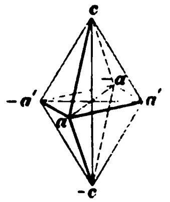


Fig. 1

21. Law of Simple Mathematical Ratio.—In order to classify and describe crystals, it is necessary to have some method of expressing mathematically the position of the crystal faces. The method adopted is to express the relative distances of the intersection of the planes of the faces with three or more lines or axes called **crystallographic axes,** intersecting at the center of the crystal. The symmetry axes are always taken as the crystallographic axes. The actual distances, or intercepts, on the axes are not considered, only their relative lengths, or the ratio they bear to one another; that is, parallel planes are always expressed by the same ratio.

Law.—*In all crystals of the same substance, if any face be taken as a unit, the axial intercepts of all other faces, expressed in terms of the corresponding intercepts of the unit face, will be either simple numbers, simple fractions, or infinity (when the face is parallel to an axis).*

SYSTEMS OF CRYSTALLIZATION

22. For convenience in classification, all crystal forms may be divided into six systems, according to the number and kinds of their planes of symmetry, which depend on the number, length, and inclination of the axes. These systems are the *isometric*, *tetragonal*, *hexagonal*, *orthorhombic*, *monoclinic*, and *triclinic*. The distinguishing characteristics of each system are as follows:

The *isometric system* has three axes of equal length intersecting one another at right angles; three principal planes of symmetry at right angles to each other; and six secondary planes that bisect each of the angles between the principal planes.

The *tetragonal system* has three axes, intersecting one another at right angles: two, which are of equal length, are considered as lateral axes; the third is the vertical axis, and may be either longer or shorter than the other two. This system has one principal plane of symmetry, and four secondary planes at 45° to each other and at right angles to the principal plane.

The *hexagonal system* has four axes; the three lateral axes are equal, intersect one another at angles of 60°, and are at right angles to the vertical axis, which is of different length. This system has one principal plane of symmetry, and six secondary planes at 30° to each other and at right angles to the principal plane.

The *orthorhombic system* has three axes, intersecting one another at right angles, but no two are of the same length. In this system there are three secondary planes of symmetry at right angles to one another.

The *monoclinic system* has three axes; the vertical ax[redacted]s and one lateral axis (the one running from front to bac[redacted]) are oblique to each other, but the transverse lateral axis i[redacted] at right angles to both of the others. In this system ther[redacted] is one secondary plane of symmetry.

The *triclinic system* has three axes, all oblique to one another. Crystals of this system are symmetrical to a cen[redacted]tral point only.

ISOMETRIC SYSTEM

23. The crystal axes of the **isometric system** being al of the same length, and all at right angles to one another[redacted] it is immaterial which one is selected as the vertical axis, a[redacted] the shape of the crystal is the same with reference to all o[redacted] them. Fig. 2 shows the holohedral, or complete, forms o[redacted] the isometric system. It will be noticed that the faces o[redacted] any one of these forms are alike. The distinguishing characteristics of these forms are as follows:

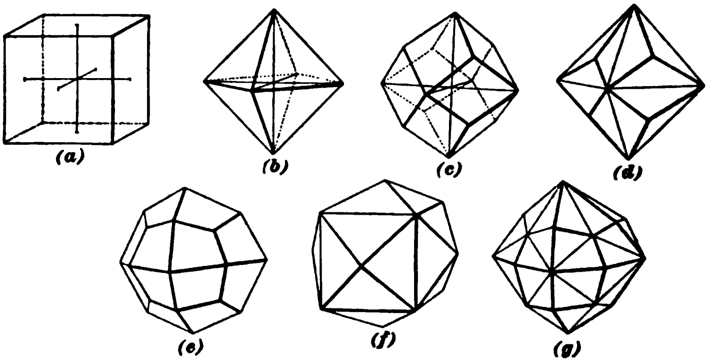


FIG. 2

Cube, or *hexahedron* (*a*), has six square faces meeting at right angles, each of which is parallel to two axes as shown.

Octahedron (*b*) has eight faces, each of which is an equilateral (equal sided) triangle. The axes are cut by the planes of the faces at the vertices of the crystal angles.

Dodecahedron (*c*) has twelve diamond-shaped faces and fourteen crystal angles. The position of the axes is as shown.

Trisoctahedron, or more accurately *trigonal trisoctahedron* (*d*), has twenty-four triangular faces. Comparing it with the octahedron (*b*), it is seen that it differs from it by having each face of the latter replaced by three trigonal (three-cornered) faces, which form a low pyramid.

Trapezohedron, *tetragonal trisoctahedron*, or *icositetrahedron* (*e*), has twenty-four faces, each of which is an irregular four-sided figure called a *trapezium*. Like the preceding form, the trapezohedron resembles the octahedron by having each face of the latter replaced by three trapezoidal faces.

Tetrahexahedron (*f*) has twenty-four triangular faces, arranged in groups of four. Each group forms a low, square pyramid, the base of which corresponds to one of the faces of the cube, or hexahedron, hence its name.

Hexoctahedron (*g*) has forty-eight faces, arranged in eight groups of six triangular faces each. The general form is that of the octahedron, each group of six faces corresponding to a face of the octahedron.

24. Combination of Isometric Holohedral Forms. The simple forms frequently occur in combination with one another, producing a great variety in the shape and number of faces of the crystals. A few of these combined forms are shown in Fig. 3: (*a*) is a combination of a cube and an octahedron; (*b*), a cube and a trapezohedron; (*c*), an octahedron and a dodecahedron.


(*a*) (*b*) (*c*)

FIG. 3

25. Hemihedral Forms. — Besides these ordinary, whole, or *holohedral* (all-sided) *forms*, the elementary *hemihedral forms* should be included in a list of elementary forms. **Hemihedral forms** have only every other face developed; the intermediate ones are omitted. Thus, if in the octahedron (*b*), Fig. 2, each alternate face be omitted and the planes of the remaining faces be extended till they intersect one another, there will be a new form—the *tetrahedron*, or four-faced form, which is shown in Fig. 4 (*a*).

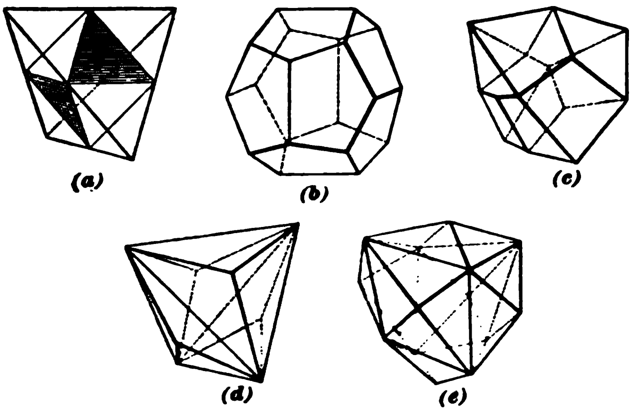


FIG. 4

In the figure, the two shaded faces of the small octahedron included in the tetrahedron illustrate how the alternate faces are developed. The tetrahexahedron, treated in the same way, gives the *pentagonal dodecahedron*, or *pyritohedron* (twelve-faced form), shown at (*b*). The hemihedral forms of the trisoctahedron, trapezohedron, and hexoctahedron, which are shown at (*c*), (*d*), and (*e*), respectively, are obtained in the same general way, but instead of developing every other face, as in the other forms, the faces are developed in alternate sets, corresponding to the faces of an octahedron. Every face in one octant is developed; then the next adjacent set is skipped and the faces in the third octant developed, and so on around, developing all the faces in each alternate octant. The faces of a trisoctahedron, developed in this way, intersect one another to form the trapezoidal faces of the *tetragonal tristetrahedron* (*c*), while the faces of the trapezohedron intersect to form the triangular faces of the *trigonal tristetrahedron* (*d*), and the faces of the hexoctahedron remain unchanged in the *hextetrahedron* (*e*). The forms given in Fig. 4 are all the elementary hemihedral forms. Like the whole forms, they combine among themselves in great variety; but hemihedral forms do not combine with holohedral forms.

TETRAGONAL SYSTEM

26. In considering a crystal of the **tetragonal system,** the two equal axes are always assumed as the lateral axes, and the odd axis becomes the vertical axis. The elementary forms of this system are square and octagonal prisms, and

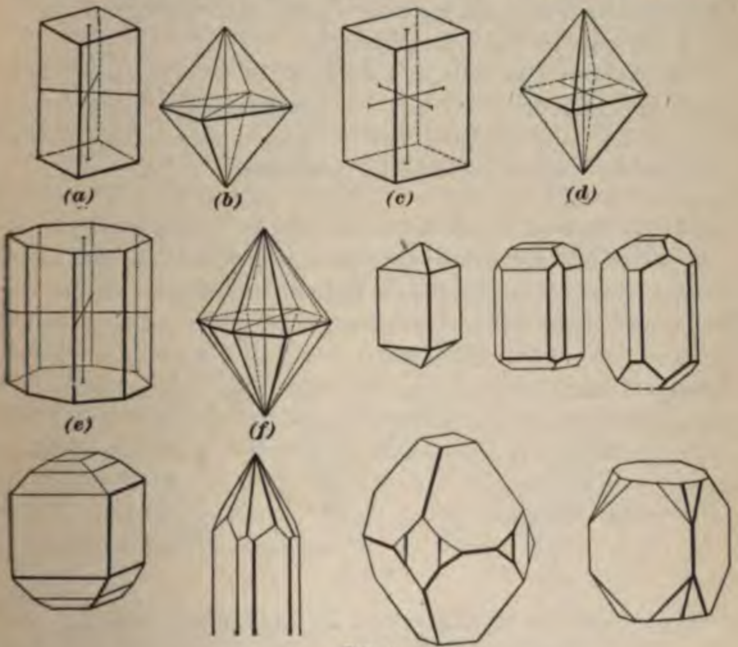


FIG. 5

double-ended square pyramids (octahedrons) and octagonal pyramids. As in the isometric system, a great variety of forms results from the combination of these elementary forms.

Both the prisms and the pyramids of the tetragonal system may be divided into two classes: *direct* and *indirect*. In the direct forms, the crystal faces intersect both lateral axes, as at (*a*) and (*b*), Fig. 5; in the indirect forms, the faces cut one lateral axis and are parallel to the other, as at (*c*) and (*d*). In all the systems except the isometric, a face parallel to both lateral axes is called a *basal plane*. Such are the faces closing the top and bottom of an ordinary prism. Cleavage parallel to a basal plane is known as *basal cleavage;* parallel to the faces of a prism, as *prismatic cleavage;* parallel to the faces of an octahedron, as *octahedral cleavage*, etc.; the cleavage in every case taking its name from the face to which it is parallel.

Fig. 5 shows the simpler forms of the tetragonal system. With the exception of the four forms already described (*a*), (*b*), (*c*), and (*d*), and the octagonal prism (*e*) and the pyramid (*f*), the forms are all compound.

27. The **hemihedral forms** of the tetragonal system, some of which are shown in Fig. 6, are derived in the same way as those of the isometric system. The tetrahedron (*a*) is derived from the octahedron; the ditetrahedron (*b*) is derived from the dioctahedron, or octagonal pyramid; and the prism, which is shown at (*c*), with its corners cut off by the faces of the ditetrahedron, is derived from the octagonal prism.

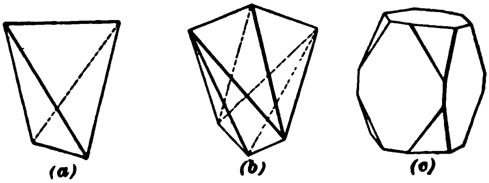

(a) (b) (c)

FIG. 6

It is somewhat difficult to distinguish certain tetragonal forms from similar isometric forms. This is particularly true of the octahedrons and their half forms, the tetrahedrons, in which there is no distinction, except that one axis of the tetragonal forms is longer or shorter than the other two, while all three axes of the isometric forms are of equal length, so that the faces of the isometric crystals are equilateral triangles, while the faces of the tetragonal crystals have only two sides of the triangle equal. Even this distinction is frequently destroyed by a distortion of the isometric crystals, so that the three axes are no longer equal. In such a case one must refer to the angles formed by the intersection of crystal faces, which remain unchanged, no matter how great may be the distortion of the crystal. Thus, if the angle at the vertex of an eight-sided crystal is *exactly* a right angle, it is known at once that the form is an isometric octahedron, for the vertex angles of the tetragonal and orthorhombic octahedrons are never exactly right angles. In the case of the isometric cube and the tetragonal and orthorhombic prisms, the distinction is much more simple, as, no matter how badly distorted the crystal may be, all the faces of an isometric crystal have exactly the same luster and markings; while the basal plane in the tetragonal and orthorhombic systems has a somewhat different appearance from the prism faces; and in the orthorhombic system the two sets of parallel prism faces differ in appearance from each other, as well as from the basal planes—a characteristic that serves to distinguish orthorhombic prisms from distorted tetragonal prisms. Distorted tetragonal pyramids are similarly distinguished from orthorhombic pyramids, the luster of adjacent faces of the latter being different, while that of opposite faces is identical.

HEXAGONAL SYSTEM

28. The **hexagonal system** is very closely allied to the tetragonal system. All the forms of the latter system have exactly corresponding forms in the hexagonal system; there being three equal lateral crystal axes in the hexagonal system, however, all the lateral faces of hexagonal forms occur in multiples of three, while in the tetragonal system they occur in multiples of two, only. The angles between lateral faces also differ correspondingly.

The elementary forms of the system are direct and indirect hexagonal prisms and pyramids (called prisms and pyramids of the *first order* and *second order*, respectively), dihexagonal prisms and pyramids—corresponding to the octagonal prisms and pyramids of the tetragonal system—and basal planes. These forms are shown in Fig. 7.

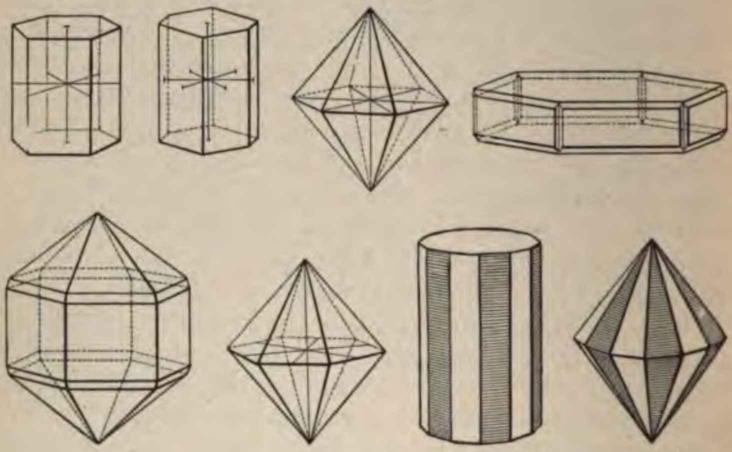


FIG. 7

29. Hexagonal Hemihedral Forms.—The **hemihedral forms** of the hexagonal system are more abundant in nature, and, consequently, more important than the holohedral forms. There are two distinct classes of hemihedral forms in this system. The elementary forms of the first class, which are called *pyramidal hemihedral forms*, are only two in number, and are derived by developing the faces in the alternate sections of the crystal forms between the six vertical symmetry planes. Thus, if in the dihexagonal prism the alternate prism faces, which are shown shaded in Fig. 7, are developed, a hexagonal prism of the third order results; and by the development of the shaded faces of the dihexagonal pyramid, a hexagonal pyramid of the third order results. The prisms and pyramids of the third order can be distinguished from those of the first and second orders only through their association with other hemihedral forms.

The hemihedral forms of the second class, called *rhombohedral hemihedral forms*, are derived in the ordinary manner, each alternate crystal face above and below the horizontal symmetry plane being developed. The class derives its name from the most common and characteristic form—the *rhombohedron*—which is the hemihedral form of the hexagonal pyramid. The rhombohedral hemihedral form of the dihexagonal prism is the *scalenohedron*, a double-ended hexagonal prism, each face of which is a scalene triangle (a triangle with no two sides equal).

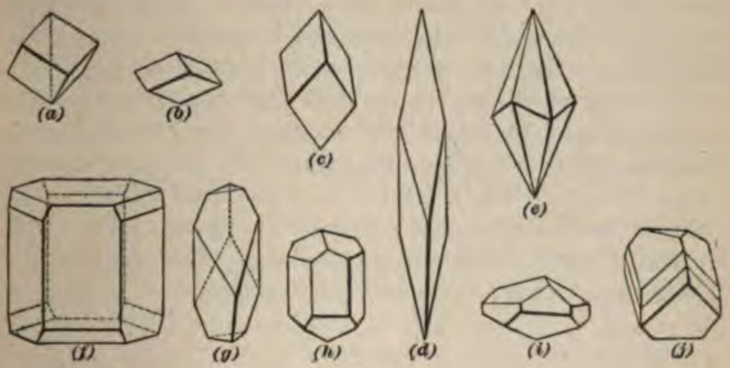


FIG. 8

Calcite always crystallizes in the rhombohedral-hexagonal system, and so also do dolomite and siderite. Calcite crystals assume a great variety of forms; Fig. 8 represents some of the many characteristic forms. The forms from (*a*) to (*d*) are rhombohedrons; (*e*) is a scalenohedron; (*f*), prisms with rhombohedron and basal plane; (*g*), a rhombohedron with basal plane; (*h*) and (*i*), prism and rhombohedrons; while (*j*) shows a rhombohedron, scalenohedron, and basal plane.

It is sometimes very difficult to distinguish rhombohedrons from cubes, but the faces of a rhombohedron are never exactly square, or even rectangular, but are always more or less diamond-shaped. The vertical axis in the rhombohedron always connects two opposite solid angles, while in the cube it connects the centers of opposite faces.

Rhombohedral hemihedral forms may be easily distinguished from any other forms from the fact that the intersection of the upper and lower pyramidal faces of this class with one another, or with prism faces, forms a broken, jagged line, with angles alternately above and below an intermediate horizontal plane, whereas the basal edges of pyramidal faces in all other forms are horizonal.

Prisms and pyramids of the third order have still further hemihedral forms, formed in the ordinary manner, and called *tetartohedral forms*, because they have developed only one-fourth of the faces of the holohedral forms. The principal forms are a rhombohedron, identical with the rhombohedron of the rhombohedral section, and a trapezohedron, almost identical in form with the rhombohedron, the only difference being that each of the six faces is trapezoidal (has four sides, in two pairs of equal sides, but the sides of one pair are not equal to the sides of the other) instead of rhomboidal (diamond-shaped—four equal sides). These forms sometimes occur in quartz crystals.

ORTHORHOMBIC SYSTEM

30. The three axes of the **orthorhombic system** being all of different lengths, but at right angles to one another, any one of them may become the vertical axis, the selection resting with the operator, and usually depending more or less on the general shape of the crystal. For instance, if the crystal is flat and tabular, the main faces of the tablet are usually considered as basal planes; while if it is long and prismatic, pyramidal, or barrel-shaped, the longest axis is usually selected as the vertical axis. The longer lateral axis is usually selected as the transverse axis.

The crystal forms of this system correspond to those of the tetragonal system. The direct prisms and pyramids correspond exactly with the similar tetragonal forms, except in the different luster and markings of adjacent faces and the measurement of the solid crystal angles (angles made by the intersection of three or more faces). Instead of the indirect prism, however, there are two pairs of parallel, vertical faces, which, when both pairs are developed, intersect to form a vertical, rectangular prism with its faces parallel to the lateral axes of the crystal; the pair of faces parallel to the longer, or *macro-*, axis constitutes a *macropinacoid*, and the pair parallel to the shorter, or *brachy-*, axis is a *brachypinacoid*. And in the same way, instead of the indirect pyramid, we have two horizontal prisms, each formed by the four faces parallel to one lateral axis and cutting the other lateral axis and the vertical axis; the faces of the prism parallel to the longer lateral axis (the macro-axis) constitute a *macrodome*, and those parallel to the brachy-axis constitute a *brachydome*. If both domes are developed, the resulting form is a rectangular pyramid, or octahedron.

31. Fig. 9 shows the principal simple forms of this system. There is only one purely elementary form—the true octahedron, or pyramid, shown at (*a*). The other forms of the system are, necessarily, all compounds of two or more forms, as, excepting the pyramid, none of the forms has more than four faces, and the basal planes and pinacoids have only two, and it requires at least six faces to form a complete holohedral crystal. The hemihedral forms of the system are unimportant—in fact, so far as is known, there are no true hemihedral orthorhombic forms in nature—hence they will not be discussed. The forms shown in Fig. 9 are as follows: (*a*) Octahedron or pyramid; (*b*) prism *1 1*, and basal plane *2*; (*c*) pinacoidal prism, made up of macropinacoid *1* and brachypinacoid *2*, and basal plane *3*; (*d*) tabular prism, made up like (*c*), but with the long edges beveled by

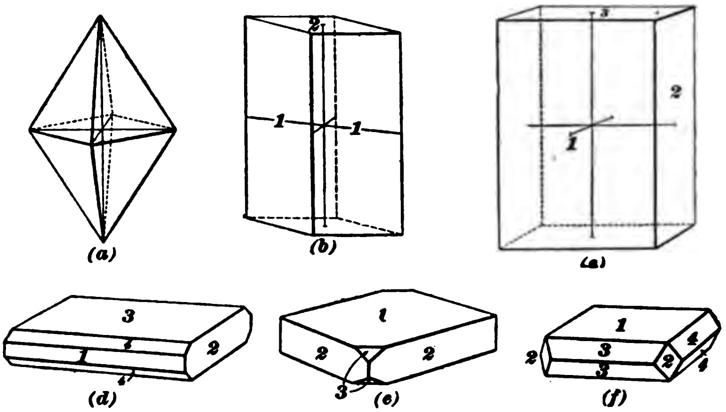


FIG. 9

a macrodome *4*; (*e*) basal plane *1* and prism *2 2*, with front and back corners truncated by a macrodome *3 3*; (*f*) basal plane *1*, prism *2 2*, macrodome *3 3*, and brachydome *4 4* The tabular orthorhombic forms are very characteristic of the mineral barite.

MONOCLINIC SYSTEM

32. The crystals of the **monoclinic system** are symmetrical with reference to only one plane. In examining a crystal of this system, the symmetry plane is always considered as being vertical and running from front to back; the symmetry axis, therefore, coincides with the transverse lateral crystal axis. This axis, being at right angles to the symmetry plane, is, consequently, at right angles to both the other axes, since they both lie in that plane, and for this reason it is called the *ortho-* (right) *axis*. The other lateral axis is oblique to the vertical axis, inclining from back to front, and is called the *clino-* (inclined) *axis*.

The forms of this system are prisms, pinacoids, pyramids, domes, and basal planes, as in the orthorhombic system. Instead of macrodome, brachydome, and pinacoids, however, we have the *orthodome* and *orthopinacoid* with their faces parallel to the ortho-axis, and the *clinodome* and *clinopinacoid* with their faces parallel to the clino-axis.

The elementary forms whose faces intersect both the clino-axis and the vertical axis are divided into two classes—positive and negative—according to the position of their faces with reference to the central angles of the crystal. Thus, if a plane be assumed through the vertical axis and the ortho-axis, and another through the two lateral axes, these planes will, of course, intersect each other along the ortho-axis, as it is common to both of them, and at their intersection will form four plane angles, the alternate angles being equal, but one pair—the top-front and lower-back angles—being larger than the other pair, on account of the inclination of the clino-axis; and all crystal forms whose faces are in the two sections of the crystal lying within the planes of the two larger plane angles are known as *positive*, while those whose faces are in the smaller sections are known as *negative*. Fig. 10 shows the four faces forming a positive pyramid. The prism, clinodome, and the pyramid are made up of four faces each; the orthodomes, pinacoids, and basal plane have only two faces to each form.

FIG. 10

33. As the least number of faces a solid, holohedral crystal of any form can have is six, none of these elementary forms occurs alone in nature; but all monoclinic crystals are made up of combinations of two or more of the elementary forms. In Fig. 11 are shown a few of the simpler and more common forms. To assist the student in identifying them each kind of face is numbered: *1*, orthopinacoidal face; *2*, clinopinacoidal face; *3*, prism face; +*4*, positive pyramidal face; −*4*, negative pyramidal face; +*5*, positive orthodome face; −*5*, negative orthodome face; *6*, clinodome; 7, basal plane.

The last three forms are called *twinned* crystals, twinning being merely a combination of two (or more) crystals of the same form, but with their axes in different positions. It sometimes produces what are apparently entirely new forms, but generally the individual forms can be readily distinguished. Twinned crystals usually have reentrant, or concave, angles, by which they can be readily distinguished from normal crystals, in which concave angles never occur. They may frequently be recognized also by the tiny ridges or striæ on the common face, meeting in a line down the middle of the face, as in the case of gypsum, shown normal

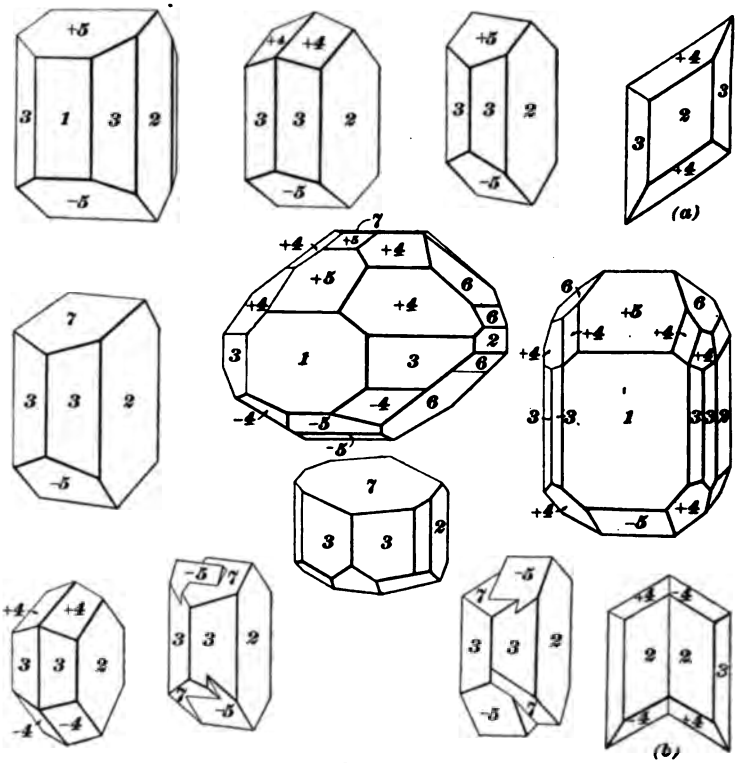


FIG. 11

at (*a*) and twinned at (*b*). This indicates that the face is really made up of two faces in the same plane, but with their striæ in different positions.

TRICLINIC SYSTEM

34. As the axes of the **triclinic system** are all of different lengths and all inclined to one another, the system can have no symmetry planes, and there can, under no circumstances, be more than two faces of a kind identical in form, luster, and position with reference to the axes. The simplest crystals thus require at least three different forms to complete the crystal. Thus, the simplest prismatic crystal is made up of two sets of prism faces (two faces to a set)—or the prism may be made up of two sets of pinacoidal faces—and a pair of basal planes; six faces in all, representing three different forms.

The forms of the triclinic system are practically the same as those of the monoclinic prisms—pyramids, domes, pinacoids, and basal planes. Since both lateral axes are inclined to the vertical axis, however, one cannot very well specify either as the clino-axis, so the terms *macro-* and *brachy-* are used to distinguish the long and short lateral axes, respectively, as in the orthorhombic system; the domes and pinacoids are distinguished in the same way, macrodomes and macropinacoids having their faces parallel to the longer lateral axis, and the faces of brachydomes and brachypinacoids being parallel to the shorter lateral axis.

Fig. 12 shows some of the simpler triclinic crystals with the faces of the different forms marked as follows: *1*, Macropinacoid; *2*, brachypinacoid; +*3*, positive prism; −*3*, negative prism; +*4*, positive macrodome; −*4*, negative macrodome; +*5*, positive brachydome; −*5*, negative brachydome; *6*, pyramid; *7*, basal plane.

Occasionally the inclination of the lateral axes to each other is so slight that it becomes very difficult to distinguish the triclinic forms from similar monoclinic forms. In such a case the student should remember that the angle between the pinacoidal crystal (and cleavage) faces of the monoclinic crystals is always exactly a right angle, while in the triclinic system there is never any angle less than 3° or 4° away from a right angle.

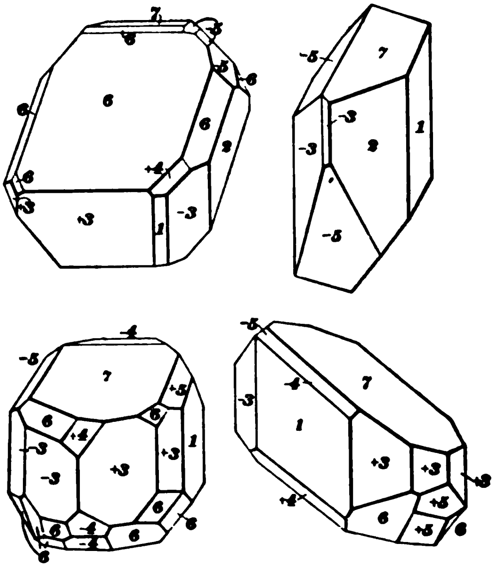


FIG. 12

DISTORTION

35. Natural crystals are usually more or less distorted—in fact, perfect natural crystals are comparatively rare. The crystal axes are extended lineally, destroying their proper proportion to one another, and making faces that should be identical in shape, very different; or the axes may be bent or twisted—sometimes very much so, twisting completely around—giving curved crystal faces instead of the normal planes. This curvature of the crystal axes appears to be characteristic of a few certain minerals, as dolomite, siderite, quartz, and chlorite, but linear distortion is common in all minerals.

However badly a crystal may be distorted, it nevertheless always retains certain characteristics of its crystal system, by which it can be identified. Besides the similar luster and markings of corresponding faces, which have already been discussed, the fact is that the crystal axes, however badly they may be distorted as to relative length, are never distorted as to their relative position to one another; that is, if all or any two of the axes in the normal crystal intersect at a given angle, this angle is maintained in the distorted crystal, and the corresponding angles between the faces are likewise never distorted. Thus, in Fig. 13, there are shown a normal isometric octahedron and three distorted octahedrons, and it will be seen that the faces on the distorted forms are in every case exactly parallel to the corresponding faces in the normal form. Fig. 14 shows a dodecahedron treated in the same way. This same peculiarity runs through all the systems, and forms an infallible guide in identifying them.

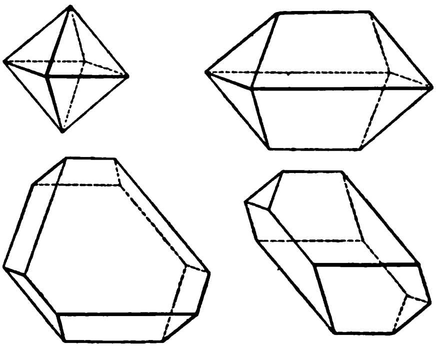


FIG. 13

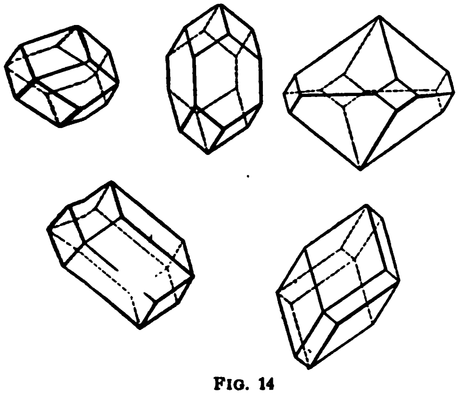


FIG. 14

MINERALOGY

(PART 2)

DESCRIPTIVE MINERALOGY

1. Introduction.—The following descriptions of the minerals are arranged according to the alphabetical order of the name of the principal element contained in the mineral; for example, cryolite is found under the aluminum minerals; gypsum under the calcium minerals, etc. Coal, petroleum, etc., and other hydrocarbon minerals are described together under carbon and hydrocarbon minerals.

ALUMINUM MINERALS

2. Corundum is **aluminum trioxide,** or **alumina,** Al_2O_3. Aluminum, 52.9 per cent.; oxygen, 47.1 per cent. It occurs crystalline, also massive and granular, and crystallizes in the hexagonal system in acute pyramids, Fig. 1 (*a*), or in truncated barrel-shaped prisms (*b*). It usually contains small amounts of impurities that affect the color and specific gravity. *Color*, white, gray, yellow, red, blue, green, brown, or black; *streak*, white; transparent to opaque; *luster*, adamantine to vitreous; *tenacity*, brittle to tough; *cleavage*, rhombohedral; G varies from 3.94 to

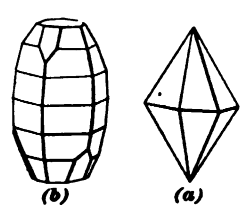


FIG. 1

4.16, depending on the purity. $H = 9$, being, next to the diamond, the hardest substance known.

Tests for Identification.—B. B. unchanged either alone or with soda. When powdered, treated with cobalt-nitrate solution, and ignited, it becomes blue. It is insoluble.

Varieties.—The clear, colored varieties are highly prized as gems. The blue is called sapphire; red, the oriental ruby; violet, the oriental amethyst; green, the oriental emerald; and yellow, the oriental topaz. Emery is an impure variety of corundum that contains considerable iron. Both emery and corundum are ground to various degrees of fineness and used as an abrasive for grinding and polishing.

3. Diaspore is a hydrated aluminum oxide, $Al_2O_2(OH)_2$. Al_2O_3, 85.1 per cent.; water, 14.9 per cent. It occurs in thin, flat, orthorhombic prisms, foliated masses, or thin scales. *Color*, gray, white, pink, yellow, and brown; *streak*, white; transparent to translucent; *luster*, pearly and vitreous; *tenacity*, very brittle, cleaves into plates; $H = 6.5$ to 7; $G = 3.3$ to 3.5.

Tests for Identification. — B. B. infusible and usually decrepitates. Treated with cobalt-nitrate solution and ignited, it becomes blue. Heated strongly in closed tube, it gives off water. It is insoluble.

4. Bauxite is a hydrated oxide of aluminum, $Al_2O(OH)_4$, in which part of the aluminum is usually replaced by iron. It occurs amorphous in disseminated grains and concretionary forms, and is also found in compact clay-like and sponge-like masses. *Color*, white, red, yellow, brown, or black; *streak*, like the color; opaque; *luster*, dull or earthy; *tenacity*, brittle or earthy; $H = 1$ to 3; $G = 2.4$ to 2.5.

Bauxite is the principal source of aluminum.

Tests for Identification.—B. B. infusible. Gives water in closed tube. When treated with cobalt-nitrate solution and ignited, it becomes blue. Difficultly soluble in hydrochloric acid.

5. Cryolite is a double fluoride of aluminum and sodium, Na_3AlF_6, or $3NaF,AlF_3$. Aluminum, 12.8 per cent.; sodium, 32.8 per cent.; fluorine, 54.4 per cent. It crystallizes in the monoclinic system, but the axial inclination is slight and the crystals very closely approach the cube or cubic octahedron in form, as in Fig. 2. It usually occurs massive and frequently in blocks somewhat resembling ice in appearance. *Color*, white, colorless, or brown; *streak*, white; transparent to translucent; *luster*, vitreous; *tenacity*, brittle; *cleavage*, nearly cubical in three directions; $H = 2.5$; $G = 2.95$ to 3.

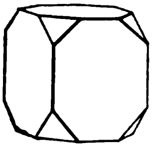


FIG. 2

Cryolite is used principally in the manufacture of soda and alum.

Tests for Identification.—B. B. fuses easily at (1) to a clear globule, coloring the flame yellow. Reacts for fluorine with potassium acid sulphate, $KHSO_4$. In a closed tube it yields fumes that etch the glass, and is soluble in acids without effervescence.

6. Gibbsite is aluminum hydroxide, $Al(OH)_3$. Alumina, Al_2O_3, 65.4 per cent.; water, 34.6 per cent. It crystallizes rarely in the monoclinic system in small six-sided crystals, and occurs usually in small stalactites, spheroidal or mamillary concretions. *Color*, white, grayish, greenish, reddish, and yellow; *streak*, white; translucent; *luster*, vitreous to pearly or dull; *tenacity*, brittle to tough; *cleavage*, basal perfect; $H = 2.5$ to 3.5; $G = 2.3$ to 2.4.

Gibbsite is used for the manufacture of aluminum.

Tests for Identification.—B. B. infusible, exfoliates, and becomes white. When treated with cobalt-nitrate solution and ignited, it becomes deep blue. It yields water in a closed tube, and is soluble in sulphuric and hydrochloric acids.

7. Spinel is magnesium aluminate, $MgAl_2O_4$; alumina, Al_2O_3, 71.8 per cent.; magnesia, MgO, 28.2 per cent. It sometimes contains iron, magnesia, and chromium, and occurs only in crystalline form. It crystallizes in the isometric system, in octahedrons more or less modified and often twinned, Fig. 3. *Color*, red to blue, green, yellow, brown, and black; *streak*, white; transparent to opaque; *luster*, vitreous; *tenacity*, brittle; *cleavage*, octahedral; $H = 8$; $G = 3.5$ to 4.5.

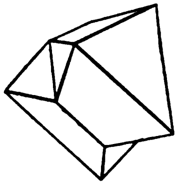


FIG. 3

Tests for Identification.—B. B. infusible. It is insoluble in acids. Its octahedral form and cleavage distinguish it from the oriental ruby.

Varieties.—The scarlet and bright red crystals are called spinel ruby; rose-red, balas ruby; orange-red, rubicelle; violet, almandine ruby; green, chloro-spinel; black, pleonaste.

8. Alunite, or alum stone, is hydrated potassium aluminum sulphate, $KAl_3S_2O_{11},3H_2O$. Alumina, Al_2O_3, 37 per cent.; potash, K_2O, 11.4 per cent.; sulphur trioxide, SO_3, 38.6 per cent.; water, 13 per cent. It crystallizes in the hexagonal system in tabular rhombohedral crystals, and occurs crystalline, massive, and fibrous. *Color*, white, grayish, or reddish; *streak*, white; transparent to nearly opaque; *luster*, vitreous; *tenacity*, brittle; $H = 3.4$ to 4; $G = 2.58$ to 2.75

Alunite is a source of alum.

Test for Identification.—B. B. infusible and decrepitates. With soda on charcoal it is infusible but gives test for sulphur on silver. It yields water when heated to redness in closed tube, and is wholly or partially soluble in hydrochloric and sulphuric acids, without gelatinizing.

9. Turquoise is a hydrated phosphate of aluminum, $Al_2(OH)_3PO_4.H_2O$. Alumina, Al_2O_3, 46.9 per cent.; phosphorus pentoxide, P_2O_5, 32.6 per cent.; water, 20.5 per cent. It always contains some copper, which gives it its color, and occurs in an amorphous condition, incrusting seams and veins, also in opaque nodules or rolled masses. *Color*, robin's-egg blue to bluish-green; opaque; *streak*, white or pale green; *luster*, waxy to dull; *tenacity*, brittle; $H = 6$; $G = 2.6$ to 2.83.

The most delicately colored turquoise is highly prized as a gem.

Tests for Identification.—B. B. infusible, turns brown, and colors flame green. It yields water in a closed tube and turns brown. It is distinguished from bluish-green feldspar, which it resembles, by its infusibility and reactions for phosphorus. It is harder than chrysocolla.

ANTIMONY MINERALS

10. Native antimony usually contains a small amount of silver, iron, or arsenic. It sometimes crystallizes in the hexagonal system in rhombohedral crystals, but ordinarily it is massive with a distinct lamellar, or granular, structure. *Color*, tin-white; *streak*, tin-white or dark gray; opaque; *luster*, metallic; *tenacity*, brittle or slightly malleable; *cleavage*, basal perfect; $H = 3$ to 3.5; $G = 6.5$ to 6.72.

Tests for Identification.—Fuses at (1), and colors flame pale green, giving copious white fumes that continue to form after cessation of blast. Charcoal becomes coated with a volatile white coat.

11. Stibnite, or **antimony glance,** is antimony trisulphide, Sb_2S_3. Antimony, 71.8 per cent.; sulphur, 28.2 per cent.; it sometimes contains gold and silver. It crystallizes in the orthorhombic system in prismatic and frequently acicular crystals. The vertical planes are striated longitudinally, Fig. 4. Its usual occurrence is in imperfectly crystallized masses, with a columnar or bladed structure; sometimes in interlaced bunches of needle-like


FIG. 4

crystals, Fig. 5; and also in granular or compact masses. *Color*, light lead-gray, often with an iridescent tarnish; *streak*, dark grayish-black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, perfect, parallel to one vertical edge.

FIG. 5

Stibnite is the principal source of antimony. In its natural state, it is used in the manufacture of rubber, safety matches, fireworks, and pharmaceutical preparations.

Tests for Identification.—B. B. on charcoal fuses, gives antimony fumes, white coat, and other tests for antimony. Strong odor of burning sulphur. In a closed tube it fuses easily, yields a little sulphur, and dark sublimate brownish-red when cold. It is completely soluble in strong boiling hydrochloric acid with evolution of hydrogen sulphide; the addition of water causes precipitation of white basic salt of antimony.

ARSENIC MINERALS

12. Native arsenic occurs with lead and silver ores and usually contains small amounts of antimony and sometimes bismuth, cobalt, nickel, iron, silver, or gold. It crystallizes n the hexagonal system in rhombohedral crystals, somemes, though rarely, needle-like. It usually occurs granu- , massive, or botryoidal. *Color*, tin-white, tarnishing to ost black; *streak*, dark gray to black; opaque; *luster*, tallic; *tenacity*, brittle; *cleavage*, basal imperfect; *H* 3.5; $G = 5.63$ to 5.73.

Tests for Identification.—B. B. on charcoal volatilizes without fusing, giving white fumes, crystalline white sub- mate, pale-blue flame, and strong garlic odor. May leave a residue of impurities, and forms a metallic sublimate in closed tube.

13. Orpiment is arsenic trisulphide, As_2S_3. Arsenic, 61 per cent.; sulphur, 39 per cent. It crystallizes in the orthorhombic system in imperfect prismatic crystals, and occurs usually in foliated masses that cleave into thin flexible pearly scales, or in granular masses or reniform crusts. *Color*, lemon-yellow; *streak*, lemon-yellow; translucent to nearly opaque; *luster*, resinous or pearly; *tenacity*, sectile to brittle; *cleavage*, perfect brachypinacoidal in plates and leaves; $H = 1.5$ to 2; $G = 3.4$ to 3.6.

Tests for Identification.—B. B. on charcoal is volatile and combustible, burning with a blue flame, and giving the odor of garlic and burning sulphur. It gives a yellow sublimate in a closed tube. It is soluble in nitric acid with separation of sulphur, and in a solution of potassium hydroxide, from which solution hydrochloric acid precipitates yellow sulphide of arsenic.

14. Realgar is another sulphide of arsenic, As_2S_2. Arsenic, 70.1 per cent.; sulphur, 29.9 per cent. It crystallizes in the monoclinic system, and occurs in transparent crystals or masses, and also compact. *Color*, aurora red to orange-yellow; *streak*, orange-red; translucent to transparent; *luster*, resinous; *tenacity*, slightly sectile or brittle; *cleavage*, clinopinacoidal and basal; $H = 1.5$ to 2; $G = 3.4$ to 3.6.

Realgar is used as a pigment and color in fireworks.

Tests for Identification.—The tests are the same as for orpiment, except that the sublimate in the closed tube is red.

15. Arsenopyrite, mispickel, or arsenical pyrites, is a sulph-arsenide of iron, $FeAsS$. Iron, 34.4 per cent.; arsenic, 46 per cent.; sulphur, 19.6 per cent. It frequently contains gold, while sometimes the iron is partially replaced by cobalt, or the arsenic by antimony. It crystallizes in the orthorhombic system in rhombic prisms, Fig. 6, often elongated horizontally, and is usually found in compact or granular masses or disseminated grains. *Color*, silver-white to steel-gray; *streak*, grayish-black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, prismatic, distinct. $H = 5.5$ to 6; $G = 6$ to 6.4.

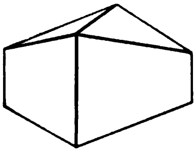


FIG. 6

It is the chief source of arsenic, and is sometimes worked for gold and cobalt.

Tests for Identification.—B. B. on charcoal fuses at (2) to a magnetic globule, giving white arsenic coat and garlic odor, also odor of burning sulphur. This globule may react for cobalt. In a closed tube, it gives sublimate of arsenic sulphide. It is insoluble in hydrochloric acid, but soluble in nitric acid with separation of sulphur.

BARIUM MINERALS

16. Barite, or **heavy spar,** is barium sulphate, $BaSO_4$. Barium oxide, BaO, 65.7 per cent.; sulphur trioxide, SO_3, 34.3 per cent. A part of the barium is sometimes replaced by calcium and strontium. It crystallizes in the orthorhombic system in rhombic prisms or flat tabular forms; some of these forms are shown in Fig. 7. It also occurs massive, columnar, fibrous, granular, and compact. *Color*, white, light yellow, blue, red, or brown; *streak*, white; transparent to opaque; *luster*, vitreous or pearly; *tenacity*, brittle; *cleavage*, basal and prismatic, perfect; $H = 2.5$ to 3.5; $G = 4.3$ to 4.6.

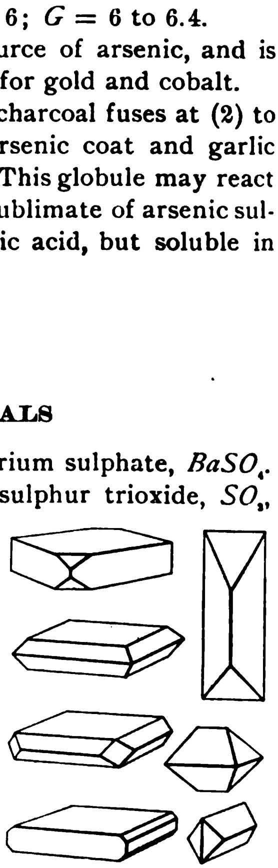


FIG. 7

Barite is sometimes ground and used as an adulterant for white lead. Colored varieties are sometimes used for ornamental slabs, etc.

Tests for Identification.—B. B. decrepitates and fuses at (3), giving a yellowish-green tinge to the flame. The residue from fusion reacts alkaline. Fused with soda, it gives a sulphur reaction on silver. It is insoluble in acids.

17. Witherite is barium carbonate, $BaCO_3$. Barium oxide, BaO, 77.7 per cent.; carbon dioxide, CO_2, 22.3 per cent. It crystallizes in the orthorhombic system in six-sided pyramids in complex forms with deep horizontal striations on the faces due to repeated twinning, as in Fig. 8. It occurs also in heavy masses, globular, or botryoidal forms, and is also fibrous or granular. *Color*, white, gray, or yellowish; *streak*, white; transparent to opaque; *luster*, vitreous; *tenacity*, brittle; *cleavage*, brachypinacoidal, distinct; $H = 3$ to 4; $G = 4.29$ to 4.35.

FIG. 8

Tests for Identification.—B. B. fuses at (2), coloring flame yellowish-green. The residue from fusion reacts alkaline. It is soluble in dilute hydrochloric acid with effervescence, but is less soluble in concentrated acid. Sulphuric acid added to the solution precipitates white barium sulphate.

BISMUTH MINERALS

18. Native bismuth is often alloyed with arsenic or is impure from sulphur or tellurium. It crystallizes in the hexagonal system, but usually occurs massive and sometimes granular. *Color*, reddish silver-white; *streak*, silver-white; opaque; *luster*, metallic; *tenacity*, sectile to brittle; $H = 2$ to 2.5; $G = 9.7$ to 9.83.

Tests for Identification.—B. B. fuses at (1), volatilizing completely. On charcoal it gives a volatile orange-yellow coat. It is soluble in strong nitric acid; water precipitates a white basic salt from this solution.

19. Tetradymite, Bi_2Te_3, is a telluride of bismuth. Composition: bismuth, 48.1 per cent.; tellurium, 51.9 per cent. The composition is somewhat variable, as it usually contains sulphur, and its composition is often given as $Bi_2(Te,S)_3$. It crystallizes in the hexagonal system in small, indistinct rhombohedral crystals, and also occurs in soft, flexible, foliated masses. It will mark paper like graphite. *Color*, pale steel-gray; *streak*, dark gray to black; opaque; *luster*, metallic; *tenacity*, laminæ flexible, slightly sectile; *cleavage*, basal, perfect; $H = 1.5$ to 2; $G = 7.2$ to 7.9.

Tests for Identification.—B. B. on charcoal fuses easily and volatilizes, giving white coating of TeO_2 followed by orange-yellow Bi_2O_3. The flame is colored blue. White sublimate in closed tube. This sublimate, if placed on porcelain and moistened with a drop of concentrated sulphuric acid, becomes rose-colored. If the mineral is dropped into boiling concentrated sulphuric acid a deep violet color is produced.

20. Bismuthinite is bismuth trisulphide, Bi_2S_3. Bismuth, 81.2 per cent.; sulphur, 18.8 per cent.; it sometimes contains copper or iron. It crystallizes in the orthorhombic system in acicular crystals and occurs usually in foliated or fibrous masses. *Color*, lead-gray to tin-white often with a yellow tarnish; *streak*, lead-gray to black; opaque; *luster*, metallic; *tenacity*, slightly sectile; *cleavage*, brachypinacoidal, perfect; $H = 2$; $G = 6.4$ to 6.5.

Tests for Identification.—B. B. on charcoal fuses at (1), giving odor of burning sulphur and orange-yellow coating of Bi_2O_3; gives all other characteristic reactions for bismuth. Fused with soda, it reacts for sulphur on silver.

BORON MINERALS

21. Sassolite, or **sassolin,** is natural boracic acid, H_3BO_3. Boron trioxide, B_2O_3, 56.4 per cent.; water, 43.6 per cent. It occurs rarely in minute monoclinic crystals, or stalactitic, but usually in solution or vapor in volcanic regions. *Color*, white or yellowish; *streak*, white;

translucent; *luster*, pearly; *tenacity*, brittle; *taste*, acid and a little saline and bitter; $H = 1$; $G = 1.43$.

Sassolite is an important source of borax.

Tests for Identification.—B. B. on charcoal fuses easily with intumescence to a clear, colorless glass, coloring the flame yellowish-green. It yields water in closed tube and is soluble in water.

22. Borax, or **tinkal,** is hydrous sodium biborate, $Na_2B_4O_7,10H_2O$. Boron trioxide, B_2O_3, 36.6 per cent.; soda, Na_2O, 16.2 per cent.; water, 47.2 per cent. It crystallizes in the monoclinic system, the crystals resembling those of pyroxene, and occurs as a constituent of certain soils, but usually in solution, in lakes in various parts of the world, or crystalline in the mud in the bottom or on the shores of these lakes. *Color*, white; *streak*, white; translucent to opaque; *luster*, vitreous or resinous to dull; *tenacity*, very brittle; *cleavage*, pinacoidal, perfect; *taste*, feebly alkaline; $H = 2$ to 2.5; $G = 1.69$ to 1.72.

Borax is an important flux in assaying and metallurgical operations. It is used extensively in the manufacture of soaps, soap powders, and glass, also in medicine.

Tests for Identification.—B. B. swells greatly and fuses easily to a clear glass, coloring the flame yellow. When mixed with potassium bisulphate and powdered fluorite, the flame is momentarily colored yellowish-green. It yields water in closed tube and is soluble in water.

23. Boracite, or **stassfurtite,** is a double borate and chloride of magnesium, $Mg_7Cl_2B_{16}O_{30}$. Boron trioxide, B_2O_3, 62 per cent.; magnesia, MgO, 31 per cent.; chlorine, 7 per cent. It crystallizes in the isometric system, usually in small cubes with alternate angles replaced, Fig. 9 (*a*), or with all replaced but four of them differently from the other four, Fig. 9 (*b*). It occurs as colorless crystals imbedded in

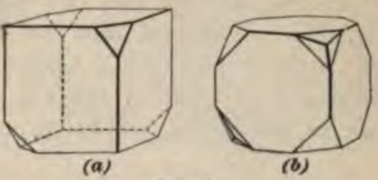


FIG. 9

gypsum or as soft masses. *Color*, white, grayish, yellowish, or greenish; *streak*, white; transparent to opaque; *luster*, vitreous; *tenacity*, brittle; *cleavage*, only in traces; $H = 7$ (crystals), 4.5 (masses); $G = 2.9$ to 3.

Tests for Identification.—B. B. fuses with intumescence to a white glass, coloring the flame yellowish-green. It yields little or no water in a closed tube; moistened with cobalt-nitrate solution and ignited, it turns pink. It is slowly soluble in hydrochloric acid.

24. Ulexite, or boronatrocalcite, is hydrous calcium sodium borate, $CaNaB_5O_9,8H_2O$. Boron trioxide, B_2O_3, 43 per cent.; calcium oxide, CaO, 13.8 per cent.; sodium oxide, Na_2O, 7.7 per cent.; water, 35.5 per cent. It occurs in white rounded masses of loosely compacted, intertwined, silky fibers that are easily pulverized between the fingers. *Color*, white; *streak*, white; translucent to opaque; *luster*, silky; *tenacity*, brittle or sectile; *cleavage*, finely fibrous; tasteless; $H = 1$; $G = 1.65$.

Ulexite is a source of borax.

Tests for Identification.—B. B. fuses at (1) with intumescence to a clear glass, coloring the flame yellow. Moistened with sulphuric acid, it colors the flame momentarily deep green. It yields water in a closed tube and is soluble in acids.

CADMIUM AND CALCIUM MINERALS

25. There are but two **cadmium** minerals known, the *sulphide greenockite* and the *silicate eggonite;* the latter is of little importance. Cadmium occurs generally as an impurity in some of the zinc minerals, particularly smithsonite, sphalerite, and calamine.

26. Greenockite is cadmium sulphide, CdS. Cadmium, 77.7 per cent.; sulphur, 22.3 per cent. It crystallizes rarely in the hexagonal system in hemimorphic crystals and occurs usually massive or incrusting, as a bright yellow powder on sphalerite or a yellow coloration in smithsonite, termed *turkey fat*. *Color*, various shades of yellow; *streak*, orange-yellow; transparent to opaque; *luster*, adamantine to resinous or earthy; *tenacity*, brittle; *fracture*, distinct conchoidal; $H = 3$ to 3.5; $G = 4.8$ to 5.

Tests for Identification.— B. B. infusible but easily volatilized in reducing flame, coating the coal with the characteristic iridescent (peacock feather) coat of cadmium oxide. It has an odor of burning sulphur and is soluble in strong hydrochloric acid with evolution of hydrogen sulphide.

27. Calcite, or **calc spar,** is calcium carbonate, $CaCO_3$. Calcium oxide, CaO, 56 per cent.; carbon dioxide, CO_2, 44 per cent. Sometimes iron oxide and other substances are mixed with it. It crystallizes in the hexagonal system in a variety of forms, the most common being the rhombohedron, Fig. 10 (*a*); other common forms are also shown in Fig. 10. It occurs massive, coarse, fine granular, fibrous, lamellar, or pulverulent. *Color*, white, colorless, yellow, pale shades of red, green, or blue; *streak*, white; transparent to opaque; *luster*, vitreous to dull; *tenacity*, brittle; *cleavage*, rhombohedral perfect and easy; $H = 2$ to 3 $G = 2.5$ to 2.8.

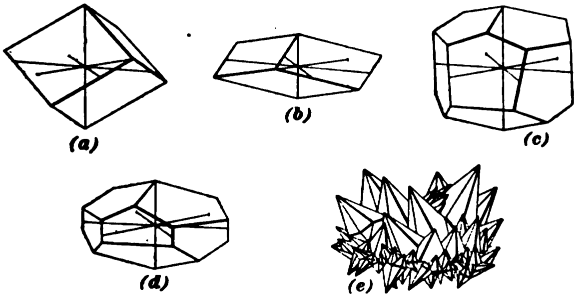


FIG. 10

Tests for Identification.—B. B. infusible; becomes opaque and incandescent; the residue reacts alkaline. When moistened with hydrochloric acid, it colors the flame red. It is easily soluble in cold dilute hydrochloric acid with effervescence.

Varieties.—Of the many varieties of calcite the following are the most important: *Iceland spar*, a clear transparent form; possesses to a marked degree the power of double refraction. *Dog-tooth spar* has scalenohedral crystals, Fig. 10 (*e*). *Satin spar* is finely fibrous with a silky or satin luster. *Marble* is a coarse- to fine-grained crystalline limestone of various colors; the best marble is white and fine-grained. *Limestone* is a dull non-crystalline compact material that on burning affords quicklime. *Chalk* is a soft, white, lusterless, earthy mass. *Stalactites* are icicle-like deposits hanging from the roofs of caves and formed by dripping water containing calcium carbonate in solution. *Stalagmites* are of the same origin and somewhat similar to stalactites, only they are built upwards from the floors of caverns by drippings from above. *Travertine*, *onyx marble*, and *Mexican onyx* are banded layers of calcium carbonate deposited by springs and rivers.

28. Aragonite is chemically the same as calcite (calcium carbonate), but differs from it in that it crystallizes in the orthorhombic system in long stellated prisms, Fig. 11 (*a*). It is usually compounded so as to have the appearance of a hexagonal prism, Fig. 11 (*b*); it also occurs in a coral-like form found in iron mines. *Color*, white, grayish, yellow, pale green, and violet; *streak*, white; transparent to translucent; *luster*, vitreous

FIG. 11

to dull; *tenacity*, brittle; *cleavage*, prismatic, imperfect; $H = 3.5$ to 4; $G = 2.93$ to 2.95.

Tests for Identification.—B. B. like calcite, but whitens and falls to pieces on heating.

29. Dolomite, pearl spar, or **magnesian limestone,** is a double carbonate of calcium and magnesium, $CaMg(CO_3)_2$. Calcium oxide, CaO, 30.5 per cent.; magnesium oxide, MgO, 21.7 per cent.; carbon dioxide, CO_2, 47.8 per cent. The proportion of calcium to magnesium may vary slightly, and either or both may be partially replaced by iron or manganese. It crystallizes in the hexagonal system in rhombohedral crystals with edges and faces sometimes curved, Fig. 12; it also occurs granular massive or compact in extensive beds. *Color*, white, pink, gray, yellowish, brown, or black; *streak*, white; translucent to opaque; *luster*, vitreous, pearly to dull; *tenacity*, brittle; *cleavage*, rhombohedral perfect; $H = 3.5$ to 4; $G = 2.8$ to 2.9.

FIG. 12

Tests for Identification.—B. B. infusible; becomes incandescent; the residue gives an alkaline reaction. When moistened with hydrochloric acid, it colors the flame red. Moistened with cobalt-nitrate solution and ignited, it becomes pink. When powdered, it is sometimes readily attacked by cold dilute hydrochloric acid, and sometimes not; the warmed acid dissolves it readily even in lumps, with effervescence.

Varieties.—The following are the principal varieties of dolomite: *Dolomite*, white, crystalline, and granular, has very much the same appearance as granular limestone. *Pearl spar* occurs in pearly rhombohedrons with curved faces. *Brown spar*, or *rhomb spar*, occurs in rhombohedrons that become brown on exposure owing to the presence of a small percentage of oxide of iron or manganese.

White massive dolomite is used extensively as a marble. Dolomite is also used as a flux in blast furnaces and to some extent for the manufacture of Epsom salts (magnesium sulphate).

30. Gypsum is hydrous calcium sulphate, $CaSO_4, 2H_2O$. Calcium oxide, 32.5 per cent.; sulphur trioxide, 46.6 per cent.; water, 20.9 per cent. It crystallizes in the monoclinic system, taking the form shown in Fig. 13 (*a*), or is twinned, as shown in Fig. 13 (*b*); it also occurs granular, foliated, laminated, fibrous, and massive. The laminated form looks very much like mica. *Color*, white, colorless, gray, yellow, red, brown, or black; *streak*, white; transparent to opaque; *luster*, pearly, silky, vitreous, to dull; *tenacity*, brittle to sectile, plates flexible in one direction and brittle in another; *cleavage*, clinopinacoidal, parallel to broad face; $H = 1.5$ to 2; $G = 2.31$ to 2.33.

FIG 13.

Gypsum is sometimes ground and used as fertilizer. One of its principal uses is for the manufacture of plaster of Paris.

Tests for Identification. — B. B. quickly becomes white and then fuses to a globule having an alkaline reaction. It colors the flame yellowish-red and yields water in the closed tube. It is soluble in hydrochloric acid. When fused with soda, it gives sulphur reaction on silver.

Varieties.—The following are the principal varieties of gypsum: *Selenite* has transparent crystals or broad plates; *satin spar*, white, translucent, and delicately fibrous, with pearly opalescence or silky sheen; *alabaster*, white or light-colored compact gypsum of fine grain suitable for carving; *rock gypsum*, scaly, granular, dull-colored, and compact.

31. Anhydrite is anhydrous calcium sulphate, $CaSO_4$. Calcium oxide, CaO, 41.2 per cent.; sulphur trioxide, SO_3, 58.8 per cent. It crystallizes in the orthorhombic system rarely, but occurs granular, and in fibrous and lamellar masses that are often contorted. *Color*, white to bluish or reddish; *streak*, white; translucent to opaque; *luster*, vitreous to pearly; *tenacity*, brittle; *cleavage*, in three directions at right angles.

Tests for Identification.—Reactions the same as for gypsum, except that it yields no water in closed tube.

32. Fluorite, or **fluor spar,** is calcium fluoride, CaF_2. Calcium, Ca, 51.1 per cent.; fluorite, F, 48.9 per cent. It crystallizes in the isometric system, usually in cubes, Fig. 14 (*a*), but also in compound forms, Fig. 14 (*b*), (*c*), and (*d*), and occurs as glassy, transparent cubes, also in cleavable masses, the colors of which are often banded. *Color*, white, colorless, yellow, blue, green, red, brown, or black; *streak*, white; transparent to nearly opaque; *luster*, vitreous; *tenacity*, brittle; *cleavage*, octahedral; $H = 4$; $G = 3$ to 3.25.

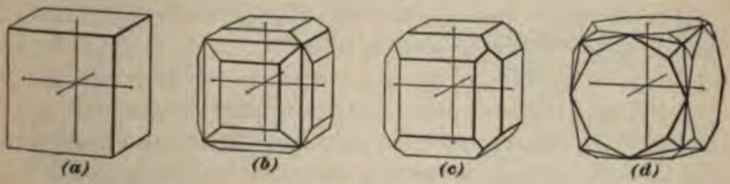


FIG. 14

Fluorite is used as a flux in smelting ores; for the manufacture of hydrofluoric acid, and opalescent glass; as an enamel for cooking utensils.

Tests for Identification.—B. B. decrepitates and fuses at (3) to a white opaque glass, giving an alkaline reaction. It colors the flame red. After gentle heating in a closed tube, it becomes phosphorescent. It reacts for fluorine when heated with potassium bisulphate in closed tube, and is soluble in hydrochloric acid.

33. Apatite, or **asparagus stone,** is a double phosphate and chloride, or fluoride of calcium, $Ca_5(Cl.F)(PO_4)_3$. When chlorine is present in place of fluorine, it is called *chlorapatite;* when fluorine is in the place of chlorine, *fluorapatite.* It crystallizes in the hexagonal system in prisms, Fig. 15 (*a*), (*b*), and (*c*), and occurs also massive and granular or nodular. *Color*, white, colorless, yellow, green, red, violet, brown; *streak*, white; transparent to opaque; *luster*, vitreous to resinous; *tenacity*, brittle; *cleavage*, basal and prismatic perfect; $H = 4.5$ to 5; $G = 3.17$ to 3.23.

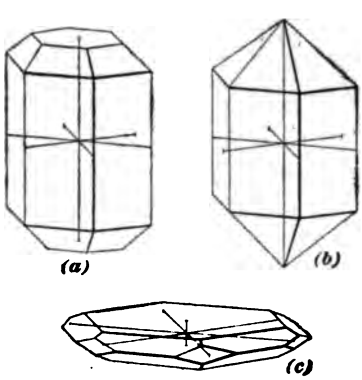


FIG. 15

Apatite or mineral phosphate finds great use as a fertilizer; by treatment with sulphuric acid the phosphoric acid is set free and rendered available. It is also used for the manufacture of phosphorus.

Tests for Identification.—B. B. fuses with difficulty at (4.5 to 5) and colors the flame yellowish-red; if moistened with concentrated sulphuric acid, it colors flame momentarily bluish-green. It reacts for phosphorus with magnesium, and is soluble in hydrochloric acid.

Varieties.—The following mineral phosphates are essentially the same in composition as apatite: ***Phosphorite,*** concretionary masses with fibrous or scaly structure, $H = 4.5$; *osteolite*, compact, earthy, and impure, of white or gray color, $H = 1$ to 2; *phosphate rock*, large, massive deposits of a white, gray, brown, or black color, $H = 2$ to 5; ***guano*** is granular to sponge-like and compact, of a gray to brown color, and consists of fossil excrement of birds, etc.

CARBON AND HYDROCARBON MINERALS

CARBON MINERALS

34. The **diamond** is practically pure crystallized carbon. It crystallizes in the isometric system in octahedrons, hexoctahedrons, dodecahedrons, and other more complex forms. The natural, or rough uncut, diamonds, frequently have worn or rounded edges, Fig. 16 (*a*), or curved faces, as in Fig. 16 (*b*); sometimes the faces are marked by small triangular pits, as in Fig. 16 (*a*). They are also found in translucent, rough, rounded, crystalline aggregates and opaque crystalline or compact masses of a gray to black color, and no distinct cleavage. The diamond is the hardest known substance. The clear, colorless stones (said to be "of the first water") are the most highly prized as gems, and when properly cut possess great brilliancy, giving a play of prismatic colors due to their great refractive power. *Color*, yellow, red, orange, green, blue, brown, gray, black, and colorless; *streak*, white; transparent to translucent; *luster*, adamantine; *tenacity*, brittle; *cleavage*, octahedral, perfect; $H = 10$; $G = 3.15$ to 3.55.

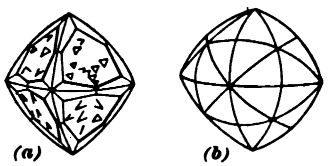


FIG. 16

Tests for Identification.—B. B. infusible, but in the form of fine powder is burned to carbon dioxide. It is insoluble. The most reliable test is its hardness.

Varieties.—Besides the beautiful variety suitable for gems, there is a translucent non-cleavable variety called *bort*, which is often harder and tougher than the well-crystallized variety. *The carbonado*, or *black diamond*, is found in Brazil in the form of black pebbles or masses having no cleavage. Both borts and carbonadoes are used in the bits of diamond drills, and their powder for cutting and polishing other diamonds.

35. Graphite, or **plumbago**, sometimes erroneously called *black lead*, is, like the diamond, composed of practically pure carbon, the difference between them being physical rather than chemical. It is found in crystalline rocks, gneiss, mica schist, and crystalline limestones, and crystallizes in the hexagonal system in six-sided prisms or plates. It occurs usually in foliated masses, granular, or in disseminated scales. When impure it often has a slaty or earthy appearance. *Color*, dark gray to black; *streak*, dark gray to black; opaque; *luster*, metallic; *tenacity*, sectile, scales flexible; *feel*, greasy; marks paper; *cleavage*, basal, perfect, cleaves into plates; $H = 1$ to 2; $G = 2$ to 2.27.

Resembles molybdenite (see Art. **92**). Graphite finds extensive use in the manufacture of lead pencils and crucibles. It is used to some extent as a lubricant.

Tests for Identification.—B. B. infusible, but is gradually burned. When impure, it may react for water, iron, and sulphur. It is insoluble in acids.

36. Coal is essentially carbon, associated with more or less hydrocarbons (chemical compounds of hydrogen and carbon, in various proportions). It is the result of the decomposition of vegetable matter in the presence of water and out of contact with the air, as, for instance, the submerged accumulations in swamps. The immense coal beds of the world were formed at periods when such vegetation was much more luxuriant than at present. These beds were in time covered by other formations, and were gradually consolidated by the weight of the accumulating strata and sometimes, as in the case of anthracite, metamorphosed into coal by the heat of the earth, or occasionally by the heat due to local faulting or volcanic action. The variety of coal sometimes depends on the age of the deposit. Peat grades into *brown coal* or *lignite*; lignite grades into one of the varieties of *bituminous* coal, and semibituminous coal grades through *semianthracite* into *anthracite*, which is the highest form of coal. Graphite represents a still higher stage in the metamorphosis of vegetable carbon into mineral matter, and the diamond is the ultimate product—pure crystallized carbon.

All varieties of coal have a more or less compact, massive structure, not crystalline, and without true cleavage, though sometimes breaking with a degree of regularity, but from a jointed rather than a cleavage structure. It is sometimes laminated, and is often faintly and delicately banded, successive layers differing slightly in luster.

The *color* varies in different coals from black to grayish-black, brownish-black, and sometimes dark brown; occasionally it is iridescent. Its *luster* varies also from dull to brilliant; sometimes either earthy, resinous, or submetallic. *Fracture* varies with the kind of coal. Its *tenacity* is brittle; rarely somewhat sectile. Without taste except from the impurities present. Infusible to subfusible, but often becoming a soft, pliant, or paste-like mass when heated. On distillation, most kinds yield more or less of tarry or oily substances, which are mixtures of various hydrocarbons.

37. The different varieties of coal are classified principally according to the proportion and character of volatile matter that they contain. This volatile matter is made up of more or less water, some sulphur, and the various hydrocarbon oils and gases. The different varieties of coal also differ from one another, and more or less among themselves, in structure, luster, and other physical characteristics. The hardness varies in the different varieties from .5 to 2.5, and the specific gravity from 1 to 1.8. The principal varieties of coal are anthracite, bituminous coal, cannel coal, and brown coal or lignite.

Anthracite has a bright luster, often submetallic. Its color is black, occasionally iridescent; its fracture, conchoidal; volatile matter, after drying (volatile hydrocarbons), from 3 per cent. to 6 per cent. (with a trace of sulphur). It burns with a feeble blue flame and contains from 80 per cent. to 95 per cent. of fixed carbon and 4 per cent. to 12 per cent. of earthy impurities (ash). Anthracite graduates into bituminous coal, becoming less hard and containing more volatile matter; an intermediate variety is called *free-burning anthracite*, or *semianthracite*.

Bituminous coal includes several varieties of coal differing widely in composition, physical characteristics, and in their behavior when heated. They have the common characteristic of burning with a smoky, yellow flame, and giving off hydrocarbon oils and tar on distillation. The proportion of these volatile hydrocarbons in the ordinary varieties varies from 20 per cent. to 45 per cent., and some varieties contain over 60 per cent. The proportion of ash varies from 1.5 per cent. to 7.5 per cent.—considerably less than that of anthracite. The explanation of this lies in the fact that anthracite was originally bituminous coal, and as its volume was reduced by the expulsion of volatile matter, the proportion of ash to combustible matter naturally became greater. The sulphur in bituminous coals ranges from a fraction of 1 per cent., in the best coals, to 2 per cent. and 2.5 per cent. in poorer varieties.

38. Bituminous coals may be divided into caking (or coking) and non-caking coals.

Caking coals soften when heated, and become pasty, or semiviscid, and the pieces gum together. If the heating is conducted in retorts or in heaps, with a limited supply of air, so that the volatile matter is distilled off without burning the carbon, the latter will remain, after the distillation is complete, as the familiar iron-gray mass known as *coke*. *Non-caking coal* is apparently in no wise different from caking coal, but will burn freely without any indication of softening or fusing together. Thus far there has been no plausible explanation advanced why one coal should cake and another apparently exactly like it should not, but the fact remains. The only way to recognize a caking coal is to cake it.

Cannel coal is frequently considered a variety of bituminous coal and is often caking, but it differs considerably from the ordinary bituminous coals in texture and to some extent in composition, as shown by its products on distillation, and is therefore given a separate place in this classification. It is compact, with little or no luster, and has a slaty appearance, but without any suggestion of a banded structure. It breaks with a conchoidal fracture and smooth surfaces. Its color is dull black or grayish-black. On distillation it affords, after drying, from 40 to 60 per cent. of volatile matter, which includes a large proportion of burning and lubricating oils, much larger than the above kinds of bituminous coal.

Albertite, or *asphaltic coal*, is a mineral intermediate between cannel coal and asphalt. It resembles coal in hardness, but is like asphalt in color and luster, is slightly soluble in ether, and about one-third of it is soluble in turpentine, and it softens slightly in boiling water.

Brown coal, or *lignite*, is sometimes pitch-black, but oftener rather dull and brownish-black. The structure is usually like that of bituminous coal, but it is occasionally somewhat lamellar. The term *lignite* should properly be restricted to those varieties of brown coal that retain the structure of the original wood. These coals usually contain 15 per cent. or 20 per cent. of moisture, and give, on distillation, acetic acid. Brown coals are non-caking, but afford a large proportion of volatile matter. *Jet* is a black variety of brown coal, compact in texture, and takes a good polish.

The varieties of coal known as *semibituminous* and *semianthracite* coals merge into one or the other of the above, and cannot be said to be distinct varieties.

HYDROCARBON MINERALS

39. Asphaltum, or mineral pitch, is a mixture of hydrocarbons, some of which contain oxygen. It is amorphous and is found in various consistency between liquid and solid. The principal source is the pitch lake on the island of Trinidad; it is also found in certain sandstones and limestones in some parts of the United States and in limestones in Europe. *Color*, brownish-black to black; *streak*, dark brown to black; opaque; *luster*, resinous to dull; *tenacity*, brittle to flexible; *fracture*, conchoidal; $H = -$ to 1.5; $G = 1$ to 1.8.

Asphaltum is used for street pavements, for roofing, for coating timber to preserve them from decay. Some qualities are used in varnishes.

Tests for Identification.—Melts at from 90° to 100° F. and burns with a bright flame. It is completely or nearly soluble in camphene.

Varieties.—*Ozokerite*, a waxy substance, is essentially paraffin; its color is white when pure, but is usually yellow, greenish to brown; distilled ozokerite yields ceresine, which is used for candles, etc., burning oils, paraffin, etc. *Gilsonite*, a black, tough substance resembling gutta percha; $H = 2$ to 2.5; $G = 1.06$ to 1.07. *Elaterite*, or *wurtzite*, also resembles gutta percha; it is hard when cold, but when heated it becomes elastic like compact rubber.

40. Petroleum, or **mineral oil**, is closely related to asphaltum. It consists of the liquid hydrocarbons of the same series. From it, by distillation, are obtained kerosene, naphtha, gasoline, benzine, paraffin, etc. It is found in certain sandstones and shales in various parts of the world.

41. Natural gas consists of the gaseous hydrocarbons of the same series as petroleum, the chief constituent being marsh gas, or methane, CH_4.

42. Amber, or **succinite**, is a fossil resin, which contains oxygen. It is amorphous, and often contains insects imbedded in it. *Color*, whitish-yellow to brownish; *streak*, white; transparent to translucent; *luster*, resinous; *tenacity*, brittle; *cleavage*, none; $H = 2$ to 2.5; $G = 1$.

Amber is used for jewelry and ornamental purposes and for mouthpieces to tobacco pipes.

Tests for Identification.—B. B. fuses readily and burns with a yellow flame. It is partially soluble in alcohol and ether.

CHROMIUM MINERALS

43. Chromite, or **chromic iron**, has the composition, $FeCr_2O_4$. Ferrous oxide, FeO, 32 per cent.; chromic oxide, Cr_2O_3, 68 per cent. It crystallizes in the isometric system, rarely in octahedral crystals, and usually occurs massive associated with serpentine, which causes green and yellow spots and streaks. *Color*, black; *streak*, dark brown; opaque; *luster*, submetallic to metallic; *tenacity*, brittle; *cleavage*, absent; sometimes slightly magnetic; $H = 5.5$; $G = 4.3$ to 4.6.

Chromite is used in the manufacture of chrome steel and is the principal source of chromium compounds.

Tests for Identification.—B. B. infusible, but becomes magnetic. With S.Ph., it reacts for chromium. Fused with soda and niter on platinum foil, the mass becomes yellow when cold.

44. Crocoite, or crocoisite, is lead chromate, $PbCrO_4$. Lead oxide, PbO, 68.9 per cent.; chromium trioxide, CrO_3, 31.1 per cent. It crystallizes in the monoclinic system in oblique rhombic prisms, and occurs also in granular and columnar forms. *Color*, bright red like potassium bichromate; *streak*, orange-yellow; translucent; *luster*, adamantine; *tenacity*, sectile; *cleavage*, prismatic; $H = 2.5$ to 3; $G = 5.9$ to 6.1.

Tests for Identification.—B. B. blackens and fuses and is reduced to metallic lead. It coats the coal yellow, and reacts for chromium in borax and S. Ph. beads. In the closed tube, it decrepitates and becomes dark, but returns to natural color on cooling. Fused on platinum foil with potassium bisulphate, it gives a dark violet mass that is red on solidifying and greenish-white when cold, which distinguishes it from vanadinite. It is soluble in nitric acid, giving a yellow solution.

COBALT MINERALS

45. Linnæite, or cobalt pyrites, is cobalt sulphide containing nickel, $(Co.Ni)_3S_4$. Cobalt and nickel, 58 per cent.; sulphur, 42 per cent. It crystallizes in the isometric system usually in octahedrons or in combinations of the cube and octahedron, and occurs usually massive, frequently mixed with chalcopyrite. *Color*, pale steel-gray with reddish tarnish; *streak*, dark grayish-black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, cubic imperfect; $H = 5.5$; $G = 4.8$ to 5.

Linnæite is a source of both cobalt and nickel.

Tests for Identification.—B. B. on charcoal fuses to a magnetic globule, giving fumes of burning sulphur and often of arsenic. In a borax bead, after roasting, it gives blue color. By treating the bead on charcoal, metallic nickel may be obtained.

46. Smaltite is cobalt nickel arsenide, $(Co.Ni)As_2$. The proportion of cobalt and nickel varies widely, and usually some iron is present. It crystallizes in the isometric system often in cubes with curved faces, but also occurs massive or granular. *Color*, tin-white or steel-gray; *streak*, dark grayish-black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, octahedral in traces; $H = 5.5$ to 6; $G = 6$ to 6.6. Smaltite is the chief ore of cobalt.

Tests for Identification.—B. B. on charcoal fuses, yields white fumes, arsenic coat, and garlic odor; the residue is magnetic. When roasted in contact with frequently replaced borax, it yields successively slags colored by iron, cobalt, nickel, and sometimes copper. An arsenic mirror is formed in the closed tube. It is soluble in nitric acid, giving a red to green solution, according to the proportion of cobalt or nickel present.

47. Cobaltite, or **cobalt glance**, is a double sulphide and arsenide of cobalt, $CoAsS$. Cobalt, 35.5 per cent.; arsenic, 45.2 per cent.; sulphur, 19.3 per cent. It crystallizes in the isometric system in cubes, pyritohedrons, etc., and their combinations; it also occurs massive. *Color*, silver-white to steel-gray; *streak*, dark grayish-black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, cubic perfect; $H = 5.5$; $G = 6$ to 6.3.

Cobaltite is used in porcelain painting, and in the manufacture of smalt.

Tests for Identification.—B. B. on charcoal fuses easily to a magnetic globule, yielding white fumes, an arsenic coat, and an odor of garlic and of burning sulphur; with borax it forms a blue bead after roasting. It is soluble in warm nitric acid, giving a rose-red solution with residue of sulphur and arsenious oxide.

COPPER MINERALS

48. Native copper is comparatively pure copper, but often contains metallic silver, and sometimes mercury or bismuth. It crystallizes in the isometric system, the cube and tetrahexahedron being the most frequent forms; the crystals are seldom distinct. Usually it occurs in sheets or disseminated masses, varying in size from small grains to several hundred tons in weight, also in threads and wire consisting of a string of crystals. *Color*, copper-red tarnishing nearly black; *streak*, copper-red; opaque; *luster*, metallic; *tenacity*, malleable and ductile; *cleavage*, none; $H = 2.5$ to 3; $G = 8.8$ to 8.9.

Native copper is an important source of copper, especially that of the Lake Superior Region.

Tests for Identification.—Fuses easily to malleable globule, and reacts for copper in borax and S. Ph. It is soluble in nitric acid with evolution of brown fumes, giving a green solution that becomes deep blue on addition of ammonia in excess.

49. Chalcocite, or **copper glance,** is cuprous sulphide, Cu_2S. Copper, 79.8 per cent.; sulphur, 20.2 per cent. It crystallizes in the orthorhombic system, in tabular forms, frequently twinned so as to resemble hexagonal forms like aragonite; it often occurs in black granular or compact masses frequently coated with the green carbonate. *Color*, blackish lead-gray with dull-black tarnish; *streak*, blackish lead-gray; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, prismatic; $H = 2.5$ to 3; $G = 5.5$ to 5.8.

Chalcocite is an ore of copper.

Tests for Identification.—B. B. fuses easily to a globule yielding fumes of burning sulphur and coloring the flame green, or azure-blue if moistened with hydrochloric acid. It reacts for copper in borax and S. Ph. beads, and is soluble in nitric acid, leaving residue of sulphur.

50. Chalcopyrite, or **copper pyrites,** is a copper and iron sulphide, $CuFeS_2$. Copper, 34.5 per cent.; iron, 30.5 per cent.; sulphur, 35 per cent. It crystallizes in the tetragonal system, in octahedrons, or tetrahedral sphenoids, and usually occurs massive, though sometimes in imitative shapes. *Color*, bright brass-yellow, often tarnished deep yellow or iridescent; *streak*, greenish-black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, indistinct.

Chalcopyrite is an important ore of copper.

Tests for Identification.—B. B. on charcoal fuses at (3) to a brittle magnetic globule, and gives a strong odor of burning sulphur; with soda, it yields metallic copper. In O. F., with borax or S. Ph. it gives a green bead when hot, and a greenish-blue bead when cold; in R. F., it is opaque and red. It is soluble in nitric acid with separation of sulphur; on adding ammonia to the solution, ferric hydroxide is precipitated and the solution is turned deep blue.

51. Bornite, or **erubescite,** purple or variegated copper ore, is also a copper-iron sulphide, Cu_3FeS_3, containing 55.5 per cent. copper, 16.4 per cent. iron, 28.1 per cent. sulphur. The composition is somewhat variable and often there is an admixture of chalcocite. It crystallizes in the isometric system in small cubes or other forms and occurs usually massive. *Color*, brownish copper-red, violet-blue, often varied; *streak*, dark grayish-black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, octahedral in places; $H = 3$; $G = 4.5$ to 5.5.

Bornite is an important ore of copper.

Tests for Identification.—B. B. on charcoal blackens, but becomes red on cooling. It fuses easily to brittle magnetic globule, giving odor of burning sulphur. The other tests are the same as for chalcopyrite.

52. Tetrahedrite, or **gray copper ore,** is a double sulphide of copper and antimony, $Cu_8Sb_2S_7$, in which the copper is often partially replaced by iron, zinc, silver, lead, and mercury, and the antimony by arsenic. It crystallizes in the isometric system in tetrahedral forms, Fig. 17, the crystals being sometimes incrusted with yellow chalcopyrite. It usually occurs massive. *Color*, light steel to dark lead-gray or iron-black; *streak*, black or reddish-brown; opaque; *luster*, metallic; *cleavage*, uneven.

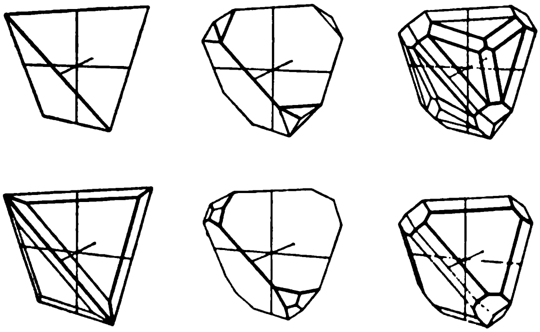


FIG. 17

Tetrahedrite is sometimes worked for both silver and copper.

Tests for Identification.—B. B. fuses at (1.5) to a globule that is sometimes slightly magnetic. It gives fumes and a coat of antimony and an odor of burning sulphur. The roasted residue reacts for copper.

53. Cuprite, red, or **ruby copper ore** is cuprous oxide, Cu_2O. Copper, 88.8 per cent.; oxygen, 11.2 per cent. It crystallizes in the isometric system, usually in transparent octahedrons or cubes, but occurs also in fine-grained masses and capillary form. *Color*, bright red to brownish-red; *streak*, brownish-red; transparent to opaque; *luster*, adamantine to dull: *tenacity*, brittle: *cleavage*, octahedral; H = 3.5 to 4: G = 5.85 to 6.15.

Cuprite is an important ore of copper.

Tests for Identification.—B. B. on charcoal blackens and fuses readily to a malleable red button, coloring the flame green. It is soluble in strong hydrochloric acid, forming a brown solution, in which, on dilution with water, a white precipitate is formed. It has all other reactions for copper.

54. Tenorite, or **melaconite,** is the black oxide of copper, CuO. Copper 79.85 per cent.; oxygen, 20.15. It crystallizes in the orthorhombic system, but occurs usually in black earthy masses or as black powder or shining scales, also as botryoidal concretions along with other copper ores. *Color*, black; *streak*, black; opaque; *luster*, metallic, in scales, dull in masses; *tenacity*, brittle to earthy; *cleavage*, uneven; $H = 3$ to 4; $G = 5.82$ to 6.25.

Tests for Identification. — B. B. infusible; colors flame green, or azure-blue when moistened with hydrochloric acid. Soluble in nitric acid, forming a green solution that becomes dark blue on addition of ammonia in excess.

55. Malachite, or green carbonate of copper, $Cu_2(OH)_2CO_3$. Cupric oxide, CuO, 71.9 per cent.; carbon dioxide, CO_2, 19.9 per cent.; water, 8.2 per cent. It crystallizes in the monoclinic system, crystals rare, and occurs usually as bright green masses or incrustations, often with a delicately fibrous structure or banded with lighter or darker shades of green. It also occurs stalactitic or earthy. *Color*, bright emerald-green to grass-green or nearly black; *streak*, pale green; translucent to opaque; *luster*, adamantine, silky, or dull; *tenacity*, brittle; *cleavage*, basal, perfect; $H = 3.5$ to 4; $G = 3.9$ to 4.03.

Malachite is an ore of copper. It is used for the manufacture of ornamental articles, as it is very beautiful when polished.

Tests for Identification.—B. B. on charcoal decrepitates, blackens, and fuses at (2), coloring the flame green and giving globule of metallic copper. It decrepitates, blackens, and yields water in a closed tube. Soluble in acids, with effervescence; the solution becomes deep blue on addition of ammonia in excess.

56. Azurite, or blue carbonate of copper, is also a hydrated carbonate of copper, $Cu_3(OH)_2(CO_3)_2$. Cupric oxide, 69.2 per cent.; carbon dioxide, CO_2, 25.6 per cent.; water, 5.2 per cent. It crystallizes in the monoclinic system in modified rhombic prisms. It also occurs globular, massive, and earthy, and often as an incrustation on other copper ores. *Color*, dark blue to azure blue; *streak*, paler blue; translucent to opaque; *luster*, vitreous to dull; *tenacity*, brittle; *cleavage*, parallel to the inclined axis; $H = 3.5$ to 4; $G = 3.77$ to 3.83.

Azurite is an ore of copper and is sometimes used as a blue paint.

Tests for Identification.—Its reactions are the same as for malachite; it is readily distinguished by its physical characteristics.

57. Chrysocolla is a hydrous silicate of copper, $CuSiO_3, 2H_2O$. Cupric oxide, CuO, 45.2 per cent.; silica, SiO_2, 34.3 per cent.; water, 20.5 per cent.; it is often quite impure. It does not crystallize and occurs usually as green to blue incrustations, also botryoidal and massive. *Color*, clear bluish-green to blue; *streak*, white; translucent to opaque; *luster*, vitreous to dull; *tenacity*, brittle to sectile; *cleavage*, absent; $H = 2$ to 4; $G = 2$ to 2.3.

Chrysocolla is used as an ore of copper and as an imitation turquoise.

Tests for Identification.—B. B. infusible, darkens, and colors flame green. When fused with soda it gives metallic copper. It yields water in a closed tube. It gives bead reactions for copper. Decomposed by hydrochloric acid, it leaves a residue of silica. It is distinguished from malachite by the absence of effervescence in acids.

58. Dioptase is also a hydrated silicate of copper, $CuSiO_3, H_2O$. Cupric oxide, CuO, 50.4 per cent.; silica, SiO_2, 38.2 per cent.; water, 11.4 per cent. It crystallizes in the hexagonal system in six-sided prisms with rhombohedral terminations, and occurs also massive. *Color*, emerald-green; *streak*, green; transparent to opaque; *luster*, vitreous; *tenacity*, brittle; *cleavage*, rhombohedral, perfect; $H = 5$; $G = 3.28$ to 3.35.

Tests for Identification.— B. B. infusible, decrepitates, blackens, and colors flame green. It blackens and yields water in a closed tube. It gives reactions for copper and gelatinizes with acids.

GOLD MINERALS

59. Native Gold.—Gold occurs mostly in the nati state either pure or alloyed with silver or other metals, copper, bismuth, rhodium, or palladiu It crystallizes in the isometric system octahedrons, Fig. 18, and dodecahedron the crystals are rarely perfect and di tinct, but in skeleton, distorted, and wir like forms. It occurs usually in nugget grains, or thread-like form, termed *wi gold*, and often disseminated through othe minerals in such condition as to be detecte only by assay. *Color*, gold-yellow; *streak*, gold-yello opaque; *luster*, metallic; *tenacity*, malleable; *cleavag* none.

FIG. 18

Gold is used principally for the manufacture of jewelr and for coinage.

Tests for Identification.—B. B. fuses at (3) to a brigh yellow malleable button. It is soluble only in aqua regia; if this solution is evaporated to a sirup and diluted with water and heated with a little of a solution of stannous chloride, it becomes purple. Gold may be distinguished from other substances of similar appearance by its dull yellow color, which is the same in all lights, by its malleability, and by its insolubility in any single acid.

60. Calaverite is a telluride of gold containing about 40 per cent. of gold, $AuTe_2$, the gold being sometimes partially replaced by silver. It occurs massive and fine-grained, never crystallized. *Color*, bronze or steel-gray to silver-white, yellow; *streak*, pale yellow; opaque; *luster*, metallic; *tenacity*, brittle; *fracture*, uneven to subconchoidal; $H = 2.5$; $G = 9.04$.

Calaverite is an important ore of gold in the Cripple Creek, Colorado, district.

Tests for Identification.—B. B. on charcoal burns with bluish-green flame, yielding globules of very bright yellow and nearly pure gold. The white coat on the coal disappears in R. F., coloring the flame green. Tellurium sublimate is formed in the open tube. If powdered and dropped into boiling concentrated sulphuric acid, the acid is colored intense purple. Soluble in nitric acid, the addition of hydrochloric acid throws down silver chloride if silver is present.

61. Sylvanite, or **graphic tellurium,** is a telluride of gold and silver $(Au.Ag)Te_2$. Gold, 28.5 per cent.; silver, 15.7 per cent.; tellurium, 55.8 per cent.; but its composition varies. It crystallizes in the monoclinic system in flat plates, which are united together in peculiar shapes resembling Hebrew letters, and occurs also in bladed and granular masses. *Color*, silver-white to steel-gray; *streak*, silver-white to steel-gray; opaque; *luster*, metallic; *tenacity*, sectile; $H = 1.5$ to 2; $G = 7.9$ to 8.3.

Tests for Identification.—Its tests are the same as for calaverite, except that the button obtained on charcoal is lighter yellow and contains more silver.

IRON MINERALS

62. Native iron contains more or less nickel, cobalt, chromium, or manganese. It crystallizes in the isometric system, and usually occurs compact in grains disseminated through some dolerite, basalt, and other igneous rocks. It is also found in meteorites alloyed with nickel. *Color*, iron-gray to black; *streak*, iron-gray to black; opaque; *luster*, metallic; *tenacity*, malleable; *cleavage*, octahedral. It is strongly attracted by magnet.

Native iron is only of rare occurrence.

Tests for Identification.—B. B. infusible, gives all reactions for iron. It is soluble in acids.

63. Hematite, specular iron, or **red-iron ore,** is ferric oxide, Fe_2O_3. Iron, 70 per cent.; oxygen, 30 per cent. It often contains silica, phosphorus, sulphur, alumina, titanium, lime, and magnesia as impurities. It crystallizes in the hexagonal system in scalenohedral or rhombohedral forms, Fig. 19, and occasionally thin and tabular, but occurs usually in masses in various forms, as columnar, radiated, kidney-shaped, and earthy. *Color*, iron-black, blackish-red, to cherry-red; if the ore is crystallized it does not have a red color; *streak*, always red; opaque; *luster*, metallic to dull; *tenacity*, brittle, except when micaceous; *cleavage*, usually indistinct; $H = 5.5$ to 6.5; $G = 4.9$ to 5.3. It is sometimes slightly magnetic.

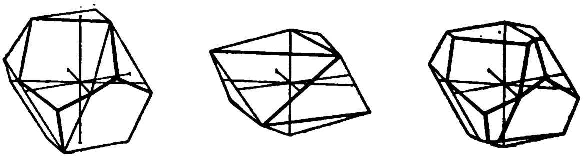


FIG. 19

Hematite is the most important iron ore mined. The earthy varieties are used for making cheap paint and for polishing.

Tests for Identification.—B. B. infusible, becomes black and magnetic on charcoal. It yields no water in closed tube. It gives all reactions for iron. It is soluble in hot hydrochloric acid.

Varieties.—The following are the principal varieties of hematite: *Specular iron*, black, blue-black, crystalline, or micaceous, with a perfectly metallic luster; when samples are shaken, small, shining scales drop off. *Red hematite*, massive, blackish-red to brownish-red color; luster, submetallic to dull. *Red ocher*, soft and earthy hematite, usually with clay; often pulverulent. *Red chalk*, more firm and compact than red ocher, and of a fine texture. *Clay ironstone*, hard, compact, red material, mixed with much clay or sand; the name clay ironstone is also applied to related varieties of siderite and limonite.

64. Limonite, bog ore, or **brown hematite,** is hydrous ferric oxide, $2Fe_2O_3,3H_2O$. Iron, 59.8 per cent.; or ferric oxide, Fe_2O_3, 85.6 per cent.; water, 14.4 per cent. It is often quite impure from sand, clay, manganese, phosphorus, etc.; it never occurs crystallized, but grades from the loose, porous bog ore and ocher to hard, compact variety, having a black varnish-like luster, and fibrous radiated structure. It is frequently stalactitic. *Color*, yellow, brown to nearly black, mostly reddish-brown; *streak*, yellowish-brown or yellow; opaque; *luster*, submetallic to silky and dull; *tenacity*, brittle to earthy; *fracture*, uneven or splintery; $H = 5$ to 5.5; $G = 3.6$ to 4.

Limonite is the most abundant ore of iron, but as it contains a relatively low percentage of iron and a higher percentage of impurities than hematite and magnetite, it is of less importance. The earthy varieties are used in cheap paints, and after burning are darker in color.

Tests for Identification.—B. B. infusible except in thin splinters. It becomes black and magnetic on charcoal in R. F., and yields water in closed tube. It gives all reactions for iron. It is soluble in hydrochloric acid, and may leave a gelatinous residue.

Varieties.—The following are the principal varieties of limonite: ***Brown hematite***, the botryoidal, stalactitic, and associated compact ore; ***bog iron ore***, a loose, earthy ore, of a brownish-black color, from marshy ground, often mixed with, and replacing leaves, twigs, etc.; ***yellow ocher, umber, etc.***, earthy variety mixed with clay; ***brown and yellow clay ironstone***, impure, hard, and compact ore, of a yellow or brown color, often in nodular masses.

65. Magnetite, or **magnetic iron ore,** is an oxide of iron, Fe_3O_4. Iron, 72.4 per cent.; oxygen, 27.6 per cent.; it often contains titanium and sulphur. It crystallizes in the isometric system, usually in octahedrons or dodecahedrons, and also occurs massive, granular, and as loose sand, or in masses made of imperfect crystals. *Color*, iron-black; *streak*, black; opaque; *luster*, metallic to submetallic; *tenacity*, brittle; cleavage, octahedral; $H = 5.5$ to 6.5; $G = 4.9$ to 5.2. It is strongly magnetic.

Magnetite is an important ore of iron.

Tests for Identification.—B. B. difficultly fusible in R. F. Gives all reactions for iron. Soluble in hydrochloric acid, but not in nitric acid.

66. Franklinite is an oxide of iron, similar to magnetite, in which part of the iron is replaced by zinc and manganese $(Fe, Mn, Zn)_3O_4$. It crystallizes in the isometric system in octahedrons, and occurs also in compact masses and rounded grains. *Color*, iron-black; *streak*, brown to black; opaque; *luster*, metallic or dull; *tenacity*, brittle; *cleavage*, indistinct; $H = 6$ to 6.5; $G = 5$ to 5.2. It is slightly magnetic at times.

Franklinite is worked for zinc oxide, and the residue smelted for spiegeleisen, an alloy of iron and manganese used in the manufacture of steel. It is sometimes ground and made into a dark paint.

Tests for Identification.—B. B. infusible. With soda, or soda and borax on charcoal, it gives a coat of zinc oxide. It gives a bluish-green color when fused with soda and niter on platinum foil, and a manganese bead when fused with borax. It is slowly dissolved by hydrochloric acid with evolution of chlorine.

67. Siderite, or **spathic ore,** is ferrous carbonate $FeCO_3$. Ferrous oxide, 62.1 per cent.; carbon dioxide, CO_2, 37.9 per cent.; it usually contains some calcium, magnesium, or manganese. It crystallizes in the hexagonal system, usually in rhombohedrons, with curved faces, Fig. 20, and occurs usually massive, with foliated or granular structure. *Color*, gray, yellow, brown, or black; *streak*, white or pale yellow to brown; translucent to opaque; *luster*, vitreous to pearly; *cleavage*, rhombohedral, perfect; $H = 3.5$ to 4; $G = 3.83$ to 3.88.

FIG. 20

Siderite is used as an ore of iron, and when high in manganese, for the manufacture of spiegeleisen.

Tests for Identification.—B. B. decrepitates, blackens, and becomes magnetic. It fuses with difficulty, but reacts for iron, and sometimes for manganese. It is soluble in warm hydrochloric acid with effervescence.

68. Pyrite, iron pyrites, or **fool's gold,** as it is sometimes called, is iron disulphide, FeS_2. Iron, 46.7 per cent.; sulphur, 53.3 per cent.; it often contains small amounts of gold, arsenic, copper, nickel, and cobalt. It crystallizes in the isometric system usually in cubes, Fig. 21 (*a*) and (*b*), and pyritohedrons, Fig. 21 (*c*), or their combinations; the cubes have striations on the faces, Fig. 21 (*b*), those on one face being at right angles to those on the adjacent face. It occurs also in crystalline masses of various shapes; sometimes in non-crystalline masses. *Color*, pale brass-yellow; *streak*, brownish-black to greenish-black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, cubic, imperfect; $H = 6$ to 6.5; $G = 4.9$ to 5.2.

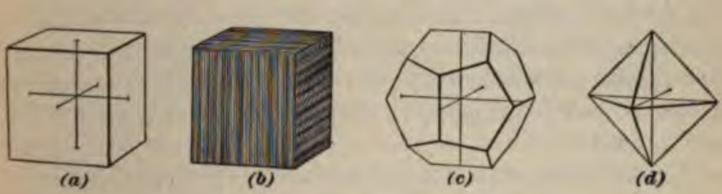

(*a*) (*b*) (*c*) (*d*)

FIG. 21

Pyrite is used for the manufacture of sulphuric acid. It is also often worked for gold and copper when containing these elements.

Tests for Identification.—B. B. takes fire and burns with a blue flame, giving a strong odor of burning sulphur. It leaves a magnetic residue on charcoal. A sublimate of sulphur is formed in a closed tube. It is insoluble in hydrochloric acid, but soluble in nitric acid with a separation of sulphur. Pyrite is distinguished from chalcopyrite by its color and streak, and by not showing the presence of much copper.

69. Marcasite, or white iron pyrites, has the same chemical composition as pyrite. About the only difference is in the color and crystalline form, and the fact that it is more easily decomposed by the atmosphere. It crystallizes in the orthorhombic system usually in tabular crystals, Fig. 22 (*a*) and (*b*); and twinned crystals, as in *spear pyrites*, Fig. 22 (*c*), *coxcomb pyrites*, etc.; it also occurs in crystalline masses, and globular and massive. *Color*, grayish-yellow, becoming darker on exposure; *streak*, dark brownish-black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, prismatic, imperfect; $H = 6$ to 6.5; $G = 4.6$ to 4.9.

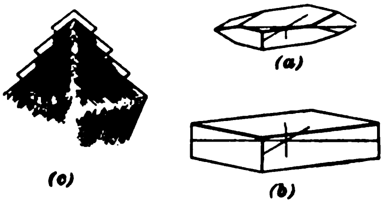


FIG. 22

The uses of marcasite are the same as for pyrite.

Tests for Identification.—The same as for pyrite.

70. Pyrrhotite, magnetic pyrites, or mundic, is also a sulphide of iron approximately, Fe_7S_8. It frequently contains small percentages of cobalt and nickel. It crystallizes in the hexagonal system, but usually occurs massive. *Color*, bronze-yellow to bronze-red, but subject to tarnish; *streak*, dark grayish-black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, uneven; $H = 3.5$ to 4.5; $G = 4.5$ to 4.6. It is attracted by the magnet.

Pyrrhotite is one of the chief ores of nickel. It is used to some extent as a source of sulphur.

Tests for Identification.—B. B. fuses easily to a black magnetic mass, giving fumes of sulphur, but does not take fire. It yields sulphur in small amount in closed tube, and is soluble in hydrochloric acid, with evolution of hydrogen sulphide leaving residue of sulphur. It may react for nickel and cobalt.

71. Other Iron Minerals.—*Arsenopyrite* (see Art. **15**); *chromite* (see Art. **43**); *columbite* (see Art. **166**); *wolframite* (see Art. **153**).

LEAD MINERALS

72. Native lead sometimes contains antimony and silver. It is a rare mineral, and crystallizes rarely in the isometric system, in octahedrons or dodecahedrons; it occurs usually in thin laminæ or globules imbedded in other minerals. *Color*, lead-gray; *streak*, lead-gray; opaque; *luster*, metallic; *tenacity*, malleable; $H = 1.5$; $G = 11.37$.

Tests for Identification.—It gives all the reactions for lead.

73. Galenite, or **galena,** is lead sulphide, PbS. Lead, 86.6 per cent.; sulphur, 13.4 per cent.; it usually contains silver and sometimes antimony, bismuth, and cadmium sulphides. It crystallizes in the isometric system usually in cubes or combination of the cube and octahedron, but sometimes in trigonal trisoctahedrons; it also occurs massive, rarely fine grained or fibrous. *Color*, dark lead-gray; *streak*, dark lead-gray; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, cubic, perfect; $H = 2.5$ to 2.75; $G = 7.4$ to 7.6.

Galena is the principal ore of lead. It often carries considerable silver, and for that reason is often worked for this metal.

Tests for Identification.—B. B. decrepitates and fuses easily. In O. F. it forms a white coat on coal, and gives a strong odor of burning sulphur; in R. F. it forms a yellow coat and malleable metallic button of lead. It is soluble in an excess of hot hydrochloric acid, from which solution white lead chloride separates on cooling; also soluble in strong nitric acid, with separation of sulphur and lead sulphate.

74. Anglesite is lead sulphate, $PbSO_4$. Lead oxide, PbO, 73.6 per cent.; sulphur trioxide, SO_3, 26.4 per cent. It crystallizes in the orthorhombic system, in various forms and occurs usually massive and often in concentric layers around a core of unaltered galena. [illegible] sometimes gray. [illegible] green, *streak*, white; transparent to opaque; *luster*, adamantine t vitreous; *tenacity*, very brittle; *cleavage*, basal and pri matic; *fracture*, conchoidal; $H = 2.75$ to 3; $G = 6.1$ to 6.39.

Anglesite is one of the ores of lead.

Tests for Identification.—B. B. decrepitates and fuses a (1.5) to a glassy globule that becomes pearly on cooling. I R. F., it gives yellow coat on coal. With soda, on charcoal it is reduced to metallic lead and gives sulphur reaction o silver.

75. Cerussite, or **white-lead ore,** is lead carbonate $PbCO_3$. Lead oxide, PbO, 83.5 per cent.; carbon dioxide CO_2, 16.5 per cent.; it often carries silver. It crystallize in the orthorhombic system, in prisms, pyramids, etc., an also occurs massive, stalactitic, granular, silky, and earthy *Color*, colorless, white to gray; sometimes colored b impurities; *streak*, white: transparent to opaque; *luster* adamantine to pearly, silky, or vitreous; *tenacity*, ver brittle; *cleavage*, prismatic and brachydome, imperfect *fracture*, conchoidal; $H = 3$ to 3.5; $G = 6.46$ to 6.51.

Cerussite is smelted for both lead and silver, and is use for the manufacture of white lead.

Tests for Identification.—B. B. on charcoal decrepitate and fuses, coating the coal yellow. It gives metallic lea with soda. In a closed tube, it first turns yellow, then dark but becomes yellow again on cooling. It effervesces in acids

76. Minium is red oxide of lead, Pb_3O_4. Lead, 90.6 pe cent.; oxygen, 9.4 per cent. It occurs earthy or in a loosel compacted mass often intermixed with yellow. *Color* bright red; *streak*, orange-yellow; opaque; *luster*, dull o greasy; *tenacity*, earthy; $H = 2$ to 3; $G = 4.6$.

Tests for Identification.—B. B. reduces to metallic lea and gives characteristic lead coats.

77. Pyromorphite is a double phosphate and chlorid of lead, $3Pb_3(PO_4)_2.PbCl_2$. Lead oxide, PbO, 82.2 pe cent.; phosphorus, P_2O_5, 15.7 per cent.; chlorine, 2.6 pe cent.; it often contains some calcium, arsenic, or iron. It crystallizes in the hexagonal system in short prisms and branching and tapering groups of prisms in parallel position; often in crusts of crystals; it also occurs moss like, massive, and botryoidal. *Color*, gray, green, brown, also white-yellow, orange; *streak*, white or yellowish; translucent to opaque; *luster*, resinous; *tenacity*, brittle; *cleavage* in traces; $H = 3.5$ to 4; $G = 5.9$ to 7.1.

Tests for Identification.—B. B. fuses at (1.5) and crystallizes on cooling. It gives metallic lead with soda on charcoal, a test for phosphorus with magnesium ribbon, and a blue coloration to flame in S. Ph. bead with copper oxide. It is soluble in nitric acid, from which solution ammonium molybdate throws down a yellow precipitate.

MAGNESIUM MINERALS

78. Magnesite is magnesium carbonate, $MgCO_3$. Magnesia, MgO, 47.6 per cent.; carbon dioxide, CO_2, 52.4 per cent.; sometimes part of the magnesium is replaced by iron or manganese. It crystallizes in the hexagonal system, rarely in rhombohedral crystals like dolomite, and often occurs massive, either granular or compact, sometimes fibrous, and in chalk-like lumps in veins in serpentine. *Color*, white, gray, yellow, brown; *streak*, white; opaque to translucent; *luster*, dull, vitreous to silky; *tenacity*, brittle; *cleavage*, rhombohedral, perfect; *fracture*, conchoidal; $H = 3.5$ to 4.5; $G = 3$ to 3.12.

Magnesite is used as a refractory lining for furnaces and converters in basic processes for the manufacture of steel. Also used for the manufacture of carbon dioxide, Epsom salts and other magnesium compounds.

Tests for Identification.—B. B. infusible but becomes alkaline on heating; it does not color the flame. Moistened with cobalt nitrate and ignited, it becomes pink. It is soluble with effervescence in warm hydrochloric acid, but not in cold.

79. Brucite is magnesium hydroxide, $Mg(OH)_2$. Magnesia, MgO, 69 per cent.; water, 31 per cent. It crystallizes in the hexagonal system in tabular crystals and prisms and usually occurs in foliated masses; it is also fibrous. *Color*, white, bluish, or greenish; *streak*, white; translucent; *luster*, pearly or wax like; *tenacity*, flexible and sectile; *cleavage*, basal, perfect.

Tests for Identification.—B. B. infusible and becomes alkaline. Moistened with nitrate-of-cobalt solution and ignited, it becomes pink. It yields water in a closed tube and is soluble in hydrochloric acid.

MANGANESE MINERALS

80. Braunite is oxide of manganese, Mn_2O_3. Manganese, 69 per cent.; oxygen, 31 per cent., when pure, but usually it contains manganese silicate, $MnSiO_3$. It crystallizes in the tetragonal system in minute octahedrons and usually occurs in granular masses. *Color*, brownish-black to steel-gray; *streak*, brownish-black; opaque; *luster*, submetallic; *tenacity*, brittle; $H = 6$ to 6.5; $G = 4.75$ to 4.82.

Braunite is used as an ore of manganese.

Tests for Identification.—B. B. infusible. It gives an amethystine bead with borax. It is soluble in hydrochloric acid with evolution of chlorine gas, and generally leaves gelatinous silica.

81. Hausmannite is an oxide of manganese, Mn_3O_4. Manganese, 72 per cent.; oxygen, 28 per cent. It crystallizes in the tetragonal system in both simple and twinned octahedrons that are more acute than those of braunite; it also occurs granular in strongly coherent masses. *Color*, brownish-black; *streak*, chestnut-brown; opaque; *luster*, submetallic; *tenacity*, brittle; *cleavage*, basal, nearly perfect; $H = 5$ to 5.5; $G = 4.72$ to 4.85.

Tests for Identification.—B. B. The same as for braunite, but differs from it in hardness, streak, and absence of silica.

82. Pyrolusite is manganese dioxide, MnO_2. Manganese, 63.2 per cent.; oxygen, 36.8 per cent. It crystallizes in the orthorhombic system in small rectangular prisms, Fig. 23, more or less modified, and occurs usually columnar, fibrous, and radiated, dendritic or massive. *Color*, black or steel-gray; *streak*, black; opaque; *luster*, metallic or dull; *tenacity*, brittle; *cleavage*, prismatic; $H = 1$ to 2.5; $G = 4.7$ to 4.86.

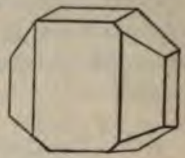


FIG. 23

Pyrolusite is used in the preparation of chlorine and spiegeleisen. Also as an oxidizing agent and for coloring and decolorizing glass, etc.

Tests for Identification.—B.B. infusible, and turns brown. It usually yields oxygen and a little water in closed tube and gives all tests for manganese. It is soluble in hydrochloric acid with evolution of chlorine.

83. Manganite is a hydrous oxide of manganese, Mn_2O_3,H_2O. Manganese, 62.4 per cent.; oxygen, 27.3 per cent.; water, 10.3 per cent. It crystallizes in the orthorhombic system in rhombic prisms often grouped in bundles, and occurs rarely massive, granular, or stalactitic. *Color*, iron-black to steel-gray; *streak*, brownish-black; opaque; *luster*, submetallic; *tenacity*, brittle; *cleavage*, prismatic, perfect; $H = 4$; $G = 4.2$ to 4.4.

Tests for Identification.—B. B. the same as for pyrolusite, but it yields much water in the closed tube.

84. Psilomelane, or **black hematite,** is essentially manganese dioxide with some barium oxide or potassium oxide, $MnO_2 + (H_2O, K_2O$, or $BaO)$. It occurs massive and smooth, usually botryoidal or in layers with pyrolusite. *Color*, iron-black to steel-gray; *streak*, brownish-black; opaque; *luster*, submetallic or dull; *tenacity*, brittle; *fracture*, even or conchoidal; $H = 5$ to 6; $G = 3.7$ to 4.7.

Psilomelane is used for the same purposes as pyrolusite, but the products are not so pure.

Tests for Identification.—B. B. infusible, but may become magnetic from impurities. It gives all tests for manganese, and yields oxygen and usually water in closed tube. It is soluble in hydrochloric acid with evolution of chlorine; on adding a drop of sulphuric acid to the solution a precipitate of barium sulphate is usually formed. It is distinguished from pyrolusite by its hardness and from limonite by its streak.

85. Wad, or **bog manganese,** is a mixture of oxides of manganese, principally manganese dioxide (30 to 70 per cent.) mixed with more or less ferric oxide, sometimes oxides of cobalt, copper, and lead, and 10 to 25 per cent. of water. It occurs earthy to compact and often soft and loose. *Color*, dark brown to black; *streak*, brown to black; opaque; *luster*, dull; *tenacity*, earthy; often soils the fingers; $H = \frac{1}{2}$ to 6; $G = 3$ to 4.26.

Wad is used as a paint and in the preparation of chlorine.

Tests for Identification.—B. B. infusible. It yields water in a closed tube, and gives all tests for manganese. It often gives strong reactions for copper or cobalt, and is soluble in hydrochloric acid with evolution of chlorine.

86. Rhodochrosite is manganese carbonate, $MnCO_3$. Manganous oxide, MnO, 61.7 per cent.; carbon dioxide, CO_2, 38.3 per cent.; part of the manganese is often replaced by calcium, magnesium, or iron. It crystallizes in the hexagonal system usually in rhombohedrons, but occurs usually massive, granular, or compact, sometimes botryoidal or incrusting. *Color*, rose-red to brownish-red and brown; *streak*, white; transparent to opaque; *luster*, vitreous to pearly; *tenacity*, brittle; *cleavage*, rhombohedral, perfect; $H = 3.5$ to 4.5; $G = 3.3$ to 3.6.

Tests for Identification.—B. B. infusible, decrepitates, and becomes dark and sometimes magnetic. It gives all tests for manganese, and is readily soluble in warm hydrochloric acid with effervescence, but slowly soluble in cold acid.

87. Alabandite, or **manganblende,** is manganese sulphide, MnS. Manganese, 63.1 per cent.; sulphur, 36.9 per cent. It crystallizes in the isometric system in cubes and regular octahedrons, and occurs usually massive, also massive granular. *Color*, iron-black with brown tarnish; *streak*, olive-green; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, cubic, perfect; $H = 3.5$ to 4; $G = 3.95$ to 4.04.

Tests for Identification.—B. B. fuses at (3), gives odor of burning sulphur, and turns brown. It gives bead tests for manganese after roasting, and is soluble in dilute hydrochloric acid with effervescence of hydrogen sulphide.

MERCURY MINERALS

88. Native mercury, or **quicksilver,** occurs as a tin-white liquid in little globules scattered through the gangue; it usually contains a little silver. When cooled below 39° F., mercury solidifies and crystallizes in the isometric system. *Color*, tin-white; opaque liquid; *luster*, metallic; $G = 13.59$.

Mercury is used for extracting gold and silver from ores, and for many other purposes in the arts and medicine.

Tests for Identification.—B. B. entirely volatile, if pure. It yields globules of mercury in closed tube, and is soluble in nitric acid.

89. Native amalgam is an amalgam of silver and mercury, $AgHg$. Silver, 35.1 per cent.; mercury, 64.9 per cent.; also, Ag_2Hg_3, silver, 26.5 per cent.; mercury, 73.5 per cent. It crystallizes in the isometric system in cubes, octahedrons, dodecahedrons, etc., and also occurs massive. *Color*, silver-white; *streak*, silver-white; opaque; *luster*, metallic; *tenacity*, brittle, and gives grating noise when cut with a knife; *cleavage*, dodecahedral in traces; *fracture*, conchoidal, uneven.

Tests for Identification.—B. B. the mercury is volatilized and a globule of silver is left. It yields a sublimate of mercury in closed tube, and is soluble in nitric acid.

90. Cinnabar, or **natural vermilion,** is sulphide of mercury, HgS. Mercury, 86.2 per cent.; sulphur, 13.8 per cent.; it is often impure. It crystallizes in the hexagonal system, rarely in small, transparent rhombohedral cryst or six-sided prisms, and occurs usually massive, sometim earthy. *Color*, cochineal-red, scarlet to brownish-red black; *streak*, scarlet; transparent to opaque; *luster*, ad mantine to dull; *tenacity*, brittle to sectile; *cleavage*, later perfect; $H = 2$ to 2.5; $G = 8$ to 8.2.

Cinnabar is the most important ore of mercury.

Tests for Identification.—B. B. completely volatile if pur with an odor of burning sulphur. Sulphur test on silv when fused with soda. In a closed tube, it yields black su limate that turns red when rubbed; with soda, it giv mirror of mercury, which may be collected into a drop b rubbing with a splinter. It is soluble in aqua regia.

Varieties.—*Metacinnabarite* is a black sulphide of mercury, HgS. Rarely occurs crystallized. *Luster*, metallic $H = 3$; $G = 7.75$.

Guadalcazarite is also sulphide of mercury, HgS, bu sometimes part of the mercury is replaced by zinc, and par of the sulphur by selenium.

91. Calomel, or **horn mercury,** is mercurous chloride, $HgCl$. Mercury, 84.9 per cent.; chlorine, 15.1 per cent. It crystallizes in the tetragonal system, and occurs usually as a coating to cavities, and is either with or near by a cinnabar deposit. *Color*, white, gray, brown; *streak*, white; translucent; *luster*, adamantine; *tenacity*, sectile; $H = 1$ to 2; $G = 6.48$.

Tests for Identification.—B. B. volatilizes without fusing, coating the coal white. In a closed tube, with soda, it forms a metallic mirror. It reacts for chlorine.

MOLYBDENUM MINERALS

92. Molybdenite is molybdenum sulphide, MoS_2. Molybdenum, 60 per cent.; sulphur, 40 per cent. It crystallizes in the hexagonal system in tabular hexagonal prisms, and occurs usually foliated, massive, or in scales. It resembles graphite in appearance. *Color*, bluish lead-gray; *streak*, greenish lead-gray (best seen on glazed porcelain); opaque; *luster*, metallic; *tenacity*, sectile to malleable; *cleavage*, basal; $H = 1$ to 1.5; $G = 4.44$ to 4.9.

Molybdenite is the source of molybdenum salts.

Tests for Identification.—B. B. infusible; it colors flame yellowish-green at high heat. It gives an odor of burning sulphur on charcoal and in open tube, and a sulphur reaction, with soda, on silver. It is soluble in strong nitric acid, and with sulphuric acid yields a blue solution. It reacts for molybdenum in S. Ph. bead; when this bead is crushed between damp, unglazed paper, it becomes red, brown, purple, or blue, according to the amount present. Distinguished from graphite by streak and blowpipe reactions.

93. Molybdite is molybdenum trioxide, MoO_3. Molybdenum, 66.7 per cent.; oxygen, 33.3 per cent. It crystallizes in the orthorhombic system, rarely in tufts, hair like, and radiated crystals, but occurs usually as an earthy powder or incrustation. *Color*, yellow or yellowish-white; *streak*, straw-yellow; translucent to opaque; *luster*, dull or silky; *tenacity*, earthy; $H = 1$ to 2; $G = 4.49$ to 4.5.

Tests for Identification.—B. B. on charcoal fuses; yields crystals—yellow while hot, white when cold, made deep blue by R. F. It gives all the reactions for molybdenum.

NICKEL MINERALS

94. Millerite, or capillary pyrites, is nickel sulphide, NiS. Nickel, 64.4 per cent.; sulphur, 35.6 per cent. It crystallizes in the hexagonal system in acicular fibrous or hair-like crystals, often interwoven and wool like, or in crusts made up of radiating needles visible on fracture. *Color*, brass or bronze-yellow; *streak*, dark greenish-black; opaque; *luster*, metallic; *tenacity*, brittle; crystals, elastic; *cleavage*, rhombohedral; $H = 3$ to 3.5; $G = 5.3$ to 5.65.

Millerite is an important ore of nickel.

Tests for Identification.—B. B. on charcoal fuses easily to a brittle magnetic globule yielding odor of burning sulphur.

After roasting, it gives bead reactions for nickel. It i soluble in aqua regia, giving a green solution from whic potassium hydroxide precipitates green nickelous hydroxide which dissolves in ammonia to a blue solution.

95. Pentlandite is a sulphide of iron and nickel $(Fe.Ni)S$ usually containing some copper; the composition is variable It crystallizes in the isometric system, but occurs als massive and granular, usually with chalcopyrite an pyrrhotite. *Color*, bronze, yellow; *streak*, black; opaque *luster*, metallic; *tenacity*, brittle; *cleavage*, octahedral $H = 3.5$ to 4; $G = 4.6$ to 5.

Pentlandite is mined in Sudbury, Ontario, for nickel.

Tests for Identification.—B. B. fuses to a magnetic globul that reacts for iron and nickel. It gives an odor of burnin sulphur.

96. Niccolite, or copper nickel, is arsenide of nickel $NiAs$. Nickel, 43.9 per cent.; arsenic, 56.1 per cent.; th nickel is sometimes partially replaced by cobalt or iron an the arsenic by antimony or sulphur. It crystallizes in th hexagonal system and occurs usually massive with a smoot impalpable structure. *Color*, pale copper-red with dar tarnish; *streak*, brownish-black; opaque; *luster*, metallic *tenacity*, brittle; *cleavage*, uneven; $H = 5$ to 5.5; $G = 7.$ to 7.67.

Niccolite is an important ore of nickel.

Tests for Identification—B. B. on charcoal fuses easily giving white fumes, garlic odor, and leaving a magneti residue that gives bead reactions for nickel and sometime for cobalt. In an open tube, it gives white sublimate an yellowish-green residue. It is soluble in nitric acid an forms a green solution.

97. Chloanthite is also an arsenide of nickel, $NiAs_2$. Nickel, 28.1 per cent.; arsenic, 71.9 per cent.; the nickel i often partially replaced by iron and cobalt. It resemble smaltite, into which it merges. *Color*, tin-white to steel-gray; *streak*, grayish-black; opaque; *luster*, metallic *tenacity*, brittle.

Tests for Identification.—B. B. like smaltite except that it reacts for nickel.

98. Gersdorffite is nickel sulph-arsenide, $NiAsS$. Nickel, 35.4 per cent.; arsenic, 45.3 per cent.; sulphur, 19.3 per cent.; the nickel is often replaced by iron or cobalt. It crystallizes in the isometric system in forms similar to pyrites, and occurs usually massive and fine-grained and incrusting decomposed galenite and sphalerite. *Color*, silver-white to steel-gray; *streak*, dark-grayish black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, cubic; $H = 5.5$; $G = 5.6$ to 6.2.

Tests for Identification.—B. B. decrepitates and fuses easily to a metallic globule giving white arsenic fumes and an odor of garlic, and of burning sulphur. The residue is magnetic and reacts for sulphur; it will react for nickel in borax bead unless obscured by the presence of cobalt and iron.

99. Garnierite, or **noumeite,** is hydrous silicate of nickel containing magnesium, $H_2(Ni.Mg)SiO_4,H_2O$. It occurs amorphous in loosely compacted masses and in crusts. *Color*, bright apple-green to pale greenish-white; *streak*, light green to white; opaque; *luster*, resinous or varnish like to dull; *tenacity*, friable; $H = 2$ to 3; $G = 2.27$ to 2.8. It is unctuous and adheres to the tongue.

Garnierite is the most important ore of nickel.

Tests for Identification.—B. B. infusible, decrepitates. It yields much water in a closed tube, and gives bead reactions for nickel. It is decomposed by hydrochloric acid without gelatinizing.

POTASSIUM MINERALS

100. Sylvite is potassium chloride, KCl. Potassium, 52.4 per cent.; chlorine, 47.6 per cent. It crystallizes in the isometric system with octahedral faces, often in cubes, and occurs also massive in white masses having the appearance of common salt. It absorbs moisture from the atmosphere and becomes damp. *Color*, white, bluish, reddish, colorless; *streak*, white; transparent to translucent; *lu* vitreous; *tenacity*, brittle; *cleavage*, cubic, perfect; *t* nearly like common salt; $H = 2$; $G = 1.97$ to 1.99.

Tests for Identification.—B. B. fuses readily and gi violet flame. In S. Ph. bead with copper oxide gives a blue coloration to flame. It is soluble in water and aci

101. Niter, or **saltpeter**, is potassium nitrate, *K* Potassium oxide, K_2O, 46.5 per cent.; nitrogen pento N_2O_5, 53.5 per cent. It crystallizes in the orthorho system in needle-like prisms, and occurs also as white c and silky tufts in caverns and on the earth's surface, on rocks, etc. *Color*, white, colorless, gray; *streak*, w translucent or subtransparent; *luster*, vitreous; *ten* brittle; *taste*, saline and cooling.

Niter is used in the manufacture of gunpowder, in cine, etc.

Tests for Identification.—B. B. fuses easily and color flame violet. On charcoal it deflagrates violently. soluble in water.

SILICA AND SILICATES

102. The element silicon occurs principally in the of silica or silicon dioxide, SiO_2, and combinations o latter with other elements in the form of silicates. It is, to oxygen, the most abundant element in nature. Owi the large varieties of silicates and their complex nature, difficult to classify them arbitrarily. The classific here adopted is as follows: *Silica*, *anhydrous sili* *hydrous silicates*, *titano silicates.*

SILICA

103. Quartz is silicon dioxide, SiO_2. Silicon, 46.7 cent.; oxygen, 53.3 per cent.; it often contains va impurities that give it characteristic colors. It crystal in the hexagonal system, in six-sided prisms terminated by six pyramidal planes, Fig. 24 (*a*), (*b*), (*c*),. and (*d*); the striations shown on the faces are often well marked. In Fig. 24 (*b*), the prism is absent and the crystal is made up of the two terminal pyramids. The crystals are often much distorted and twinned. It occurs also as translucent non-crystalline layers in cavities having usually a mammillary, nodular, or stalactitic structure, also as non-crystallized opaque material highly colored by iron, etc. *Color*, white or colorless when pure; when impure it is found of all colors; *streak*, white; transparent to opaque; *luster*, vitreous to greasy; *tenacity*, brittle to tough; *cleavage*, rhombohedral, difficult; *fracture*, conchoidal; $H = 7$; $G = 2.6$ to 2.66.

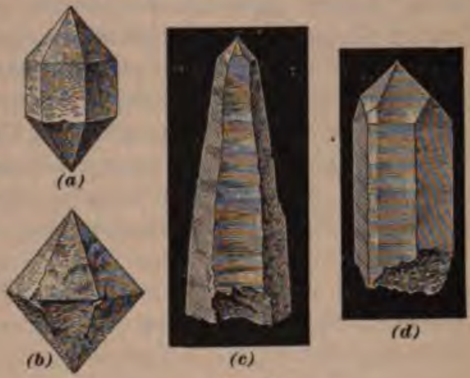


FIG. 24

Varieties.—1. The *crystalline varieties* are vitreous in luster, often transparent; occur in isolated or grouped crystals, drusy surfaces, crystalline. They have a glassy fracture. *Rock crystal*, pure, colorless, or nearly colorless, quartz crystals; *amethyst*, a purple or violet variety of quartz crystal that is often very beautiful; the color disappears on heating and is probably due to the presence of manganese; *yellow quartz* or *false topaz*, light yellow quartz crystals often cut and used for topaz, but distinguished from the true topaz by the absence of cleavage; *smoky quartz*, quartz crystals of a smoky brown color, sometimes quite dark; *milky*, or *greasy*, *quartz*, a milky-white variety of quartz of common occurrence, it is translucent but nearly opaque and often has a greasy luster; *ferruginous quartz*, opaque, yellow-brownish, yellow, or red crystals; color due to the presence of ferric oxide; *cat's eye*, opalescent, grayish-brown or green quartz containing parallel fibers of asbestos.

2. The *chalcedonic varieties* are translucent and have a waxy luster, they are frequently nodular, mammillary, stalactitic, and filling cavities, and are never crystalline. *Chalcedony*, pale blue or gray varieties of a uniform tint; *agate*, banded, showing the successive depositions, which are often of different tints and irregularly mixed, giving the stone peculiar markings from which subvarieties are named as follows: *banded agate*, *ruin* or *fortification agate*, *moss agate*, *etc.*; *sard*, or *carnelian*, deep brownish-red chalcedony, of a blood-red color by transmitted light; *sard* and chalcedony in alternate layers is called *sardonyx*; *onyx*, a variety of agate in which the colors are arranged in flat horizontal layers, the colors being arranged usually in alternate layers of white and black, white and red, etc.; *prase*, dull onion-top green; *chrysoprase*, apple-green, color due to nickel; *plasma*, *heliotrope*, and *bloodstone*, faintly translucent, of a green color, spotted with white, yellow, or red dots, and thread-like markings.

3. *Jaspery Varieties.*—*Jasper*, dull, opaque, silicious stone, usually of a high color due to the presence of clay and iron oxide; the color ranges from yellow, red to brown; *touchstone*, violet-black and opaque, used for testing and comparing the purity of precious metals by means of their streak on the black surface.

104. Opal is an amorphous and hydrous form of silica, $SiO_2.nH_2O$; the water varies from 5 to 12 per cent. It occurs massive, reniform, stalactitic, and earthy, and in veins. Its *luster* is vitreous to resinous, pearly or dull; *tenacity*, brittle; $H = 5.5$ to 6.5; $G = 2.1$ to 2.2.

Tests for Identification. — B. B. infusible, but becomes opaque. It yields water in a closed tube. It is insoluble in all acids except hydrofluoric, but is soluble in caustic alkalies.

Varieties.—*Precious opal*, usually milky blue externally with beautiful internal play of tints, due probably to thin curved laminæ formed and bent during solidification; *fire-opal*, reddish or brown color, with yellow and bright hyacinth or red reflections resembling fire; *common*, or *semiopal*, translucent to nearly opaque opal of various colors, usually yellow or brown, but without the colored internal reflections, though sometimes it has a milky opalescence; *wood opal*, petrified wood retaining the woody structure, the petrifying material being opal; *opal jasper* resembles jasper in color, but is softer and has resinous luster; *hyalite*, colorless transparent masses occurring as crusts or concretions, and resembling glass or gum arabic; *geyserite*, *silicious sinter*, a loose, porous rock of opal silica, deposited around geysers, grayish to white in color; *fiorite*, or *pearl sinter*, a pearly, translucent material found in volcanic tufa near hot springs; *floatstone*, a variety of opal so porous and light that it will float on water.

FELDSPARS

105. Orthoclase, potash feldspar, or **common feldspar,** is a silicate of potassium and aluminum, $KAlSi_3O_8$. Silica, SiO_2, 64.7 per cent.; alumina, Al_2O_3, 18.4 per cent.; and potassium oxide, K_2O, 16.9 per cent.; sometimes part of the potassium is replaced by sodium. It crystallizes in the monoclinic system in a variety of forms, usually in thick prisms, Fig. 25 (*a*), and in twinned forms, Fig. 25 (*b*); it also occurs massive, lamellar, and cryptocrystalline. *Color*, white, colorless, yellowish, gray, flesh-red, green; *streak*, white; transparent to opaque; *luster*, vitreous or pearly; *cleavage*, basal and clinopinacoidal, perfect; $H = 6$ to 6.5; $G = 2.44$ to 2.62.

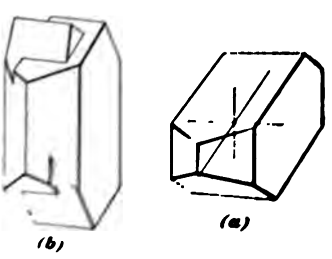


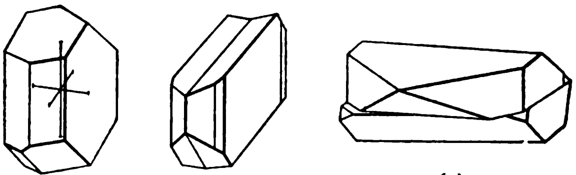
FIG. 25

Orthoclase is one of the principal constituents of granite, syenite, gneiss, and other related rocks.

Tests for Identification.—B. B. fuses with difficulty (4 to 5) to a semitransparent glass, coloring flame violet. It is insoluble in acids.

Varieties.—*Ordinary feldspar*, the common, subtranslucent variety, occurs in simple or twinned crystals of white, flesh-red, yellow, or green color; *adularia*, colorless to white, transparent, usually with a pearly opalescence, like moonstone, and sometimes with a play of colors: it is usually crystallized; *sanidin*, or *glassy feldspar*, glassy, white, colorless, transparent tabular crystals, in lavas, trachytes, etc.; *loxoclase*, grayish-white or yellowish crystals having a pearly or greasy luster; it contains much soda; *felsite*, jaspery or flint-like masses of a brown or red color.

106. Albite or **soda feldspar** is a sodium aluminum silicate, $NaAlSi_3O_8$. Silica, SiO_2, 68.6 per cent.; aluminum oxide, Al_2O_3, 19.6 per cent.; sodium oxide, Na_2O, 11.8 per cent. Soda feldspar crystallizes in the triclinic system in small but somewhat thick and tabular crystals, Fig. 26 (*a*) and also twinned as in Fig. 26 (*b*) and (*c*); it occurs usually massive, with a granular or lamellar structure, the laminæ being either straight or curved. *Color*, white, colorless, gray, bluish, red, and green; *streak*, white; transparent to opaque; *luster*, vitreous; *cleavage*, perfect; $H = 6$ to 6.5; $G = 2.62$ to 2.65.



(a) (b) (c)

FIG. 26

It is a constituent of some kinds of granite and gneiss.

Tests for Identification.—B. B. fuses in small pieces with difficulty (4 to 5) to a colorless glass or white enamel, coloring the flame intensely yellow. It is insoluble in acids.

107. Oligoclase, or **soda-lime feldspar,** is a double silicate of sodium and aluminum, and calcium and aluminum, $n(NaAlSi_3O_8) + CaAl_2Si_2O_8$, in which $n = 2$ to 6; part of the sodium is usually replaced by potassium. It crystallizes in the triclinic system. Occurs usually massive with fine striations on the cleavage surface. *Color,* white, gray, yellowish, greenish, and reddish; *streak,* white; transparent to opaque; *luster,* vitreous to pearly; *tenacity,* brittle; *cleavage,* perfect; $H = 6$ to 7; $G = 2.65$ to 2.67.

It is with orthoclase a constituent of granites, gneiss, and other rocks of igneous origin.

Tests for Identification.—B. B. fuses easily (3 to 3.5) to a clear or enamel-like glass. It is insoluble in acids.

108. Labradorite, or **lime-soda feldspar,** is a double silicate of sodium and aluminum, and calcium and aluminum, $NaAlSi_3O_8 + n(CaAl_2Si_2O_8)$, in which $n = 1$, 2, or 3. It crystallizes in the triclinic system rarely in small tabular crystals and occurs also massive, granular, and cleavable into masses that often show beautiful changing colors—blue, gold, red, etc.—like cat's eyes in the dark. It is a constituent of many eruptive rocks and lavas and also of some metamorphic rocks. *Color,* white, colorless, dark-gray, brown, or greenish-brown; *streak,* white; translucent to opaque; *luster,* vitreous to pearly; *tenacity,* brittle; *cleavage,* perfect; $H = 5$ to 6; $G = 2.7$ to 2.72.

It is used for making ornaments, table tops, etc.

Tests for Identification.—B. B. fuses easily to a colorless glass. It is partially soluble in hydrochloric acid.

109. Anorthite, indianite, or **lime feldspar,** is a silicate of calcium and aluminum, $CaAl_2Si_2O_8$. Calcium oxide, CaO, 20.1 per cent.; aluminum oxide, Al_2O_3, 36.8 per cent.; silica, SiO_2, 43.1 per cent. It crystallizes in the triclinic system in tabular crystals, and occurs also massive granular or coarse lamellar. *Color,* white, colorless, gray, yellow, and red; *streak,* white; transparent to opaque; *luster,* vitreous; *tenacity,* brittle; *cleavage,* perfect.

It is a constituent of basic eruptive rocks and of some metamorphic rocks.

Tests for Identification.—B. B. fuses with difficulty (5) to a colorless glass. When finely powdered, it is decomposed by hydrochloric acid, sometimes with gelatinization; the solution gives a white precipitate on addition of sulphuric acid.

ANHYDROUS SILICATES OTHER THAN FELDSPARS

110. Leucite is potassium aluminum metasilicate, $KAl(SiO_3)_2$. It crystallizes in the isometric system in trapezohedrons, and occurs in disseminated grains and crystals in volcanic rock. *Color*, glassy white to gray, or with yellowish or red tint; *streak*, white; translucent to opaque; *luster*, vitreous to greasy; *cleavage*, none; $H = 5.5$ to 6; $G = 2.45$ to 2.50.

Leucite rock is used for millstones.

Tests for Identification. — B. B. infusible. Moistened with cobalt-nitrate solution and ignited, it becomes blue. It is decomposed by hydrochloric acid without gelatinizing, leaving a fine powdery residue of silica.

111. Pyroxene is a metasilicate, $RSiO_3$, in which R is chiefly calcium, magnesium, manganese, iron, or aluminum. It crystallizes in the monoclinic system in short, thick oblique rhombic prisms, Fig. 27, of four, six, or eight sides terminating in two faces meeting at an edge, and occurs also granular, foliated, and as columnar masses, and rarely fibrous. *Color*, white, green, black, and brown; *streak*, white to greenish; transparent to opaque; *luster*, vitreous to dull or resinous; *tenacity*, brittle; *cleavage*, prismatic, perfect; *fracture*, conchoidal; $H = 5.6$; $G = 3.2$ to 3.6.

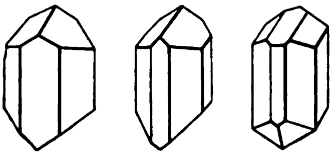


FIG. 27

It is a constituent of almost all basic eruptive rocks, and not uncommon in rocks of other kinds.

Tests for Identification.—B. B. usually fuses easily (2.5 to 5) to a dark glass and sometimes to a magnetic globule. It is generally insoluble in acids.

Varieties.—*Malacolite*, or *diopside*, a calcium magnesium pyroxene, $CaMg(SiO_3)_2$, is usually of a white, grayish, or pale-green color; *augite* consists chiefly of $CaMg(SiO_3)_2$, but also contains iron and aluminum; it is greenish-black to black; *diallage*, a thin foliated variety of pyroxene occurring imbedded in serpentine and other rocks, is green or brown in color.

112. Spodumene is a lithium aluminum metasilicate, $LiAl(SiO_3)_2$, in which part of the lithium is replaced by sodium. It crystallizes in the monoclinic system in crystals sometimes of great size (4 feet in length) and occurs also in cleavable masses. *Color*, white, grayish, or greenish-pink, rarely emerald-green; *streak*, white; transparent to opaque; *luster*, vitreous to pearly; *tenacity*, brittle; *cleavage*, prismatic, perfect; $H = 6.5$ to 7; $G = 3.13$ to 3.2.

Tests for Identification.—B. B. becomes white and opaque and fuses with intumescence to a white or colorless glass; it colors flame purple-red, especially when moistened with hydrochloric acid. It is insoluble in acids.

Varieties.—*Hiddenite*, a beautiful emerald-green variety of spodumene, is much used as a gem.

113. Wollastonite, or **tabular spar,** is calcium metasilicate, $CaSiO_3$. Calcium oxide, 48 per cent.; silica, 52 per cent. It crystallizes in the monoclinic system in tabular crystals and occurs also massive and compact to fibrous. *Color*, white, gray, tinged with yellow, red, or brown; *streak*, white; translucent, rarely subtransparent; *luster*, vitreous; *tenacity*, brittle; $H = 4.5$ to 5; $G = 2.8$ to 2.9.

Tests for Identification.—B. B. fuses with difficulty (4 to 5), coloring the flame red. It gelatinizes and usually effervesces in hydrochloric acid.

114. Amphibole, or **hornblende,** is a metasilicate of calcium, magnesium, and iron, $(Ca.Mg.Fe)SiO_3$; in composition and form it is closely related to pyroxene. It crystallizes in the monoclinic system, often in long, slender prisms, and occurs also in columnar, fibrous, and granular masses, rarely lamellar, and sometimes radiated. *Color*, white, gray, yellow, green, red, brown, and black; *streak*, white or greenish; transparent to opaque; *luster*, vitreous to silky; *tenacity*, brittle to tough; *cleavage*, prismatic, perfect; $H = 5$ to 6; $G = 2.9$ to 3.4.

Tests for Identification.—B. B. fuses from (2.5) to (5) to a colored glass that is sometimes magnetic; the darker varieties fuse easier than the lighter.

Varieties.—Tremolite, calcium magnesium amphibole, $CaMg_3(SiO_3)_4$, white to gray in color. *Actinolite*, composition $Ca(Mg.Fe)_3(SiO_3)_4$, is similar to tremolite except that part of the magnesium is replaced by iron; it is fibrous, columnar, prismatic, and massive, sometimes radiated, and bright green or grayish-green in color. *Asbestos* occurs in fine, easily separable fibers; it varies from white, gray, to greenish in color. *Nephrite*, or *jade*, is a tough, compact variety related to tremolite; it is microscopically fibrous. *Hornblende* is an aluminous variety containing much iron; it is black or green in color with a luster something like horn.

115. Rhodonite, or **manganese spar,** is manganese metasilicate, $MnSiO_3$, in which part of the manganese is partially replaced by calcium, iron, or zinc. It crystallizes in the triclinic system, the crystals being either tabular or in forms like pyroxene; it occurs usually compact in fine-grained or cleavable masses and disseminated grains. *Color*, usually deep flesh-red, brownish, greenish, and yellowish; *streak*, white; transparent to opaque; *luster*, vitreous; *tenacity*, brittle to tough; *cleavage*, indistinct; $H = 5.5$ to 6.5; $G = 3.4$ to 3.68.

Tests for Identification.—B. B. blackens and fuses easily (2.5) with slight intumescence. On coal with soda, it reacts for zinc; it also reacts for manganese. When powdered, it is partially decomposed by hydrochloric acid, leaving a white residue.

116. Beryl is a metasilicate of aluminum and beryllium, $Al_2Be_3(SiO_3)_6$; it often contains small amounts of iron, cæsium, lithium, and chromium, as impurities, some of which give the mineral characteristic colors. It crystallizes in the hexagonal system in prisms of variable size, from small threads up to several feet in length, and occurs usually crystallized, rarely massive or granular. *Color*, emerald-green to pale green, blue, red, yellow, white, colorless; *streak*, white; transparent to nearly opaque; *luster*, vitreous; *tenacity*, brittle; *cleavage*, basal and prismatic, imperfect; $H = 7.5$ to 8; $G = 2.63$ to 2.8.

Tests for Identification.—B. B. difficultly fusible on thin edges and becomes milk-white or cloudy. It is slowly dissolved in S. Ph. to an opalescent bead, but is insoluble in acids.

Varieties.—*Emerald*, a bright, rich, green variety, the green color being due to the presence of a small amount of chromium; it is used as a gem; *aquamarine*, clear beryls of sea-green, pale-bluish, or bluish-green color; it is used as a gem; *goshenite*, a colorless variety of beryl.

117. Cyanite, or **kyanite,** is a basic metasilicate of aluminum, $(AlO)_2SiO_3$. Alumina, Al_2O_3, 63.1 per cent.; silica, 36.9 per cent. It crystallizes in the triclinic system in long, blade-like crystals, seldom with terminal planes. *Color*, white, gray, blue, green, to nearly black; *streak*, white; transparent to translucent; *luster*, vitreous to pearly; *tenacity*, brittle; *cleavage*, pinacoidal, perfect; $H = 5$ to 7; $G = 3.56$ to 3.67.

Tests for Identification.—B. B. infusible. Moistened with cobalt-nitrate solution and ignited, it becomes blue. It is insoluble in acids.

118. Garnet is a complex silicate, $R''_3R'''_2(SiO_4)_3$, in which R'' is calcium, magnesium, iron, or manganese, and

R''' is aluminum, iron, chromium, or titanium. It crystallizes in the isometric system often in distinct dodecahedrons and trapezohedrons; both forms are sometimes variously modified and combined, Fig. 28 (*b*), (*c*), (*d*), and (*e*), and occurs as isolated crystals scattered through the mother rock, Fig. 28 (*a*), also in granular, lamellar, and compact masses and as rounded grains. *Color*, deep red, brown, black, green, violet, yellow, rarely colorless; *streak*, white; transparent to opaque; *luster*, vitreous or resinous; *tenacity*, brittle or tough; *cleavage*, dodecahedral, imperfect; *fracture*, uneven; $H = 6.5$ to 7.5; $G = 3.15$ to 4.38.

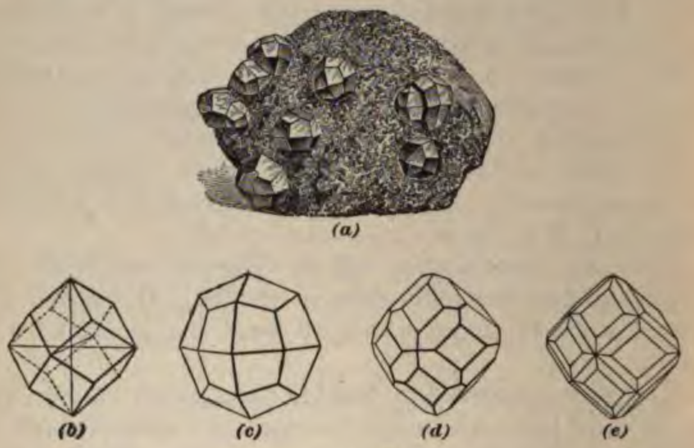


FIG. 28

Garnets are used as an abrasive and the clear varieties as gems.

Tests for Identification.—B.B. fuses quite easily (3 to 3.5), except those varieties containing chromium and yttrium, to a brown or black glass, which is usually magnetic. It gelatinizes with hydrochloric acid after ignition, but is unaffected before.

Varieties.—*Grossularite*, a calcium aluminum garnet, $Ca_3Al_2(SiO_4)_3$, is pale green, pale yellow, white, or colorless, sometimes brownish-red or rose-red; *almandite*, an iron aluminum garnet, $Fe_3Al_2(SiO_4)_3$, is of various shades of red; when transparent it is called *precious garnet; spessartite*, a manganese aluminum garnet, $Mn_3Al_2(SiO_4)_3$, is red, hyacinth-red, or brownish-red in color; *andradite*, a calcium iron garnet, $Ca_3Fe_2(SiO_4)_3$, is yellow, green, red-brown, or black in color; *ouvarovite*, a calcium chromium garnet, $Ca_3Cr_2(SiO_4)_3$, with some aluminum, is emerald-green in color.

119. Chrysolite, olivine, or **peridot,** is a silicate of magnesium and iron, $(Mg.Fe)_2SiO_4$. It crystallizes in the orthorhombic system, crystals rare, and occurs also massive and in disseminated glassy grains, and as sand. *Color*, various shades of green to brownish-red; *streak*, white or yellowish; transparent to translucent; *luster*, vitreous; *tenacity*, brittle; *fracture*, conchoidal; $H = 6.5$ to 7; $G = 3.27$ to 3.57.

The transparent varieties are sometimes used as gems.

Tests for Identification.— B. B. becomes white, but is infusible unless it contains a large proportion of iron, when it fuses to a magnetic globule. It is soluble, but gelatinizes with hydrochloric acid.

120. Zircon, or **hyacinth,** is a silicate of zirconium, $ZrSiO_4$. Zirconium oxide, ZrO_2, 67.2 per cent.; silica, SiO_2, 32.8 per cent. It crystallizes in the tetragonal system in prisms capped with pyramids, Fig. 29; the crystals are sometimes large. It occurs also in irregular lumps and grains. *Color*, brown, red, green, yellow, gray, and colorless; *streak*, white; transparent to opaque; *luster*, adamantine; *tenacity*, brittle; $H = 7.5$; $G = 4.68$ to 4.70.

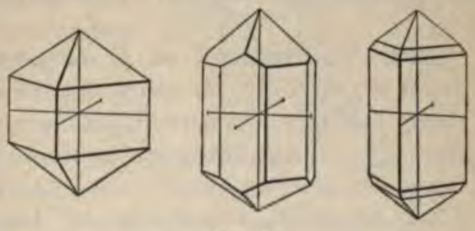


FIG. 29

Zircon is a source of zirconium oxide. The transparen red and brown varieties (Hyacinth) are used as gems.

Tests for Identification.—B. B. loses color, sometimes becoming white. It is infusible, and is insoluble in acids.

121. Topaz is an aluminum fluosilicate, $Al_2SiO_4F_2$. It crystallizes in the orthorhombic system in yellow rhombic prisms with pyramidal ends, Fig. 30, and occurs also massive in columnar aggregates and fragmentary. *Color*, pale yellow, sometimes white, pink, pale blue, green, or colorless; *streak*, white; *luster*, vitreous; *tenacity*, brittle; *cleavage*, basal, perfect; $H = 8$; $G = 3.4$ to 3.65.

FIG. 30

The transparent varieties are used as gems.

Tests for Identification.—B. B. infusible, but yellow varieties may become pink. Powdered and moistened with cobalt-nitrate solution and ignited, it becomes blue. Powdered and heated in an open tube with previously fused S. Ph., the glass becomes etched. It is insoluble in acids.

122. Tourmaline is a complex silicate containing boron, $R_{18}B_2(SiO_5)_4$, in which R is chiefly aluminum, potassium, lithium, manganese, calcium, or magnesium. It crystallizes in the hexagonal system in prismatic crystals of three, six, nine, or twelve sides, terminating in low three-sided pyramids, frequently of triangular cross-section, Fig. 31 (*c*); the sides of the prisms are often rounded and striated. It occurs also compact and massive, coarsely columnar and radiating. *Color*, almost all colors, black, brown, red, blue, green, yellow, gray, colorless—different parts of the same crystals are often of different colors; *streak*, white; transparent to opaque; *luster*, vitreous to resinous; *tenacity*, brittle; *cleavage*, difficult or absent; *fracture*, uneven; $H = 7$ to 7.5; $G = 2.98$ to 3.20.

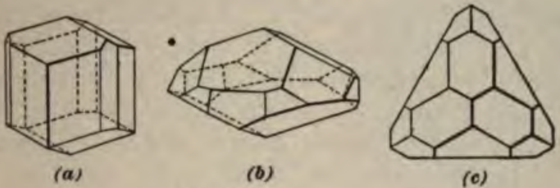

(a) (b) (c)

FIG. 31

The transparent red, yellow, and green varieties are cut and used as gems. Thin plates are sometimes used to polarize light.

Tests for Identification.— B. B. the dark varieties fuse quite easily, but the light varieties fuse only with difficulty. It colors the flame green when mixed with potassium bisulphate and fluorspar and fused. It is insoluble in acids, but gelatinizes after strong ignition.

123. Staurolite, or **cross-stone,** is a complex silicate of aluminum and iron, $HFeAl_5Si_2O_{13}$; the composition is variable, and manganese and magnesium are sometimes present. It crystallizes in the orthorhombic system in prisms, usually twinned, the crystals crossing one another either at right angles or at an angle of nearly 60°; there is a large variety of forms, of which Fig. 32 shows two. *Color*, dark brown to black; *streak*, white to gray; translucent to opaque; *luster*, vitreous to resinous; *tenacity*, brittle; *cleavage*, sometimes parallel to side plane; *fracture*, subconchoidal; $H = 7$ to 7.5; $G = 3.65$ to 3.75.

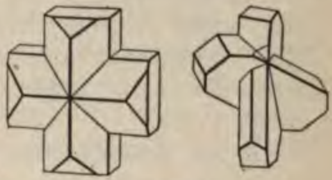


FIG. 32

Tests for Identification. — B. B. infusible except when carrying manganese. It is insoluble in acids.

HYDROUS SILICATES

124. Natrolite is a hydrous silicate of sodium and aluminum, $Na_2Al_2Si_3O_{10},2H_2O$. It crystallizes in the orthorhombic system in slender and nearly square prisms terminated with nearly flat pyramids, Fig. 33, and occurs also in globular, stellated, and divergent groups and interlaced acicular fibers. *Color*, white, gray, colorless, yellow, or red; *streak*, white; transparent to opaque; *luster*, vitreous; *tenacity*, brittle; *cleavage*, prismatic, perfect; $H = 5$ to 5.5; $G = 2.2$ to 2.25.

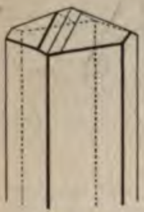


FIG. 33

Tests for Identification. — B. B. fuses quietly at (2) to a colorless glass. It yields water in a closed tube, and gelatinizes in hydrochloric acid.

125. Pectolite is a hydrous sodium calcium silicate, $Na_2Ca_4Si_6O_{17},H_2O$, that crystallizes in the monoclinic system, but distinct crystals are rare. It occurs usually massive, fibrous with radiated or stellated structure, and also with radiated crystals, Fig. 34. *Color*, white or gray; *streak*, white; translucent to opaque; *luster*, vitreous to silky; *tenacity*, brittle; $H = 5$; $G = 2.68$ to 2.78.

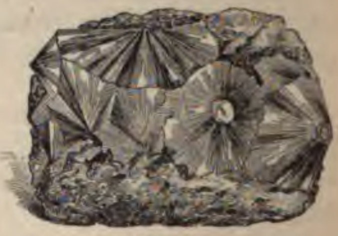


FIG. 34

Tests for Identification. — B. B. fuses easily (2.5) to a white enamel. It yields water in a closed tube and gelatinizes with hydrochloric acid.

THE MICAS

126. Muscovite, potash mica, white, or **common mica,** is a silicate of potassium, sodium and aluminum, $H_2(K.Na)Al_3(SiO_4)_3$, and also contains some iron and magnesium. It crystallizes in the monoclinic system, in crystals of rhombic or hexagonal section, and occurs usually in plates, or scales, and crystals, Fig. 35, that cleave with great ease into thin flexible, elastic, and transparent leaves; it sometimes occurs in radiated groups of aggregated scales (plumose mica), rarely spheroidal. *Color*, from white to green, brown, yellow, violet, red, and black; *streak*, white; laminæ are transparent to translucent; *luster*, vitreous or pearly; *tenacity*, elastic and sectile; *cleavage*, basal, eminent; $H = 2$ to 2.5; $G = 2.75$ to 3.

FIG. 35

Muscovite is used for doors to stoves and furnaces; as an insulator in electrical machinery, etc.

Tests for Identification.—B. B. whitens and fuses with difficulty on thinnest edges to a gray or yellowish glass. It yields a little water in a closed tube and is insoluble in acids.

127. Biotite, magnesium mica, or **black mica,** is a silicate of potassium, magnesium, and iron, $(H.K)_2(Mg.Fe)_2 Al_2(SiO_4)_3$. It crystallizes in the monoclinic system, usually in short, erect, rhombic, or hexagonal prisms, and is common in disseminated scales, also in masses made up of an aggregation of scales. It cleaves into thin elastic leaves. *Color*, usually dark green to black, rarely white; *streak*, white; transparent to opaque; *luster*, pearly on cleavage surfaces; vitreous and submetallic; *tenacity*, tough, elastic, and sectile; *cleavage*, basal eminent; $H = 2.5$ to 3; $G = 2.7$ to 3.1.

Tests for Identification.—B. B. whitens and fuses with difficulty on thin edges. It is decomposed by boiling sulphuric acid, with the separation of scales of silica. It reacts for iron.

128. Phlogopite, or **amber mica,** is a silicate of magnesium and aluminum, $R_3Mg_3Al(SiO_4)_3$, in which $R = H, K, MgF$. It crystallizes in the monoclinic system, usually in oblong tapering six-sided prisms. *Color*, yellowish-brown to brownish-red, green, or colorless; *streak*, white; transparent to translucent; *luster*, pearly to submetallic; *tenacity*, tough, elastic, and sectile; *cleavage*, basal eminent; $H = 2.5$ to 3; $G = 2.78$ to 2.85.

Phlogopite is much used in electrical work.

Tests for Identification.—B. B. whitens and fuses on thin edges. It yields water in a closed tube and is decomposed by sulphuric acid with separation of scales of silica.

129. Lepidolite, or **lithia mica,** has the composition $R_3Al(SiO_3)_3$, in which $R = H,Li,K,NaF$; it is not as common as the preceding varieties. It crystallizes in the monoclinic system. *Color*, rose-red, violet to white; *streak*, white; *luster*, pearly; *tenacity*, elastic and sectile; *cleavage*, basal, perfect; $H = 2.5$ to 4; $G = 2.8$ to 2.9.

Tests for Identification.—B. B. fuses easily (2.5) to a white glass, and colors flame purple-red. It yields a little water in a closed tube and is partially soluble in hydrochloric acid.

SERPENTINE AND TALC DIVISION

130. Serpentine is a hydrous silicate of magnesium, $Mg_3Si_2O_7,2H_2O$; part of the magnesium is sometimes replaced by iron. It occurs principally massive, granular, foliated, fibrous, and often in pseudomorphous crystals (after chrysolite and some other forms), but never in crystals of its own. *Color*, oil-green to yellow, brownish-red, red, black; *streak*, white; translucent to opaque; *luster*, silky, resinous, waxy, or greasy; *tenacity*, brittle to tough; *cleavage*, none; *fracture*, conchoidal; $H = 2.5$ to 4; $G = 2.5$ to 2.65.

Tests for Identification.— B. B. fuses with difficulty on thin edges. It yields water in a closed tube; moistened with cobalt-nitrate solution and ignited, it becomes pink. It is decomposed by hydrochloric acid, leaving a residue.

Varieties.—Precious serpentine, translucent masses of a deep oil-green color; *chrysolite*, or *serpentine asbestos*, is very finely fibrous, soft, and silky, and resembles amphibole asbestos; *verd-antique* is a limestone or marble containing serpentine, which gives it a green clouded effect, much used for ornamental purposes.

131. Talc is a hydrous silicate of magnesium, $Mg_3Si_4O_{11}$, H_2O. It crystallizes rarely in the orthorhombic system in right rhombic hexagonal crystals, and occurs usually foliated, massive, or fibrous. *Color*, green, gray, white, brown, or red; *streak*, white; translucent; *luster*, pearly waxy to dull; *tenacity*, sectile and inelastic; *cleavage*, basal, perfect, cleaves into non-elastic plates; *feel*, greasy; $H = 1$ to 1.5; $G = 2.55$ to 2.87.

Tests for Identification.—B. B. fuses on thin edges to a white enamel. It yields a little water in a closed tube; moistened with cobalt nitrate and ignited, it becomes pale pink. It is insoluble in acids.

Varieties.—*Foliated talc* is white to greenish-white and cleavable into non-elastic plates; *soapstone* or *steatite* is white, gray to green, massive, and granular; $H = 1.5$ to 2.5, used for wash tubs, etc.; *French chalk*, soft compact masses that will mark on cloth; *agalite*, fibrous masses; $H = 3$ to 4, used as a filler for paper; *rensselaerite*, compact wax-like masses; $H = 3$ to 4, pseudomorphous after pyroxene.

132. Kaolinite, or **kaolin,** a pure form of clay, is a hydrated silicate of aluminum, $Al_2Si_2O_7,2H_2O$. Alumina, Al_2O_3, 39.7 per cent.; silica, SiO_2, 46.4 per cent.; water, 13.9 per cent.; it usually contains more or less iron and organic matter. It crystallizes in the orthorhombic system in thin microscopic crystals, and occurs massive or clay like, either compact, friable, or mealy. *Color*, white, gray, yellow, red, brown, or blue; *streak*, white or yellowish; *luster*, dull or pearly; opaque or translucent; *tenacity*, plastic or earthy; $H = 2$ to 2.5; $G = 2.6$ to 2.63.

Pure kaolin is used for making porcelain and chinaware.

Tests for Identification.—B. B. infusible. It yields water in a closed tube; treated with cobalt-nitrate solution and ignited, it becomes deep blue. It is decomposed by sulphuric acid, but is insoluble in nitric and hydrochloric acids.

SILVER MINERALS

FIG. 36

133. Native silver occurs usually alloyed with copper, gold, platinum, mercury, antimony, or bismuth. It crystallizes in the isometric system in octahedrons and other forms, and occurs often in much elongated crystals of wire or thread-like form, Fig. 36; it is also arborescent and laminated. *Color*, silver-white, but tarnishes brown or nearly black; *streak*, silver-white; opaque; *luster*, metallic; *tenacity*, malleable; *cleavage*, none; $H = 2.5$ to 3; $G = 10.1$ to 11.1.

Tests for Identification.—B. B. on charcoal fuses to white metallic globule that "spurts," or throws out fine filaments of the metal when it solidifies. It dissolves in nitric acid, from whose solution hydrochloric acid or a soluble chloride precipitates white curdy silver chloride, which becomes dark on exposure to light.

134. Argentite, or **silver glance,** is silver sulphide, Ag_2S. Silver, 87.1 per cent.; sulphur, 12.9 per cent. It crystallizes in the isometric system, commonly in cubes or octahedrons. *Color*, lead-gray, blackish gray to black; *streak*, lead-gray, shining; opaque; *luster*, metallic; *tenacity*, malleable and very sectile; $H = 2$ to 2.5; $G = 7.2$ to 7.36.

Argentite is an ore of silver.

Tests for Identification.—B. B. on charcoal swells and fuses easily, (1.5), giving an odor of burning sulphur and a globule of metallic silver. It reacts for sulphur in the open tube, and on silver after fusing with soda.

135. Pyrargyrite, or **ruby silver,** is silver sulphantimonite, Ag_3SbS_3. Silver, 59.9 per cent.; antimony, 22.3 per cent.; sulphur, 17.8 per cent.; it often contains small amounts of arsenic.

FIG. 37

It crystallizes in the hexagonal system in prisms with rhombohedral or scalenohedral terminations, Fig. 37, and occurs usually massive, disseminated, or in thin films. *Color*, black or nearly so, but deep red by transmitted light; *streak*, purplish-red; translucent to opaque; *luster*, metallic, adamantine to dull; *tenacity*, brittle; *cleavage*, imperfect; *fracture*, conchoidal; $H = 2.5$; $G = 5.77$ to 5.86.

Pyrargyrite is an important ore of silver.

Tests for Identification.—B. B. fuses easily (1), spurts, and evolves dense white fumes. It forms an antimony coat on coal, and a silver button with soda on coal. In a closed tube, it forms a sublimate black while hot, and red when cold; a white sublimate is formed in an open tube. It is soluble in nitric acid, with separation of sulphur and antimony trioxide.

136. Stephanite, or **brittle silver ore,** Ag_5SbS_4, may be considered as a mixture of silver sulphide and antimony trisulphide. Silver, 68.5 per cent.; antimony, 15.2 per cent.; and sulphur, 16.3 per cent. It crystallizes in the orthorhombic system, sometimes in short, six-sided prismatic crystals, and occurs usually massive, fine-grained, and often disseminated through the gangue. *Color*, iron black; *streak*, iron black; opaque; *luster*, metallic; *tenacity*, brittle; *cleavage*, imperfect; $H = 2$ to 2.5; $G = 6.2$ to 6.3.

Tests for Identification.—B. B. on charcoal fuses easily, (1) giving an odor of burning sulphur with dense white fumes and antimony coat. It is soluble in nitric acid, leaving residue of sulphur and antimony trioxide.

137. Cerargyrite, or **horn silver,** is silver chloride, $AgCl$. Silver, 75.3 per cent.; chlorine, 24.7. It crystallizes rarely in the isometric system in cubes, and occurs usually massive or incrusting, rarely columnar. It has the consistency of horn or wax. *Color*, pearl-gray to greenish, but on exposure to light becomes violet-brown or black; *streak*, shining white; translucent to nearly opaque; *luster*, resinous or waxy; *tenacity*, waxy and very sectile; *cleavage*, none; $H = 1$ to 1.5; $G = 5$ to 5.5.

Cerargyrite is an important ore of silver.

Tests for Identification.—B. B. fuses easily (1), yielding metallic globule. It reacts for chlorine with copper oxide and S. Ph. Moistened and rubbed on the surface of iron or zinc, it swells, blackens, and silvers the surface. Fused in closed tube with potassium-acid sulphate, it yields a globule that is yellow while hot, white when cold, and made violet or gray by sunlight. It is insoluble in acids, but soluble in ammonia.

138. Bromyrite, or **bromargyrite,** is silver bromide, $AgBr$. Silver, 57.4 per cent.; bromine, 42.6 per cent. It crystallizes rarely in the isometric system, and occurs usually in small concretions along with cerargyrite. *Color*, brass-yellow to greenish; *streak*, yellow to greenish; transparent to translucent; *luster*, resinous to adamantine; *tenacity*, waxy and sectile; *fracture*, uneven; $H = 2$ to 3; $G = 5.8$ to 6.

Tests for Identification.—B. B. on charcoal, same as for cerargyrite. Fused with potassium acid sulphate, it evolves bromine vapor that colors the fluid yellow, while the fused bromyrite sinks as a dark-red transparent globule that becomes opaque and deep yellow on cooling, and dark green when exposed to the light.

139. Embolite is silver chlorbromide, $Ag(Cl.Br)$. It crystallizes in the isometric system, and occurs usually massive or compact. *Color*, green to yellow; *streak*, greenish or yellowish; transparent to translucent; *luster*, resinous; *tenacity*, waxy or sectile; *fracture*, uneven; $H = 1$ to 1.5; $G = 5.31$ to 5.81.

Tests for Identification.—B. B. fuses and gives globule of silver. Fused with potassium-acid sulphate, it behaves like cerargyrite or bromyrite, according as the proportion of bromine is small or large.

140. Iodyrite is silver iodide, AgI. Silver, 46 per cent.; iodine, 54 per cent. It crystallizes in the hexagonal system, and occurs also massive and lamellar in thin, flexible scales.

Color, gray, yellow to green or brown; *streak*, yellow; translucent; *luster*, resinous, wax like to adamantine; *tenacity*, sectile and flexible; *cleavage*, basal, perfect; $H = 1$; $G = 5.6$ to 5.7.

Tests for Identification.—B. B. fuses easily, spreads out, and gives globule of silver. With copper oxide and S. Ph., it colors the flame green. Fused with potassium acid sulphate in a closed tube, it yields violet iodine vapor and deep-red globule that becomes yellow when cold and does not change in sunlight.

SODIUM MINERALS

141. Halite, or **rock salt,** is sodium chloride, $NaCl$. Sodium, 60.6 per cent.; chlorine, 39.4 per cent.; it usually contains some calcium or magnesium chloride. It crystallizes in the isometric system in cubes, Fig. 38 (*a*), often with concave faces, Fig. 38 (*b*) and (*c*), and in related forms; it occurs also compact, granular, and fibrous, and is often found in very large deposits. *Color*, white, colorless, yellow, brown, deep blue; *streak*, white; transparent to translucent; *luster*, vitreous; *tenacity*, brittle; *cleavage*, cubic, perfect; *taste*, salt; when exposed to the air, it may absorb moisture; $H = 2.5$; $G = 2.4$ to 2.6.

FIG. 38

Halite is the source of all the salt of commerce, and of sodium and most of the sodium compounds.

Tests for Identification.—B. B. decrepitates violently and fuses easily, coloring flame intensely yellow. It reacts for chlorine with copper oxide and S. Ph. It is easily soluble in hot or cold water, from which solution silver-nitrate solution precipitates white, curdy, silver chloride, which becomes dark when exposed to the light.

142. Soda niter, Chile saltpeter, or **nitratine,** is sodium nitrate, $NaNO_3$. Sodium oxide, Na_2O, 36.5 per cent.; nitrogen pentoxide, N_2O_5, 63.5 per cent. It crystallizes rarely in the hexagonal system in rhombohedral crystals, and occurs usually in large beds, also in granular masses, crusts, and as an efflorescence. *Color*, white, yellowish, brownish, or colorless; *streak*, white, transparent; *luster*, vitreous; *tenacity*, brittle; absorbs water from the air; $H = 1.5$ to 2; $G = 2.24$ to 2.29.

Soda niter is used in the manufacture of potassium niter, nitric acid, and fertilizers.

Tests for Identification.—B. B. on charcoal deflagrates less violently than potash niter and fuses. It colors the flame yellow.

STRONTIUM MINERALS

143. Celestite is strontium sulphate, $SrSO_4$. Strontium oxide, SrO, 56.4 per cent.; sulphur trioxide, SO_3, 43.6 per cent. It crystallizes in the orthorhombic system in tabular or prismatic crystals, Fig. 39, and occurs also in fibrous and cleavable masses, rarely granular. *Color*, white, colorless, bluish, or reddish; *streak*, white; transparent to opaque; *luster*, vitreous or pearly; *tenacity*, brittle; *cleavage*, basal and prismatic, perfect; $H = 3$ to 3.5; $G = 3.95$ to 4.

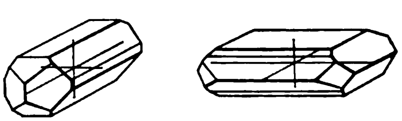


FIG. 39

Celestite is used for the manufacture of strontium nitrate.

Tests for Identification.—B. B. decrepitates and fuses at (3) to a white pearly glass coloring flame crimson. Alkaline reaction after fusion, and a sulphur reaction on silver after fusion with soda on charcoal.

144. Strontianite is strontium carbonate, $SrCO_3$. Strontium oxide, SrO, 70.1 per cent.; carbon dioxide, CO_2, 29.9 per cent. It crystallizes in the orthorhombic system in imperfect radiating needles and spear-shaped crystals, and occurs also fibrous, globular, and massive. *Color*, white, gray, yellowish to green, colorless; *streak*, white; transparent to opaque; *luster*, vitreous; *tenacity*, brittle; *cleavage*, prismatic, perfect; $H = 3$ to 4; $G = 3.68$ to 3.72.

Strontianite is the principal source of strontium salts. It is also converted to the hydroxide and used in the precipitation of sugar from molasses.

Tests for Identification.—B. B. swells, sprouts, and fuses on thin edges, coloring the flame crimson. It dissolves, with effervescence, in cold dilute acids.

SULPHUR MINERALS

145. Native sulphur, or **brimstone,** is nearly pure sulphur, but it may contain traces of arsenic, selenium, and tellurium. It is often mixed with clay or bitumen. It crystallizes in the orthorhombic system in acute octahedrons and other forms, Fig. 40, and occurs also massive, stalactitic, in crusts, as a powder, etc. *Color*, yellow, orange-yellow (when selenium is present), brown, or gray; *streak*, pale yellow to white; transparent to translucent; *luster*, resinous; *tenacity*, brittle; *cleavage*, imperfect; $H = 1.5$ to 2.5; $G = 2.05$ to 2.09.

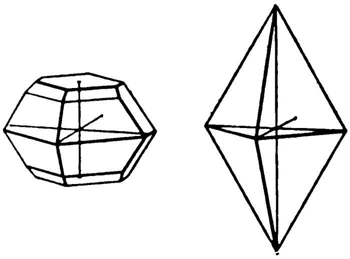


FIG. 40

Sulphur is used for the manufacture of sulphuric acid, gunpowder, for bleaching, in medicines, and for many other purposes.

Tests for Identification.—B. B. melts easily and burns with a blue flame giving strong odor of sulphur dioxide. In a closed tube, it melts and yields fusible sublimate, which is brown while hot and yellow when cold. It blackens silver, and is insoluble in acids.

TELLURIUM MINERALS

146. Native tellurium usually contains some sulphur, selenium, gold, silver, or iron. It crystallizes in the hexagonal system in minute six-sided prisms, and occurs usually fine-grained massive. *Color*, tin-white; *streak*, tin-white; opaque; *luster*, metallic; *tenacity*, somewhat brittle; *cleavage*, perfect prismatic; $H = 2$ to 2.5; $G = 6.1$ to 6.3.

Tests for Identification.—B. B. on charcoal fuses easily and volatilizes, coloring the flame green and coating the coal white. If the coat is removed to a porcelain dish and moistened, it yields a white sublimate that may be fused to colorless transparent drops. It is soluble in hydrochloric acid.

For other tellurium minerals, see Arts. **60** and **61.**

TIN MINERALS

147. Native tin has been found, but it is of no practical importance.

148. Stannite, or **tin pyrites,** is a sulphide of tin containing copper and iron, $(Sn.Cu.Fe)S$, there being about 27 per cent. of tin. It occurs massive, granular, and in disseminated grains, and is often intermixed with chalcopyrite. *Color*, steel-gray to iron-black; *streak*, black; opaque; *luster*, metallic, bluish tarnish; *tenacity*, brittle; *cleavage*, cubic, indistinct; $H = 4$; $G = 4.5$ to 4.52.

Tests for Identification.—B. B. fuses in R. F.; in O. F. it gives an odor of burning sulphur and becomes coated with white oxide of tin, which, when moistened with cobalt-nitrate solution and ignited, becomes bluish-green. It gives a sulphur reaction on silver after it has been fused with soda. It is soluble in nitric acid, forming a green solution with separation of sulphur and oxide of tin.

149. Cassiterite, or **tin stone,** is tin dioxide, SnO_2. Tin, 78.6 per cent.; oxygen, 21.4 per cent.; it usually contains some iron, and sometimes tantalum, arsenic, manganese, and silica. It crystallizes in the tetragonal system, in forms shown in Fig. 41 (*a*) and (*b*), and twinned, as in (*c*); it occurs also massive, granular, botryoidal, etc. It is a hard and heavy mineral. *Color*, brown to black, sometimes gray, yellow, or red; *streak*, white to light brown; translucent to opaque; *luster*, adamantine to dull; *tenacity*, brittle; *cleavage*, prismatic and pyramidal, indistinct.

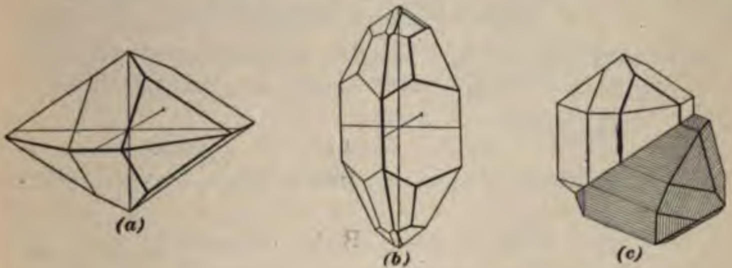


FIG. 41

Cassiterite is the source of all the tin used.

Tests for Identification.—B. B infusible, but the powdered mineral becomes yellow and luminous. The powder or sublimate moistened with cobalt-nitrate solution and ignited becomes dirty bluish-green. It may be reduced to a metallic button with soda on charcoal, and gives a faint, white sublimate near the assay. It is insoluble in acids and beads, but usually reacts for iron or manganese in the latter.

Varieties. — *Tin stone*, crystals, and granular masses; *stream tin*, a gravel-like ore found in alluvial deposits; *wood tin*, botryoidal or reniform shapes having a concentric and radiated structure.

TITANIUM MINERALS

150. Rutile is titanium dioxide, TiO_2. Titanium, 61 per cent.; oxygen, 39 per cent.; it sometimes contains iron and has a nearly black color (Nigrine). It crystallizes in the tetragonal system in prisms of four, eight or more sides, which are often twinned, as shown in Fig. 42;

crystals are often found penetrating other minerals. I occurs occasionally massive when iron bearing. *Color*, red reddish-brown to black; *streak* white or pale brown; transparent to opaque; *luster*, adamantine t nearly metallic; *tenacity*, brittle; *cleavage*, prismatic and pyramidal, distinct; $H = 6$ to 6.5; $G = 4.1$ to 4.25.

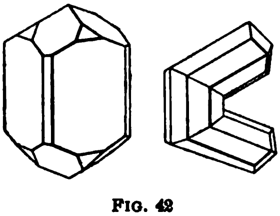
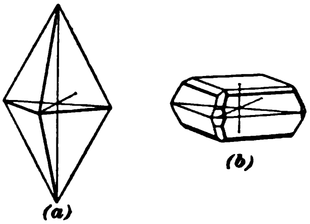


FIG. 42

Rutile is sometimes cut and used as a gem. It is also used for coloring porcelain yellow.

Tests for Identification. — B. B. infusible. In S. Ph., the bead dissolves very slowly; in the O. F., to a yellow bead that becomes violet in R. F. It is insoluble in acids.

151. Octahedrite, or **anatase**, is titanium dioxide, TiO_2. It crystallizes also in the tetragonal system in small, slender octahedrons, Fig. 43 (*a*), or tabular crystals, Fig. 43 (*b*). *Color*, brown, blue, black, yellowish, rarely grass-green; *streak*, white; transparent to opaque; *luster*, metallic or adamantine; *tenacity*, brittle; *cleavage*, pyramidal and basal; $H = 5.5$ to 6; $G = 3.82$ to 3.95.



(a) (b)

FIG. 43

Tests for Identification.—B. B. The same as for rutile, from which it is distinguished by its crystal form.

152. Brookite is also titanium dioxide, TiO_2. It crystallizes in the orthorhombic system in thin, flat crystals of varied habit. *Color*, brown, yellow, or black; *streak*, white or yellow; translucent to opaque; *luster*, submetallic to adamantine; *tenacity*, brittle; *cleavage*, basal and prismatic, indistinct; $H = 5.5$ to 6; $G = 3.87$ to 4.01.

Tests for Identification.—B. B. The same as for rutile and octahedrite, from which it is distinguished by its different crystallization.

TUNGSTEN MINERALS

153. Wolframite is a tungstate of iron and manganese, $(Fe.Mn)WO_4$, of which about 76.5 per cent. is tungsten trioxide, WO_3. It crystallizes in the monoclinic system, and occurs also granular or columnar massive. *Color*, dark gray to black; *streak*, deep brown to black; opaque; *luster*, submetallic; *tenacity*, brittle; *cleavage*, prismatic, perfect; $H = 5$ to 5.5; $G = 7.1$ to 7.55.

Wolframite is used in the manufacture of tungsten steel, tungsten salts, tungstic acid and sodium tungstate, which are used in dyeing and for rendering cotton incombustible.

Tests for Identification.—B. B. fuses easily (2.5 to 3) to a magnetic crystalline globule. It yields a reddish-yellow glass with S. Ph., which becomes green in R. F.; if this bead is pulverized and dissolved with tin in hydrochloric acid, it gives a blue solution. It reacts for manganese.

154. Scheelite is calcium tungstate, $CaWO_4$. Calcium oxide, CaO, 19.4 per cent.; tungsten trioxide, WO_3, 80.6 per cent.; it sometimes contains molybdenum. It crystallizes in the tetragonal system in octahedral crystals, and occurs also massive and as drusy crusts of yellow or brown crystals. *Color*, white, gray to pale yellow, green, or brown; *streak*, white; transparent to opaque; *luster*, vitreous to adamantine; *tenacity*, brittle; *cleavage*, indistinct; $H = 4.5$ to 5; $G = 5.4$ to 6.1.

Scheelite is a source of tungsten and tungsten compounds.

Tests for Identification.—B. B. fuses with difficulty (5) on thin edges. A clear bead is formed with S. Ph., which becomes blue in R. F.; when the bead is powdered and dissolved, with tin, in dilute hydrochloric acid, it yields a deep blue solution. Scheelite is soluble in hydrochloric and nitric acids, leaving a yellow residue.

ZINC MINERALS

155. Sphalerite, blende, rosin jack, or black jack is zinc sulphide, *ZnS*. Zinc, 67 per cent.; sulphur, 33 pe cent.; it often contains cadmium, manganese, and iron. I crystallizes in the isometric system in octahedrons, dodecahedrons, and other allied forms and combinations, Fig. 44

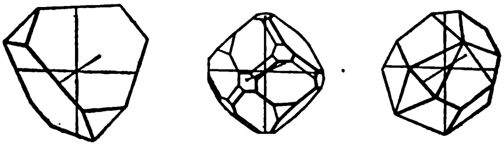


Fig. 44

and occurs usually in cleavable masses and in compact fine-grained masses, or alternate concentric layers with galenite. *Color*, yellow to brown (rosin jack), and black (black jack), rarely green, red, or white; *streak*, white; transparent to nearly opaque; *luster*, resinous; *tenacity*, brittle; *cleavage*, dodecahedral, perfect; $H = 3.5$ to 4; $G = 3.9$ to 4.2.

Sphalerite is an important ore of zinc and the principal source of cadmium.

Tests for Identification.—B. B. on charcoal fuses with great difficulty, giving an odor of burning sulphur, and a zinc coat which is yellow while hot and white when cold, but which is brown if cadmium is present. It reacts for sulphur on silver after fusing with soda. It is soluble in hydrochloric acid with effervescence of hydrogen sulphide.

156. Zincite, or red-zinc ore, is zinc oxide, *ZnO*. Zinc, 80.3 per cent.; oxygen, 19.7 per cent.; it usually contains some manganese and iron, and sometimes cadmium. It crystallizes rarely in the hexagonal system in hexagonal pyramids, and occurs usually in foliated masses or in disseminated grains in calcite or with franklinite or willemite. *Color*, deep red to orange-red; *streak*, orange-yellow; translucent; *luster*, subadamantine; *tenacity*, brittle; *cleavage*, basal and prismatic; $H = 4$ to 4.5; $G = 5.4$ to 5.7.

Zincite is an ore of zinc.

Tests for Identification.—B. B. on charcoal infusible, but reacts for zinc; the coat may show cadmium. In a closed tube, it blackens but becomes red on cooling, and often reacts for manganese in borax bead and when fused with soda and niter. It is soluble in hydrochloric acid.

157. Smithsonite, or **dry bone,** sometimes erroneously called calamine, is zinc carbonate, $ZnCO_3$. Zinc oxide, ZnO, 64.8 per cent.; carbon dioxide, CO_2, 35.2 per cent.; it often contains some cadmium. It crystallizes in the hexagonal system, usually in small rhombohedrons, and occurs usually compact, stalactitic, botryoidal to earthy. *Color*, white, gray to yellow, green, blue, brown, etc.; *streak*, white; translucent to opaque; *luster*, vitreous to dull; *tenacity*, brittle; *cleavage*, rhombohedral, perfect· $H = 5$; $G = 4.3$ to 4.5.

Smithsonite is a valuable zinc ore.

Tests for Identification.—B. B. infusible, but gives zinc coat on coal in R. F.; this coat often shows the presence of cadmium. It is soluble in acids, with effervescence.

158. Willemite is zinc silicate, Zn_2SiO_4. Zinc oxide, ZnO, 72.9 per cent.; silica, SiO_2, 27.1 per cent.; it often contains much manganese, which replaces the zinc. It crystallizes in the hexagonal system in long, slender, hexagonal prisms, and occurs usually granular or massive. *Color*, sulphur-yellow, greenish-yellow to apple-green when pure, but is often flesh-red to brown from manganese and iron; *streak*, nearly white; transparent to opaque; *luster*, resinous; *tenacity*, brittle; *cleavage*, basal and prismatic, imperfect; $H = 5.5$; $G = 3.89$ to 4.2.

Willemite is a valuable ore of zinc at Franklin, New Jersey, but has not been found extensively elsewhere.

Tests for Identification.—B. B. fuses in thin splinters on the edges to a white enamel; on charcoal, with soda and borax, it gives a zinc coat. It is soluble in hydrochloric acid, leaving a gelatinous residue.

159. Calamine, or **electric calamine,** is a hydrous silicate of zinc, Zn_2SiO_4,H_2O. Zinc oxide, ZnO, 67.5 per cent.; silicon dioxide, SiO_2, 25 per cent.; water, 7.5 per cent. It crystallizes in the orthorhombic system, usually in tabular rhombic prisms, Fig. 45 (*a*), and occurs also massive, granular, botryoidal, and stalactitic, sometimes with a drusy surface, Fig. 45 (*b*), or radiated groups of crystals. *Color*, white, colorless, yellow to brown—it is rarely blue or green; *streak*, white; transparent to opaque; *luster*, vitreous to pearly; *tenacity*, brittle; *cleavage*, prismatic, perfect.

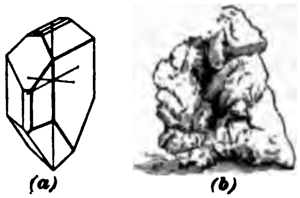


FIG. 45

Calamine is an important ore of zinc and is usually free from volatile impurities.

Tests for Identification.—B. B. fuses only thin splinters (6); with soda and borax, on charcoal, it gives a zinc coat. It yields water in a closed tube, and is decomposed by acids, leaving a gelatinous residue.

160. Franklinite is an oxide containing zinc and manganese, $(Fe.Mn.Zn)_3O_4$; it is worked for zinc oxide. See Art. **66.**

RARE MINERALS

CÆSIUM MINERALS

161. Cæsium occurs in two rare minerals, ***castorite*** and *pollucite* found on the island of Elba.

Pollucite, the chief source of cæsium, contains about 34 per cent. of this element. It occurs massive and is colorless and transparent. It has a bright vitreous luster on a fractured surface, but may be dull externally.

Tests for Identification.—B. B. in forceps whitens and fuses with difficulty, coloring the flame yellow. In a closed tube it becomes opaque and yields water. It is slowly decomposed by hydrochloric acid, leaving residue of silica.

CERIUM GROUP

162. The **cerium group** includes the elements *cerium*, *thorium*, *lanthanum*, *gadolinium*, *yttrium*, etc. Their most important occurrence is in the mineral **monazite,** which contains phosphates of cerium, lanthanum, thorium, and didymium, and often small amounts of erbium and ytterbium. Monazite crystallizes in the monoclinic system, usually in small flat crystals, Fig. 46, and occurs usually as brown resinous crystals or as yellow translucent grains, disseminated or as sand; sometimes it is in angular masses. The oxides of the constituent rare metals are used in the manufacture of mantles for incandescent gas lamps. *Color*, clove-brown, reddish-brown to yellow; *streak*, white; translucent to opaque; *luster*, resinous; *tenacity*, brittle; *cleavage*, basal, perfect; $H = 5$ to 5.5; $G = 4.9$ to 5.3.

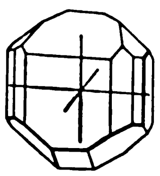


FIG. 46

Tests for Identification.—B. B. infusible but turns gray. When moistened with sulphuric acid, it colors the flame green. It is decomposed by hydrochloric acid, leaving a white residue.

SELENIUM MINERALS

163. **Clausthalite** is selenide of lead, $PbSe$. Lead, 72.4 per cent.; selenium, 27.6 per cent.; it sometimes contains silver and cobalt. It crystallizes in the isometric system, and occurs usually as granular masses, rarely foliated. It resembles galenite. *Color*, bluish lead-gray; *streak*, grayish-black; opaque; *luster*, metallic; *fracture*, granular; $H = 2.5$ to 3; $G = 7.6$ to 8.8.

Tests for Identification.—B. B. on charcoal fuses and yields an odor like decayed horseradish, and a white coat on coal with a red border; finally a yellow coat forms. It yields a red sublimate in an open tube. Fused with soda, it gives metallic lead.

164. Berzelianite is selenide of copper, $CuSe$. It is silver-white mineral occurring in thin dendritic crusts. Its *streak* is shining.

Tests for Identification.—B. B. reacts for both copper and selenium.

TANTALUM AND COLUMBIUM MINERALS

165. Tantalum occurs in several rare minerals, as tantalite, which is a tantalate of iron and manganese, $(Fe.Mn)Ta_2O_6$. It also occurs in columbite, the CbO_2 of the latter being replaced to a greater or less degree by TaO_2.

166. Columbite is $(Fe.Mn)Cb_2O_6$ and merges into tantalite. Both minerals crystallize in the orthorhombic system, in black and often iridescent prismatic crystals; also, more rarely, massive. *Color*, black; *streak*, dark red to black; opaque; *luster*, bright submetallic; *tenacity*, brittle; *cleavage*, in two directions at right angles; $H = 6$; $G = 5.4$ to 6.5.

Tests for Identification. — B. B. infusible. Fused with potassium hydroxide and boiled with tin, it gives a deep-blue solution. It is insoluble in acids.

GEOLOGY

(PART 1)

DESCRIPTIVE GEOLOGY AND PETROLOGY

FORM AND STRUCTURE OF THE EARTH

1. Definition.—Geology is the study of the physical history of the earth. In form, the earth is a sphere, and has a circumference of 24,899 miles. Its equatorial diameter is 7,926 miles, or about 26⅔ miles greater than its polar diameter. This difference in diameter is calculated, and while no man has reached the poles it is believed that the earth is slightly flattened at those places.

The earth is divided by geologists into two spheres; namely, the *lithosphere* and the *centrosphere*. The **lithosphere**, which is the outer sphere, is so named because it is composed of rocks, the study of which is the especial province of the geologist. Inside the lithosphere is the **centrosphere**, which comprises the interior and greater part of the earth, and about which man knows nothing and can only conjecture. Outside the lithosphere is the atmosphere, which is a body of gases composed chiefly of air and having a pressure of about 14.7 pounds per square inch under certain conditions of temperature and density.

2. Density of the Earth.—The average specific gravity of the earth at the surface is about 2.7, and this density is assumed to follow an arithmetical law with increasing depth.

A specific gravity equal to the mean density would be found at one-fourth the radius of the earth from the surface; this has been calculated by several independent methods as 5.6. The central density of the earth has been calculated to be 14.9, but this is considered by scientists as unreliable; the mean density of the earth has led many, however, to assume that the earth is solid. The known facts in the case are the density of the earth at the surface and the density of the earth as a whole; calculated figures are the central density and the distance beneath the surface that the mean density is found.

3. The Earth's Surface.—The outer portion of the lithosphere, or the earth's surface, is composed of land and water in the proportion of about eight-elevenths water and three-elevenths land, the water of course lying in depressions in the lithosphere. While the geologist cannot study the rocks beneath the present waters of the earth, he is able to study those that have been under ancient seas, for he has abundant proof that the outer portion of the lithosphere was at one time submerged. It has taken many years of research to gather enough facts to formulate the present science of geology, and while there is still very much to learn, yet the knowledge already possessed, and the speculations founded on causes still in operation, give the student a fairly clear insight into the structure of the lithosphere. The thickness or depth of the lithosphere is placed by some at 25 miles; but all that is known for certain is the depth of the Calumet and Hecla shaft, which is 5,300 feet, and the strata that have been exposed at the surface, or a total of about 10 miles. The lithosphere may have an indefinite depth, and any statement as to its thickness presupposes a solid crust and a liquid interior. There is nothing definite known as to the conditions of the earth's interior, the lower limit of lithosphere being merely one of definition based on many unproved assumptions.

4. Temperature of the Lithosphere.—The earth, some scientists have assumed, was once a molten mass, which has gradually cooled, and in cooling contracted so as to open cracks or fissures, and otherwise assist in causing the unevenness observed on the surface. Mountains, valleys, and the depressions that contain the seas, oceans, and lakes were caused in part by upheavals from some unknown cause and in part by subsidence of the land below water level. Whether or not cooling and contraction were the chief agents in producing these changes, geologists are sure from various observations that the temperature of the earth increases with depth. The increase is variable. At Wheeling, West Virginia, where a drill hole reached a depth of 4,462 feet, the temperature reached 111° F., or increased about 1° with every 88 feet of depth. On the Rand in South Africa, a drill hole 5,000 feet deep showed 1° rise in temperature for every 208 feet of depth. According to Professor Agassiz, the increase in temperature at the Calumet and Hecla mine in Michigan is 1° F. for every 233.7 feet of depth. On the Comstock lode in Nevada, the increase is about 1° F. in every 33 feet. At the Mapimi mine in Durango, Mexico, the increase is about 1° F. in every 50 feet. The mines on the Comstock lode are wet, while the Mapimi mine is absolutely dry for a depth of 1,900 feet. An average increase of temperature has been given at about 1° F. for every 60 feet in depth, although probably 100 feet is a closer approximation to the general average.

5. Recent Investigations.—Several geologists, notably C. R. Van Hise, have tried to harmonize the various geological conditions that exist and are known with those that exist and are unaccounted for, except by individual theorists. The treatment of the subject in this Section is based on the examinations of Van Hise and others, which in the main conform to well-known facts in other scientific departments and may consequently be applied to geology.

It is a known fact that the lithosphere is constantly under pressure due to the secular cooling of the earth or other causes of crustal shortening; and that in the deeper portions of the earth, considerable pressure is exerted by the weight of the superincumbent rocks. When and where these pressures are great enough, the rocks of the lithosphere yield to pressure and become deformed. This deformation may consist in fracturing the rock mass or in changing its form without conspicuously fracturing it—a condition known as *rock flowage*. Fracturing is observed in rocks that are deformed in the outer portion of the lithosphere, and evidence of rock flowage is observed in rocks that have been deeply buried. For this reason then, Van Hise has divided the lithosphere into three zones; namely, an outer *zone of fracture;* an intermediate *zone of fracture and flowage;* and a lower *zone of flowage.*

THE THREE ZONES

6. Determining Factors.—The three zones are necessarily very indefinite, for it is apparent that whether or not a rock will be deformed by fracture or flowage depends on a variety of factors that vary greatly from place to place and from time to time. Among these factors are pressure; the nature of the rock; the chemical and physical conditions under which the deformation occurs; and the length of time available for deformation. If a rock is put under sufficient pressure at the surface, it will ordinarily break along intersecting planes inclined approximately at 45° to the greatest pressure. If deeply buried and subjected to stresses in all directions, with even the least of these stresses more than sufficient to break the rock were it acting alone at the surface—or in other words greater than the ultimate strength of the rock—the rock tends to be deformed without conspicuous fracture; in other words, the rock practically flows. The flowage is accomplished by the chemical recrystallization of the constituents of the rock, accompanied perhaps by minute granulation of the minerals. At no time during the process of rock flowage does the rock become disintegrated. It is apparent that a hard and brittle rock, like a granite, will tend to yield by fracture to a greater extent than a soft one like shale or clay; and the depth of burial or, what is virtually the same thing, the amount of pressure necessary to make the granite yield by rock flowage—must necessarily be far greater than in the case of shale. Also, there are differences between two rocks apparently of the same hardness or brittleness, because of the different behavior of their mineral constituents under processes of rock flowage. Where the temperature is high, the rock will yield by flowage more readily than where the temperature is lower, because of the assistance afforded by high temperature to the process of recrystallization, which is the principal process of rock flowage. Where the rock mass contains considerable water, the conditions are favorable to recrystallization. The length of time during which deformation occurs also determines whether the rock will yield by flowage or by fracture. A marble slab, for instance, if put under pressure will break, but if supported at the ends for a considerable length of time will sag in the middle, thus indicating that the rock has actually changed its form without breaking or, in other words, has been deformed by rock flowage. This phenomenon is noticeable in the old cemeteries of the Eastern States. It is apparent, then, that the depth of the zone of fracture in which rocks are deformed by fracture rather than by flowage is likely to be most variable, depending on conditions. Van Hise has attempted to show what this depth would be for some of the hardest rocks, and has found it comparatively small. This he discovered by calculating what pressure would be sufficient to close any cavities that might be supposed to exist in the rock mass and by determining the height or thickness of a column of rock sufficient to give such pressure. Rock flowage occurs mainly through the minute granulation of the mineral constituents and through chemical recrystallization [illegible]. The latter process is an important one and [illegible] as in metals.

Prof. J. H [illegible] that changes [illegible] both on heating and [illegible] others that [illegible] recrystallize.

Professor Ewing found that:

1. In lead that has been severely strained, recrystallization goes on at all temperatures, from that of the ordinary room up to the melting point.
2. The higher the temperature, the more rapid are the changes in the crystalline structure.
3. The structure of a cast specimen of lead remains unaltered at temperatures that cause a strained specimen to show rapid change.

ZONE OF FRACTURE

7. Deformation by Stress.—Any force or combination of forces tending to alter the shape or size of a body is termed a **stress.** The process by which the internal structure and external configuration of the lithosphere are changed is termed **deformation,** provided the causes originate below the surface.

Rocks are subject to physical forces and chemical changes the same as most other matter. If a rock mass is subject to stress in one direction, it is perfectly elastic and will return to its original shape when the stress is removed (this may be verified by bounding a boy's marble on a stone), provided the stress has not been so great that it has passed a certain point called the **elastic limit.** No deformity will be permanent until the stress exceeds the elastic limit, and then the rock will assume a new form.

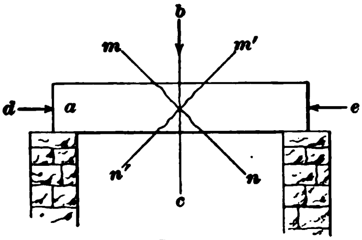


Fig. 1

8. Rupture.—The breaking strength of material is its ultimate strength, or the resistance it offers to rupture. If the rupture is caused by tensile forces, it is usually normal, that is, at right angles to the line of force; if caused by compressive forces, it is tangential, occurring by sliding along planes diagonal to the normal stress. To illustrate this, let Fig. 1 represent a stone slab *a* supported at both ends. If tensile forces act on the slab then the fracture will be along the line *b c*. Again, let *d* and *e* represent compressive forces; then rupture will occur along either the line *m n* or the line *m′ n′*, which are diagonal to the normal direction of the stress *b c*.

9. Ultimate Strength.—Rocks under less weight than their ultimate strength, when rapidly deformed, are in the zone of fracture, and under such conditions break, while crevices separate the broken parts. The crevices may be wide, deep, and long, or short, narrow, and shallow. The fractures may be very small and parallel, as in slates, or they may cause the rock to be broken into innumerable fragments that are either rounded or angular. The strength of the rock has much to do with the depth at which weight from strata above will cause deformation, for soft rock is more susceptible to weight than hard rock. In the case of soft rock, a small thickness of strata might prevent crevices from forming; while in hard brittle rock a crevice can extend to great depth. It has been noticed that, where a fissure in hard rock was of considerable size, it became a mere crease and finally was entirely lost in soft rock adjacent and below.

10. Depth at Which Rock Cavities Will Close.—Van Hise has attempted to show the depth of the zone of fracture by calculating the pressure sufficient to close any cavities that might be supposed to form in the rock mass, and determining the height of a column of rock sufficient to give such pressure. The intensity of stress on a horizontal plane at any depth is equal to the weight of a column of rock of unit cross-sectional area extending to the surface. Assume, for calculation, that the strongest rock has a specific gravity averaging 2.7 and a crushing strength of 25,000 pounds per square inch. These figures are in excess of ordinary granite, and are about equal to the strongest average granites and traps. The numerical value of the required depth at which cavities will close cannot be determined with certainty because of the [illegible] experiments requiring [illegible] before [illegible] any deformation observed. As cavities in the earth may be filled with water under pressure, the specific gravity of the rock mass will be opposed by the specific gravity of water, which is 1; hence, to find the height of the column of rock that will produce the required pressure, divide the crushing strength by the weight of a rock 1 inch square and 1 foot high, whose specific gravity is $2.7 - 1 = 1.7$. Then, $25{,}000 \div 62.5 \times 1.7 \times 12$ gives 33,882 feet as the depth at which cavities can exist under the conditions.

A second calculation is based on the rock above the cavities being solid to the surface and of a specific gravity of 2.7. Then,

$$\frac{62.5 \times 2.7 \times 12}{1{,}728} = 1.172$$

and $25{,}000 \div 1.172 = 21{,}331$ feet is the depth at which the cavities will close.

The first calculation, which assumes that the rocks are porous and are therefore supported by hydrostatic pressure, gives a depth of 6.5 miles as the point at which cavities must close. The second case, which assumes that the rocks are not porous but solid, gives 4 miles as the depth at which cavities must close. As the calculations are based on the strongest rocks, it is considered by Van Hise that the depth at which cavities will close is from 3 to 8 miles.

There are other factors entering into the problem that will affect the results, but the extremes have been taken as a basis of calculation. In numerous instances, veins have pinched out with depth, and there is no means of determining how much of the original vein has been eroded; *hence, in mining, it is customary to assume a long wide vein as one that will have considerable depth.*

11. **Fracture Folds.**—The unevenness of the earth's surface is supposed to be caused, in part at least, by the wrinkling of the lithosphere in its attempt to adjust itself to more rapid cooling and more rapid shrinking of the interior. An old comparison that illustrates this phenomenon is the wrinkling of an apple skin when the moisture begins to dry out prior to decay. According to Van Hise, the so-called

folds in the zone of fracture are the results chiefly of numerous parallel joint fractures across the strata, with slight displacements at the joints, giving each block a slightly different position from the previous one and thus as a whole making a fold, as shown in Fig. 2. For instance, the folds of the rigid rocks in the Alleghanies are not in the main true flexures, but a series of slightly displaced blocks. That movements have occurred and that such folds are due to them can be determined by the microscope.

FIG. 2

If the pressure is sufficient, the strongest and most brittle rock beds may be crumpled on themselves within their own radius. In fact, it is to be inferred that, the thinner and softer the beds, the shorter and steeper are the folds and the more nearly does their material approach in its movements to the flowage of tallow under pressure. In a series of beds of different lithological character, the thick strong beds are less closely folded than the thin weak beds, and the softer layers will be thickened here and weakened there, as demanded by the stronger layers.

ZONE OF FRACTURE AND FLOWAGE

12. The Argument.—As already noted, rock flowage occurs mainly through the process of minute granulation of the mineral constituents of the rock mass, and through chemical recrystallization of the particles. The marble slabs that have been mentioned as bending would probably have broken if pressure had been applied quickly; but, as the particles had time to meet the changed conditions, there was a flow of particles that caused a change in structure. Professor Hoskins points out that a rock under pressure in two directions may fracture when rapidly deformed by pressure in a third direction, and may flow when less rapidly deformed. This is due to the fact that the elastic limit of a rock is less than its ultimate strength. The fractured rock material of this middle zone may be coarse in size and hence have large spaces between the various fragments, or else grade down to very fine particles, with no apparent spaces between them as the zone of no cavities is approached. Since the dividing line for the zone of fracture and flowage is at different depths for rocks of unequal strengths, there is a zone where one rock will be in a fractured state and another rock in a state of flowage. It is also evident that, with increased pressure for the same rock, fractures become more frequent; the particles are in a state of mobility, being free to move in whatever direction the compression may be least; and finally the pressure becomes so great that particles are flattened out. Van Hise states that on Doe River, Tennessee, massive beds of quartzite are bent on themselves within their own radius with no evidence of crevice or fracture, but that the microscope shows that fracturing and resultant flattening of the quartz grains were almost universal.

13. Stress Difference.—Assume a cube of rock, Fig. 3, to be buried; it will have three mutually perpendicular directions in which the stress is normal, as shown by the lines *a a*, *b b*, and *c c*. In case the three stresses are equal, there will be no rupture or no movement, no matter what their intensity, and the density of the material may increase as the stresses increase. In general, however, the stresses are unequal, and the difference between the greatest and the least is termed the **stress difference.** Assuming that there is always a stress difference, it is evident that at a certain depth, which will vary for each rock, mashing of the rock particles will occur. This mashing will occur at different depths, according to the strength of the rock and the amount of moisture and heat present. The depth is important, inasmuch as it explains many peculiarities present in rocks. Water at this depth of fracture and flowage may be in such a condition as to greatly assist mashing, and in such cases plastic rocks or magmas may be formed much sooner than if water were absent. The movement of rock particles would be aided to a greater degree if water were present. It is evident that the natural place for water to perform solvent action most thoroughly is in the zone of fracture, and that when it reaches the zone of flowage it is saturated and in a better condition to cement rocks by the material it bears in solution than to dissolve them.

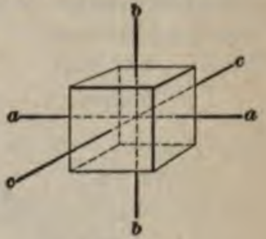


FIG. 3

ZONE OF FLOWAGE

14. The Argument.—Rocks buried to such a depth that the weight of the strata above them exceeds their ultimate strength are in the zone of plasticity. Cracks and crevices cannot form under such circumstances, for rock would flow toward the opening and close it. All rocks in this zone are under compressive stress, and the material being plastic will move from a place of great compression to one of less compression, or, in short, would endeavor to obey the laws of hydrostatics. If the mass were homogeneous it would flow in the direction of least resistance, like a mass of putty. But rock masses are heterogeneous, and the alternating layers of different plasticity may retain their individuality, there being no considerable mingling of one layer with another. The strong thick beds will vary the direction of movement of the material at a given place, and thus develop folds of great length and breadth. On account of their character and relative resistance, when deformation occurs so that they are arched above, they will carry part of the load above them and thus relieve to some extent the softer beds below. The softer beds, as shown by the black stratum in Fig. 4, will flow in the direction of least resistance and even press against the confining arch, and thus do their part in carrying the superincumbent load. In a similar manner, when strong formations are deformed so that they are bowed downwards, they will give increased pressure to softer beds and add to the ordinary thrust that is already forcing the material to the arches of the rocks bowed upwards.

FIG. 4

15. Plutonic Theory of Magmas.—It has been assumed by geologists that Plutonic rocks, such as granite and syenite, were deeply subterranean in their original positions, and were crystallized from a fused condition at great depths. To account for the difference in structure between Plutonic and igneous, or eruptive, rocks, it has been stated that the former were cooled slowly under pressure, while the latter were cooled quickly. Plutonic rocks are evidently the result of wet heat—that is, heat combined with moisture—and not dry heat, such as results from fusion by fire with no moisture present, as in the case of furnace slag. According to observation, all volcanic eruptions show the lavas to be of magmatic origin, and intrusive rocks show the same origin, from which it may be deduced that nearly all deep-seated rocks were formed as plastic magmas, the Plutonic rocks having been cooled slowly under great pressure, and the eruptive rocks having been cooled quickly under little pressure. To agree with this hypothesis, a **magma** may be defined as a soft putty-like mass formed by heat and pressure and given plasticity by its water of crystallization. This definition also covers the expression *aqueo-igneous fusion*.

16. Aqueo-Igneous Solutions.—From what has been said, it becomes possible to suppose that, at great depths and pressures, water is capable of causing a superheated magma to exist. Such solutions may be termed **aqueo-igneous**, when they are saturated with water and rock material in a semi-fluid state. It does not require much water to form such a mass, and it is presumed that the water of crystallization is sufficient. If this is the case, and from any cause pressure is removed, crystallization such as is observed in many rocks can be accounted for to a large extent.

17. Flowage Folds.—In the zone of rock flowage the deformation is by granulation or recrystallization, no openings being produced that are discernible. That cracks and crevices must close at a certain depth has been decided, and F. D. Adams, of McGill University, has actually deformed marble under conditions supposed to exist at the necessary depth below the surface, with the result that the rock changed its form without rupture and with no perceptible openings or cracks. Since water and rock may be mixed in all proportions under certain conditions of heat and pressure, it is probable that rocks may form a plastic magma and be of all grades of viscosity; that is, they may range from a very thin fluid, like water, to a semifluid state or magma until almost solid rock is reached. This is borne out by observations made of some rocks in which no evidences of crevices or cracks could be determined by the microscope. In other cases, the microscope shows in a most remarkable manner that the mineral particles have

FIG. 5

been flattened out, whence it may be assumed that such particles were in a plastic state. Fig. 5 is an illustration of a gneiss fold in which the rocks seem to have been a plastic magma.

SOLUBILITY OF ROCKS

SOLUTIONS AND HEAT

18. Depth and Water.—The conclusions reached in e preceding discussion are to be supplemented by another; mely, that, if no cavities can exist, the rocks must be lidly welded or be in a condition grading from a plastic to luid state. As previously demonstrated, the temperature the earth increases with depth, and consequently the tem- rature of liquids will assume that of the rocks with which ey are in contact, or will be raised 1° for every 60 feet of pth. The pressure increases with depth with sufficient pidity to probably hold water in the form of a liquid; nce, the work of water in the zone of fracture below ,000 feet is that of superheated water. It is well known at the solvent action of pure water when cold is slight, d rapidly increases as the water is heated. Barus found at hot water above 365° F. greatly increased the solubility glass. The solvent qualities of water will be active until turation is reached, no matter what the temperature, but t solutions will materially hasten the operation. Alkaline rbonate or sulphide solutions, when cold, might require onths to dissolve silicates and sulphides to the point of turation that at a temperature of 365° F. would require but few moments to reach the point of saturation. The sol- nt action of underground waters is, in some cases, doubt- ss increased by pressure as well as by temperature; on the her hand, the solubility of some natural salts may be minished by pressure.

In the lower part of the zone of fracture, increase in mperature with depth may lessen the average amount of aterial that may be held in solution, but in most cases crease in pressure promotes solubility.

19. The Relation of Solutions and Pressures.—In eneral, the volume of the solvent plus that of the substance issolved is greater than that of the solution. For a given quantity of solution, the contraction in volume is greater according to the quantity of solvent used. Sometimes, the volume of the salt and the solvent is less than that of the solution, in which case expansion results from dissolving the solid. When the volume of the solution is less than that of the solvent and salt, as is usually the case, pressure increases solubility by bringing the molecules closer together in solution. Conversely, when the volume of the solution is greater than that of the solvent and salt, pressure decreases solubility, by causing the molecules to separate still further.

PRECIPITATION FROM SOLUTIONS

20. Whenever a number of chemical substances are united by a solvent, interactions may occur between them that after a time appear to cease. This interaction may result in the precipitation of compounds, if the solution is supersaturated. It is evident that the supersaturation of underground waters is a necessary condition for the precipitation of dissolved substances. Precipitation may be caused: (1) by a change in temperature; (2) by a change in pressure; (3) by reactions between solutions differing in their chemical properties; (4) by reactions between liquid solutions and solids, including electrolytic action; and (5) by reactions between gases and solutions; gases and solids; or gases, solutions, and solids. The laws of chemical precipitation from aqueous solutions are complex, and belong to the province of chemistry; but for present purposes this statement of chemistry will suffice: *When solutions of two or more kinds come together and compounds can form that are insoluble in the liquids present, they will do so and precipitation will follow.*

The most important case of precipitation in nature is that resulting from the mingling of aqueous solutions and solids. In some instances this will produce rock cementation, in others crystallization. In order that crystals in a solvent shall grow, it is necessary that the solutions be saturated or supersaturated at the immediate place of growth. Under conditions of saturation in which a superabundance of solid is present compared with the amount of solution, it is a fact that the larger crystals grow at the expense of the smaller, and this process goes on more rapidly in proportion as the temperature is high and the pressure great.

In Fig. 6 is shown a rock formed by water running from the Sutro tunnel. This water comes from the Comstock lode, Virginia City, Nevada, and in the mine is quite warm. On reaching the tunnel, it begins to cool, and when in the air, cools sufficiently to precipitate the aluminum sulphate of which the rock is mainly composed.

FIG. 6

PETROGRAPHY

THE CHEMICAL CONSTITUENTS OF ROCKS

21. Definitions.—**Petrology** treats of the origin, mode of occurrence, constituent minerals, and structure of rocks. **Petrography** is that branch of petrology that deals with the structural, mineral, and chemical character of rocks. Petrology is the study of rocks in the field, while the term **lithology** signifies the study of rocks under the microscope.

An **element** is the simplest form of matter; that is, it cannot be divided into other elements by any means known to science. For example, gold is an element, and cannot be decomposed into copper or iron. At the present time, seventy-two elements have been discovered; 97 per cent., however, of the lithosphere consists of but nine of these elements. Three of the nine—oxygen, silicon, and carbon—are non-metals. **Oxygen** is the most abundant, since it composes 21 per cent. of the atmosphere, 88.89 per cent. of the water, and 50 per cent. of the rocks. **Silicon** is the next most abundant, and is said to form fully one-quarter of the lithosphere. **Carbon,** while not found in such large proportions as the other elements mentioned, is widespread in the form of coal and limestone beds. The other six most important elements are aluminum, calcium, magnesium, potassium, sodium, and iron. The elements of minor importance, but very abundant in some localities, are sulphur, phosphorus, fluorine, manganese, and barium. The remainder of the seventy-two elements are rare, and need not be mentioned here.

22. Minerals.—The materials of which the earth consists are termed **minerals.** Usually they are inorganic compounds, but in some instances they are of organic origin, such as coal and limestone. Certain minerals can be identified by their qualities; such as, their composition; crystalline form; hardness; brilliancy, or luster; density, or specific gravity; cleavage and fracture; and the mark—termed *streak*—that they make on unglazed porcelain. While the number of minerals that have been examined and received names is large, yet there are very many more that have not as yet been classified.

23. Principal Rock-Forming Minerals.—The rocks that are most abundant in the lithosphere are composed of some form of the elements silicon, carbon, and calcium. Other rocks that are quite common are made up of sodium and iron compounds. These elements form large numbers of minerals that in turn form large masses of rock.

24. Silica.—Chemists recognize two varieties of **silica:** one kind, which may be formed by melting sand, is ordinary **glass** and has a specific gravity of 2.2; the other kind, called **quartz,** is deposited from solutions and is found in rocks, in the form of six-sided crystals, as well as in masses, and has a specific gravity of 2.6. Quartz is slightly harder than glass, for it will scratch the latter. Both glass and quartz enter largely into rocks of the lithosphere, and it is well to remember that the glass has been formed by the dry process, while the quartz has been formed by the wet process.

25. Silicates.—Most of the rock-making minerals are compounds of silicon and oxygen with such elements as aluminum, magnesium, calcium, potassium, iron, and sodium. Such combinations are termed **silicates,** when silica is in excess of the other minerals, and are also known as **acid rocks.** Quartzite is a silicate.

26. Feldspars.—Silicates of aluminum with one or more of the metals potassium, sodium, and calcium are termed **feldspars.** The color is usually white or flesh red, and, rarely, brown or greenish. The cleavage is in two directions, and the cleavage surfaces are smooth and glassy-looking. The fracture gives a step-like appearance. **Orthoclase** is the most common feldspar and contains potash. **Albite** is a white feldspar containing soda. **Anorthite** is a lime feldspar; **oligoclase** is a soda-lime feldspar; and **andesine** is a lime-soda feldspar. It will be noticed that oligoclase contains more soda than lime, and hence the predominant element is placed first. **Labradorite** is a lime-soda feldspar, andesine being between oligoclase and labradorite.

27. Mica.—A silicate of aluminum and potash that splits into thin sheets is termed **mica.** This mineral can always be determined by its softness (the finger nail will scratch it) and by its cleavability. It is used in the doors of some stoves, as heat has little effect on it, and also as an insulating material for electrical machines. It enters into the composition of many rocks. When it predominates in a rock, as scales, that rock is termed a *micaceous rock* or *mica schist.* Sometimes mica is colored brown or black, especially when it contains iron, in which case it is termed **biotite,** or *black mica.*

28. Hornblende and Pyroxene.—**Hornblende** and **pyroxene** are so nearly alike, both in appearance and composition, that they may be described together. They are silicates of magnesium, calcium, and iron. The most common variety in rocks has a black or greenish-black color. They are not so hard as feldspar, and unlike mica are brittle. Pyroxene is sometimes fibrous in texture, with long brittle threads, when it is termed **asbestos**. When in this state it is sometimes taken for *chrysotile*, but the fibers of the latter are silky and not brittle. *Actinolite* and *amphibole* are varieties of pyroxene.

29. Magnesian Silicates.—Talc is a silicate of magnesia containing water. It is very soft, and is usually of some shade of green. When powdered, it has a soft greasy feeling. It is sometimes found in foliated plates, like mica; at other times, it is without foliation, like soapstone. When powdered, it is almost white, and is used for many purposes, such as a toilet powder, a paper filler, and as an adulterant of drugs and paint.

Another magnesian silicate, termed **serpentine**, forms large areas of rock, and is sometimes mineral bearing, that is, contains minerals of value, like chrome-iron ore and chrysotile. Serpentine is usually dark green, although in some localities it varies from this to a light grayish green. Serpentine receives its name from its peculiar texture, which is winding or banded, one band being a different color from that next to it, thus giving the rock a mottled appearance. The mineral can be cut with a knife, and its powder feels greasy, like talc. The true asbestos of commerce is fibrous serpentine or chrysotile, and as it is silky and not brittle it can readily be distinguished from fibrous hornblende or pyroxene. Serpentine rock frequently contains chrome iron and nickel, and in one case at least a vein of rich gold ore.

30. Carbonates.—The carbonate minerals contain carbon dioxide. **Calcite**, or *calcium carbonate*, is the material that forms limestone and marble. When comparatively pure, it cleaves in three directions, with bright smooth surfaces along the cleavage planes. It is much softer than feldspar and is usually white, but is sometimes transparent or tinted. As it may be scratched with a knife, and effervesces when a little acid is put on it, there is not much chance of making a mistake in regard to its character. The mineral **dolomite** is a calcium-magnesian carbonate; according to Dana, it

(a)

(b)

Fig. 7

contains 54.4 per cent. of calcium carbonate and 45.6 per cent. of magnesium carbonate. Calcium-magnesian carbonates are sometimes burned to form cement. They are then called *hydraulic limestones* or *cement rocks*. A calcite crystal is shown in Fig. 7 (*a*); but the crystals may take many forms, all of them, with one exception, having the planes at either end in threes or multiples of three, and those above alternate in position with those below. Fig. 7 (*b*) illustrates groups of calcite crystals as found in nature.

(a)

(b)

(c)

FIG. 8

31. Sulphur Minerals.—**Sulphur** enters into combination with a large number of other elements to form minerals. Occasional large deposits of almost pure sulphur have been discovered, and large deposits of **gypsum** (composed of sulphur trioxide, lime, and water) are found. Pure gypsum is white; it occurs sometimes massive, and again in clear vitreous crystals, such as are shown in Fig. 8 (*a*). The rock alabaster is massive gypsum. Sulphur combines with iron, copper, zinc, lead, and other metallic minerals to form sulphides of those metals. It is not difficult to distinguish sulphur compounds, for on being heated they give off a sulphur gas. Sulphur crystals are usually cubical, as shown in Fig. 8 (*b*), when combined with copper or iron, and have in most instances a brassy look. **Galena,** or sulphide of lead, is bluish black and has cubical cleavage, as shown in Fig. 8 (*c*). It is also found in grains as well as in masses, especially in limestone and dolomite rocks.

32. Sodium.—Sodium chloride, or common salt, forms large beds of rock in various parts of the world. This mineral is termed *halite*, and can be told by its taste and softness. **Sodium-aluminum fluoride** is known as cryolite. It is found in extensive deposits in Greenland and in small deposits in other places. The soda business is of great importance in the United States; and while halite enters into the manufacture of soda, cryolite enters into the manufacture of aluminum by the electric-smelting process. Cryolite resembles calcite and anorthite in cleavage.

FIG. 9

FIG. 10

33. Iron.—The iron minerals, although widespread, are found in massive quantities in certain localities only. The sulphide of iron seems to be the parent mineral from which hematites, limonites, and other similar iron ores were formed. All the ores of iron, outside of the sulphides and carbonates, are oxides of iron. Iron oxide is found in small quantities in almost every clay and rock formation. Fig. 9 shows the crystals of **magnetite** as they occur in magnetic iron ore. Fig. 10 shows an unusual form of red hematite iron ore, given here for the purpose of exposing its oolitic structure. **Bauxite** is an iron ore with aluminum that resembles the hematite in Fig. 10 in structure but not in color.

DESCRIPTION OF ROCKS

DEFINITIONS

34. So many terms are used to describe rocks that it is considered necessary, in order to avoid confusion, to define them.

Arenaceous rocks are rocks that are composed more or less of sand.

Argillaceous rocks are clayey rocks or rocks resembling clayey rocks.

Calcareous rocks are those that contain lime.

Ferruginous rocks contain oxide of iron, and are usually red or brown in color.

Quartzose rocks contain a large proportion of quartz grains.

Saliferous rocks are those that contain salts.

Silicious rocks contain silica as quartz or glass.

Rocks are said to be **crystalline** when they show crystals; **amorphous**, when they do not show crystalline structure; **compact**, when they are close-grained; and **massive**, when they have no cleavage planes. Rocks that are easily crumbled or pulverized are said to be **friable**; those that have a glassy look are called **vitreous**; and those that are porous or full of holes are said to be **cellular**. Rocks that have crystals of some one mineral larger than those of the other crystals are termed **porphyritic**. When the minerals are comparatively uniform in size, a rock is said to be **granular.** **Oolitic** rocks are composed of small rounded mineral grains resembling fish eggs (see Fig. 10). **Pisolitic** rocks are those having grains the size of shot or of small peas. **Amygdaloid** rocks have almond-shaped cavities, which are formed by gas. The rock shown in Fig. 11 is Lake Superior rock in which copper or limestone fills the cavities of an amygdaloid rock. **Shaly** rocks are those that split in leaves. **Slaty** rocks are those that are hard and crystalline and split in leaves. **Foliated** rocks are those that have the leaves overlapping. Such rocks are termed **schistose,** as they seem to be made up of flattened grains and layers of minerals; when of mica scales and quartz, they are sometimes said to be **sericitic.**

FIG. 11

ROCK GROUPS

35. Definition.—The term **rock** applies to any mineral combination that forms a part of the lithosphere. Thus, soil, sand, gravel, and coal are rocks as well as hard, compact, mineral compounds. For convenience of description, rocks are grouped as nearly as possible according to natural characteristics.

36. Fragmental Rocks.—Sand, gravel, soil, till, loess, clay, sandstone, conglomerate, and breccia are rocks derived from the disintegration or cracking up of other rocks. Some of these rocks were broken and the minerals they contained cemented together by some other substance; others again exist in loose particles; while still others are simply dried or consolidated by pressure.

37. Clay Group.—The clay group of fragmental rocks is characterized by fineness of texture. The group includes the clays used for pottery, red brick, and firebrick, as well as the shales and slates. **Marl** is clay containing considerable calcium carbonate; **loam** is sandy soil containing some lime; **mud** and other argillaceous rocks belong to this group.

38. Limestone Group.—Limestones, dolomites, and shell limestones, both amorphous like chalk and crystalline like monumental marble, belong to the limestone group. Impure limestones may also be classed in this group.

39. Bituminous Group.—Coal, bituminous limestone, bituminous sandstone, and bituminous shale, which are found in immense beds, belong to the bituminous group. Asphaltum, gilsonite, ozokerite, and oil sands may also be included. Sands that contain natural gas and petroleum should properly be classed under the heading of the bituminous group.


FIG. 12

40. Igneous Rocks. The term **igneous** is applied to all rocks that have been in any way influenced in their formation by heat. Geologists divide them into three classes; namely, Plutonic; volcanic, or eruptive; and metamorphic, or rocks so changed as to become crystallized—probably by heat. Plutonic and volcanic rocks are termed **intrusive** when they have been interjected or intruded between other rocks; both are probably of aqueo-igneous origin. If they reach the surface they form a **dike**, as shown in Fig. 12. If


FIG. 13

they do not reach the surface but form a mound, as shown in Fig. 13, they are termed **laccolites.**

41. Sedimentary Rocks.—Rocks that have been formed under water are called **sedimentary.** It is probable that all such rocks were formed from older rocks, then subsequently subjected to compression from the weight of rocks formed above them, and finally had their particles cemented with the aid of aqueous mineral solutions. Coal is a sedimentary rock formed from vegetable matter.

ROCK FORMATION

IGNEOUS ROCKS

42. Aqueo-Igneous Rocks.—Such rocks as have been reduced in the zone of flowage with the aid of heat and solutions have a crystalline texture that is unmistakable. These are the older rocks, and while later some sedimentary rocks have been subjected to similar treatment their texture makes them discernible from the older crystalline rocks. It has been stated that water in contact with most rocks will change them at a temperature of 365° F.; and at a temperature of 450° F. it is stated that quartz, feldspar, mica, and other crystals are formed. Solutions of alkaline carbonates or sulphides greatly reduce the temperature at which aqueo-igneous fusion takes place; for instance, at 400° F. rocks become pasty and at 800° F. become fluid.

43. The **granite rocks,** which are probably aqueo-igneous, represent the oldest rock formation. Granite rock consists of quartz, feldspar, and mica. It is a massive rock with no appearance of layers in the arrangement of the mica or other minerals. The quartz is usually whitish or grayish, the feldspar whitish or flesh-colored, and the mica either whitish or black. The crystals are similar in size—hence the name *granite* from *grain.* The rock is common in some sections, and may be seen in almost any cemetery. When it has been cut, dressed, and sometimes polished it is made into monuments and, as it is a very strong and durable rock, is also much used for building purposes. There are several classes of granites, which are named according to their texture or from some associated mineral other than those named. Granite varies in texture, but is nearly always an acid rock.

44. **Syenite** consists of feldspar, hornblende, and mica, with no quartz or with but very little. It seems to be classed in the granite group. It derived its name from Syene, in Egypt. The pyramids and the obelisks are made of this rock, which was at one time considered extremely rare in America; however, syenite is found in many places to be what hitherto was called *granite*. The colors of syenite are gray and flesh red. Cleopatra's needle brought from Egypt and placed in Central Park, New York, is syenite.

45. **Quartz Syenite.—Quartz syenite** is the syenite of America, and has the mica of granite replaced with hornblende. When mica and hornblende are both present, the rock is termed **syenite granite**. The general aspect of the rock is similar to granite.

46. **Gneiss.—Gneiss** is composed of the same minerals as granite and often grades into granite, but usually the minerals are arranged in bands so as to give it a very different appearance. Some consider the gneissoid granite of the earlier periods similar to the gneissoid granites of the later periods, which are probably eruptive rocks. Even if this is true, they will fall within the definitions of aqueo-igneous rocks so long as they do not contain quartz in the form of glass.

THEORY OF CLEAVAGE

47. To account for the banded structure of gneiss, some suggest selective agency—that is, that minerals of the same class crystallize by themselves—and this theory is probably as good as any. To account for the flatness of small particles in gneiss, as well as their parallel arrangement, the

theory of Sharp and Tyndall, as developed by Professor Hoskins, is advanced. This theory is based on the assumption that cleavage structure is produced by the action of great compressive forces, which would cause a shortening of the rock mass as a whole in one direction, and a lengthening in some other direction—or, in short, *mashing.* A very close, smooth, slaty cleavage would not develop in a coarse-grained schistose rock like gneiss; nevertheless, the same principles would apply. In Fig. 14 (*a*), let the circles represent spherical fragments of rock, and let it be supposed that the rock is under such conditions that it flows without rupture. In case there is a shearing strain, as shown in Fig. 14 (*b*), the spherical fragment becomes an ellipsoid. If the process of shearing is continued, the ellipsoid would be still further flattened, and its major axis would become more nearly parallel to *AB*, Fig. 14 (*c*). In this manner, the banded structure of gneiss could be explained as well as the cleavage structure in some other finer-grained schistose rocks. The crystalline schists of older formations are probably aqueo-igneous, as they all have that appearance and are probably cooled under pressure.

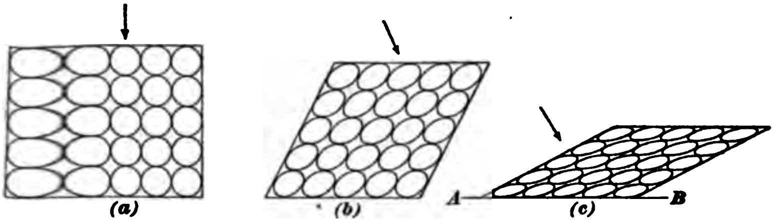


FIG. 14

AQUEO-IGNEOUS FUSION OF SEDIMENTARY ROCKS

48. Factors Entering Into Aqueo-Igneous Fusion. In the transformation of sedimentary rocks to crystalline rocks, not only must heat and water be taken into account, but also consolidation, welding, cementation, injection, metasomatism, and mashing. Usually, two or more of these processes act together, but in some cases no one process shows greater prominence than the others.

49. Consolidation.—The cause that produces consolidation is the pressure, which prevents aqueo-igneous rocks from cooling fast, and forces the mineral particles of all rocks closer together. The coherent power of rocks is particularly efficient in rocks composed of fine particles.

50. Welding.—If rocks are deeply buried in the zone of flowage, it is possible that the particles may become welded together and thus form a crystalline rock. This depth would vary for different rocks; that welding, however, assists consolidation at modern depths for softer materials can hardly be doubted.

51. Cementation.—It has been shown how minerals may be taken up by underground waters so as to soften rock and so form a zone of flowage; also, that changes in temperature and pressure and some other causes will produce precipitation of the minerals in solution. Cementation can occur whenever it is possible for mineral solutions to circulate between the interstices of the rocks in the zone of fracture. Of these mineral cements, the most important are quartz, calcite, ferrite, mica, feldspar, fluorspar, barite, and serpentine. Many other minerals act as cements, but their importance is small. Quartz is most important, calcite next, and ferrite third. The last mineral is a reddish indeterminable substance containing more or less hydrous iron oxide. Hematite, limonite, magnetite, and other oxides of iron are included in the term ferrite, of which hematite and limonite form the most abundant cements.

The process of cementation may apply to all porous as well as fragmental rocks, and minerals from extraneous sources may permeate the rock through and through, so that they predominate in some cases, although in others they are relatively unimportant. The result is sometimes a complex structure, the places between the original minerals being filled by flattened or foliated matter having interlocking mineral materials between the laminæ or leaves.

52. Injection.—By **injection** is meant the penetration of rock by molten magma. Pure igneous injection does not usually penetrate surrounding minerals any great distance from a contiguous mass of the magma. If the material is injected between the grains, it may add a large amount of some new mineral. For instance, if in a mica schist a feldspar is plentifully added, a gneiss could be formed. If the injections were parallel to regular planes, the rock would be banded. Observations show that injection is particularly likely to occur adjacent to igneous material, especially intrusive rocks.

53. Cementation and Injection.—Rocks of a coarse-grained granitic structure are termed **pegmatites.** Their origin has been the subject of much speculation, and Van Hise thinks that in some cases they are due to igneous injection, in others to aqueo-igneous action, and in still others to pure water cementation. In crevices, the secondary minerals interlock; in the larger spaces, they may have a coarsely crystalline structure. The new mineral material may attach itself to old grains of like mineral character, or it may be deposited as independent material. **Graphic granite** with its large crystals is a pegmatite that may have been produced in this manner. But there is no reason why all the phenomena attendant on aqueo-igneous fusion should not accompany pegmatization.

ALTERATION OF ROCKS

METASOMATISM

54. When a mineral is altered into other minerals, or is replaced by other minerals, or is recrystallized without chemical change, the process by which the change takes place is termed **metasomatism.** As a result of such changes, a new rock may give variety to or lose variety in the minerals composing it. The alterations of mineral particles mentioned here are for those of the common rock-forming minerals.

Quartz does not alter into other minerals, although it unites with other compounds, and assists in the modification of adjacent minerals. Quartz is silica in whatever compound it is found.

55. **Alteration of Feldspar.**—The feldspars are extensively altered. Some of the more common alterations are as follows: Feldspar passes into quartz and **muscovite**, that is, mica, the secondary muscovite being in minute flakes, and the rock formed often being called **sericite**. Feldspar passes into quartz and **kaolinite**, that is, china clay; also, into quartz and biotite, and quartz and chlorite. These alterations are not always distinct and separate in the same mineral, and out of the same granule another feldspar and quartz may form; that is, a basic feldspar may become an acid feldspar, or either may be converted into feldspar different from the original.

56. Amphibole or hornblende may alter into chlorite, and from this other forms develop. Tremolite, actinolite, asbestos, and nephrite are light-colored amphiboles; while cummingtonite, hornblende, and bergamoskite are dark-colored amphiboles. Biotite, a black micaceous substance, may result from hornblende. The micas are extensively produced from rock materials by metasomatic processes.

57. **Calcite and Dolomite.**—A part of some calcium minerals may be replaced by magnesium, and dolomite be produced. Carbon dioxide may be liberated and permit the calcium oxide formed to unite with other compounds. In place of dolomite—in case there is loss of carbon dioxide and a union of the magnesium and calcium oxide with silica—**tremolite**, a light-colored calcium-magnesium amphibole—may be formed.

58. **Ankerite** is an iron-calcium-magnesium carbonate occupying a position between dolomite and siderite. By its loss of calcium, magnesium, and carbon dioxide and its gain of oxygen, hematite, limonite, and some other iron ores may result. From **siderite**, which is carbonate of iron, magnetite, hematite, limonite, and other iron compounds could be formed.

ALTERATIONS DUE TO CEMENTATION AND CONSOLIDATION

59. Strength of Rock-Cementing Material.—Usually, cementation works in conjunction with consolidation. The relative strengths of the common cementing materials are as follows: Iron oxide is the weakest cement, calcium carbonate a medium cement, and silica the strongest of the three.

60. Quartzite, one of the most important of rocks, is produced by the cementation process. The term quartzite is applied to sandstones that have become so compact that when broken the fractures pass through the grains and not around them. As an exaggerated case of this description, a piece of banket, from Johannesburg, South Africa, is shown in Fig. 15 (*a*). The Pottsville conglomerate of the anthracite fields in Northeastern Pennsylvania is somewhat similar in this respect, although not so strong. A specimen of it is shown in Fig. 15 (*b*). Quartzite in the main, however, is of a finer texture, and differs from the conglomerate shown.


(*a*) (*b*)

FIG. 15

ROCKS MODIFIED BY METASOMATISM, CEMENTATION, CONSOLIDATION, AND MASHING

61. **Grits and Mudstones.**—Thick, bedded, massive rocks produced from grits and mudstones are called **gray-wackes.** If the grit is composed of quartz and feldspar, it is termed **arkose,** which Dana says is meaningless. If the original rock is fine-grained, it receives the name of **slate,** which may be arenaceous or argillaceous.

62. **Chert and Jaspilite.**—**Chert** is a term for impure silicious rocks that are non-fragmental. Ferruginous cherts that are sometimes termed slates have been formed from iron-bearing rocks. When the silica is in the form of finely crystalline interlocking quartz, each grain may be coated with a film of hematite, thus giving it a red color. In this case a banded iron oxide and jasper, called **jaspilite,** is produced. The rock is found in the iron regions of Lake Superior and in the West.

63. **Hornblende schist** may be produced from an impure dolomite or ankerite. In the alteration of an augitic rock, hornblende schist is sometimes produced. This is a common rock in the metamorphic series of the Appalachian region.

64. **Marble.**—Limestone may be changed to marble. The transformations, so far as crystallization is concerned, is not surprising, as limestone forming in warm localities at the present time with the assistance of water assumes a granular crystalline structure. Dynamic action and metamorphic action also produce crystallization in limestone. Recrystallization is perfected according to the depth at which the limestone has been buried.

ROCKS MODIFIED BY MASHING, INJECTION, CEMENTATION, AND CONSOLIDATION

65. Quartz schists are produced from quartzites, by cementation and metasomatism. All stages of the changes that take place may be seen in a region not too strongly folded. The mineral particles have a tendency to parallel arrangement, and in proportion as this tendency appears the rock passes from quartzite to quartz schists.

The chief constituents of slate are usually quartz and feldspar. Feldspar alters into mica and quartz, and from a grain of feldspar many individual interlocking minerals of quartz and mica are introduced into slates. The mineral particles, especially mica, have well-developed parallel crystals, with their longer axes and cleavage in a common direction. As mashing continues, the rock may become *schistose*, and as metasomatism progresses it finally passes into *mica schist*.

In the case of graywackes, the alteration of the feldspar may produce quartz and chlorite instead of quartz and mica, in which case a chlorite schist is produced. Also, from volcanic rocks, which are likely to contain considerable pyroxene and basic feldspar, chlorite schists are abundantly developed.

When completely crystalline rocks result from metasomatism, they have a laminated or schistose structure.

VOLCANIC ROCKS

ERUPTIVE AND INTRUSIVE ROCKS

66. General Characteristics.—Igneous rocks, which are ejected from volcanoes or through rents in the lithosphere, are distinguishable from aqueo-igneous rocks if their quartz is in the glassy form. It is stated by some geologists that there are all graduations between igneous eruptive and aqueo-igneous eruptive rocks, and that undoubtedly some granites are of true igneous origin. It is admitted that granites may be eruptive; it is known also that they are intrusive. Unless, however, they show distinctly the glassy form of quartz due to fire, they may be considered as aqueo-igneous. It is usual to state that the glassy or amorphous form of eruptive rocks is due to quick cooling, and that the crystallized rocks have been cooled slowly. From furnace slag it may be observed that the acid slags are vitreous, while the more basic slags do not show so much glass. This peculiarity extends to furnace slags, whether they are cooled quickly or slowly. If, however, they are run into cool water, they granulate and their specific gravity is much less, owing to air cells created by the steam expanding. The slag, however, remains glassy on quick cooling, and in many instances resembles scoria and pumice in structure. The malpais of New Mexico is undoubtedly eruptive, and shows air cells; but it is not glassy like obsidian, which would class it as aqueo-igneous.

67. Texture of Volcanic Rocks.—Volcanic rocks usually have a fine texture, although there are many coarse-grained and vesicular rocks among them, as well as ashes and breccia. Their structure is at times amorphous and glassy, showing no gradations or crystallization. Volcanic rocks consist for the most part of some form of feldspar with hornblende or pyroxene. The rocks have almost any shade from white to black, but are usually drab or gray. Often they are porphyritic, showing no indications of quartz until pulverized, the ground mass being very fine and close, with feldspar or other crystals prominent, although small in size.

68. Acid Rocks.—Volcanic rocks are divided into two subclasses; namely, *acid* and *basic*. The **acid rocks** contain **sanidin**, which is the name given to the glassy potash feldspar found in rocks of this description. They are often light-colored, contain considerable silica, and have a high fusion point. Dana places the fusion point of acid rocks between 2,700° F. and 3,100° F., and states that some of them are viscid or only partly fluid, even at the latter temperature.

69. The **basic rocks** contain little silica, are dark and heavy, consisting mostly of a lime and a soda feldspar termed *labradorite*. The fusion point of this class of rocks Dana places at 2,250° F.

70. Neutral Rocks.—A third group of rocks, holding an intermediate position between acid and basic rocks in regard to specific gravity and the percentage of silica, are known as **neutral rocks**. The fusibility of these rocks is placed by Dana at 2,520° F. They consist chiefly of hornblende and a soda-lime feldspar such as oligoclase.

ROCKS OF THE ACID GROUP

71. Trachyte is not common in North America, and where found is usually of a light color, varying from an ash gray to a brownish gray. The ground mass is glassy sanidin, and has as accessory minerals small needles of hornblende, scales of biotite, magnetite, and augite. Various names have been given to this rock, according to the mineral that predominates or to some accessory mineral observed in its composition. Owing to the forms of the glassy feldspar and the porosity of the rock it has a harsh rough feeling to the fingers—hence its name, which means "rough."

72. Rhyolite, or **quartz trachyte,** takes the place of trachyte in America, the latter being more common in Europe. Rhyolite is similar in feeling and composition to trachyte, but contains more silica. The structure is also at times coarse, and the crystallization fairly developed. The silica ranges from 72 to 82 per cent. Rhyolite is abundant west of the Rocky Mountains, where numerous varieties are found, one of which—termed *pearlyte*, because of its enamel-like look and pearly luster—is particularly worthy of mention. Rhyolite is said to be *scoriaceous* at times; that is, it contains large cells due to the escape of gas from the rock. General Grant's sarcophagus, in New York, and the monument to the Iron Brigade, at Gettysburg, Pennsylvania, are made of Wisconsin rhyolite.

73. Phonolite.—**Clinkstone** is the name sometimes given to phonolite, on account of its peculiar ring when struck with a hammer. **Phonolite** is usually of a light-gray color with a spotted appearance, shading from pale green to bluish gray. It breaks in thin tile-like slabs, which feature will distinguish it in the field from rhyolite. Another distinguishing feature is the absence of roughness when handled. Recently, this rock has come into prominence in North America, due to its being associated with the rich ores of Cripple Creek, Colorado. The American rock does not have the same ring as the European.

The ground mass of phonolite is sanidin and nepheline, but it contains sometimes as accessory minerals hornblende, titanite, and pyrite. **Nepheline** is a complex mineral that can be distinguished by its becoming cloudy in acid; the expression is derived from a Greek word meaning "a cloud."

74. Obsidian is a true volcanic glass, varying in color from gray to brown and black. It has substantially the same composition as rhyolite, but, on account of its vitreous and amorphous appearance, is not easily mistaken for other rocks. Sometimes, needle-like bodies that are only discernible by close observation are found in the rock. Large masses of obsidian are found in Yellowstone Park, Wyoming, as well as in Mexico and New Mexico.

75. Pumice is a drab- to gray-colored rock, containing from 70 to 78 per cent. of silica. It is a finely scoriaceous variety of obsidian, so filled with cells containing air that it will float on water.

76. Scoria is a light-colored cellular obsidian.

ROCKS OF THE BASIC GROUP

77. Basalt has a vitreous ground mass, and is dark and very close-grained. That portion which is exposed to the weather becomes a rusty brown color. It is one of the most common kinds of igneous rock, and is peculiar inasmuch as it takes the columnar and crystalline form shown in Fig. 16.

Its chief constituents are labradorite, olivine, augite, and magnetite. Analysis gives 52 per cent. of silica. Basalt is often mentioned as a **trap rock**, because it breaks in step-shaped benches in cliffs.

Fig. 16

78. Andesite contains a lime-soda feldspar termed andesine or **andesite**, associated with mica and hornblende. It consists of a vitreous ground mass of various colors, but usually is a dark greenish-gray rock. The andesite in the vicinity of Cripple Creek, Colorado, has a purple hue. It is slightly crystalline and close-grained, although at times it is mottled and could be called porphyritic. One variety is termed **andesite tufa**, it having a coarse-grained structure. Another variety is termed **andesite breccia**, or old conglomerate; still another variety is banded.

79. Dolerite is very similar in composition to basalt and andesite. In texture, it varies from fine-grained to scoriaceous. It consists of labradorite and pyroxene, with olivine and magnetite in minute grains as accessory minerals. The color grades from dark gray to greenish black. This rock is frequently intrusive, and with the other rocks of the basic group is termed trap.

METAMORPHIC ROCKS

80. Definition.—According to the scheme followed, aqueo-igneous rocks differ from igneous rocks in the method of formation. Between these extremes there are rocks that have been changed by heat. Such rocks are of *secondary* nature; that is, they have been formed from older rocks, and then crystallized—either by their nearness to eruptive rocks, by the injection of heated waters, or by movements of the strata. **Metamorphism** in geology means the change that takes place in rocks, due to recrystallization of the constituent particles, either with or without alteration in the chemical composition of the mass. Heat, mineral waters, chemical affinity, and pressure are the chief factors in the process. In a broad sense, it has been used to cover the alteration of rocks by all processes; but is here restricted to changes produced by such processes as have not been defined as directly volcanic or aqueo-igneous.

81. Causes of Metamorphism.—The heat necessary for metamorphism may have resulted from movements of the strata, from the heat of liquid rock intruded from below, or from the heat of the earth by normal increase due to depth. In the chemical changes, water is the menstruum through which most of the transformations were made, as it carries materials from one place to another, thus changing the composition of great masses of rocks.

82. Processes of Metamorphism.—The chief processes considered in the transformation of sedimentary rocks were consolidation, welding, cementation, injection, metasomatism, and mashing. Usually, more than one of these processes will act together, but in some cases one or even two may be more instrumental than the others in performing the work. The same processes are applicable to metamorphism, and the same character of rocks may be changed by the processes; consequently, with two exceptions, they will not be repeated.

83. Metasomatism comes into action in metamorphism, as the latter covers recrystallization. In the case of the silicification of rocks, silica in solution may decompose the silica that is within the interstices of rocks, and there may be a replacement of other minerals by silica. In reality, this is a combination of the cementation and metasomatic processes.

Among the basic sedimentary rocks, serpentine develops in a manner similar to that described for silica. Material for serpentine may come from an extraneous area of serpentine rocks.

84. Structure of Metasomatic Rocks.—If the conditions of pressure are unequal, the arrangement of minerals will be such that their shortest diameter will be in the line of greatest stress. The cleavable minerals chlorite, biotite, and other micas form under such conditions, and usually so interform among themselves that their crystals interlock. During the rearrangement of some minerals by metasomatic processes, large individual minerals may develop in the interspaces between other minerals, often enclosing the latter or else absorbing the material of which they are composed. A single mineral of this kind may be larger than hundreds of others adjacent. This change in particles probably gives

Fig. 17

Fig. 18

to rocks their porphyritic appearance; and as this class of rocks shows no evidence of pressure, it is probable that they developed after strong pressure had ceased.

Porphyritic minerals sometimes make their appearance according as the degree of metamorphism increases. In feebly metamorphosed rocks the andalusite mineral **chiastolite** appears first. The crystals of this mineral, **Fig. 17**, show a crossed or checkered appearance when broken across. Chiastolite is frequently found in cleavable slates.

As metamorphism becomes a little more intense, **garnet** is found. This mineral may be abundant in the mica slates. Crystals of garnet are sometimes quite large, and take the forms shown in Fig. 18.

Stauròlite, shown in Fig. 19, develops as metamorphism increases, and with garnet is sometimes abundant in the mica schists. Chlorite and feldspar may also appear, but probably a little later than staurolite; and these may be followed by **cyanite,** which is a light-blue species of andalusite. The latter minerals are particularly characteristic of mica schists and mica gneisses. In the extreme stage of metamorphism, hornblende and mica are abundant. **Tourmaline** is found in a somewhat advanced stage of metamorphism, and is often present in schists adjacent to intrusions, when it is formed in various colors and has the shapes shown in Fig. 20.

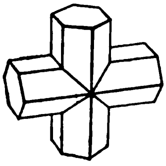


FIG. 19

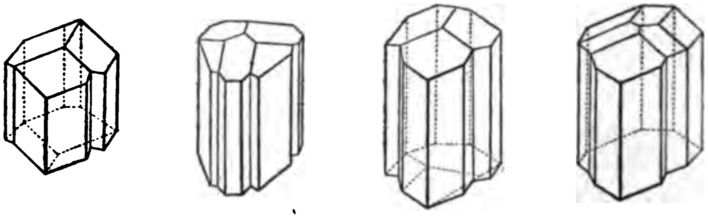


FIG. 20

85. Mashing, in the sense in which it is used here, means the spreading out of mineral grains, thus forming laminated or foliated schists, with a regular alternation of minerals of different kinds. If the original rock was a coarse conglomerate, and metamorphism was complete, each pebble would make a lamina of a different kind from those adjacent, and thus gives the rock a banded character. When mashing occurs, probably consolidation, welding, cementation, injection, and metamorphism are more active than under other conditions.

86. Metamorphism in General.—It is impossible to consider all the metamorphic forms of sedimentary rocks, as that could only be done in an exhaustive treatise; in general, however, when completely crystalline rocks result from the metamorphism of sediments, they have a laminated or schistose structure. Quartzite is an exception, but quartz schist comes under this definition. Marble seems to be a completely granular rock produced from a sediment. The difference between the schists of ordinary metamorphosed beds and marble is probably due to the fact that calcium carbonate readily recrystallizes after dynamic movement has ceased; as a rule, this is not the case with other minerals. The Adirondack marbles sometimes contain fragments of gneiss that show strongly the effects of dynamic action; while the crystals of calcite show no strain effects. By *strain*, as used here, is meant any definite alteration of form or dimension produced in a solid by the action of stress; this alteration, or deformation, may be either temporary or permanent.

87. Local Metamorphism.—When heated magmas are intruded in fissures formed in sedimentary rocks, or are injected between beds of sedimentary rocks, local metamorphism occurs, due to the intense heat and such solutions as accompany the phenomena. Such local metamorphic effects extend but a few feet away from dikes; while on the other hand the metamorphism may extend over a wide area when it is a case of injection. Another cause for local metamorphism arises from volcanic overflows of molten lava, which spread over rocks and effect a change. In some cases, the conditions are such that lavas produce scarcely any change;

as, for example, in California, where the ancient river beds of gravel are capped with lava.

88. Dynamic Metamorphism.—Although simple pressure resulting from the weight of the strata will not cause heat, it is evident that the tangential stress that ruptures rock will cause heat by the conversion of stress into energy and so into heat. In examining the deformations of the lithosphere, the geologist finds abundant evidence that metamorphism has occurred through dynamic causes.

SEDIMENTARY ROCKS

FORMATION OF SEDIMENTARY ROCKS

89. Sources of Material.—**Sediment** is that material which settles from water, and in this discussion the term applies only to rocks thus formed. The greater part of the material from which sedimentary rocks have been formed and are being formed comes from the disintegration of rocks that existed before them and that may be called the *primary rocks*. Another kind of sedimentary rock has been formed by the precipitation of calcium carbonate held in solution; and similar rocks have been formed through the agency of life that existed in seas and lakes. A third class of sedimentary rocks, because formed under water, comprises those whose entire mass is presumed to be derived from vegetable growth. Bituminous rocks and shales are also widespread, but it is questionable whether they are formed charged with bituminous matter as now found. It is believed that, in some cases, they were impregnated with bituminous matter after sedimentation and possibly consolidation; however, in the case of bituminous shales highly charged with hydrocarbons, it is difficult to satisfy this supposition.

90. Sandstones.—The term *fragmental* is applied to sandstones because they are made up of sandy particles cemented together. Such rocks as sandstone will have all degrees of fineness and coarseness, as well as strength. The cementing material is usually quartz, ferrite, or calcite, or it may be a mixed cement. If the rock is made up of pebbles or angular fragments of rock of any kind, it is termed a *conglomerate*. If the pebbles are rounded, it is termed a *pudding stone;* if they are angular, it is termed a *breccia*.

91. Freestones.—Sandstones that split into slabs, such as the bluestones of the Hudson River, are well known, from their use as pavements. Others, such as the Connecticut brownstones, are well known in the vicinity of New York City, as many of the house fronts are constructed of this material.

Near Berea, in Cuyahoga County, Ohio, there is a light-colored fine-grained sandstone that is easily cut and dressed when first quarried. After the stone has lost its quarry water it becomes quite hard. Such stones are included under the general name of **freestones.**

92. Grits.—Hard silicious sandstones that are even-grained and not coarse enough to be classed as conglomerate are termed **grits.** What is known as the *Pottsville conglomerate* in the anthracite regions of Northeastern Pennsylvania becomes a millstone grit in some bituminous coal fields, and is the lower stratum of the lower productive coal measures.

93. Conglomerates are coarse sandstones, so far as their constituents are concerned. In some cases they are made up of quartz pebbles, and at other times of argillaceous pebbles. The cementing material also differs, as in the case of limestone.

94. A **shale** is a soft, fragile, argillaceous rock, having an uneven slaty structure. Shales have various colors, from gray to black, including red and green. Virtually, shale is consolidated mud.

95. Argillite, or true slate, is a sedimentary rock that has been metamorphosed. It is quite hard and brittle, and cleaves readily, so that it may be worked up into roofing slates or slabs for various useful purposes.

96. **Tufa** is a sedimentary rock made from volcanic or igneous rock. The colors are usually from yellowish brown to red. The texture is loose, and varies from fine to coarse conglomerate.

97. **Earths.**—**Sand** is broken rock material, usually consisting of quartz particles mixed with feldspar; other minerals are frequently mixed with it, such as garnet, magnetite, mica, etc.

Volcanic sand is composed of cinders ejected from volcanoes and reduced in size.

Gravel is a sand mixed with pebbles and stones.

Green sand is an olive-green sand mixed with grains of **glauconite**, the latter consisting of green grains composed mostly of iron and potassium. Its high specific gravity is somewhat of a distinguishing feature, as well as its color.

Clay is a soft impalpable more or less plastic material. It is chiefly aluminous in composition. If it does not burn red it may be considered **kaolin**, or *potter's clay*. **Fireclay**, which is drab in color, contains some mineral that gives it a yellowish color when burned, and is consequently not fitted for pottery. Ordinary **brick clay**, which may be bluish before being burnt, turns red owing to the iron oxide with which it is associated. All brick clays do not burn red, but still are unfitted for pottery clay.

Alluvium is an earthy deposit made by running streams, especially during times of floods.

Silt is the mud deposited in bays or harbors.

Loess is a fine yellowish clay or loam or even angular particles of sand deposited chiefly along rivers.

Till, possibly better known as hard pan, is unstratified sand, gravel, and stones with more or less clay. It is usually overlaid with soil.

Soil is clay, quartz sand, and other particles of rock material, mixed with decomposed animal and vegetable matter.

Loam is composed of sand having calcareous particles mixed with more or less soil as a top dressing.

Detritus is the name applied to all earthy and sandy materials derived from the wearing away of rocks by running water.

98. Diatomaceous Earth.—**Tripolite** resembles clay or chalk in appearance, but is harsh and scratches glass. It consists mostly of the minute silicious shells of **diatoms.** Tripolite, which is also termed **infusorial earth,** exists in large quantities in some localities, usually beneath peat bogs, and again as slaty or amorphous rock. It is so fine that it can easily be taken for clay and rotten stone unless examined under the microscope.

LIMESTONE FORMATIONS

99. Classes of Limestone.—**Limestones** are divided into the crystalline and the massive varieties. Both are composed of calcium carbonate; but one seems to have been deposited in a pure state, while the other contains numerous shells and often other minerals.

100. Massive Limestone.—**Massive limestone** is usually compact and varies from dull gray to black in color. It consists of carbonate of lime, with some clay or sand. Most limestones of this character have been formed from shells, and frequently the shells can be observed in them. The Bedford limestone of Indiana, much prized as a building stone, is composed almost entirely of small shells

FIG. 21

cemented together. A coarse shell limestone is shown in Fig. 21.

101. Magnesium limestone, or dolomite, consists of carbonate of calcium and magnesium. In some limestones the shells are magnesian, while the rock is pure limestone. This stone at times contains zinc, lead, and silver minerals; it also finds use in metallurgy as a basic flux and as a basic refractory furnace lining.

102. Hydraulic limestone contains carbonates of lime and magnesia, silica, alumina, and a little iron oxide. **Hydraulic cement** made from this limestone has the property of setting or hardening under water after being burned, sintered, and pulverized. **Portland cement** is an artificial cement. Hydraulic limestone from Rondout, New York, and from which Rosendale cement is manufactured, is magnesian limestone, containing, in addition to lime and magnesia, 15.37 per cent. of silica, 9.13 per cent. of alumina, and 2.25 per cent. of ferric oxide. Its hydraulic properties depend on the clay mixture of silica and alumina in the magnesian limestone.

103. Various Limestones.—Chalk is a white earthy limestone.

Marl is a clay containing a large proportion of carbonate of lime. The green sands near Freehold, New Jersey, are called marls, and are used as fertilizers; they are, however, composed mostly of glauconite.

Coral limestone is built up by little coral animals. There are large and dangerous coral reefs in the tropical seas, and between Key West, Florida, and Cuba. Havana is built on a coral reef.

Travertine is a massive limestone formed by the deposition from calcareous springs.

Stalactites and **stalagmites** are deposited by calcium-bearing waters in limestone caverns. Fig. 22 is a section illustrating a limestone grotto, in which *a* is the entrance; *b* are stalactites hanging from the roof; *c* are stalagmites growing upwards from the floor; and *d* is a pillar formed by stalagmites and stalactites meeting.

104. Crystalline limestone, termed *granular limestone* and *marble,* is of all shades and colors. Sometimes, it is a pure white or a blue black; again, it may be banded, mottled, or variegated. The colors are derived from minerals or oxides of metals in the vicinity of the rocks. Crystalline limestones are termed metamorphic, although there are instances of their forming away from heat. Taconic marble, found in Vermont and elsewhere, has the appearance of onyx, and is quite valuable. In Kentucky, onyx limestone occurs in the formation known as *St. Louis limestone.*

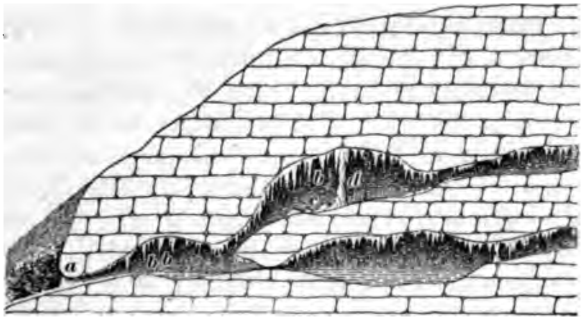


FIG. 22

DYNAMICAL GEOLOGY

ATMOSPHERIC AGENCIES

105. Composition of the Atmosphere.—The gaseous matter surrounding the earth is termed the *atmosphere*. It is supposed to be 50 miles high and to exert a pressure of 14.7 pounds per square inch on objects at sea level with the temperature at 32° F. or 0° C., and a pressure of 30 inches or 750 millimeters of mercury. The composition of the atmosphere is chiefly nitrogen and oxygen, with small quantities of watery vapor and carbon dioxide. The active agents in the atmosphere that produce changes in rocks are oxygen, carbon dioxide, and moisture.

106. Weathering.—All exposed rocks are subject to atmospheric influences, and, if they are carefully examined, practically all of them will be found more or less cracked, scarred, seamed, and pitted with small openings, which will allow water to percolate through or otherwise affect them. The circulating water may contain some acid in solution, which will either eat away the rock or leave it in such condition that oxygen may affect it until by the combined actions of water and air the rock falls apart. This disintegration of rock produces soil, which may be formed from the rock where the soil is found, or from rock particles transported to their present location by wind or water.

107. Process of Disintegration.—Almost all rocks contain mineral matter, which may be dissolved by water or by solutions containing acid or alkaline compounds, thus leaving the insoluble portions of the rock as soil. Certain metallic sulphides when alternately acted on by water and the oxygen of the air become changed into oxides of the same metals. The sulphur is converted into sulphuric acid that attacks other elements, forming soluble or insoluble sulphates. This explains the change that has taken place in the outcrop of most mineral veins, and accounts for the absence of sulphide ores near the outcrop of some metallic beds and veins.

Quartz is practically unaffected by atmospheric agencies on the surface, although it is acted on to some extent by underground waters. Mica is slightly attacked and changes very slowly. Feldspar is composed of a soluble lime-soda-potash material that will dissolve and leave the insoluble silicate of alumina as kaolin. As pegmatites are largely cemented by feldspar, their disintegration will occur slowly when exposed at the surface. Eruptive rocks are decomposed in a similar manner.

The cementing materials of limestones, sandstones, and slates are so acted on by weathering that they sometimes disintegrate quite rapidly.

108. Boulders of Disintegration.—Where the soil is formed by the disintegration of rock in place, the harder masses of material are slower in falling to pieces, and hence may form boulders of disintegration, as shown in Fig. 28.

FIG. 28

Here, the soft rock *b* at the upper part of the hill has been gradually decomposed and washed away, and the harder formation *a* exposed, which in turn has been undermined by the decomposition of the formation *c*. Pieces of the rock *a* have broken off and fallen down, forming the boulders *e*. In time the corners have become rounded until the rocks assume the usual appearance of boulders. The débris and disintegrated material from the softer portions of the hill have formed soil, as at *d*, while on the top of the hill the rock *b* has decomposed and formed soil in place, as at *f*. The face of the hill above the rock *a* being too steep for soil to remain where it was formed, this portion has naturally been washed off and serves to increase the depth of the soil in the valley. Sometimes, the softer portions of the rock are protected to a certain extent by the harder overlying formations, and this results in the formation of rocking stones or pillars. Fig. 24 illustrates one of these rocking stones formed by disintegration, and Fig. 25 the manner in which pillars are sometimes formed.

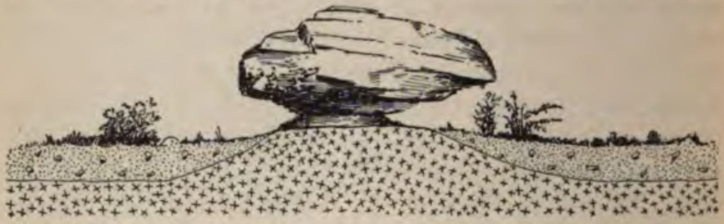


FIG. 24

FIG. 25

109. Effect of Frost.—In cold climates, water percolates into the cracks in the rocks, and, becoming frozen, splits up the material, often throwing down great masses of rock from cliffs, thus forming piles of boulders and broken material at the foot of cliffs, as illustrated at *a*, Fig. 26. Such a pile of broken material is spoken of as **talus**, or *slide rock*. The frost is not only active in breaking off large masses from the cliff, but it is continuous also in its action. Moreover, it not only breaks up small stones, but also pulverizes grains of rock in the soil. Water in the act of freezing expands $\frac{1}{35}$ of its bulk. This expansion has a powerful action, which will often tear fissured or jointed rocks apart in such a way that water can enter and the frost convert the water into ice. If the rock is porous and exposed after separation from the parent bed, frost will freeze any water absorbed by the rock and cause still further disintegration; in fact, this process will extend also to soils.

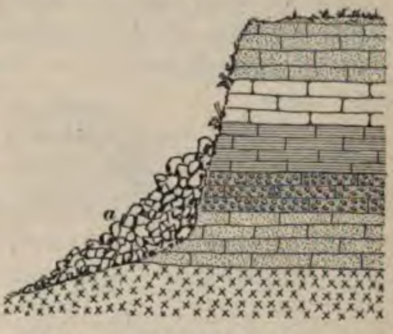


FIG. 26

110. Effect of Wind.—The direct effect of air on rocks is considerable, but much of this effect depends on the velocity of the air when in motion. The force of the wind in its movements against objects varies as the square of its velocity. The chief dynamical effect of wind is produced by its transporting power. In some localities—as, for instance, in Egypt and near Norfolk, England—once fertile districts are now sandy wastes. Common sand, while 2,100 times heavier than dry air, will, when traveling at the rate of 60 miles an hour, produce a pressure of 2 ounces per square inch. This pressure would move material of considerable size, for a cubic inch of quartz would weigh about .17 ounce. In a number of cases—notably at Cape Cod, Massachusetts, at Grand Haven, Michigan, at San Bernardino, California, and on Long Island—sand is continually drifting and wearing away rocks by abrasion. On the dry plains of the Mohave and Great American deserts, the wind drives the sand with abrasive effect. In Bermuda, eolian or wind rocks have been formed by calcareous sands cemented with water. These rocks are now quarried, although as a usual thing rocks formed in this way are mere sand heaps having little or no cohesion. Sand banks caused by winds are termed dunes; these are frequent in the United States and in the Copper River Basin, Alaska.

AQUEOUS AGENCIES

CLASSIFICATION OF AQUEOUS AGENCIES

111. Mechanical Effects of Water.—The general effect produced by water on the lithosphere is that of tearing down in one place to build up in another. This destruction and reconstruction takes place both chemically and mechanically. Water descends from the clouds in the form of dew, fog, rain, or snow, and eventually reaches the sea.

Fig. 27

The proportion of water that flows directly into the sea depends on the vegetation of the rain area; that is, countries having little vegetation are eroded more than those covered with forests and vegetable growths. At the time of a rainfall every little rill excavates a channel, and these rills uniting and forming brooks excavate gullies. The brooks unite to form streams, which excavate ravines, gulches, cañons, and coulées. Streams unite to form rivers, which empty into lakes or seas.

112. Waterfalls.—The erosion due to water falling from a height is illustrated in Fig. 27. The hard-ro formation shown at *a* is underlaid by a softer formation *b*, which the stream in falling from a height erodes in the manner shown at *c*. This undermining, together with the aid of rock joints or cracks usual in stratified beds, causes the top rock to break off and fall down to the stream bed below. The water falling on these broken rocks disintegrates them, and while doing this splashes against the rocks *b* with sufficient violence to erode them. In this way the cañon *d* has been formed, the length of which will increase as the erosion progresses. In Fig. 28, which is a cross-section taken at *AB*, Fig. 27, the soft surface rock *e* through which the stream flows above the waterfall is shown. The hard rock *a* and the soft rock *b* are shown to form the cañon through which the river flows. Fig. 29 is a Rocky Mountain view showing how a comparatively small stream cut its way down through the softer rocks until it has reached the hard strata. The Victoria Falls, on the Zambesi River, in South Africa, is said to be due to a fissure in the basalt through which the river flows and to a fault over which the river falls. The Victoria Falls is 400 feet high and the river wider than at Niagara Falls.

FIG. 28

113. Cause of Rapids.—Usually, in the streams below waterfalls, there are rapids, caused by the erosion of rocks coming from the falls and by material carried along by the current, which in such places is swift. If the upper strata over which a stream flows were softer than the underlying material, or if the material were of uniform composition and the fall were considerable, the river would erode a channel having a quick descent, and thus form rapids. If the bed of a river is alternately of hard and soft rock, rapids with visible ledges of rock cropping above the water, such as may be seen in the New River, Virginia, are formed.

114. Erosion by Water.—Water in motion strikes obstacles with an amount of force depending on the velocity

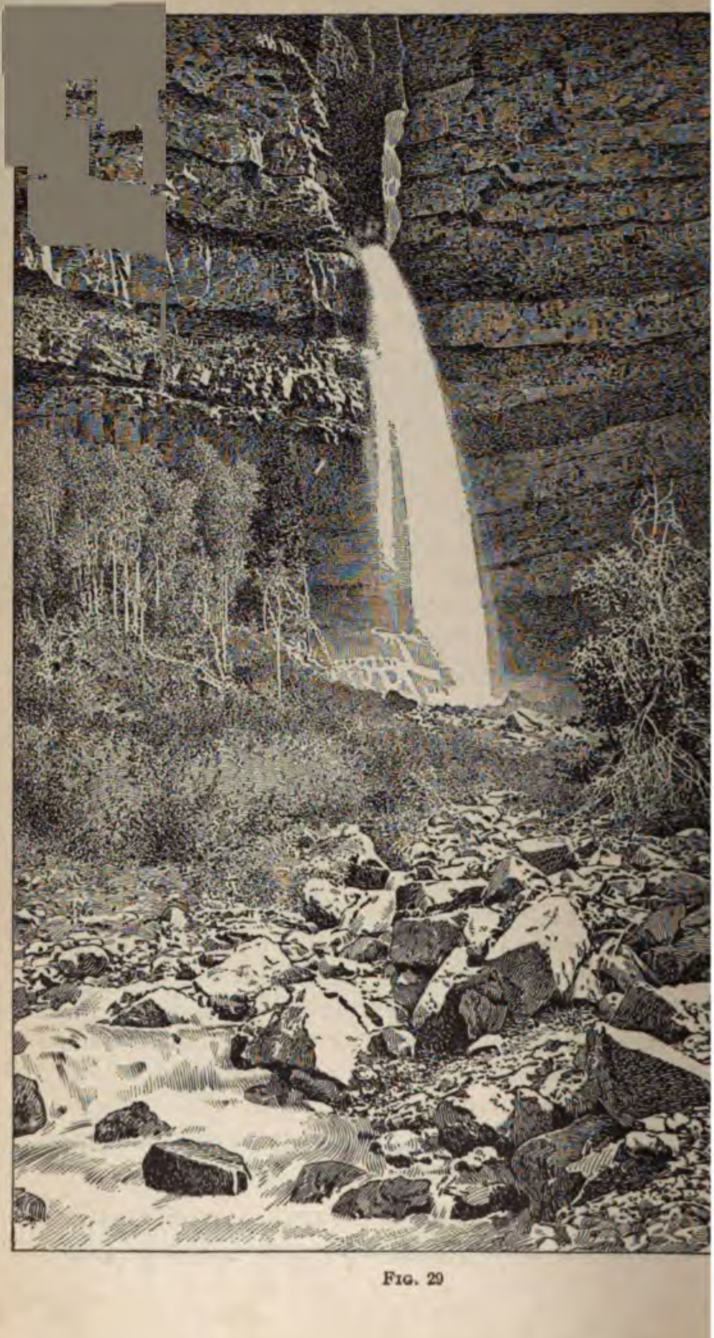


FIG. 29

of flow. Falling water—whether in mass or drop by drop—exerts a force proportionate to its velocity, which is based on the law of falling bodies, or $v = \sqrt{2gh}$. In both of these cases, the rocks that the water strikes are gradually eroded,

FIG. 30

or worn away. The particles of rock thus worn off will aid in still further erosion of the rocks, first by increasing the density of the water, and second by abrading or scratching the rocks. An example of this kind of erosion is given in Fig. 30, which is a view of the Grand Cañon of the Colorado

River. This cañon is more than 300 miles long, and varies from 3,000 to 6,000 feet in depth. Comparatively recent formations of a sedimentary character, like those of the Green River bed in Wyoming, Fig. 31, are more easily eroded than some others, particularly if the formations are nearly horizontal. The sediment and rocks transported during periods of heavy freshets aid greatly in the erosion of river beds.

FIG. 31

115. Relation Between Carrying and Eroding Power of Water.—The eroding power of water varies as the square of its velocity. This may be proved as follows: The eroding power of water, or its ability to overcome the cohesion of the rock, must vary with the force that the water exerts on any given area of rock material. If the surface of the rock is constant, the force of the running water will vary with the square of the velocity; for instance, if a stone pier is standing in running water and the velocity of the current is doubled, then, since the momentum or force is equal to the quantity of matter multiplied by the velocity ($M = Q \times V$), the force of the current against the pier will be quadrupled, for there will be double the quantity of water striking against it in a given time with double the velocity; hence, $M' = 2\,Q \times 2\,V$, or $M' = 4\,Q\,V$. In like manner, if the velocity of the current is tripled, there will be three times the quantity of water striking with three times the velocity, and the force will be increased to nine times the original force; while, if the velocity is quadrupled, the force will be sixteen times as great. This shows that the force that a current exerts against a fixed object varies with the square of its velocity. By means of mathematics, it may be proved that the power of a current to carry objects of the same density varies with the sixth power of the velocity. This fact is illustrated in Fig. 32. Suppose that the cube of rock *a* is just moved by a certain velocity of flow; then, double the current velocity will move a mass of rock of equal density sixty-four times as large. From this, it is evident that the increased velocity of the current has an area sixteen times as large to act on, and, as doubling the velocity of the current increases the force as the square, it is evident that this new current can move a body four times as deep; hence, the new current should have force enough to move the body *b*, which is just sixty-four times as large

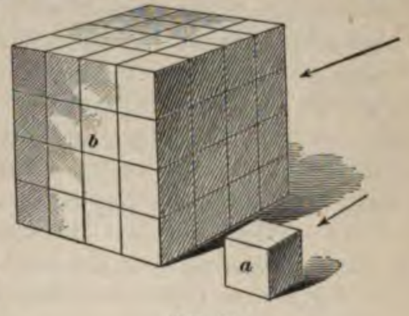


FIG. 32

as the body *a*. This statement is borne out by experiment. Thus, it has been found that water flowing 6 inches a second will move fine sand; flowing 8 inches a second, coarse sand; flowing 12 inches a second, gravel; flowing 24 inches a second, pebbles; and flowing 3 feet a second, angular stones the size of a hen's egg. From this it will be seen that the carrying power increases much more rapidly than the velocity; for instance, a current moving 1 foot a second will carry gravel, while a current moving 3 feet a second, or with three times the velocity, will carry stones many times as large as the grains of gravel. It was owing to the discovery of these facts that investigation showed that the carrying power of the water varies as the sixth power of its velocity. This transporting or carrying power of water must not, however, be confounded with its erosive power. In one case, the resistance to be overcome is weight and bulk, while in the other it is cohesion; hence, erosion varies as the square of the velocity, and transportation as the sixth power of the velocity.

It follows from the preceding discussion that a sufficient body of water having a velocity of 10 miles an hour will carry fragments having a weight of 1½ tons, and similarly that a current of 20 miles an hour will carry fragments having a weight of 100 tons. Hence, from these considerations, it can be understood why water rushing through the mountain gorges has such a tremendous carrying power, and why mountains themselves are eroded so rapidly and great cañons and valleys formed. One would think that streams would be able to carry through some of the mountain gorges a stone of any size whatever; but the fact is that the water in its course passes through a series of cascades and the bed of the stream is extremely rough, which factors act as obstacles to the speed of the stream and reduce its carrying power. Advantage is taken of the carrying power of water in the prosecution of hydraulic and placer mining. If, however, the solid particles are too numerous, the carrying power and velocity of the stream will be reduced, since the mixture will then partake more of the nature of a solution of water with solids than of solids with water.

116. Sorting Power of Water.—If a mass of stones, earth, and clay is thrown into still water, the coarser stones will fall to the bottom first, and each succeeding layer will be composed of finer material, the fine clay settling last. Now, if the operation were to be repeated with the same body of water, the second mass would be sorted in the same manner, the coarse material settling first and the fine last. This would result in layers of material. In the case of running water carrying material in suspension, the coarse material would be dropped first if the current were slightly reduced, and on this material the finer particles would be deposited should the flow be still further retarded. The heavier or coarse material will be deposited farther up the stream and the fine carried farther down, unless after the coarse material is deposited the velocity is decreased and the fine deposited thereon. From this it will be seen that every change in the velocity of a current of water carrying material in suspension will result in layers of different sizes and classes of material at the same point. It is in this way that stratified deposits are formed. Such deposits are called **sedimentary deposits**; and, as all moving water is constantly changing its velocity, it is evident that sedimentary deposits will always be stratified. Conversely, it may be taken as a rule that all stratified masses in which the stratification is the result of sorted material are of sedimentary origin. These facts are of great assistance in the study of the various rock formations, as they furnish the data by means of which the origin of any particular formation can, to a large extent, be determined.

117. Meandering Rivers.—Practically all rivers have a winding course. The various causes acting to produce these turns in streams can be explained by referring to Fig. 33. If the river originally flowed from *f* to *e* in a practically straight line, as indicated by the dotted lines, and if the current were of a constant velocity and the bed smooth, the straight course might be maintained until some obstruction, such as a log or a stone, would turn the stream slightly against one bank, when it would begin to cut away the bank and form a bend in the stream. As the bend becomes greater, the velocity of the current on the outside increases and that on the inside decreases; hence, the course tends to become more and more irregular as the stream cuts material from the outside of the curve and deposits it on the inside. Finally, a loop, such as shown at *a c b*, would be formed; then, during some freshet or high-water period, the water would cut across from *a* to *b* and leave the part *c* as a curved lake or lagoon, similar to that shown at *d*. These lagoons are common where large rivers have flowed through comparatively flat plains.

FIG. 33

118. Flood Plains.—All streams have channels, through which they flow, and many streams have plains, over which they spread in times of freshets. This condition is illustrated in Fig. 34, which is an ideal cross-section of a river confined on each side by bluffs *a* and *c*. The original river channel was *a b c*, on the bed of which has been deposited material *d*, as shown. During ordinary periods, *e* represents the water level, but in time of flood the line *a c* is supposed to represent water level.

In some cases the flood plains are termed **river bottoms.** The sediment so deposited acts frequently as a fertilizer, so that such lands are in many cases very fertile and are extensively cultivated. On the other hand, there are also **river swamps,** or tracts of low spongy land so saturated with water that they are unfit for tillage. In such swamps, certain species of trees and coarse grasses flourish luxuriantly.

The flood plains shown in Fig. 34 are river swamps and are formed by a natural slope from the bluffs to the river banks, thereby forming slight natural levees at the points *f*. These levees are due to the fact that the water rushing down the main channel carries a greater amount of matter in suspension, and where it breaks over the bank its velocity is reduced, so that in consequence the heaviest deposits are made at the points overflowing. Owing to this action, the river at low water sometimes flows slightly above the adjacent country, and in times of high water the bed of the stream may change its course, by breaking through these natural levees and filling up its own bed, thus leaving lagoons.

FIG. 34

119. Deltas.—When a river empties into a lake or ocean, the velocity of the current being reduced by meeting a great body of water, the river naturally drops its sediment and forms deposits at the river mouth. These deposits continue until what is called a **delta** is formed. In Fig. 35 a stream is represented as flowing into a lake at *a*. The stream has gradually formed a deposit, or delta, through which it finds its way to the waters of the lake by a number of mouths. In general, all the matter brought down the river in suspension is left in the lake, the overflow from *b* being clear water. Fig. 36 is a cross-section of such a delta,

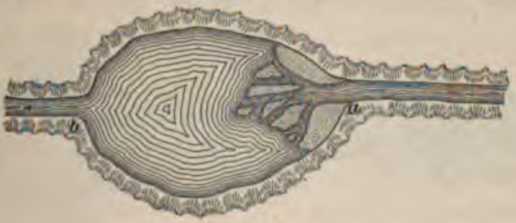


FIG. 35

and shows successive layers or strata as they would appear where comparatively coarse material was brought down by a rushing stream. In the case of large rivers emptying into a sea as, for instance, the Mississippi emptying into the Gulf of Mexico, the greater part of the material carried in suspension is fine, and hence the deposit would not end so abruptly as that shown in Fig. 36. The delta of the Mississippi is very irregular, but its area is estimated at over

FIG. 36

12,000 square miles. The word *delta* is the name of the fourth letter of the Greek alphabet, Δ, and is applied to these river-mouth deposits because of the resemblance they bear to the triangular form of the letter.

120. Estuary.—Where rivers empty into tidal seas or oceans, a wide-mouthed bay, or, as it is called, an **estuary**, is formed by the eroding action of the tide, which rushes in and out again twice in the 24 hours, carrying out

FIG. 37

into the sea much of the débris brought down by the river and eroded from the land by the action of the tide. Where the force of the water rushing out with the tide is arrested by the water of the ocean, bars of sand or other material will be deposited, as shown at *d*, Fig. 37. At the head of the estuary, where the tide overcomes the current of the river, thus causing still water at high tide, there will be a flood-plain swamp from *a* to *b*. If there are any coves *c* or indentations in the side of the estuary which are not subject to scouring action, they may become filled with débris and ultimately form marshes. The deposit from *a* to *b* would form the salt marsh so common near the sea. The bars at the mouth of the estuary form an obstruction to navigation, and when removed by mechanical means they reform in the same place and under the same conditions and agencies. To overcome this difficulty, it is necessary to confine the flow, and thus cause the water to scour away the bar, but the best that this can accomplish is the formation of the bar farther out. Hence, human ingenuity can never effectually prevent the formation of bars at the mouth of an estuary.

121. Wave Erosion.—Waves driven by the wind during a storm strike against the land with considerable force. During heavy storms the waves will dash rocks of considerable size and weight against cliffs and against each other, thus breaking them to pieces. The waves beating against the rocks form sands, which the tide in receding carries into deep water, thus furnishing new rock surfaces for the waves to disintegrate.

122. Ocean Currents.—Currents in water are caused by differences in temperature and by the revolution of the earth. Those going to sea carry sediment with them which they deposit in the ocean. It is probable that such large currents as the Gulf Stream carry sediment long distances before depositing it, and possibly it was this current that assisted in the formation of the Bahama Banks and the banks and shoals at Florida on which the coral reefs have subsequently been formed. The Banks of Newfoundland are supposed to have been formed from material transported by icebergs floating South in the Arctic currents.

123. Glaciers.—Glaciers are formed on mountains whose summits extend into the region of perpetual snow.

As this snow falls more rapidly than it melts, if it had no means of escape there would be no limit to the height to which it might pile, but by alternately melting and freezing the snow becomes a mass of ice crystals, which gradually become compacted into solid ice and work down to the valleys from the mountains as rivers of ice called **glaciers.** For the formation of a glacier, there must be a mountain extending above the line of perpetual snow, and there must also be a considerable change in temperature between the seasons, so as to form the ice crystals and compact them into the glacial ice. Glaciers not only extend for a considerable distance below the snow line, but even below the line of the mean annual temperature. This is on account of the fact that the ice formed at a higher elevation crowds forwards and it requires a long time to melt the mass.

In Fig. 38 is shown the Rendu glacier, of Alaska. The mountain topped with snow is seen in the background; the glacier between the mountains looms up like the crest of a waterfall, while the glacier débris is in the foreground.

124. Ice Flows.—It is sometimes a matter of wonder as to how ice can flow. The explanation is, however, comparatively simple. If molasses candy at a temperature at which it is practically solid, is struck a sudden blow, it may be easily broken; if, instead, it is subjected to a slow pressure, it will assume any shape into which it may be pressed. In the same way, ice under a very slow pressure will assume nearly any shape, while if struck a sudden blow it will crack or break. This, to a large extent, explains the phenomena of glacial flow, although there are many other factors entering into the case. The surface of the glacier is not smooth, like that of a river, but is always covered with broken and jagged pieces of ice; deep fissures or crevices are also often characteristic features. Stones and earth fall from the sides of the valley through which the ice river flows and are carried on its surface; while the under surface of the ice picks up stones and by their means scours or scores the bed over which it passes, thus eroding a large amount of material,

FIG. 38

much of which becomes frozen into the ice and is carried along with it. This material, which consists of stones, gravel, and clay, is deposited at the end of the glacier in more or less crescent-shaped masses called **terminal moraines,** which in reality constitute the delta of the ice river. In addition to these terminal moraines, **lateral moraines,** or rows of boulders borne by the glacier, are formed along the sides of the ice river, being deposited there as the glacier melts or recedes. Where the rock in its path is softer than the adjoining material, the glacier often scours out basins, which, after the ice has melted, become small lakes. This is a common occurrence, especially in mountain regions; as these small glacial lakes become filled with débris washed into them, meadows or marshes are formed. As glaciers carry with them very large masses of rock, their enormous eroding power enables them to cut through almost any obstacle. On this account, glaciers have been very active in effecting geological changes, especially in the northern hemisphere, as, for instance, in North America, Europe, and Asia. The terraces, or horizontal step formations, of gravel and sand on the side of a somewhat steep slope are probably in part due to the erosion and melting of glaciers.

125. Icebergs.—When glaciers run into the sea, great masses of ice break off and float away, carrying their burden of rock and gravel. Icebergs are often of enormous size, and may carry many tons of material. Bergs have actually been grounded in nearly 2,000 feet of water. At times they form great ice floes, which work along through the shallow water, scouring and scratching the bottom and depositing their burden as they melt. Much of the material on the banks of Newfoundland was undoubtedly transported and deposited in this manner.

126. Avalanches.—In the mountain districts of the West, large bodies of snow at times slide down the mountains. The mass of snow or ice, which may at first be comparatively small in amount, gathers more snow and greater momentum as it descends, until it is powerful enough to destroy anything movable in its path, and erode and transport rock material. While an avalanche is comparatively a local affair, it will cause enough erosion in its locality to place it in geology as an erosive agent.

UNDERGROUND WATERS

127. Hydrostatic Pressure.—The pressure of a column of water of any area increases at the rate of .434 pound per square inch for every foot in depth. This law remains true for underground waters, especially in the zone of fracture and in the upper part of the zone of fracture and flowage; below these zones, where crevices cannot exist, the law would not apply. The flow of water underground may be divided into the upper and the lower zone, both of which are in the zone of fracture. Openings between rocks—such as crevices—as well as pores in the rock that are sufficiently large, permit those portions of the rainfall that soak into the ground to pass through them.

128. Flow of Water Through Rocks.—The quantity of flow of liquids through tubes is dependent on the head, the diameter of the tube, and the fluidity of the liquid. In hydrostatics, the velocity of flow of water is equal to $\sqrt{2gh}$. The rule in this case would give results that are too high, because it does not take into account the friction due to the length and the diameter of the tube through which the water flows. In long, rough, irregular, underground passages not of determinable size, the friction may become so great as to render the rule for flow inapplicable. There is, however, no question of doubt that the flow of water with a given head is more rapid in large rock openings than in very small capillary openings.

According to Poiseuille's law, the quantity of flow of water under constant head in capillary openings is proportional not to the square, as in tubes, but to the fourth power of the radius. Moreover, the velocity of flow is proportional to the pressure, and not to the square root of the pressure, as in pipes. Finally, the velocity of flow is inversely proportional to the length of the opening, and is indirectly proportional to the viscosity of the fluid.

129. Viscosity.—By **viscosity** is meant the *thickness* of water or other fluid. The viscosity of underground water decreases rapidly with increase of temperature, being only one-fifth as much at 194° F. as at 32° F. Therefore, with capillary tubes of a given size, the increased velocity of flow would be five times as much at 194° F. as at 32° F. This increased velocity of flow is very favorable to flowage through openings at considerable depth. Notwithstanding the increased mobility of water, the circulation in capillary openings is very slow, so that rocks having openings of capillary size—such as dense clays and shales—are spoken of as impervious to water. Although this is not exactly true, the movement of water through such material is slow compared with its movement through rocks having a large number of capillary openings in layers, such as brown sandstones and limestones. The flow of water deep down in the lithosphere cannot take place, since the openings that may be termed *subcapillary* would, if they contained water, be filled up by it as if it were glue, and there would be no free water. In other words, *the viscosity of liquid has reached its limit and liquid cannot pass through subcapillary openings.*

130. Cause of Underground Flowage.—The rain that soaks into the lithosphere circulates only through the upper portion of the zone of fracture and flowage, and chiefly through the zone of fracture. Gravity is the chief factor in the flow of water, aided in some cases by difference in temperature, it being a well-known law that warm water seeks to rise, while cold water, owing to its greater density, seeks to fall. This difference in head is due to density, which causes upward and downward currents. According to Austin, the expansion of water with increase of temperature is such that an average difference between 32° F. and 212° F. is sufficient for a column of 100 feet of water at 32° F. to balance a column of 104 feet at 212° F. This 4-foot head of water will cause an upward and downward circulation, if more heated water is supplied from below. The heat for such purposes may arise from the heat due to depth, or from chemical action, such as is evidently the source from which hot and warm springs obtain their heat.

131. Upper Belt of Underground Circulation.—The circulation of underground water is divided into two belts for the purpose of separating the water that flows off at water level from the water that acts on rocks and circulates below water level. In using the term *water level*, the miner's definition is assumed; namely, that it is the depth at which water will not flow away without aid. Water level is the horizontal plane beneath the surface of the ground that is the upper boundary of the belt of saturation. The thickness of this upper belt varies greatly, depending on the elevation, the character of the rocks, and the rain precipitation.

The complex movements of underground water may be divided into *vertical* and *lateral* movements.

132. Lateral Movements.—The flowage of water—say from *a* to *b*, Fig. 39—is not a direct path, according to Professor Slichter's investigations, but rather a number of converging paths, as shown in the plan, which is intended to represent the horizontal course that water takes in flowing from the well *a* to the well *b*. This knowledge is of practical value in the oil-well, gas-well, and brine-well boring, and applies to any rock in which the pores are arranged in an open manner, as are gas and oil sands.

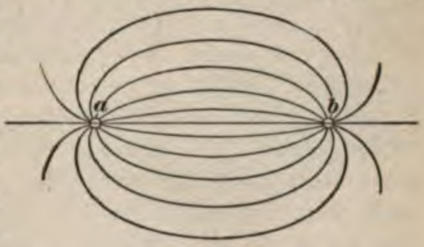


FIG. 39

133. Vertical Movements.—In Fig. 40 is shown an elevation of the vertical course of underground water from *b* to *a*. In the passage of water through a uniform rock from many points on a hill to a point of issue at the foot of the hill, supposing that those are the only points of entrance or issuance of the water, the vertical course would be represented as at *a*. In such instances, water carries with it more or less air and carbon dioxide, thus aiding in the disintegration and erosion of the rocks. In case the rock should be nearly impervious to water, as at *b*, Fig. 41, the water that flows through the formation *a* will appear as a spring at the point *c*, and in flowing away will erode rock in the same manner as other streams. If the level of the ground water *a* is below the surface *b*, the circulation of the ground water will appear somewhat as shown by the curved lines in Fig. 42, and will find its exit at *c*.

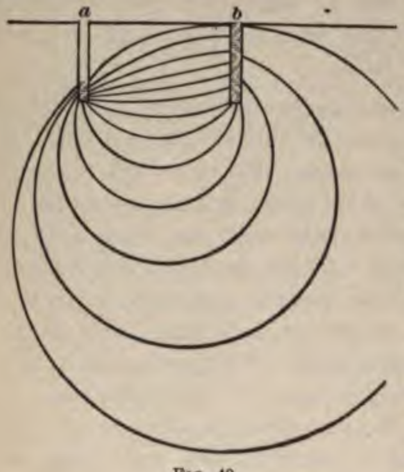


FIG. 40

134. Lower Belt of Underground Circulation.—The vertical component of the journey of underground waters below water level may be considered as confined to the zone of fracture, and probably reaches its maximum at a depth of 39,000 feet. The lateral movement, on the other hand, may vary from a few feet, as in the case of oil and gas wells, to a thousand or more miles. It is probable that the amount of flowage is far greater in the upper part of the zone than in the lower part, but even in the lower part the amount of flowage cannot be considered small.

FIG. 41

Owing to difference in temperature, it follows that on an average the downward movements of water are through the small openings and the upward movements through the large openings. Of course, where large openings are available for downward moving water, they will be utilized. Water below ground will sink through channels offering the least resistance to its passage, and it is probable that, in the course of time, water will enlarge those passages by erosion or chemical action. There is considerable opposition to this theory, on the ground that in deep mines water is encountered mostly in the upper levels. This is not always the case, as the quantity of water depends on the character of the rock; in fact, the level for no water varies in different localities as surely as the quantity of water varies in strata.

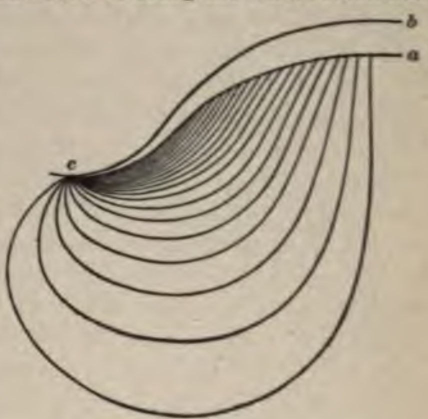


FIG. 42

135. Artesian Wells.—When a water-bearing stratum, as *b*, Fig. 43, is between apparently impervious strata, as at *c* and *d*, it will offer the least resistance to the passage of water

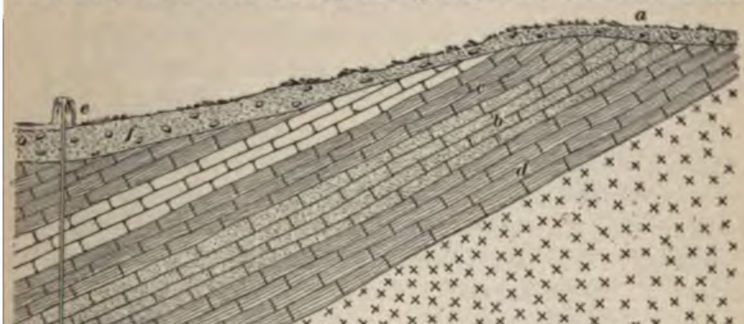


FIG. 43

vertically or laterally, and the water will go downwards through this stratum and increase in pressure with depth. If, therefore, a well *e* is put down, the water will sometimes rise from the rock *b* up through the well and flow naturally. This was the original definition of an artesian well, but the term has been broadened to cover any well drilled into the earth from which water may be obtained. This condition is illustrated at *a* and *b*, Fig. 42; while the journey that water may take in supplying those wells is shown by the curved lines. The water is seen to reach nearly to the surface at *b*, so that an ordinary pump can draw from it, while in the case of well *a* a deep-well pump must be used. This also approximately illustrates oil wells. In West Virginia, a well struck a little water at 350 feet depth, and then found no more up to 1,000 feet. Another well not 300 feet away was drilled, which furnished an immense amount of water at a depth of 105 feet. At Plainfield, New Jersey, there seems to be an underground river with sufficient water to supply that city and neighboring towns.

CHEMICAL ACTION OF UNDERGROUND WATERS

136. Reactions.—Water circulating underground—whether at ordinary temperature and pressure or at high temperature and pressure—may take into solution substances with which it comes in contact. By this means it may dissolve material from one rock and perhaps deposit it in some distant locality where conditions favor selective agency or where differences in the temperature, pressure, and reactions of the various solutions coming together are favorable to deposition. All these changes are of a chemical nature, to which also may be added an interchange of solutions with solids. The formation of rocks and their cementation by the chemical action of water has been treated elsewhere, but some additional statements may be made here. The zone of fracture has been divided into the upper and lower belts of underground-water circulation. The upper belt—or at least that portion of it above water level—may be termed the *belt of weathering;* while the lower belt may be termed the *belt of cementation*. The reactions in the belt of weathering involve gases, liquids, and solids, besides the complicated reactions of organic bodies on inorganic bodies.

137. Carbonation.—The process of **carbonation** takes place in the belt of weathering, producing abundantly carbonates of the alkalies, alkaline earths, and iron, and less abundantly carbonates of other metals. Where vegetation is lacking, the air contains only a small amount of carbon dioxide; but where vegetation is decaying, the carbon dioxide in the soil is from fifteen to three hundred times more than in the air. The process of carbonation occurs on a larger scale where vegetation is abundant.

The dominant compounds on which carbonation acts are the silicates, the silica separating as silicic acid. Since the quantity of silicates decomposed by carbonation is very great, the amount of silicic acid that passes into solution and is transferred below to the belt of cementation is enormous. Of the substances deposited in the belt of cementation, silica or quartz undoubtedly predominates over all others. This result could naturally be inferred, since silica is so abundantly distributed in the lithosphere.

138. Hydration.—The process by which a chemical compound absorbs water is termed **hydration.** Virtually, such water is the water of crystallization. Underground waters in their movements may combine with substances and form hydrates, as in the conversion of hematite into limonite. Water also reacts on the salts it holds in solution when removed to form free acids and hydrates of the bases. The dominant acids of nature are the very weak acids, silicic and carbonic, and therefore dissociation is very important. The silicates of the alkalies in dilute solutions are practically entirely decomposed, the liberation of free silicic acid and hydrates of the alkalies taking place as demonstrated by Kahlenberg and Lincoln. The carbonates of the alkalies are also to some extent similarly decomposed.

A ferrous solution containing oxygen will cause a change from ferrous to ferric iron, and the latter will be precipitated as hematite or limonite. In this case, hydration occurs simultaneously with the oxidation.

139. Importance of Hydration.—While hydration and deposition are in their extent next in importance to carbonation, they are the characteristic reactions in the belt of cementation, in which carbonation and oxidation are subordinate. The reactions take place by metasomatic change within the original minerals and by deposition of material within the openings. Many of the minerals are hydrated, and because of hydration and deposition the volume of the rocks is increased. Cracks and crevices produced by mechanical action, and openings originally present in the rocks—such as pore spaces in the mechanical sediments, and **vacuoles**, or minute cavities, in volcanic rocks—are slowly but surely filled by the action of the ground water and the rocks cemented. This process, which may be called *construction*, has taken place in some rocks having amygdaloid structure, as shown in Fig. 12. In the Calumet and Hecla conglomerates, many of the pebbles have been completely replaced with copper. In some instances, the copper is in the form of carbonate, but more frequently it is native copper. At Cape d'Or, Nova Scotia, in similar rock, the air spaces have been filled with calcite. In the New Mexico malpais, they are empty or but partly filled. There is, however, a great difference in the ages of the Nova Scotia and New Mexico rocks, the latter being later than the Tertiary.

140. Dehydration.—While hydration is usual in the belt of weathering, under some conditions, and especially those of dryness and high temperature, **dehydration**—that is, the complete removal of water—may occur.

141. Oxidation.—In the belt of weathering, the most important gases present are carbon dioxide and oxygen, which act chemically and aid solutions in dissolving materials. Oxidation is general in the belt of weathering, but deoxidation probably occurs in regions of luxuriant vegetation, where there is proper reducing material. If all the compounds formed in the belt of weathering remained in place, the volume of rocks would increase; but, owing to the fact that solutions carry the soluble material away, the volume of rocks in some localities actually decreases. In consequence of this preponderance of solution, the openings in the belt of weathering tend to increase in size. This is not apparent with unconsolidated materials at the surface, for gravity brings the particles together as fast as material is dissolved; but in rocks below the soils which have sufficient strength to support themselves the openings become wider.

142. Recapitulation of Weathering and Cementation.—The belt of weathering is characterized by disintegration, decomposition, carbonation, hydration, oxidation, solutions, and decrease in the volume of material. The belt of cementation is characterized by cementation, induration or process of hardening, hydration, deposition, and increase of the volume.

143. Caves.—The dissolving action of solutions is illustrated by the large underground passages that have been formed at Luray in the Shenandoah Valley, Virginia, and at the Mammoth Cave, Kentucky. The depositing action of solutions is also shown in the same caverns. The result of both actions is shown in Fig. 44, which has been drawn from a photograph of a portion of the Luray cavern. The passages were formed by the underground streams, which for some cause subsequently stopped flowing, thus leaving the passages empty. Water from the surface subsequently seeped into the caverns by way of the roof, and in its passage downwards collected lime, which it holds in solution. The water as it drips from the roof contains limestone in solution, and as it comes in contact with air the pressure is relieved and it evaporates, leaving the calcium carbonate and forming **stalactites**, which hang from the roof like icicles. Where the water falls to the floor, it forms inverted stalactites called **stalagmites**. When the stalactites and stalagmites meet they form pillars. In some instances the stalactites and stalagmites have the appearance of waterfalls

Fig. 44

without water. The surplus water usually finds daylight in some manner, although in the Mammoth Cave there are lakes containing fish without eyes. Zinc and lead deposits are formed on the walls of limestone caves near Joplin, Missouri, and Morristown, Tennessee. Very extensive caves exist in the lime rock of New South Wales.

144. Deposits From Mineral Springs.—If deposits of limestone or calcareous matter were formed only by the evaporation of water, their growth would be very slow, but by some mineral springs large deposits are built up, and hence some other explanation must be advanced. Calcium carbonate is practically insoluble in pure water, but it becomes soluble if the water contains carbon dioxide, CO_2, and the amount that can be dissolved in a given quantity of water increases with the percentage of carbon dioxide in the water, and this in turn increases with the pressure. Some carbon dioxide comes from the atmosphere and vegetation, but much of it may be derived from underground sources, and this is especially true in volcanic regions or in regions where sulphides are decomposed, forming acids that attack carbonates and liberate the carbon dioxide. This gas is absorbed by the water under pressure, and in consequence it can dissolve greater amounts of calcium. When the waters escape at a spring or other opening, the pressure is relieved and much of the carbon dioxide

FIG. 45

escapes, hence the calcium carbonate is deposited. This explains the rapid growth of stalagmites in some caves and the large deposits of calcareous matter at some springs, and especially at hot springs in regions that have been affected by volcanic action, as, for instance, Yellowstone National Park, Wyoming. Fig. 45 is a view of one of the deposits at the hot springs of the Yellowstone National Park. Under certain conditions, water charged with carbon dioxide may dissolve iron, and as the water comes to the surface this will be redeposited as an oxide, the carbon dioxide escaping. In volcanic regions, hot alkaline springs often carry silicious matter in solution, and as the water cools this is deposited in a soft gelatinous mass that ultimately hardens into a hard silicious rock. Springs that contain hydrogen sulphide, H_2S, are usually called *sulphur springs*, and under certain conditions may deposit sulphur, or, where the sulphur is also associated with lime salts, deposits of gypsum may be formed. Sulphate of aluminum is another rock-building material, as stated in Art. 20 and shown in Fig. 6. Sulphate of lime is also common in mineral waters, especially in mines, where it sometimes clogs the pump pipes.

145. Chemical Deposits in Lakes.—Salt lakes may be formed in two ways: portions of the sea may be cut off, or waters of rivers containing salt may empty into a basin having no outlet. The waters under such conditions evaporate slowly, and the small amount of salt contained in the waters remaining accumulates gradually until the lake becomes salty or brackish. In case the water in the salt lake had the composition of sea-water, gypsum, salt, and chloride of magnesium would be deposited in practically the order stated. Lakes that are fed by rivers and whose waters are gradually evaporated, sometimes deposit other substances, such as carbonate of lime, sulphide of lime, carbonate of soda, borax, and, under certain conditions, iron. The latter, however, usually requires the presence of organic matter.

146. Chemical Deposits in the Sea.—Comparatively little is known in regard to the chemical deposits formed in the sea. Many of the rivers flowing into the sea carry a much larger percentage of carbonate of lime than is found in sea-water. Much of this, however, is undoubtedly taken up by the shellfish and coral, although in some locations the material of deltas is cemented together by carbonate of lime, and in other places, especially in the tropics, where evaporation is rapid, the sand or gravel of the sea beaches is becoming cemented into conglomerates by means of the carbonate of lime contained in the sea-water.

IGNEOUS AGENCIES

147. Constructive Tendency.—The surface of the lithosphere, while being eroded and dissolved by the agencies mentioned, is also subjected to constructive agencies that to a certain extent counteract the destructive agencies. The igneous agencies raise the land directly or lower it indirectly, thereby increasing the differences in elevation on the earth, and hence increasing the land area.

Molten rock matter exists in some locations, for which reason it has been claimed by some geologists that the interior of the earth is a molten mass.

148. Condition of the Interior of the Earth.—At first geologists supposed that the earth had simply a thin shell of rock and that the interior was a mass of melted rock, which burst through the shell in places, forming volcanoes; but astronomy has shown that the earth behaves as a solid sphere whose density is very much greater than that of the rocks at the surface. If the temperature increased equally from the surface downwards, a point would be reached where all rocks would be in a molten state if they are under the pressures existing at the surface.

Owing to great outflows of lava from the earth at different times, it is supposed that there are great reservoirs of molten material from which the outbursts are fed.

149. Volcanoes.—It is supposed that as the lithosphere cooled it shrank, causing the surface to fold and rise in places and form mountains. When shrinkage occurred, great fissures were opened, which in some cases penetrated to such great depths that molten matter and plastic magma were released and overflowed large areas. There are openings in various parts of the earth, which from time to time permit lava to flow out. Some of these openings have become surrounded with eruptive material to such an extent as to form what are called **volcanoes.** Usually, volcanoes are intermittent, at one time being active, and then lying dormant, to break out afresh later. When eruptions occur, they are usually accompanied by earth tremors, termed **earthquakes,** which are due to the upheaval or the subsidence of the land. The volcanoes now in existence seem to be of two classes. The first class comprises those volcanoes in which the melted rock is perfectly fluid and issues from the throat of the volcano, as shown at *a*, **Fig. 46**, or possibly is ejected through rents in the side of the mountain, as shown at *b*. The second class of volcanoes comprises those in which the eruption usually commences by blowing out the lava that has cooled since the previous eruption. These explosions are accompanied by great rushes of steam, blowing the lava into fine ashes and dust, which in settling covers the surrounding country. In the event of rain, this dust is precipitated as volcanic mud, which may subsequently flow down the mountain. During the eruption of Mt. Pelee, on

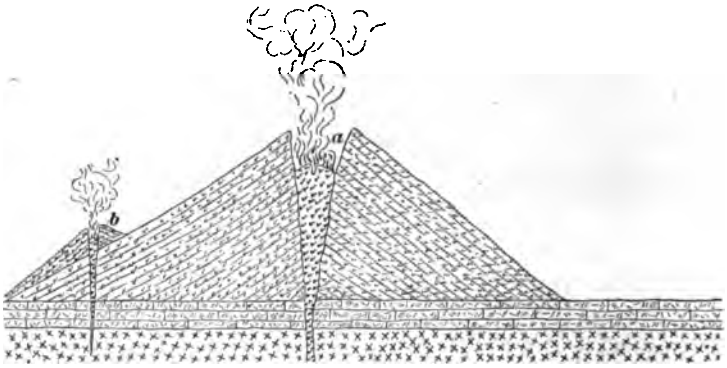


FIG. 46

the Island of Martinique, a deadly hot gas was emitted that burned everything with which it came in contact. The volcanoes in the Hawaiian Islands are of the first class, and eject lava, which flows with great rapidity down the mountain slopes. The volcanoes on the Mediterranean littoral are of the explosive class. Pompeii and Herculanium were completely covered with ashes from Mt. Vesuvius.

Fig. 46 is an ideal section of a volcanic cone or mountain; *a* is the original crater through which the material has flowed out and been deposited in successive layers so as to form the mountain. When the mountain has attained considerable height, the great force necessary to raise the lava to the top of the crater often rends the side of the mountain, thus forming **monticules**, or secondary cones, on the side.

FIG. 47

150. Laccolites and Dikes.—Sometimes an eruption of rock (especially when it is of a semifluid character) does not have sufficient force to break through and overflow the original strata, but may simply form a great mass between the layers of rock, thus forcing the strata up into a great mound or mountain, as shown in Fig. 47. Such a formation is called a **laccolite.** When the action simply causes a crack into which rock material is injected or intruded, it is called a **dike,** as shown in Fig. 47. Where these dikes are composed of harder material than the surrounding rock, they stand out in the bold walls shown in the figure and are then called **trap dikes,** the word *trap* meaning "stair-like."

151. **Subordinate Phenomena of Igneous Origin.** Some of the subordinate phenomena connected with volcanic action are hot springs, which are charged with carbonates or carbon dioxide and occur in various parts of the earth. **Solfataras,** or waning volcanic actions, furnish springs carrying sulphureted hydrogen derived from the passage of water through hot volcanic rocks. **Fumaroles** are hot springs accompanied with more or less steam and vapor. **Mud volcanoes** are hot springs carrying mud with them. **Geysers** are intermittent hot springs, from which water is thrown forth in a solid column. All these phenomena are found in regions that contain active volcanoes or where the volcanic action has not long been absent. The most noted hot springs and geysers are in Iceland, in the Yellowstone National Park in the United States, and in New Zealand.

ORGANIC AGENCIES

152. **Peat Bogs.**—Vegetable growth in swamps becomes after a time a mass of intertwined roots called **peat.** These roots increase from year to year, the decayed portion being replaced with new vegetation that is for the most part of a rank growth. The bog formed by the roots may attain a considerable thickness, depending on the depth of the water originally, and the material will become so compact that a person may walk on it without difficulty, while trees and bushes will grow on it. This peat growth is claimed by some scientists to be the original source of the coal formation, the

bogs being covered with layers of earth, which eventually formed rock and by their pressure converted the vegetable matter into coal.

153. Formation of Coal.—Coal is undoubtedly of organic origin, and was probably formed from bogs and trees that grew in warm climates and swampy localities. There is scarcely any question that coal was formed under water, for sedimentary rocks rest on the coal measures. In whatever manner the coal attained such thicknesses as the beds disclose is a mystery, but that it did is a fact. Coal is found in the western hemisphere from the Arctic Ocean to Cape Horn, and from Nova Scotia to British Columbia, and it is probably forming at the present time. Forests are known to exist under cover of earth changed to stone, and if under water and in favorable localities it is no more than reasonable to expect them to be changed to coal. In the Mississippi Valley, buried trees exist; in Colorado, New Mexico, and Arizona, silicious wood is found; and in Ireland, trees are found in the peat bogs that are still well preserved.

GEOLOGY

(PART 2)

STRUCTURAL GEOLOGY

STRATIGRAPHY

EXPOSURES AVAILABLE FOR OBSERVATION

1. Origin of Continents.—The general geological phenomena of the earth are supposed to have resulted from irregular cooling and shrinkage of the outer portions of the lithosphere. It is supposed that, after the earth became sufficiently cool for the water to remain on its surface, oceans were formed in the depressed places. The mountains are considered to be the results of subsequent foldings and upheavals.

2. Geological Exposures.—The geologist makes use of artesian-well holes, diamond-drill cores, mines, railroad cuts, and other excavations from which to secure information. Sometimes, depths exceeding a mile can be studied in this manner. **Natural exposures** consist of cliffs, ravines, cañons, and upheavals, which in some cases allow of very extensive examinations. Foldings and contortions of strata afford admirable opportunities for study, especially when they have been eroded so as to expose great thickness. Fig. 1 illustrates a fold that has been partly eroded, so that, in passing from the point *a* to the point *b*, the observer would cross the outcrop of several stratified beds, and then in passing from *b* to *c* would cross the same beds in the opposite order. Such flexures have given the geologist an

FIG. 1

opportunity of studying the formation and determining to some extent the nature of the rocks to a great depth such as, for instance, in the Wasatch mountain range in Utah, where a depth of 40,000 feet has been uncovered.

3. Strata.—The term **strata** is sometimes used to

FIG. 2

mean either a series of stratified-rock beds having a sedimentary origin or a series of rocks having an igneous origin;

in general, however, the term may be applied to any series of rocks. **Stratum,** the singular form of the word *strata*, is used to distinguish an individual formation or a continuous series of stratified-rock beds. Stratified rocks were formed in nearly horizontal layers, and are sometimes found in almost their original position; but the greater number of those rocks in which ore deposits are discovered have been inclined and folded by dynamic influences.

Fig. 2, which is taken from a photograph, shows the strike *a*, the dip *b*, and the outcrop *c* of strata.

4. Dip.—Most strata are inclined, particularly those that form hills and mountains. The degree of inclination, or angle that the stratum makes with a horizontal plane, is called its *dip*, *pitch*, or *slope*. The **dip** is measured by clinometers or pitch rules, as shown in Fig. 3. When the upper instrument is horizontal, the pointer will be at 0°; but when inclined as in the illustration, the pointer registers the number of degrees from the horizontal—in this case about 19°. When the lower arm of a pitch rule corresponds to the dip of a stratum and the upper arm is horizontal, the angle of dip can be read on the upright or scale arm.

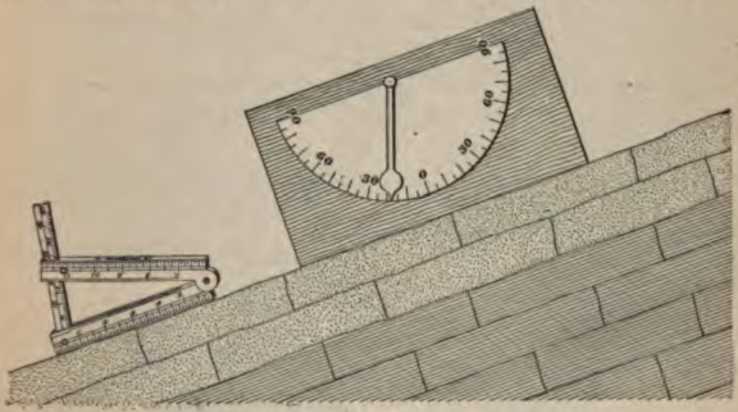


FIG. 3

Veins, like strata, have dip, but, owing usually to their formation, are more highly inclined than strata.

The word **hade** is often used as being synonymous in meaning with the word **underlie,** and the latter as being synonymous with dip. There is, however, a considerable difference in the meaning of these terms, as will be seen by referring to Fig. 4. Assume that the plane *a b d c* is inclined somewhat as shown. Then, the dip *b d* is measured from a horizontal plane; the underlie is measured at right angles to the vertical *b e*, and is the distance *d e*; while the hade is measured from the vertical *b e* by the line *d f* at right angles to the plane *b d e*. Usually, there are two inclinations to a deposit; namely, the inclination *b d* and the side dip *b f*; the latter is the hade. The underlie of a hade is different from that of the dip, as shown by *f e*. Since the underlie is measured by the distance *d e*, it will vary with the depth and with any variation in the dip.

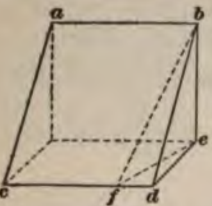


FIG. 4

5. **Strike.**—The direction or course of a bedded deposit or vein in a horizontal plane is the **strike.** To understand better the strike of a deposit, let a horizontal tunnel be conceived as being driven on a vein, turning when the vein turns and running straight when the vein runs straight; then, the tunnel is said to follow the strike of the deposit. Any horizontal straight line in the strike plane of a deposit will be at right angles to the dip. The strike of a vein is likely to be more uniform than that of bedded deposits, since the former are fissures caused by contraction, while the latter, if inclined, are distorted by dynamic influences, or, if flat, are eroded.

FIG. 5

8. Conformable Strata.—Strata are said to be **conformable** when they are parallel or continuous, and were formed under the same conditions. They are said to be **unconformable** when they are not continuous, or were interrupted by an old land surface that had been eroded. Fig. 10 illustrates unconformable strata. The strata shown at *a* were deposited, contorted, and tilted, and subsequently eroded to the form shown in the figure. After this, they were once more submerged, and the strata shown at *b* deposited in such a manner as to be unconformable with the original strata; after the strata had been deposited, the entire mass was once more elevated and tilted slightly, so that the strata *b* were no longer horizontal. There are cases in which unconformable strata are practically parallel, as, for instance, when a land surface has been eroded and then submerged without tilting or contortion, and the subsequent strata deposited parallel or practically parallel to the original

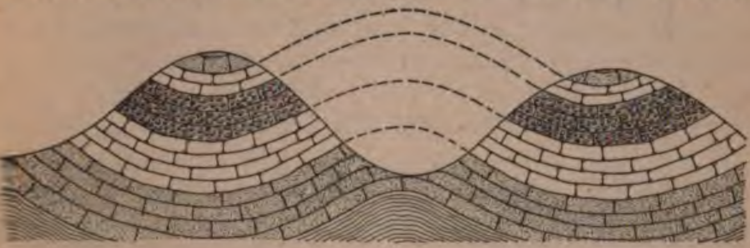


FIG. 9

FIG. 10

ridge is called the **anticlinal axis,** and the course or direction of the valley the **synclinal axis.** Subsequent erosion may have entirely removed the original hills and valleys and produced a comparatively level surface, as illustrated in Fig. 8. The dotted lines show the manner in which the strata were originally bent. When the strata have been eroded in such a manner that the anticlines and synclines are no longer hills and ridges, the anticline may be known from the fact that the same strata are repeated on each side of the axis and that they dip away from the axis, as shown at *b*; while a syncline may be known from the fact that the same strata are repeated on each side of the axis and dip toward the axis, as shown at *a*. The action that forced or crushed the material together frequently opened fissures along the anticlines, thus increasing the tendency to erosion along the ridges; and this may have caused the ultimate removal of the ridge and the formation of a valley along the anticline, resulting in syncline mountains or hills, as shown in Fig. 9.

FIG. 7

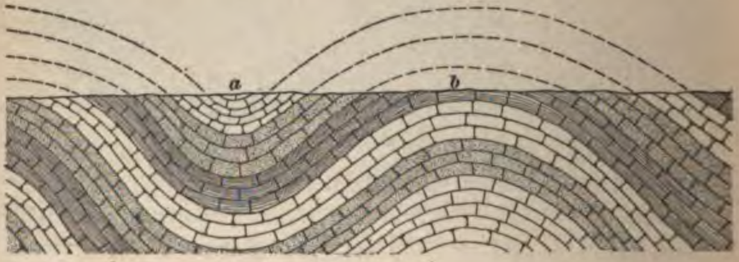


FIG. 8

8. Conformable Strata.—Strata are said to be **conformable** when they are parallel or continuous, and were formed under the same conditions. They are said to be **unconformable** when they are not continuous, or were interrupted by an old land surface that had been eroded. Fig. 10 illustrates unconformable strata. The strata shown at *a* were deposited, contorted, and tilted, and subsequently eroded to the form shown in the figure. After this, they were once more submerged, and the strata shown at *b* deposited in such a manner as to be unconformable with the original strata; after the strata had been deposited, the entire mass was once more elevated and tilted slightly, so that the strata *b* were no longer horizontal. There are cases in which unconformable strata are practically parallel, as, for instance, when a land surface has been eroded and then submerged without tilting or contortion, and the subsequent strata deposited parallel or practically parallel to the original

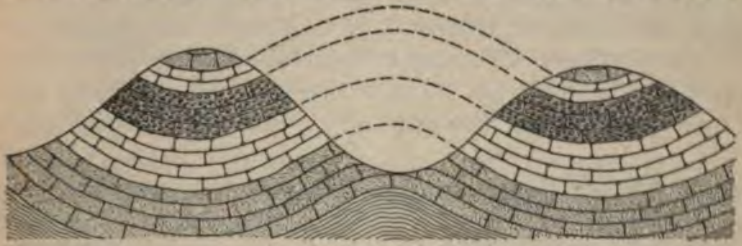


FIG. 9

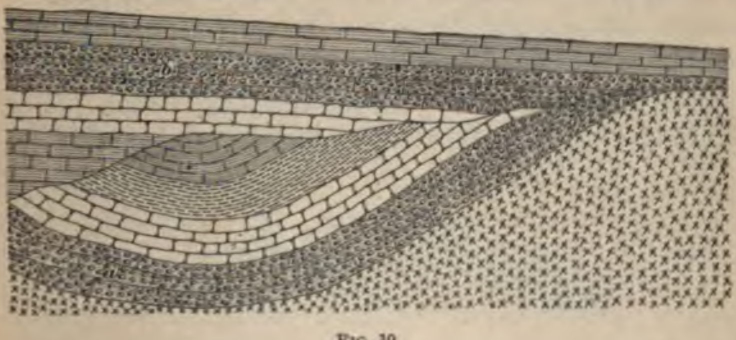


FIG. 10

strata. Such cases can always be recognized from the fact that the eroded land surface has intervened between the depositing of the formations.

9. Unstratified Rocks.—Most of the unstratified rocks have been consolidated from an igneous or aqueo-igneous condition. They are found in many different localities; for the sake of illustration, some of the common situations are grouped together as shown in Fig. 11. Unstratified rocks may be under other rock masses, as at *a*, or form a ridge of mountain ranges, as at *r*. They frequently appear as vertical sheets, filling fissures or cracks in the rocks, forming dikes, as at *h*, *g*, *i*, *n*, or *m*. They sometimes occur as beds of material forced in between the strata, as at *f*; or as overflows on the surface, as at *k*; or the overflow may form a volcanic cone, as at *o*. Whenever eruptive rocks *k* and *n* come in contact with sedimentary rocks *e*, *d*, *c*, and *b*, the latter are usually metamorphosed in the immediate vicinity.

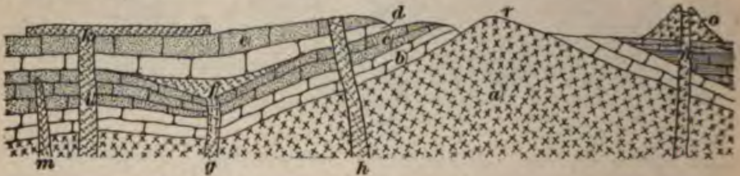


FIG. 11

10. Occurrence of Aqueo-Igneous Rocks.—The aqueo-igneous rocks, especially granite and syenite, which are termed *Plutonic*, occur in large masses forming the axes of great mountain ranges, as, for instance, the California and Colorado mountain ranges. As shown in Fig. 12, they may appear in rounded masses in the midst of stratified rocks, as

FIG. 12

in several New England States, around Lake Superior, and in various parts of Canada. The rocks of the aqueo-igneous Plutonic group are never found in connection with scoriæ, glass, ashes, or other evidences of an igneous nature. Most aqueo-igneous rocks, particularly the Plutonic, have evidently been consolidated under pressure in great masses and at great depths. Hence, when they are found on the surface, they must have been exposed by extensive erosion.

11. **Modes of Eruption.**—There have been two general modes of eruption. In one case, great fissures were opened during extensive crust movements, and if they extended to the surface igneous matter or plastic magma has flowed from them; at times, fissures were filled, even though they did not come to the surface. The other general mode of eruption was that in which lava came to the surface through chimneys or openings and flowed away as streams. The first constitute what are known as **fissure eruptions**; the second are the so-called **crater eruptions**, or volcanoes proper. There are no records of fissure eruptions, either at the present time or during very recent periods, and hence, in dealing with the subject of modern volcanoes, only the chimney or crater eruptions need be considered.

12. **Positions in Which Lava May Occur.**—Lava deposits may occur in any one of several positions, especially when they have been produced by the great fissure eruptions of the past. (1) These lava deposits may appear as vertical sheets filling great fissures, which by subsequent erosion have been made to outcrop as dikes; or else they may fill small radiating volcanic fissures as volcanic dikes. (2) They may occur as sheets between the strata (*intercalary beds*), as if forced between the separated strata or else outpoured on the sea bottom and subsequently covered with the other deposits. (3) They may occur as great sheets or streams that have been outpoured on the land. (4) They may occur as great domes or masses between the strata.

13. **Dikes.**—**Dikes** are fissures filled with igneous material. They may outcrop for great distances (some of

them being more than 100 miles long), and may vary in width from a few inches to more than 100 feet. They extend down to great, but unknown, depths. If the dike is composed of hard material, it will resist erosion and appear as a stone ledge rising above the surrounding rock. If the dike is composed of material that is softer than the adjoining rocks, it will be weathered or eroded so as to leave a hollow or trench across the surface of the country. The effect that dikes produce on the strata through which they cut depends largely on the character of the strata and the character of the material filling the dike. If the strata are composed of limestone on each side of the dike, and the dike is filled with a material that was injected at a high temperature, the limestone on each side of the dike will be converted into a crystalline marble. If the dike cuts through a seam of bituminous coal, the latter will be converted into anthracite, or possibly be reduced to coke, for a few feet on each side of the dike. In Colorado, a material is found that resembles charcoal; and deep down in the Bassick mine, charcoal was found in the mineral vein. In both cases, this charcoal was found adjacent to eruptive strata.

14. Lava Beds, Sheets, or Masses.—When the lava occurs as sheets or beds between the strata, it would be located as shown at *f*, Fig. 11, and subsequent erosion may expose part or all of the deposit. When the material forced between the beds has been of a somewhat more viscous nature, and hence did not have such a tendency to flow or take a flat form, it may crowd the strata up and form a laccolite. When lava has been poured out in sheets or streams on the surface, it will appear as shown at *k*, Fig. 11; or, if there have been several successive outpourings, the lava may appear in successive beds, as shown at *b*, *c*, and *d*, Fig. 13. Some of these great outpourings from large fissures have covered very extensive territories. The great outpourings in the northwestern part of the United States covered Northern California, Northwestern Nevada, the greater part of Oregon, Washington, Idaho, part of Montana, and extended into British Columbia. In places where this overflow is cut through by the Columbia River, it is shown to be from 3,000 to 4,000 feet thick, and covers, approximately, 200,000 square miles of territory. The Des Chutes River, in Oregon, has eroded cañons in this lava field from 1,000 to 2,500 feet deep without reaching the bottom. About a dozen extinct volcanoes can be found over this area, but it is probable that such a large amount of lava did not come from these volcanoes, but must have been the result of great fissure eruptions. I. C. Russell, of the United States Geological Survey, who made an extensive survey of this region, says the rock is basalt and came through fissures at various intervals, as shown by the fossil forests enclosed between layers.

FIG. 13

15. Basalt Columnar Structure.—Many of the eruptive rocks exhibit a remarkable columnar structure. This is most conspicuous in basalt, probably on account of the fact that basalt has evidently been heated much hotter than the other eruptive rocks; that is to say, it has been superfused, for the melting point of basalt is lower than that of many other rocks. That it was exceedingly hot can be seen from the manner in which it spread into thin sheets. Fig. 14 illustrates a rough columnar structure as exhibited in the basalt rock on the shore of Lake Superior. Sometimes, the columns are more perfect prisms than those shown, and they may be regular hexagons. The columns are often of considerable length (varying from a few feet to 50 or 100 feet), and varying in diameter from a few inches to a foot or more. When a structure of this nature has been eroded by the sea, by the action of a river, or by atmospheric agencies, it often results in very bold and picturesque cliffs. The Palisades on the Hudson, some of the cliffs at Mt. Holyoke in Massachusetts, and on Lake Superior, and a number of places in the Rocky Mountains furnish examples of this structure. In Great Britain, the Giant's Causeway on the coast of Ireland, and Fingal's Cave on the island of Staffa, on the

FIG. 14

FIG. 15

west coast of Scotland, may be mentioned as especially noted localities for this form of basalt structure.

16. Basalt Horizontal Structure.—The direction of the columns is usually at right angles to the cooling surfaces; hence, in horizontal sheets the columns would be vertical, while in a dike the columns would be formed horizontally, and if the dike was subsequently exposed by the erosion of the adjoining strata, it would stand out much like a pile of cordwood. Fig. 15 is an illustration of such a dike.

There is little doubt that this columnar structure was produced by contraction while the rock was cooling, but it is not known why the structure should be more regular in basalt than in any other known substance.

17. Volcanic Conglomerate and Breccia.—If a stream of fused rock from a crater or fissure ran down the bed of a stream, it would gather up pebbles in its course, and, after solidification, would form a **conglomerate,** which differs from the ordinary conglomerate in that the cement is of igneous material. In the same manner, a stream of igneous material flowing over a surface with broken rock or rubble would take up the material and form a **breccia;** or the front and upper surface of the lava may become cooled, and subsequently be crushed and broken by a flow of liquid lava. This broken lava would become mixed with the molten lava and thus form a breccia. The disintegration of volcanic rock and the transportation and depositing of the pieces would give rise to an aqueous cemented conglomerate or breccia composed of volcanic material, and it is often difficult to distinguish such a deposit from the true volcanic breccia. These breccias and conglomerates graduate into volcanic **tufas,** which consist of the materials thrown out by volcanoes of the explosive type, and which have flowed down the surface of the mountain or valley as volcanic mud. A short time ago a steamship in the Pacific Ocean passed through a field of pulverized pumice stone, the area of which was unknown, but whose length was estimated at 500 miles. It is supposed that eruptions take place beneath the oceans, and the lava coming in contact with the water becomes granulated and floats. This lava will eventually sink and possibly be the foundation of a new rock formation.

ANALYSIS OF FOLDS

18. Deformation.—The zone of fracture being near the surface, the rocks are deformed chiefly by fracture. They are adjusted to their new positions mainly by rupture and differential movements between the separated parts. The so-called folds in the zone of fracture are chiefly the result of numerous parallel fractures across the strata with slight displacements at the joints, giving each block a slightly different position from the previous one, and thus as a whole making a fold. Occasionally, true folding may be detected, but as a usual thing close examination will disclose the fact that slippage has occurred, and wherever such action has occurred between rocks of different characters, or sometimes the same character, polished surfaces termed **slickensides** are discernible.

The zone of fracture and flowage naturally gives fractured folding and true folding. The deformation in this case is by granulation or recrystallization, no openings being produced except those of microscopic size. When rocks have been deformed in the zone of flowage, if any folding takes place it will be true folding. During the time in which the rock migrates toward the surface as the rocks above are eroded, deformation by fracture may occur from earth movements, which will in some cases obliterate true folding.

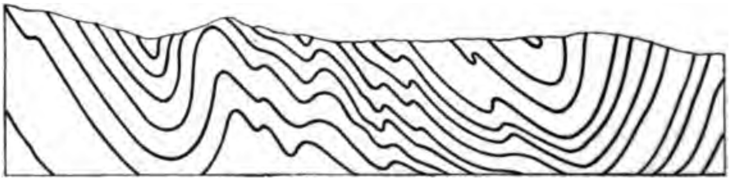


FIG. 16

19. Complex Folds.—Folds as they occur in nature are complex flexures in three dimensions. Folds are due to thrust, which may come from one or two sides; consequently, if one thrust is greater than another, folds may occur with almost any conceivable bend or series of bends, as in Fig. 16.

FIG. 17

Thrust will give the lateral dimensions to folds; but when a fold is followed longitudinally in the third dimension, it changes continuously in size and shape. A fold of the greatest magnitude may be followed longitudinally until it dies out, as shown at *a*, Fig. 17. If there are sufficiently strong thrusts at right angles, two sets of folds are produced

FIG. 18

that intersect each other. The more important folds corresponding to the greater thrust are **longitudinal folds,** as at *b*, Fig. 18; while those corresponding to the lesser thrust are the **transverse folds,** as at *a*. As complex folds occur in nature the compression is not close in both directions; and when the major folds are close, as compared with the minor folds, the complex folds have great length compared with the breadth, and are canoe-shaped, or **lenticular.** These folds are particularly noticeable in the Pennsylvania anthracite regions, where they are termed *coal basins.* In proportion as the major and minor thrusts approach each other in power, the folds become shorter and broader, sometimes forming smaller basins. The effect of synclinal folding is shown in Fig. 17, where basins *c* are formed between hills. The effect of anticlinal folding is shown at *c*, Fig. 18.

20. Cleavage.—The tendency of certain rocks to rupture along certain planes, or, as it is termed, **to cleave,** seems to be due to several causes, of which probably the chief is that the small particles of rock are flat parallel to that direction. Cleavage may be in one, two, or three planes, in the same rock, or may be parallel to a line rather than to a plane. The cause of cleavage is compression, and cleavage develops in planes normal to the greatest shortening of the rock mass. This comes about through flattening of the original particles, either through the recrystallization or in other ways, and by the rotation of original or secondary grains to a parallel position. This flatness facilitates rupture along cleavage planes, and in rocks whose particles overlap it prevents smooth fracture in other directions. In the case of sedimentary rocks, cleavage occurs along lines of bedding; in metamorphic rocks, along lines of pressure and bedding; in aqueo-igneous rocks, along lines of flowage—that is, parallel to flowage.

The theory advanced to account for cleavage is that the structure has been produced by the action of great compressive forces, causing a shortening of very small particles in one direction and an elongation in another perpendicular to the direction of shortening. A very close, smooth, slaty cleavage would develop in very fine-grained rock only, such, for example, as slate and shale. This idea was graphically illustrated in *Geology*, Part 1.

21. Clues to Bedding.—Besides the structural difficulties arising from complex folding and metamorphism, there occurs now and then false bedding. Whenever bedding is obscured by cleavage, the bedding should be traced out by the continuity of some sedimentary grains. When the sediment is homogeneous, however, this becomes very difficult. On a close inspection, lines of holes will be seen on the transverse joint faces, as shown in Fig. 19 (*a*), (*b*), and (*c*). Weathering attacks these planes more readily, but at irregular intervals, and the effect is as if small limestone pebbles had been dissolved out.

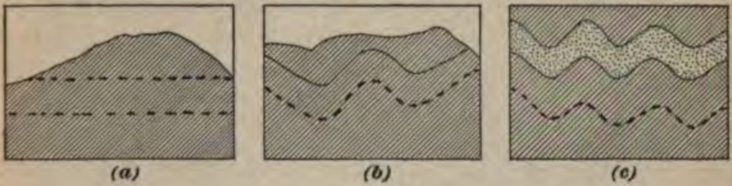

(*a*) (*b*) (*c*)

FIG. 19

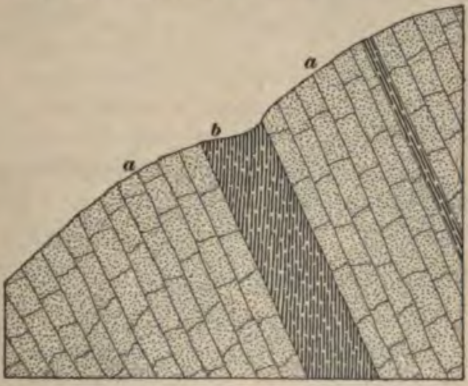


FIG. 20

22. Differential Cleavage.—Where there is a bed of shale or slate enclosed in a coarse-grained rock, cleavage is likely to be confined to the former—at least it is more pronounced in beds of shale. Where the adjoining strata are not folded, such localities may afford a clue to the relation between the dip of the cleavage and the direction of the pressure that produced it. Fig. 20 is the diagram of a ledge of grit *a* and slate *b*. The vertical cleavage in the slate does not extend into the grit. If this slate cleavage originated at the time of folding, the force that produced the fold would seem to have been nearly at right angles to the cleavage; on the other hand, if the cleavage was produced while the beds were horizontal, the direction of the pressure would be about 45° to the dip of the cleavage. That the angle of the dip of the cleavage is determined in part by the physical character of the rocks is shown in Fig. 21, where the different rock materials—that is, the slate *a* and the limestone *b*—show different cleavages in opposite directions, although both must have been subjected to the same pressure.

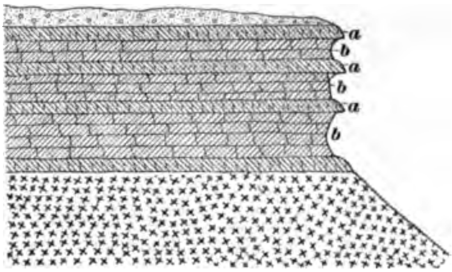


FIG. 21

STRUCTURE COMMON TO ALL ROCKS

23. Common Peculiarities.—Thus far a brief description only of the different classes of rocks has been given. There are, however, certain peculiarities—such as joints, fissures, and veins—that occur only in the zone of fracture, and are common to all rocks. These will now be taken up in order.

24. Joints.—All rocks, whether stratified or igneous, are divided by cracks or division planes, which run in three directions and separate the material into irregular prismatic

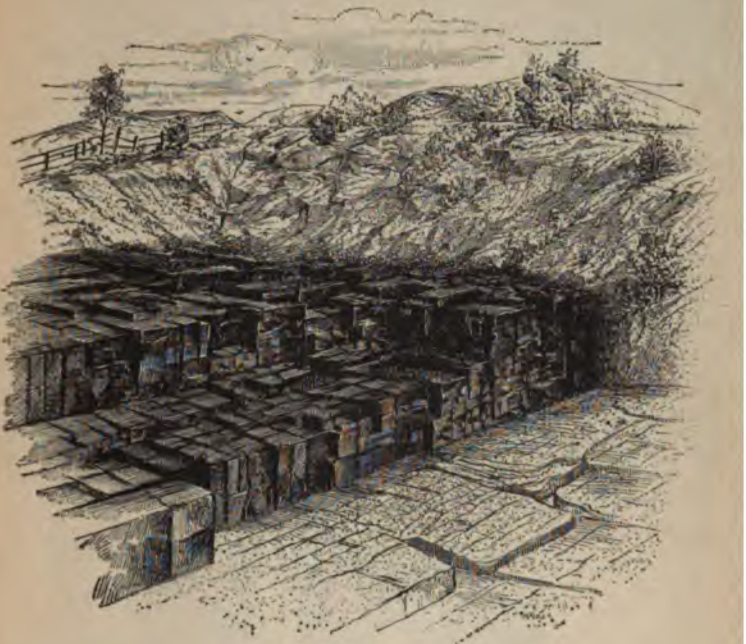


FIG. 22

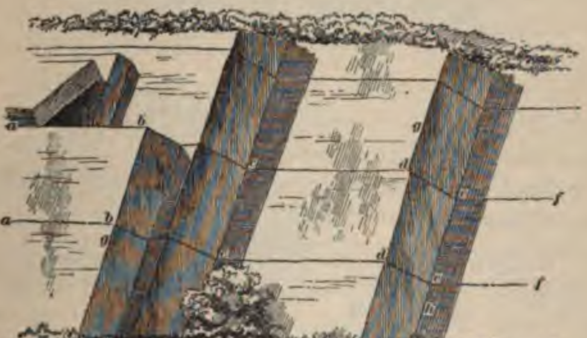


FIG. 23

blocks of various shapes and sizes, as shown in Fig. 22. These divisions are called **cracks,** or **joints.** Fig. 23 illustrates the bedding planes *a b*, *c d*, and *d f*, and the joints *b b*, *c c*, and *e e*, in a mass of rock, as well as the secondary or slaty cleavage *g h*, which has been induced by pressure. In stratified rocks, the planes between the bedding constitute one of the series of joints. In igneous rocks, all division planes partake of the nature of joints. In sandstone, the blocks are large and irregularly prismatic. In shale, they are in long parallel divisions. In slates, they are small and confused plates, though sometimes slates partake of the same nature as shale. In limestone, the divisions are large, regular, and frequently cubical. In basalt, they are regular, and the joints frequently give the material a columnar structure as previously shown. In granite, the joints are large, and frequently divide the material into rough right-angular prisms. On account of these divisional planes, and the way in which they divide the rock, perpendicular or rocky cliffs often present the appearance of huge masonry walls laid up without cement, as shown in Fig. 24.

FIG. 24

25. Origin of Joints.—The various causes that have been assigned for joints may be classified under tension and compression. When rocks are folded and not too deeply buried, the convex halves of the anticlines and synclines are subjected to simple tension. If the tension goes beyond the limit of elasticity, radial cracks will be formed having the strike parallel with the longitudinal axis of the fold. Joints kind are at right angles to the tensile force. Fig. 25 this class of joints as they occur in some rocks. there are two sets of stresses at right angles to each there will probably be two intersecting sets of joints, ich the set parallel to the more conspicuous folds would led *strike joints*, while the set would be called *dip* It has been suggested me geologists that, when rata are in a state of tenan earthquake shock may the jointing. Joints might been produced by comon, which might also have 1 shearing. It is well known that the peculiar columnar g of trap rocks is due to the contraction and consequent n caused by cooling; also, that the mud-cracks of sediry rocks are due to the contraction and consequent n caused by drying out. However, it is not probable ese causes were more than locally important.

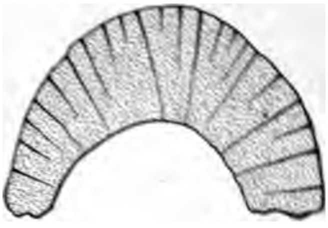


FIG. 25

FAULTS

Normal Faults.—Faults differ from other rock res in that there is dislocation along the fractures, and re far more extensive. There are two classes of faults, tension and compression: the first form in the normal planes and are known as **normal faults**; the second form in the shearing planes and are known as **reverse faults.** In the case of normal faults there has been a fissure d, and the strata on one side or the other have slipped wards by gravity. The reverse fault is due to tangential t, which causes strata on one side of the fissure to pass

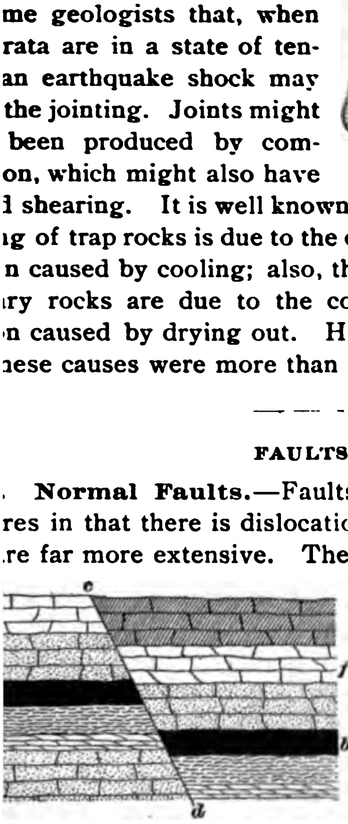


FIG. 26

over those on the other side, or vice versa. In Fig. 26 is shown a normal or gravity fault, in which the hanging-wall side has slipped downwards assuming that the foot-wall side has remained stationary. The line *c d* is the fissure, or slip, line. Originally, the beds *f* and *b* were at the same level as *e* and *a*, but owing to some disturbing influences they have moved downwards; this is what is known by the coal miner as the **down throw.** Assume now that Fig. 27 is a plane of nearly perpendicular strata cut by a fault fissure *c d*; in this case, there will have been a movement downwards and sidewise, and what is known by the metal miner as the **right-hand** and **left-hand heave** occurs.

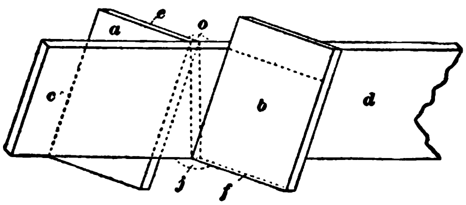


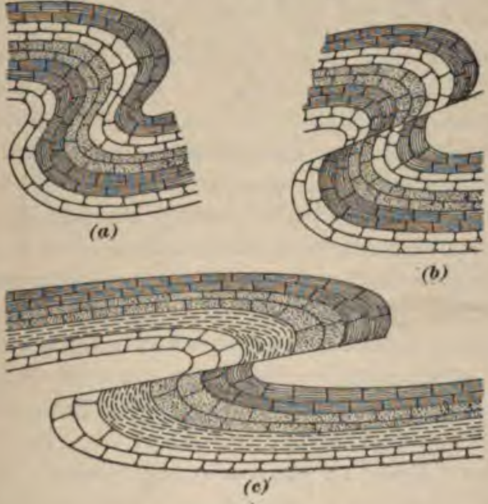
Fig. 27

In the case of the coal miner, to determine in which direction movement has occurred, if the miner meets the fault in the roof side of the bed first, as at *a*, the lost bed is below him, while, on the other hand, if he meets the fault in the floor side first, as in *b*, the lost bed is above him. This may be stated as follows: *If the fault slip pitches downwards away from the miner, the lost bed is below; if it pitches downwards toward the miner, the lost bed is above.*

In the case of the metal miner, the heave will be determined according to the direction in which the miner approaches the fault. If he approaches it from *b*, he will meet the fault line *c d* first on his right-hand side and later on his left-hand side, so that the angle that the fault makes with the bed is greater on his left-hand side and he has a left-handed heave. The same reasoning will apply when working from *a*, to the fault line *c d*, and there will also have been a left-handed heave. In general, therefore, *the lost part of a normal fault is found by following the fault in the direction of the greater angle, made by the strata and the fissure intersecting.*

27. Reverse Faults.—In the case of the normal and reverse faults, gravity enters into the discussion on the principle of the inclined plane. According to LeConte, when the hade of the fault plane (that is, the inclination of the line *c d*, Fig. 26, from a vertical position) is greater than 45°, the forces of gravity and tangential thrust are equal, and the fault is normal because gravity controls its movement. On the other hand, should the hade be less than 45°, tangential thrust is the predominate force, and the fault is a reverse one, as

FIG. 28



(a)

(b)

(c)

FIG. 29

shown in Fig. 28. If the hade is very steep, gravity may be able to overcome the tangential thrust, even if the latter is several times as great as the former. In cases, it is probable that tangential thrust even much weaker than gravity may overcome and produce a reverse fault. In Fig. 29 (*a*), the strata are shown before the fault line has occurred; while in Fig. 29 (*b*), the strata are shown after the fault has occurred. It may be assumed here that some shock has caused the line of faulting. Finally, Fig. 29 (*c*) shows a further faulting, due to the thrust sliding the strata along the hade of the fault. The reverse fault shown in Fig. 29 (*b*) is an **overlap fold**, which afterwards received some shock, and for that reason could be termed an **overlap fault**. It is to be noted that the rule for greater angle does not apply in this case, and that there is no rule to follow except what the rock formation on the other side of the fault teaches. It is necessary, for a true solution of the fault problem, to have a thorough knowledge of the strata above and below the fault before deciding on which angle to begin work in order to find the lost bed. Fortunately, normal faults are more frequent than reverse.

28. Tension Faults.—Since faults might occur from tension as well as from compression, they too will form in normal planes, and will be steeply inclined. It is such faults as these that the metal miner more particularly encounters, and as tension has no thrust in connection with it gravity has full effect and there is a downward slide of the strata, possibly with some side motion, making it necessary to drive either to the right or to the left in order to find the lost vein. Fig. 27 illustrates a vein that has been so cut by a fault plane *c d* as to be separated into two portions *a* and *b*. The sections *e* and *f* were on the same plane before faulting occurred. It will be noticed that *f* has descended perpendicularly with reference to *e*, as the dotted lines indicate; and, since every other plane in the faulted part *b* has done the same, a left-handed heave has occurred. In driving on the vein *a* toward the fault, the greater angle *o* is to the left; while driving on the vein *b* toward the fault, the greater angle *j* is to the left.

MINERAL VEINS

29. Definition.—Fissures have different depths and widths. Usually, they are narrow, although long, and are confined to the zone of fracture. In case a fissure is long, it may generally be taken as having considerable depth. When fissures are filled with minerals that have been deposited from solutions, they are called **veins.** In many fissures, metallic minerals have been concentrated by nature, in which case they are termed **metalliferous veins.** If the concentration has been such that the metallic minerals are sufficiently abundant to make it worth while excavating them, the vein becomes an **ore deposit.** Ore deposits are not all confined to veins, but occur as regular replacements in both igneous and sedimentary rocks. The great iron-ore deposits of the Lake Superior region are concentrates in regular sedimentary formations, and the famous copper deposits of Keweenaw Point are replacements, in both igneous and sedimentary rocks, that are in no sense veins.

30. Fissure Veins.—**Fissure veins** cannot extend below the zone of fracture, in fact, every vein is a fissure vein, although in all probability long and wide veins extend to a greater depth than short or narrow veins. This has been determined by excavating tunnels in mountains to cross-cut veins known to exist at the surface. In some instances, veins have been cut; in others, they have not; again, veins not found at the surface have been cut by the tunnel. Experience has developed the fact that cross-cut tunnels are only sure of cutting veins that outcrop at the surface when the vein has been sunk on to a depth equal to that of the tunnel below the surface.

31. Theory of Mineral Deposits.—There have been endless discussions as to whether ore deposits are produced by descending, lateral, or ascending mineral waters. A broad view of the subject shows that when the ideas are combined they furnish a more satisfactory theory than any one alone. In the first stage of concentration of many deposits, the waters are descending. During the descent, they are widely dispersed in small passages, have an exceedingly large surface of contact with rocks, come under conditions of increasing temperature and pressure, and move slowly downwards. All these conditions favor solution to the point of saturation. There is no doubt a lateral movement of the waters that sooner or later reaches the trunk channels or fissures, and this lateral movement is greater near water level, whence it steadily decreases to the bottom of the zone of fracture.

As fissures die out with depth, all waters that enter them must do so from the side or top and not from the bottom. While the amount of water laterally entering a fissure steadily decreases from near its top to the bottom, the amount of mineral material per unit volume in all probability steadily increases; hence, if deep rocks can furnish metalliferous materials, such waters will be heavily charged.

32. Location of Ore Deposits.—Ascending waters usually follow the larger rock fissures, so that ore deposits occur mainly in such openings. Water enters this channel laterally from possibly very many levels; as it does so, it begins also to ascend. The movement of water in these fissures is slow and increases from above; and, since slow movement of water is favorable to deposition, it is possible that, at moderate depth, and especially in the deeper parts of a channel from which the flow at the surface is rapid, conditions are those of slow movement and rapid precipitation of mineral deposits.

As the water passes upwards, each stream issuing into the fissure differs in its solutions and the character of the wall rock may vary from place to place; pressure and temperature are also lessening; and, as all these conditions are favorable to precipitation, it may be stated with considerable safety that many ores are precipitated by ascending waters in fissures. Van Hise considers the Lake Superior iron-ore deposits to have been formed by downward moving waters in trunk channels formed by fracturing the rocks, as these channels occur for the most part in synclinal troughs in the iron formation or in troughs formed by the intersection of a dike with a foot-wall.

33. Variation in the Richness of Ore Deposits. It is well known that an ore deposit varies in richness in an exceedingly irregular manner. At a place in a fissure where a mineral is found abundantly, the explanation is that, at or near that place, there entered a stream that either carried the precipitated metal or carried an agent capable of precipitating the metal. For instance, it is believed that, where the great bonanza of the Comstock lode in Nevada was found, there or near there solutions rich in gold and silver entered that met a solution capable of precipitating these metals.

34. Ore Shoots.—**Ore shoots, or chimneys,** of ores of exceptional richness are some of the vein phenomena. Their direction is sometimes parallel with the dip of the strata; at other times its underlay is to the right or to the left of it. In some instances, chimneys are supposed to be the necks of extinct volcanoes; in other instances, they are cross-fractures where two fissures meet, each carrying metalliferous materials or solutions capable of precipitating the metalliferous metals at their junction. Again, they are probably the larger channels through which the solutions have ascended from greater depths or wider areas. It is certain that, where two fissures cross each other, each will have different ores that may change completely after crossing the junction. Jenney says that lead-zinc deposits are large where fissures cross. The rich Mapimi silver-lead deposit in Mexico is at the junction of several veins. Spurr states that in the Aspen, Colorado, silver district, the rich ore bodies are generally found at the intersection of two faults. Rickard states that at the Enterprise mine, Rico, Colorado, the cross-veins are barren, but that rich ore bodies overlie them in the contact zone. Penrose states that in Cripple Creek, Colorado, many of the rich ore bodies occur at cross-fissures.

35. Contact Deposits.—Many ore deposits occur where two different rocks come in contact—not always in the contact but in one of the near-by rocks. A solid when placed in contact with a liquid may precipitate some compound held in solution, part of the solid going into solution at the same time. The wall rock may furnish the precipitating solutions, or it may furnish the mineral to be precipitated, and thus have influence on the deposit. Where the wall rock is easily soluble, enlargements of the openings occur, furnishing places for the deposition of the metalliferous material; or again changes, such as metasomatism, may produce with the acids of solutions metal deposits termed **veins of segregation.** As illustrations of this action may be cited the tin ores of Cornwall, England; the association of lead, silver, and zinc ores with limestone; and of the copper carbonates with limestone.

In case a circulating water was acid the limestone would neutralize it, and the precipitation of a sulphide might be the consequence; or, as in Missouri, the wall rock might furnish the lead. Another instance of precipitation resulting from the influence of wall rock is the well-known occurrence of metallic copper about grains of magnetite, and in the openings of the sandstone, conglomerate, and amygdaloid of Keweenaw Point, Lake Superior. Where the copper is about grains of magnetite, it seems perfectly clear that the iron oxide in the magnetite was the reducing agent that precipitated the metallic copper. The metallic copper between the particles of sandstone was doubtless precipitated by ferrous solutions furnished by the wall rocks, which in many cases are basic volcanics. The relations due to country rock are more likely to be effective when that rock is sufficiently porous to permit solutions to permeate it. Electric calamine in the Clark mine, near Allisonia, Virginia, has evidently been precipitated from zinc solutions by limonite; while the smithsonite at the Bertha mine about 10 miles away has been precipitated on the limestone wall rocks in a somewhat similar manner. Frequently, both silicate and the carbonate of zinc are found in the same mine.

36. Size of Veins.—In Fig. 30 is shown a mountain scarred with veins that are termed **fissure veins,** because of their great length and apparent depth. They may be wide, like dikes, and are then in Australian parlance termed **reefs** or **ledges.** In South Africa on the Transvaal, the conglomerate formation containing the gold is termed a **banket reef.** It is known to reach a depth of 5,000 feet, while the copper vein in Lake Superior is more than a mile deep.

FIG. 30

Veins are exceedingly irregular in form and width, due to the movements that have occurred after fracture. For example, assume that *a b*, in Fig. 31 (*a*), is a rock fissure, and that the side *c* has moved downwards and come to rest in some such position as that shown in Fig. 31 (*b*), forming alternate wide and narrow spaces that become filled with vein material. Where the vein becomes small as at *e f*, it is said to **pinch.** There is a limit to the length of all fissures, and where they gradually become lost by merging into the country rock the vein is said to **die out.** Veins, like fault fissures, may be a few feet long or extend several miles on the surface. Besides the lenticular form shown in Fig. 31 (*b*), which is quite common, there is a side dip to veins that is, on an examination and reflection of the fault illustrated in Fig. 27, seen to be quite natural, for downward movement infers that there must be some lateral movement, which will give the mass the form of shoots shown in Fig. 32, with a dip *a* instead of a dip *b*, or the regular dip of the vein. The strike *c d* is not changed, and the dip *a* also conforms to the dip *b*, but has a side inclination or hade. The lenticular form of ore bodies, whether in veins or in beds, has some significance, although the cause of these forms has not been fully worked out. As a general statement, the quantity of metalliferous minerals in a vein is uniform, so that in case the vein widens the ore becomes leaner, or as it pinches the ore becomes richer. Again, as a general statement, the ore becomes richer in localities that are in some instances quite uniform distances apart both on the strike and on the dip. These may be termed **pockets.** Frequently, the metalliferous portions of a vein will not be continuous, but will jump from the hanging to the foot-wall, or again be in the center of the deposit, or still again be separated into one or more **stringers.** Sometimes, these stringers are only 1 inch wide, but have all the values concentrated in them.

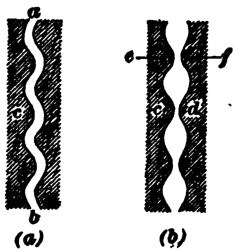


FIG. 31

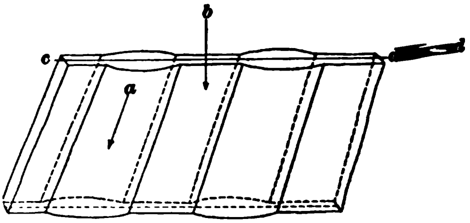


FIG. 32

37. Horses, Gangue, and Gouge.—When rock is faulted, it does not always move in perfectly straight planes and frequently the break is irregular in the direction of both the hade and the strike. Sometimes, the fissures are filled with numberless pebbles, and then the conglomerate is formed by some cementing material, as in the case of the Transvaal banket, and the Calumet and Hecla amygdaloid structure. The Bassic mine at Silver Cliff and the Bull Domingo at Rosita, Colorado, are chimneys containing rounded boulders covered with layers of lead and zinc minerals carrying gold. When masses of country rock have fallen into the fissure, or the vein has surrounded some portion of the wall rock, as shown in Fig. 33, it is termed a **horse.**


FIG. 33

Between the walls of a vein there is, besides metalliferous minerals, deposits of barren mineral termed **gangue.** The most of a vein is composed of gangue, which as a usual thing is barren of valuable mineral. The chief gangue minerals are feldspar, fluorspar, calcspar, and quartz, with now and then barium sulphate or carbonate with lead ores and wolfram. In case there has been a movement between the vein and the vein walls, another slight fissure will be formed, due to abrasion. This will be filled with material that has been pulverized by the movement, or by other material that has seeped into the crack from the surface. Such filling is usually soft and clayey, and to it has been given the names **gouge** and **selvage.** Sometimes, it may contain valuable minerals, but more often it does not. Frequently, slickensides are noticeable on the wall back of the gouge or on the vein mineral, thus giving positive proof of movement having occurred.

38. Contact Deposits.—Deposits of ore frequently occur at the contact between igneous rocks and the adjoining sedimentary rocks, or between joints or cracks of country rock, especially where two different rocks meet. Fig. 34

illustrates a number of these cases. In the lower part of the figure, the original country rock was gneiss. This was cut by a large porphyry dike, and subsequently contact veins formed at *t m* and *n o* on each side of the dike. The fissure *p r* was filled as a regular or true fissure vein. Subsequently, the surface was eroded and the deposit of quartzite *h i j k* laid down, probably as a sandstone. Then, on top of this the limestone was deposited; subsequently, the region was again disturbed, and the intrusive porphyry dike *c* forced into limestone. After this, contact deposits formed along both sides of the intrusive sheet of porphyry, as at *a d* and *b d*. Farther down in the limestone, the bedding plane *e f* became an ore bed, and the vertical joints through the limestone became mineralized. The contact *h i* between the quartzite and the limestone also became a contact deposit, the ore extending slightly into the joints of the quartzite; but no contact ore body was formed along the line *j k* between the quartzite and the gneiss. It is evident that the porphyry played an important part in the formation of these ore bodies in the limestone.

FIG. 34

FIG. 35

Fig. 35 illustrates another case in which a dike and an overflow of porphyry have been instrumental in forming contact veins between the porphyry and the limestone.

39. Surface Changes.—Mineral veins seldom show on the outcrop their original condition, as their surface exposures have been changed by the influence of atmospheric agencies, which render their appearance along the outcrop quite different from that of the same vein at a greater depth. A practical knowledge of these changes is of great importance to any one searching for minerals of value, but the changes are extremely various, differing not only according to the metallic contents of the vein, but also according to the gangue material and to the country rock; therefore, a knowledge of the conditions in any given case can only be obtained by observation in that locality. It may be well to take up the general changes that occur in a few of the most prominent minerals as examples of this class of atmospheric effects.

40. Copper Veins.—Most copper minerals exist as some form of sulphide, and frequently as a double sulphide with iron, $CuFeS_2$. On the outcrop of such copper deposits, the vein usually contains little or no copper, but consists of altered gangue materials, among which are scattered masses of brownish hydrated ferric oxide usually in a light spongy condition. This peculiar form of iron oxide is characteristic of the outcrop of copper veins, and is called **gossan.** Below the gossan there occurs a rich deposit of copper minerals composed of native copper, red and black oxide of copper, green and blue carbonates of copper, etc.

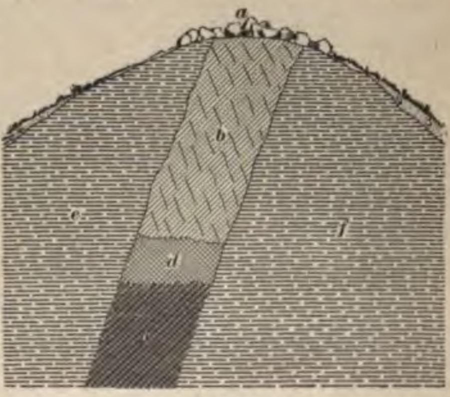


FIG. 36

Below this, at water level, the vein will be found in its unaltered condition. Sometimes, the rich deposit is located on one wall more than on the other; at other times, it extends entirely across the vein at or near the drainage level of surface waters. These conditions are illustrated in Fig. 36. The outcrop of the vein is at *a*; *b* is the gossan; *d* represents the rich deposit of secondary mineral; *c* is the unaltered portion of the vein; *e* is the hanging wall; while *f* is the foot-wall. The portion of the vein *b* undoubtedly contained originally the mineral in practically the same condition in which it is found in the portion *c*; but the action of the surface water has leached out the copper and redeposited it at *d*. The deposit *d* may represent the copper from not only the portion of the vein *b*, but also from a greater portion, for probably the process of erosion has gone on simultaneously with the process of leaching, and hence a considerable portion of the leached ore may have been removed by erosion. Sometimes, where gold or silver ores occur associated with the copper ores, the gold may remain in the gossan, together with a portion of the silver, so that the outcrop of the vein appears to be a gold or silver ore rather than a copper ore. This was especially true of most of the mines at Butte, Montana. The rich deposit of secondary mineral may occur quite near the surface or may be several hundred feet below the surface, depending largely on the topography of the country and on the depth at which water circulates. As sulphate of copper is soluble in water, considerable copper in this form has in all probability passed off from the deposit during the time the gossan has been forming, as well as after it had formed.

41. Lead Deposits.—The natural form in which lead occurs seems to be that of sulphide of lead, or **galena**, but along the outcrop of the veins it is commonly found as a **carbonate**. The explanation seems to be that the galena, PbS, is decomposed by atmospheric agencies and becomes a sulphate, $PbSO_4$, and then the sulphate, by reaction with carbonate of lime derived from the wall rocks, or from calcspar in the gangue material, becomes carbonate of lead. In proof of this, it is stated that the galena thrown out from lead mines in England along with the rubbish of limestone, has all in the course of time been changed into carbonate. Moreover, it is common to find in lead deposits masses of sulphide changed on the outside to carbonate. Near Knoxville, Tennessee, carbonate of lead is found that has been deposited from solutions of lead derived from zinc-lead deposits near by.

42. Gold Deposits.—Gold is found associated largely with pyrite or other metallic sulphides. Gold always seems to be in a metallic state, even when contained within the crystals of the sulphides. At the outcrop of a vein the sulphides become oxidized and converted into sulphates, which are leached out by the circulating waters, leaving in the case of pyrite some ferric oxide and free gold. On this account, the gold in the outcrop of most veins is in a free condition; while at greater depths a large portion of the gold may be incased in the sulphides. The quartz of the vein that originally contained the sulphide is left in a granular or porous condition by the leaching out of the sulphide, and it is frequently colored red by the remaining oxide of iron. As in the case of the ores previously described, the effect of these surface agencies may extend to a depth of several hundred feet, but below that point the gold is usually found associated with the sulphides. In case the ore at the outcrop of a vein is not oxidized, the ore is not considered as extending downwards any considerable depth, since veins usually afford some opportunity for surface waters to percolate through them, and the fact that they do not, indicates that the vein matter is tight and that naturally the vein is not deep. Gold crystals are found which would indicate that gold has been deposited from solutions. The Crystal mine, near Douglas Island, Alaska, contained many such crystals and possibly contains some at the present time.

43. Richness With Depth.—Many assertions have been made in regard to the effect of depth on the richness of ore deposits. Some claim that fissure veins become richer with depth, while others hold to the opposite theory. There seems to be no particular ground or reason for either belief, and so far as is now known no definite law can be stated concerning this point. Some veins have been explored to a depth of a mile, and have not been found to change to any considerable degree in value, while others may have a number of alternate changes, first becoming richer and then poorer. As previously stated, the walls enclosing a deposit may possibly have some effect on the value of the vein; for instance, it is not uncommon to find a vein containing good ore while passing through limestone, but on following it into the underlying granite it may be pinched out and become barren or almost barren, or it may carry some other mineral than the one that formed the principal value of the ore in the limestone. From this it will be seen that the statement so often met in the prospectuses of different mining companies that fissure veins always become richer as they gain in depth has no foundation whatever.

In many cases, the proportion of iron sulphide becomes greater as the depth of a vein below water level increases, and there is generally a lessening proportion of other metals. While it is known that iron is the most abundant mineral, this fact does not explain the relative increase of iron sulphide and the decrease of more valuable sulphides. To do this, for there are many cases where sulphide deposits continue to a great depth without diminution in richness, an oxidized belt must be assumed to have formed before preglacial or, in some instances, before Permian times; if this is the case, the belt has been swept away, and sufficient time has not since elapsed for another to form. The ore deposits now worked have apparently remained practically unchanged since the time of their first concentration. In this fact there is an explanation of the great richness of some deposits to extraordinary depths.

44. **Placer Deposits.**—During the process of erosion and disintegration of rock, it has been observed that the material eroded undergoes a sorting action while being

transported and deposited by water. During this sorting action the heavier particles settle first. Certain heavy minerals or metals are unaffected by the atmosphere, and hence would naturally collect as deposits near the places from which they were eroded. Among this class of material may be mentioned gold, platinum, tinstone, or oxide of tin, monazite sands, and some precious stones. Those deposits that contain metallic gold are termed **placer deposits.** It is probable that many of the placer deposits contain practically all the gold from very large areas of strata that have been eroded, the greater part of which has been washed to the sea, leaving the gold and other heavy minerals deposited comparatively near the parent rocks from which they came.

45. Drift Gravel Beds of California.—Some evidences in regard to the formation of placer deposits can be obtained from a study of the gold-gravel beds of California. These deposits are in ancient river beds, which have subsequently been covered with lava flows. Fig. 37 illustrates such a condition. The original river bed was in the hollow *a*, *a*, and its gravel deposit was subsequently covered by an overflow of lava *b*; *c*, *c* are the present river beds. The lava in these overflows is frequently underlaid by a deposit of volcanic scoriæ or mud, and the lava itself is not of dense character. The gravel in the ancient river deposits usually contains more or less driftwood and other organic matter. Waters percolating through the lava beds have become alkaline, and have taken silica and various sulphides in solution, which they have subsequently deposited in the old river channel. Some of the organic material has been **petrified,** that is, turned into stone. Iron pyrites have been deposited in some parts of the gravel formation, and these pyritic

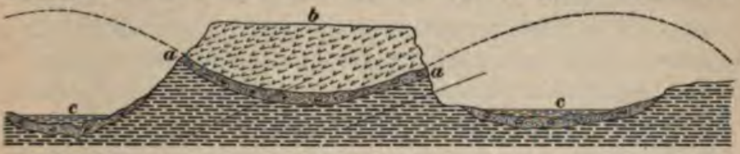


FIG. 37

crystals frequently carry gold very similar to that found in the ordinary gold vein. But probably the strangest part of the deposit consists in the growth of gold nuggets. The placer gravel undoubtedly originally contained small gold nuggets, and in many cases they seem to have been enlarged by the subsequent deposits of gold on the outside, until they have grown to masses that in some cases weigh several pounds. Just as the dentist with a slight blow welds gold, so it is probable that the growth of gold is due to a welding process, and not to depositions of gold from solutions.

46. Lead and Zinc Deposits.—Sulphide of lead and sulphide of zinc frequently occur together in dolomite rocks. By the action of circulating waters it sometimes occurs that deposits of zinc silicate and carbonate are formed near by. Galena is also converted in the same manner into carbonate of lead, but not on such an extensive scale. Lead-silver deposits are not uncommon, but only few mines in the United States are worked for lead alone. At Allisonia, Virginia, there are pillars of zinc silicate rising in beds of limonite, while near by there are beds of carbonate of zinc in limestone pockets. The dolomite from which these ores come still carries quantities of **black-jack**, or zinc sulphide, and galena. Large zinc-lead deposits occur in the Appalachian Mountains, but up to the present time there has been no process discovered for separating lead and zinc that has proved commercially profitable. Zinc and lead do not alloy, and considerable difficulty is experienced in their separation when reduced to a metallic form.

HISTORICAL GEOLOGY

FOSSILS

47. Definition.—While historical geology gives the stages in the formation of the outer portion of the lithosphere, it does not do so by marked lines, as has been supposed. There are instances in which the age of a rock can be easily determined, but there are others where it cannot.

In tracing and locating the age of rocks, the geologist is guided to some extent by **fossils**, or the remains of ancient life that are found in the rocks. All plant life has a beginning, a time of full blooming, and finally a gradual fading away and ending. Animal life does not differ in this respect, and nature always allows some species to begin, then become abundant, and finally pass away.

As a usual thing, the characteristic fossil of any age begins in a preceding age to that in which it is found most developed, and from that height of predominance it gradually decreases until it becomes extinct. The Aztec, buffalo, auk, wild pigeon, lobster, and Indian are modern examples of organic life that are giving way to advancement and stronger organism.

48. Condition of Fossils and Their Use.—Where the fossil consists of all or a part of an organism, it may be presented in any one of a number of forms. In the older rocks the material of the bones or the tissue of the object is rarely ever present, the fossil consisting of a cast or impression of the object, or the object may have been replaced, particle by particle, with solid matter in such a manner as to form a perfect model of the original. This latter class of fossils are said to have been **petrified**; one of the best examples of this class is petrified wood. Fossils are useful in determining the relative age of the rocks, and it is by this means that the rocks of different countries can be compared. When life first appeared on the earth, it was of the simplest form, and the organisms on the different continents differed but little; but in each succeeding geological period greater differences appeared between the different continents, until the conditions existing at the present time came into being.

49. Fossils in Rocks.—Some rocks show little or no traces of organic life; these are the aqueo-igneous and igneous formations, whose heat and chemical reactions would naturally destroy the original appearance of organic life. Volcanic rocks are another example. Finally there are sedimentary rocks whose chemical composition is such that organic remains would be obliterated. There are some earlier rocks that show a very low order of organism, but fossil life is most distinctly marked in rocks that are sedimentary and have a composition that has not undergone decided changes.

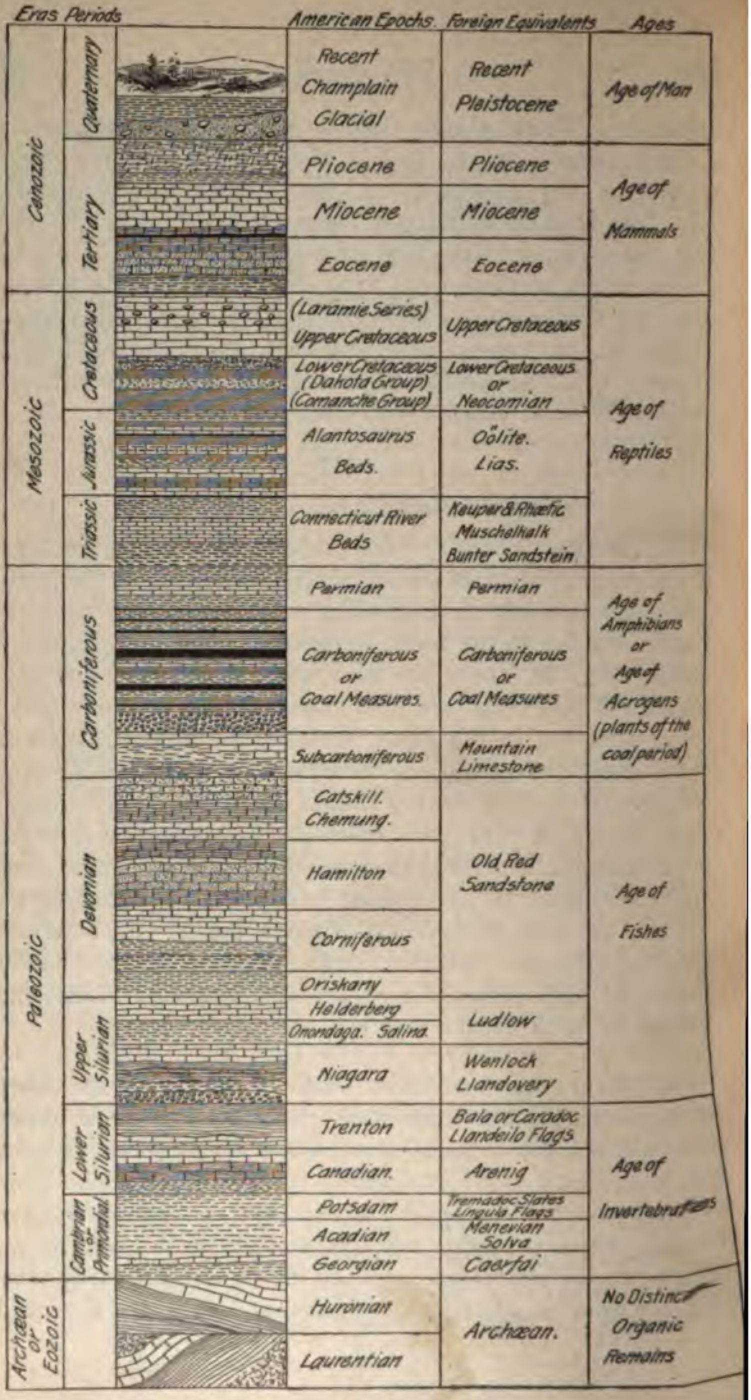
Stratified rocks are composed of material that has been deposited in water, and hence such deposits would naturally contain any shells, bits of coral, leaves, logs, or other material that might lodge when the deposit was being formed, or that might be washed from the land into a river or lake. Bodies of animals from the land have been washed into the water and their bones deposited and covered with sediment, together with the bodies of fish and the various living forms that inhabited the water. Animals walking over soft ground or mud left tracks that became covered with sediment and are now found in rocks. These evidences of the previous existence of living organisms are the fossils, or means by which geologists assign rock formations to different ages.

50. Development of Life.—Animal life, especially the higher species of animals, cannot take nutriment or material for life directly from minerals, and hence vegetable life was naturally the first to appear, probably in the form of seaweeds. These simple forms were soon followed by sponges, shells, coral, etc. Animal life could not have existed on the continents at first, for several reasons. (1) The animals could not have obtained the necessary food, on account of the lack of vegetation or other animal life on which to feed. (2) It is probable that the atmosphere of that period was so heavily charged with carbon dioxide that no animal breathing through lungs could have existed. (3) The probabilities are that the rocks and the atmosphere were entirely too hot.

GEOLOGICAL CHARTS

51. Definition.—For the purpose of reducing geology to a science, geologists have arranged the rocks of the lithosphere into sections corresponding with certain chronological events recorded in the rocks themselves. In the geological section, Fig. 38, there are four eras recorded in the first column. These eras are the bases for the chronological events recorded in the Ages, Periods, and Epochs columns of the chart. With the one exception of Archean, the eras are periods of time during which rocks were formed and certain kinds of organisms existed. The eras are divided into seven ages, according to characters of the organisms that made their appearance and show evidence of their abundance. The eras are also divided into periods, during which certain rocks were formed over the earth. The epochs are subdivisions of the periods, and are distinguished from one another by their fossils and composition.

52. Archean Era.—The word **Archean** means "from the beginning"; consequently, Archean rocks are the oldest rocks and are the foundation on which all other rocks rest, and from which in all probability they were derived. This era is considered the earth's prehistoric age, for there have been no distinct organic remains discovered in these rocks, although some observers supposed they had discovered a very indistinct outline of organic remains, and advanced the word



Eras	Periods	American Epochs	Foreign Equivalents	Ages
Cenozoic	Quaternary	Recent Champlain Glacial	Recent Pleistocene	Age of Man
	Tertiary	Pliocene	Pliocene	Age of Mammals
		Miocene	Miocene	
		Eocene	Eocene	
Mesozoic	Cretaceous	(Laramie Series) Upper Cretaceous	Upper Cretaceous	Age of Reptiles
		Lower Cretaceous (Dakota Group) (Comanche Group)	Lower Cretaceous or Neocomian	
	Jurassic	Alantosaurus Beds.	Oölite. Lias.	
	Triassic	Connecticut River Beds	Keuper & Rhætic Muschelkalk Bunter Sandstein	
Paleozoic	Carboniferous	Permian	Permian	Age of Amphibians or Age of Acrogens (plants of the coal period)
		Carboniferous or Coal Measures.	Carboniferous or Coal Measures	
		Subcarboniferous	Mountain Limestone	
	Devonian	Catskill. Chemung.	Old Red Sandstone	Age of Fishes
		Hamilton		
		Corniferous		
		Oriskany		
	Upper Silurian	Helderberg Onondaga. Salina.	Ludlow	
		Niagara	Wenlock Llandovery	
	Lower Silurian	Trenton	Bala or Caradoc Llandeilo Flags	Age of Invertebrates
		Canadian.	Arenig	
	Cambrian or Primordial	Potsdam	Tremadoc Slates Lingula Flags	
		Acadian	Menevian Solva	
		Georgian	Caerfai	
Archæan or Eozoic		Huronian	Archæan.	No Distinct Organic Remains
		Laurentian		

FIG. 38

Eozoic to cover those rocks adjacent to the Paleozoic. The term *Eozoic* was advanced by Darwin, but *Azoic*, meaning "no distinct life," is preferable, and is adopted by the United States Geological Survey.

53. Paleozoic Era.—The **Paleozoic era** is the second chronological event on the chart. The word *Paleozoic* means "ancient life," and includes three ages and five periods, as shown in Fig. 38. The rocks formed in this era first contained a low order of organism, such as seaweeds, but those developed toward the end of the era contained amphibians, which could live on land or under water. The vegetation at the close of this era was very luxuriant and of a vastly higher order than at the beginning.

54. Mesozoic Era.—The third chronological era is termed the **Mesozoic**, by which is meant that time on the earth when middle life only existed. This era represents the earth's middle age and the age of reptiles. Extensive eruptions occurred at the close of this era, and probably those mountains which have been forced through the Cretaceous system of rock formations were formed at this time.

55. Cenozoic Era.—The latest chronological era is termed the **Cenozoic**, meaning "recent life." This era practically includes the earth's modern history, embracing as it does the age of mammals and of man.

56. Geological Sectional Elevation.—Fig. 39 is a geological section of Colorado, designed by Prof. Arthur Lakes. This method of making sectional elevations of a state or district will be found exceedingly useful to the compiler and others that wish to obtain general information or have an accurate guide to certain localities. It requires time to work out the geology of a section, and any mining engineer that has the time and opportunity to prepare and publish such a chart confers a boon on other mining men, besides acquiring information that will be of the greatest value to himself in the prosecution of his work.

57. United States Geological Chart.—The chart shown in Table I differs from that given in Fig. 38 in that it

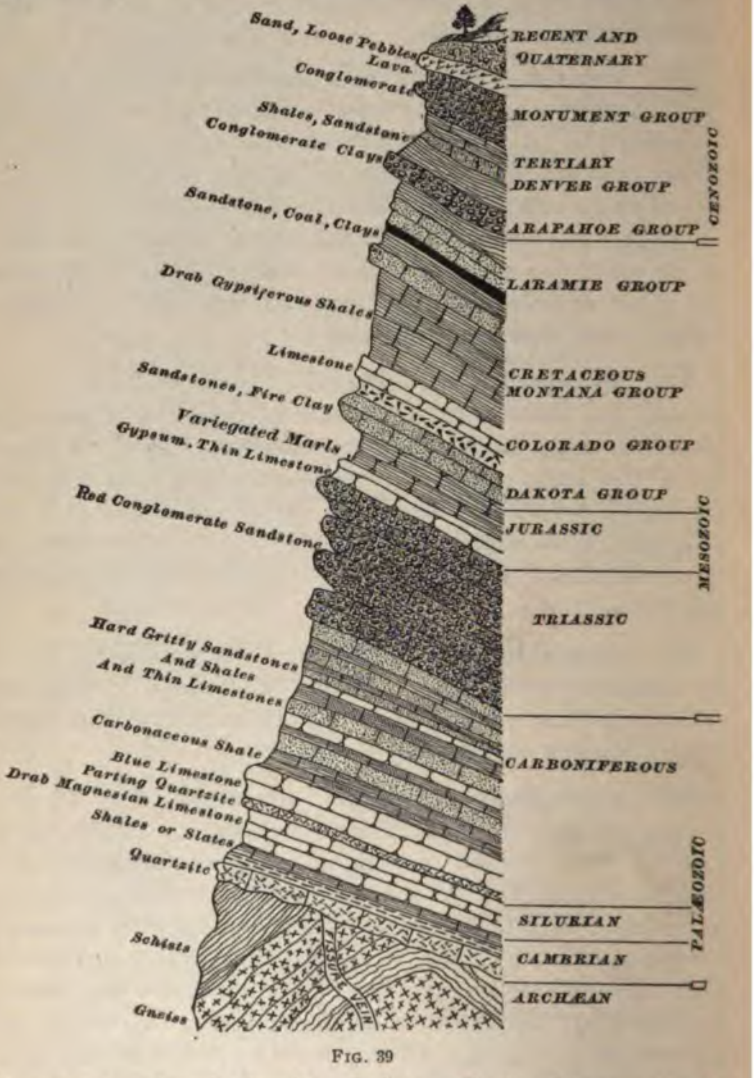


FIG. 39

is more complete in details. It is practically the same as the chart followed by the United States geological surveyors. In this chart there are seven ages, five eras or systems, and twelve periods. In further explanation of the chart, it is well to know that the term Laurentian is not now used by the United States geological surveyors, the term Azoic being supposed to cover the Archean era. The Algonkian and Archean rocks are found in many other localities than those mentioned in the chart; for instance, in Eastern Canada, New England, the Adirondacks, Southern Appalachians, the Cordilleras, and the Little Belt area of Montana.

TABLE I

GEOLOGICAL CHART

Age	System or Era	Period	Formations and Subformations		
Man	Psycho-zoic	Recent	Modern alluvium, formed by water, wind, glaciers, coral polpy, etc. Ancient village débris, mounds, mines, canal, and railroad grading, quarries, etc.		
Mammals	Cenozoic	Pleistocene	Post-glacial	Terrace Epoch—Terraces along river valleys, lakes, seashores in higher latitudes	
				Champlain, or (Ice-Melting) Epoch	High level alluvial plains and "second bottoms" in the North, playas (mud-flats) and later adobe (clay) deposits in the West. Marine and lake clays in Hudson, Champlain, and New England Valleys. The inland beaches and deposits of the interior. Leda clays, Saxicava sands, Algoma sands, with marine and lacustrial beaches and deposits in Canada
			Glacial	Third Glacial Epoch	Terminal moraines and most aqueo-glacial deposits of Northern United States and Canada; also of Rocky Mountains and Sierras, probably upper lake beds of Bonneville and Lahontan
				Second Interglacial Epoch	Local forest beds, buried soils, and alluvial deposits. Epoch principally represented by erosion
				Second Glacial Epoch	"Upper Till" of the interior, with most of the loess of the Missouri and Mississippi Rivers; older glacial deposits toward northern border of United States and Canada
				First Interglacial Epoch	Principal forest bed of Iowa, Illinois, and other interior states with old soils. Nodules and other ferruginous accumulations. Also represented by erosions toward the Atlantic Coast
				First Glacial Epoch	"Lower Till" of the interior and extra-morainic drift of Pennsylvania and New Jersey. Part of the loess, yellow loam, and Port Hudson clays of Mississippi, with the formation in the Eastern United States. Not identified with glaciation during later epochs
		Neocene	ATLANTIC AND GULF AREA Lafayette Sumter Reynosa Chesapeake Chipola Grand Gulf Fayette Beds Chattahoochee Pascagoula		INTERIOR Loup Fork Beds Ticholeptus Beds White River Beds John Day Beds

Mammals	Cenozoic	Eocene	**Atlantic and Gulf Area** Vicksburg } White { Ashley and Cooper Beds Jackson } limestone { Santee Beds	**Interior** Upper { Uintah Beds Bridger Beds Huerfano Beds Middle { Green River Beds Wind River Beds Amyzon Beds Manti Beds Lower { Wasatch Puerco Denver Arapaho Laramie, in part	**Pacific Area** { Tejon Puget, in part
Reptiles	Mesozoic	Cretaceous	**Atlantic and Gulf Area** Severn { Tombigbee Rotten limestone Ripley Raritan Potomac { Eutaw Tuscaloosa	**Interior** Laramie, in part Montana (marine) (Salt Wells) { Fox Hills Fort Pierre Colorado (marine) (Sulphur Creek) { Niobrara { Woodbury Fort Dodge Benton Dakota (marine) (Henry Fork) } Nishnabotna **Texas Area** Comanche Series { Washita Fredericksburg Trinity	**Pacific and Canadian Area** Puget (marine), in part Nanaimo Chico marine Wallala Belly River (non-marine) Queen Charlotte (chiefly marine) Kootanie (non-marine) Shasta, Horsetown } Correlation uncertain
		Jura-Trias	**Atlantic Slope Area** Rhaetic of Virginia Newark formation { Acadian area Connecticut, Palisade, Richmond, Va., and Dan River, N. C., area } Apparently contemporaneous		**Rocky Mountain and Pacific Slope Area** Red Beds { Star Peak Group Auriferous slates, in part

TABLE I—(*Continued*)

Age	System or Era	Period	Formations and Subformations				
Acrogens	Paleozoic	Carboniferous	Permian—Permo-Carboniferous				
			Carboniferous Proper	Upper Middle Lower Conglomerates	Appalachian	Limestones, shales without coal of Utah, Wyoming, and California	
			Mississippi or Subcarboniferous	Genevieve	Chester St. Louis Warsaw	Mississippi Valley	
				Osage	Keokuk Burlington		
				Chouteau or Kinderhook	Chouteau of Missouri Kinderhook of Illinois and Iowa Waverly of Ohio Marshall of Michigan	Cuyahoga shale Berea shale Berea grit Bedford shale	Mauch Chunk and Pocono sandstone of Northeastern Pennsylvania
Fishes		Devonian	New York	Catskill sandstone—Catskill			
				Chemung Portage and Oneonta Ithaca	Chemung		
				Genesee Tully Hamilton Marcellus	Hamilton		
				Onondaga limestone Schoharie grit Caudagalli grit	Corniferous		
				Oriskany sandstone—Oriskany			
			Ohio shale	Cleveland Erie Huron			
			Iowa	Hackberry shale Cedar Valley limestone Independence shale			

Invertebrates

Paleozoic	Silurian	Salina (westerly) Niagara limestone Clinton Dyestone or Rockwood Medina sandstone Oneida conglomerate. Clinch sandstone, Tennessee	
		Lorraine and Cincinnati terrane. Nashville terrane	
		Utica slate. Maqnoketa. Iowa slate. Galina limestone. Quebec series Trenton limestone (Black River and Bird's-eye). Chazy limestone, New York Calciferous { Calciferous sandstone, Mohawk Valley Knox dolomite, Tennessee Oneota limestone (magnesian) Upper Mississippi Valley Levis Beds, Canada	**Hudson River series**
	Cambrian	Potsdam { Oneota limestone, Upper Mississipp. Sandstone, Potsdam, New York St. Croix, Knox Dolomite, Connasauga Beds Tonto and other limestone, sandstones, and shales Acadian { Slates of Braintree, Massachusetts Slates of St. John, New Brunswick Limestones of Stissing, New York, Tennessee, Alabama, Nevada, and British Columbia Georgian { Red sandrock, shales, and limestones Shales and quartzites, Appalachian Range	
	Algonkian	Lake Superior Area Keweenawan Upper Huronian Lower Huronian	Grand Cañon Area Chuar Grand Cañon Vishnu
Azoic	Arch-	Archean	

ARCHEAN ERA

AZOIC ROCKS

58. Archean Rocks.—The word *Azoic* means "without organic life"; the word *Archean* means the "oldest period of time." The rocks of this system are sometimes termed the *basement complex*, by which is meant the foundation on which other rocks rest. The Archean period is supposed to embrace all crystalline rocks underlying the clastic* Algonkian. The Archean rocks are the oldest and have been termed Laurentian because they form a ridge of hills between Canada and the United States, which are separated by the St. Lawrence River and the Great Lakes.

Geologists are in a state of uncertainty concerning the origin of the rocks of this period, but nearly all the older schools have classed them as igneous. In this instance, to carry out our premises, it is thought to be as well, for the sake of uniformity and because it cannot be rebutted, to say they are aqueo-igneous in origin. In order to be conformable, all clastic rocks are eliminated from the series. The rocks of the series are therefore granites, gneisses, and those schists that have crystalline interlocking texture and a schistose structure due to parallel or foliated arrangement of the mineral ingredients. The schists of the series contain biotite, muscovite, chlorite, and hornblende and are usually dark colored. Whether originally igneous or aqueo-igneous, these rocks were subjected to the movements that occurred in later times, if not so deeply buried as to be beyond the influence of the outer foldings, in which case they were buried beyond the crushing strength of the rock or were latently plastic, and probably at a high temperature.

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* Clastic rocks are those composed of fragments, which feature distinguishes them from crystalline rocks.

59. Limitations of the Archean.—It is generally accepted that the Archean rocks have no limit downwards; that this system is the oldest system; and that, wherever it reaches the surface, it has done so by denudation or intrusion. As denudation progressed, material far within the lithosphere approached the surface, thus permitting the aqueo-igneous rocks to cool gradually and crystallize.

Whenever there are unconformable clastic rocks above these crystalline rocks, it is usual to assign the latter to the Archean series, and this can be done with satisfaction only when they are limited to the crystalline varieties stated. The graduations from granite to gneiss and from gneiss to schist are so very gradual that at times it is almost imperceptible, but still, when the rocks do not differ in composition, and do not show evidence of being formed from shale or grit, but keep the same general composition of the original basal granite rocks, they are to be classed as Archean. In the Appalachian mountain region, magnetic-iron ore is found in the Archean as segregated magma of probably aqueo-igneous origin.

PRE-CAMBRIAN ROCKS

60. Algonkian.—It has been customary hitherto to refer to the Archean all crystalline rocks and many semi-crystalline rocks whose age has not been determined. Under this practice large areas in the Appalachians have been classed as Archean that have been found on examination to be clastic and to belong in other periods ranging from the Archean proper up to the Cambrian period. It was this necessity for naming a group of rocks that were sedimentary but metamorphosed that led to the adoption of the term Algonkian by the United States Geological Survey. There are at times signs of organism in these rocks, while there are none in the Archean; yet the signs are not so distinguishable as in the Cambrian, where trilobites are abundant. At other times, they are absolutely barren of distinguishing marks other than the natural formation based on chemical and physical features. These rocks have been classed as Algonkian, but where no absolutely distinguishing marks are found they are termed pre-Cambrian.

61. Limitations of the Algonkian.—The Algonkian has been defined as including all recognizable pre-Cambrian clastic rocks. Its lower plane is the lowest of recognizable clastic rocks, while its upper plane is limited by the *Olenellus fauna*, which includes all systems of the animal kingdom except *vertebrates*, or animals having a backbone. In the application of the term Algonkian to rocks in the field, it should be used only when the geologist is perfectly satisfied that the series are pre-Cambrian and post-Archean. Rocks in a crystalline or semicrystalline condition that chance to be devoid of fossils should not be called Algonkian without strong evidence of pre-Cambrian age.

62. Classification of Rock Series.—A good plan to follow in the classification of rocks of any series, when they are of uncertain age and below a determined fossiliferous series, is to state that they are older than the known series; for instance, the rocks below the Carboniferous belong to some other period and may be termed the pre-Carboniferous until they can be definitely classified. In some regions, the pre-Cambrian rocks are predominantly fine-grained crystalline schists, gneisses, and gneissoid granites; in other regions, they may be limestones, slates, and quartzites. Consequently, unless a structural break or some unconformity occurs between the Archean and the Algonkian, the latter term should be applied to rocks that certainly belong to this period, while the term pre-Cambrian should be applied to rocks that are granitic, gneissic, and schistose, but that may also prove to be Archean.

63. Succession in Algonkian-Rock Series.—In the Algonkian-rock series, gneisses are in some localities the predominant rocks, but they present a varied mineral composition, are strongly foliated, and often occur as well-defined layers like strata of sedimentary rocks, thus varying somewhat from Archean gneisses. Analyses of these gneisses by Adams show that they have the composition of shales and slates rather than that of the Archean granites and gneisses, as they contain less alkali than the latter. Interstratified with the acid gneisses are hornblende gneisses and schists, beds of quartz schists, and thick beds of crystalline limestone. The limestones and sometimes the gneisses are graphitic, and in certain localities in New York and New Jersey are so rich in magnetite as to furnish iron ores. Algonkian rocks are divided into Lower Huronian, Upper Huronian, and Keweenawan series; and, where best studied, consist of ordinary crystalline quartzites, slates, limestones, and iron formations with subordinate amounts of aqueo-igneous material. The Algonkian rocks contain most of the great iron deposits of the Lake Superior region, although some iron-ore deposits are said to exist in the Archean.

64. The **Lower Huronian series** consist mainly of sedimentary rocks, but in certain districts they include volcanic rocks. The series are cut by intrusive rocks in the Lake Superior region, where they have been most studied. The series are called Huronian because they cover a considerable area north of Lake Huron.

The Lower Huronian series rest on the Archean and consist from below up of (1) conglomerate or quartzite, (2) dolomite, (3) slate conglomerate, (4) Negaunee, or chief iron-bearing formation, (5) slate-graywacke conglomerate, and (6) cherty limestone. The thickness of these beds will vary in localities, and sometimes one or more beds will be wanting.

65. The **Upper Huronian series,** as the name suggests, rest on the Lower Huronian, and seem to have been less closely folded and are less crystalline in structure than the former series; unless, however, some unconformity exists, the two series are difficult to separate. There seems to be three general formations: a quartz slate being the lowest member, an iron-bearing formation next, and lastly an upper slate. These formations are not uniform, but are locally subdivided and may contain cherty iron carbonates, ferruginous slates, ferruginous cherts, jaspilites, ore and jasper conglomerates, and ore bodies. The rocks are plainly sedimentary, although great bosses of intrusive granite and diorite sometimes abound. The total thickness of the rocks is given as 12,920 feet by Logan, but will vary according to locality. The Penokee, Gogebic, Mesabi, and Vermilion iron ores are probably in the Upper Huronian series.

66. The Keweenawan Series.—The name of the **Keweenawan series** is derived from Keweenaw Point, which juts out into Lake Superior from the northeastern extremity of Michigan. These rocks cover nearly the entire area of Lake Superior, and are of aqueo-igneous and sedimentary origin. They are composed of gabbros,* diabases, porphyrites amygdaloids, felsites, quartz porphyries, sandstones, and conglomerates. Many of the rocks of this series are surface flows, and their total thickness varies widely. From the base up, the Keweenaw series are separated into three great divisions, as follows: (1) Basal gabbro, which covers a wide area, and has everywhere a typical granitic structure. It includes magnetic gabbro, olivine gabbro, normal gabbro, and masses of basic feldspar. Much of the gabbro has a laminated arrangement of its mineral particles, and corresponding with this arrangement has a bedded appearance. (2) Interstratified lavas and clastic rocks, the material of which seems to have been derived from lava flows. In the lower portion of this series, the rocks are all volcanic, but passing upwards the sandstones and conglomerates become more numerous and of greater thickness. (3) The third division is composed wholly of sandstone and conglomerates, derived very largely from the erosion of the lower divisions.

The Keweenawan is the thickest of the series about Lake Superior and varies in thickness from 50,000 feet to nothing. The native-copper deposits of Lake Superior occur in this series of rocks, as replacements in both igneous and sedimentary rocks.

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*A granitoid mixture containing labradorite and a pyroxene.

PALEOZOIC ERA

CAMBRIAN PERIOD

67. Cambrian Fossils.—The Paleozoic era and the Cambrian period commenced when **trilobites** first appeared. Three distinct kinds of trilobites made their appearance during the Cambrian period; and, on account of the separated zones in which they occur, the rocks have been divided into three groups.

FIG. 40

FIG. 41

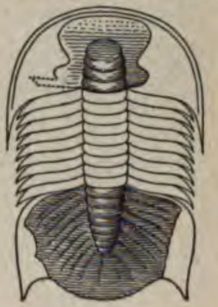


FIG. 42

68. Georgian Rocks.—The **Georgian group** or series of rocks is composed of the red sandstones, shales, and limestones of the town of Georgia in Vermont; also of the shales and quartzites of the Appalachian type. Georgian rocks are in the Olenellus zone; that is, they contain only the trilobite of the species shown in Fig. 40, by which means they may be distinguished. The rocks rest on the Upper Huronian quartzites and conglomerates. Usually they are more or less metamorphosed, especially the marbles, which in some instances are colored so as to present the appearance of onyx. These are called *Taconic marbles*.

FIG. 43

The word *Taconican* is sometimes used to designate rocks adjacent to these marbles, although the Taconic-rock period comes later.

69. Acadian Rocks.—The trilobite shown in Fig. 41, makes its appearance in the Acadian rocks, and is termed **paradoxides.** It is a more elaborate crustacean than the other trilobites mentioned, but belongs to the same family. The rocks are named from their outcroppings in Newfoundland, New Brunswick, and Nova Scotia, and consist of limestones, sandstones, and shales. The limestones of New York, Tennessee, Alabama, and British Columbia belonging to this system sometimes furnish excellent marble. The slates that outcrop at Braintree, Massachusetts, are in this system.

FIG. 44

70. Potsdam Epoch.—The dikellocephalus, or trilobite, illustrated in Fig. 42, is characteristic of the Potsdam rocks. The paradoxides seem to have become extinct in this epoch, although a hundred different species are said to have been observed in the Acadian rocks. The lowest members of the Potsdam epoch are sandstones, limestones, and shales. Above these are the St. Croix and the lower part of the Knox dolomite. Next above these is the sandstone of Potsdam, New York, from which the epoch receives its name. The lower Oneota limestones of the Upper Mississippi Valley are classed in this epoch.

71. Cambrian Fossils.—In the lowest Cambrian rocks the few fossils that are found are indistinct remains of seaweeds, and are fragile and easily obliterated on exposure. There have also been found a few sponges, graptolites, and corals, and some very small pteropods, or foot-winged mollusks.

The brachiopods or mollusks shown in Fig. 43 abound in some places in the Potsdam epoch. They are quite small, being less in size than a man's finger nail. Articulates, tracks, and ripple marks are found in the rocks of this epoch. Fig. 44 shows ripple marks and tracks probably made by trilobites. Worms have also left tracks in the rocks, and as an additional reminder of their existence have left worm holes in the rocks, as shown in Fig. 45.

FIG. 45

SILURIAN PERIOD

72. The word *Silurian* is derived from the name of an early British tribe that inhabited a certain portion of Great Britain where Silurian rocks predominated. The rocks of this system are divided into two groups, Upper and Lower Silurian. Murchinson, who spent many years in making his researches among the rocks of the Lower Silurian, termed them *Ordovician*, because a British tribe called *Ordovices* was said to have once inhabited the place where he made his observations. The Ordovician group of rocks is divided into two periods, called the *Trenton* and the *Canadian*. The latter is the older, and hence contains fewer fossils than the former. The Lower Silurian rocks and probably most of the Upper Silurian belong to the period in which no vertebrates are known to have existed, although in the Devonian rocks of the Upper Silurian fishes make their appearance. The Silurian system is characterized mainly by the corals that were developed.

LOWER SILURIAN SYSTEM

73. Canadian Epoch.—The oldest group of rocks belonging to the Lower Silurian system is subdivided into two stages termed the *calciferous* and the *chazy*. The rocks of these epochs are not confined to any one locality, but are found in Canada, New England, New York, Missouri, Minnesota, and some of the Southern States. Two isolated areas of clayey limestones are exposed; namely, one over Southern Ohio, part of Kentucky, and the border of Indiana, and the other in Tennessee. This region has been termed from these rocks the **Cincinnati Uplift.**

The Taconic range on the western borders of New England and the eastern border of New York, with its crystalline schists and limestones, is considered as belonging to this period.

74. Calciferous Stage.—The **calciferous** formation embraces mainly a mixture of lime and silica formed into rock—hence, the first rocks above the Potsdam sandstone are more silicious than the others. The rocks above those just mentioned are variable mixtures of silica and magnesian limestone, which when fractured show a good grain. This rock is in layers with the other rocks, and is sometimes called *calcareous sandstone*. Above this latter rock is a granular magnesian limestone that sometimes receives the name of **bird's-eye marble.** The color is yellowish and sometimes grayish. The rocks weather rough and leave hard silicious particles exposed. Cavities are sometimes formed in these rocks in which remarkable quartz crystals are found, especially in the Mohawk Valley, New York.

The oldest beds are in Canada and are known as the **Levis.** The magnesium limestone of this formation in the Upper Mississippi Valley is given the name of **Oneota limestone.** The magnesian limestone of Tennessee belonging to this formation is termed **Knox dolomite**; this rock is also exposed on New River in Pulaski County, Virginia. The rocks are not very fossiliferous.

75. Chazy Stage.—The Chazy beds next above the calciferous are mostly limestones. The name is derived from the town of Chazy in Clinton County, New York, where the formation is 730 feet thick. The limestone is gray to black, and contains many rough, irregular, flinty masses. The limestone is purer than that of the calciferous, and is free from the brown earthy spots and brown calcareous spar common in the calciferous sand rock. It is often recognizable by a large fossil shell 3 inches or more across, as shown in Fig. 46. The **St. Peter's sandstone** of the northern part of the Mississippi Valley is referred to the Chazy epoch, but it contains few fossils of any kind and hence its position is doubtful. St. Peter's sandstone is seen near St. Paul, Minnesota; on the streams in Northeast Iowa; and at La Salle, Illinois. It is remarkable for its uniform thickness of about 100 feet over a space 400 miles in width and 500 miles in length. The sandstone is usually white, but at times assumes a buff color. When not colored, it is used as a glass sand. The character of St. Peter's sandstone is similar throughout its entire extent, and as it contains but a mere trace of cement its fine grains can be moved with pick and shovel.


FIG. 46

TRENTON EPOCH

76. Trenton Limestone.—Next in order above the Chazy beds is the **Trenton limestone,** a name derived from Trenton Falls, north of Utica, New York. The rock is blackish to dark gray, owing its color to bituminous matter. The lower portion of the Trenton formation is termed the **Black River limestone.** A stratum 30 feet thick at the bottom of this limestone in Central New York is called **bird's-eye limestone.** It is a gray dove-colored rock, speckled with white crystalline points that are in part due to fossil coral and its change into calcite. Kentucky Chazy limestone contains bird's eyes as well as the calciferous mentioned. Trenton limestone carries lead and zinc-lead ores, and is at times bluish gray, particularly in Wisconsin, Illinois, and Iowa. This rock is well developed at Glens Falls, New York, and at Blacksburgh and Fincastle, Virginia, in each locality appearing as black marble. The petroleum found in Western Ohio and Eastern Indiana comes from these rocks. The fossils characteristic of the Trenton epoch are, besides sponges, the coral shown in Fig. 47; the pteropod termed the *Conularia Trentonensis*, Fig. 48; the straight-chambered cephalopod, Fig. 49, a section of which is shown in Fig. 50. The trilobite, Fig. 51, of this period grew to 10 inches in length. Another species is shown in Fig. 52, and in Fig. 53, the same species rolled up.


FIG. 47


FIG. 48


FIG. 49

77. Utica Slates.—Above the Trenton limestone the Utica slates appear. These are dark-colored carbonaceous slates and shales, which are soft and fissile and often contain *Graptolites*, shown in Fig. 54, and graphite. In Patrick County, Virginia, the graphite shales are so pronounced that they resemble a bed of stove blacking. The shales are at times interstratified with thin beds of impure limestones, and again shade into sandstones and grits. The whole Lower Silurian series is also known in New York as the


FIG. 50


FIG. 51


FIG. 52


FIG. 53

FIG. 54


FIG. 55

Hudson River series. Maquoketa shale, Nashville shale, Lorraine shale, Pulaski shale, and other local names are given to Utica shale. It varies in thickness from 15 to 1,000 feet. At Glens Falls, New York, the shale is 15 feet thick and shows graptolites in each cleavage plane. North of Cincinnati, Ohio, the shales become 1,000 feet thick. When broken down and weathered, the shales have an ash-clay color. Good roofing slate is found in this formation at Slatington, Pennsylvania. No corals appear in the Utica shale, although a chain coral is found in the Hudson River series, of which the Utica slate is a member. The crinoid shown in Fig. 55 is found in the Utica slate; and a starfish is found in the blue limestone of the Cincinnati epoch of the Lower Silurian period.

UPPER SILURIAN PERIOD

78. The rocks of the Niagara, Onondaga, and Helderberg epochs are not found in any great quantities west of the Mississippi, with the exception of Missouri. The Upper Silurian rocks of the Eastern States do not border directly on the coast, but are inland, along the Appalachian mountain range.

NIAGARA EPOCH

79. Oneida Conglomerate.—The **Niagara epoch** is divided into three stages, the lowest being the Medina, whose lowest member, the **Oneida conglomerate,** is named after the town of Oneida in Central New York. It is a hard gray rock composed of quartz pebbles and sand. This rock shades into the Medina sandstone above it, and is distinguishable probably only by its color. The Clinch sandstone of Tennessee is classed as Oneida.

80. Medina Sandstone.—Above the Oneida conglomerate, an almost invariably red-colored sandstone, known as the **Medina sandstone,** is found. The color varies from light red, brown red, and yellowish to greenish. It is both fine-grained and coarse, and between layers of sandstone variegated shales are interposed, especially in New Jersey. The lower beds are usually dark red and very hard, while the upper beds are brownish red and more argillaceous, and also sometimes calcareous.

FIG. 56

Neither the Oneida nor the Medina sandstones are found west of Ohio, unless they have been recently found in Missouri in what is known as the **Ozark uplift.** A distinctive fossil of the Medina sandstone is shown in Fig. 56. This fossil is termed *Fucoides Harlani*, and is supposed by some to be the tracks of sea worms; by others it is considered to be the cast of a seaweed. These impressions, however, are seldom found elsewhere than in Medina sandstone.

81. Clinton Stage.—The **Clinton group** of rocks is named from the town of Clinton, in Oneida County, New York, where they were first noticed and classified. The

FIG. 57

Clinton epoch comprises various kinds of rocks, such as green and black-blue shales; greenish-gray and red shales, or soft marly layers; calcareous sandstone, often laminated; encrinal sandstone; and red fossiliferous iron-ore beds. On the Niagara River, the rocks are about one-half limestone, and further west in Ohio are wholly limestone. The group contains an abundance of marine shells, particularly the brachiopods shown in Fig. 57.

A section of the Clinton group on the Genesee River gives, green shale, 24 feet thick, the upper part of which is iron ore; limestone, 14 feet thick, called *Pentamerous limestone*, from a characteristic fossil shown in Fig. 58 (*a*) and (*b*); green shale, 24 feet thick; and limestone, 18½ feet thick. These sections vary in thickness in different localities; in Virginia, they are 850 feet thick; in Tennessee, 250 feet thick; in Pennsylvania, they reach a thickness of 1,000 feet and more.

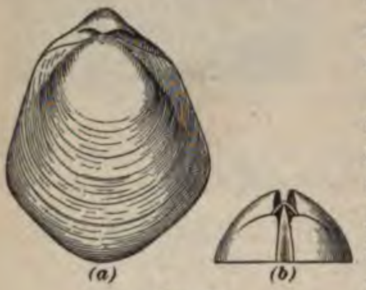


FIG. 58

The Clinton iron ore is fossiliferous; sometimes it is öolitic, and sometimes, as in Northern New York and Alabama, it seems to be formed in the limestone by replacement. It is about the only stratified iron-ore bed in the United States—at least the only stratified hematite—and is the chief source of iron ore in Alabama. In Eastern Tennessee, the ore is called *dyestone;* in some other localities, it is called *rock wood.*

82. Niagara Stage.—The group included in the **Niagara epoch** consists mostly of shale and limestone, and is the topmost of the Niagara period. The shale is usually below, with the limestone above. The name is derived from the Niagara River. At Niagara Falls this limestone is 164 feet thick, with 80 feet of shale beneath. The Niagara limestone occupies the peninsula in Wisconsin between Green Bay and Lake Michigan, and extends southwards into Illinois and Indiana. The rock covers wide areas and has received local names; in general appearance it is a massive gray dolomitic limestone. At Guelph, Ontario, it is termed *Guelph limestone;* in Wisconsin, it is divided from the top downwards into *Guelph*, *Racine*, *Waukesha*, and *Mayville beds*. In Iowa, the rock has a wide distribution, and is termed *Leclaire limestone*. In Tennessee, it is termed *Meniscus limestone*, on account of its fossil sponges in that locality being crescent-shaped. In Fig. 59 (*a*), (*b*), and (*c*) are shown fossil sponges and corals, the later being so numerous in some localities as to give the term *Coralline limestone* to the rock. The Niagara rocks have been identified in the Black Hills of Dakota and also in Alaska by the chain corals, which are shown in Fig. 59 (*c*). In the lower part of (*a*) is given a diagrammatic section showing the cellular structure of the sponge above it.

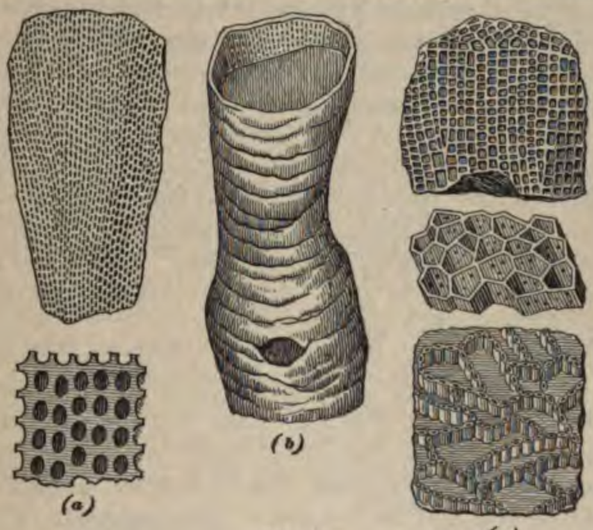


FIG. 59

ONONDAGA EPOCH

83. Salina Stage.—The **Salina** is an important group of rocks in New York, as it contains the salt beds. It receives its name from the Onondaga Indians, whose reservation covers a large part of the salt area. The rocks are gypsum, salt, red shale, water lime, and Tentaculite limestone. The lowest of the group is a blood-red shale, with green spots. This shale has no regular fracture or division lines, and breaks up into irregular fragments. No fossils are found in this shale, which is fine-grained and free from pebbles.

The deposit above the Salina is composed of gypseous shales, calcareous slates of a light green and drab color, with a little whitish and greenish sandstone. The colors of these rocks change in different places, and the reddish or salmon-colored fibrous gypsum deposits are not extensive.

The third member of the Salina group is the gypsum deposit, often containing cavities, for which reason it has been termed *Vermicular lime rock*. These rocks are porous and contain no water, and the hopper-shaped cavities are supposed to have been formed by salt that subsequent to its formation has been leached out by water. Animals cannot live in water saturated with gypsum; hence, no animal remains are found in this formation. Numerous sulphur springs occur in this group.

The fourth division of the Salina group contains a dark gray or drab-colored impure magnesian limestone, with cavities containing crystals. This rock breaks with an earthy fracture. The salt beds occur in this group, and extend from Pennsylvania into Canada, ranging from 12 feet to 250 feet in thickness. The salt beds alternate with shales, and occur at great depths. At Syracuse, New York, the thickness of the Onondaga rocks is stated to be 600 feet; at Ithaca, New York, 1,230 feet; and at Goderich, Canada, 1,400 feet. The number of salt beds also varies. At Leroy, New York, there is one bed 40 feet thick; at Ithaca there are several beds having a thickness altogether of 250 feet; and at Goderich there are six beds from 6 to 35 feet in thickness. The strata are non-fossiliferous and abound in mud cracks, as if they were once mud flats or salt marshes. The rock salt varies in color from white to dark bluish. It is not to be understood that Salina rocks contain all the salt or gypsum deposits, for they are frequently found in other formations.

84. Water-Lime Rock.—**Water-lime rock** is a natural cement rock, and is an earthy, drab-colored, impure, magnesian limestone. It is the rock termed **hydraulic limestone,** from which Rosendale cement is made, near Rondout, New York. The formation is in layers, the drab-colored limestones being separated by a mass of blue. This rock extends over a wide area, and crops out in several distinct localities. It weathers to a gray ash color. While trilobites are found in this period, a species of crustacean called *Eurypterus,* Fig. 60, makes its appearance.

FIG. 60

85. Tentaculite limestone, so called from its characteristic fossil, which is shown in Fig. 61, is sometimes classed as a member of the Lower Helderberg group, which is geologically classed by some as next above the water-lime rock of the Onondaga period, and by others is classed in the Onondaga group. This limestone is solid, free from cracks, and hence makes a fine building stone that can be procured in blocks of large size. The color varies from ash gray to black, its color and texture contrasting with the water-lime rock below. The strata are usually intersected by two systems of joints nearly perpendicular to each other.

FIG. 61

LOWER HELDERBERG EPOCH

86. The third and upper subdivision of the Upper Silurian period is termed the **Lower Helderberg,** because the rocks of this division are well developed in the Helderberg Mountains, near Albany, New York. The epoch is divided by Dana into three stages, but four stages are given here, in order to place the Oriskany sandstone proper at the base of the Devonian system. The Lower Helderberg rocks have their greatest thickness east of Central New York.

87. Lower Pentamerous Limestone.—The **Lower Pentamerous limestone** is rarely pure, being more or less mixed with black shale, which gives it a dark color. It is crystalline and compact, and is found mostly in layers about 50 feet thick. The stone has a rough appearance, and its joint lines are uneven and irregular; hence, it does not make a good building stone. The fossil brachiopod from which it receives its name is shown in Fig. 62.


FIG. 62

88. The **Catskill,** or **Delthyris shaly limestone,** which lies next above the Lower Pentamerous, consists, as its name implies, of shale and impure thin-bedded limestone. It is interesting from the number of species and abundance of its fossils. In Fig. 63 is shown a species of brachiopod that is common in the shaly limestone.


FIG. 63

89. Encrinal limestone is a compact crinoidal limestone, called also by Vanuxem, **Scutella limestone.** It is classed in the New York State Report with the shaly limestone, both together having a thickness of 65 feet. It is confined to the eastern part of the state.


FIG. 64

The **enchinoderms** are conveniently divided into three orders; namely, (1) the *Echinoids*, or sea urchins; (2) the *Asteroids*, or starfishes; and (3) the *Crinoids*, or stemmed Enchinoderm, which is attached to the rocks when young but is free when mature.

The **Crinoids** are divided into three families, as follows: (1) *Crinids*, Fig. 64, which have branching arms; (2) *Cystids*, which are bladder-like in shape, as shown in Fig. 65. These pass away with the close of the Silurian era, and are therefore characteristic; (3) *Blastoids*, which have a bud-shaped body, with five petalloid spaces radiating from the top and reaching halfway around the body, as shown in Fig. 66. The Blastoids pass away before the end of the Carboniferous era, and are especially characteristic of the Devonian and Carboniferous rock systems.


FIG. 65

90. The **Upper Pentamerous** is, according to Rogers, from 50 to 100 feet thick in Pennsylvania. It is a calcareous formation of some shade of blue, argillaceous and flaggy in its lower beds, and shaly toward the middle, with layers of chert. A characteristic brachiopod of this formation, known as *Pentamerus galeatus*, is shown in Fig. 67. The Upper and Lower Pentamerous beds can be distinguished by the shell marks on the brachiopods.


FIG. 66


FIG. 67

SILURIAN PERIOD IN GENERAL

91. The Cambrian period ushers in the Silurian period, or Invertebrate age. The rocks are metamorphosed crystalline sandstone, slates, and schists, with an occasional bed of limestone.

In the Canadian and Trenton epochs, limestones predominate, although there are slates and shales at the close of the Trenton.

The Niagara epoch starts in with conglomerate and sandstone; then come limestones, salt, and limestones again, until the Oriskany sandstone is reached, which is, in the subdivision adopted, the base of the Devonian period. The formations are thicker in the Appalachian region than in the interior, varying from 15,000 feet in Tennessee to 1,200 feet in Iowa. The proportion of limestone in the East, however, is less than in the West. The earliest Silurian rocks give indications of having been formed in comparatively shallow waters, and that this part of the period was generally quiet except during the Canadian epoch in the region of Lake Superior, where there were extensive igneous ejections. The long quiet was finally interrupted by the Green Mountain and Cincinnati uplifts. The strata originally horizontal are now inclined at angles varying from 30° to 60°, and it is probable that these folded and crystallized rocks made dry land. The limestones that were once common fossiliferous limestones are now crystalline, having been converted into white and colored marbles. During the Upper Silurian period, large limestone beds were formed, which show that the earth was again under water; and, as these beds are again thicker in the East than in the West, it would indicate that a vast subsidence occurred after the Lower Silurian upheaval. Salina beds would indicate another upheaval, during which time the salt beds were formed in shallow water. The iron ores of the Clinton epoch are the most remarkable economic formations of this period, as they extend from Canada to the Gulf of Mexico. The iron ores of Tennessee and Alabama are mostly Clinton ores.

92. The Lower Silurian, and probably a portion of the Upper Silurian, belongs to the period before any vertebrate life came on the earth; but in the Upper Silurian a few fishes appeared, although the Devonian is really the age of fishes. The Silurian period is characterized mainly by the large number of shells and coral that were developed during this time. Figs. 68 and 69 illustrate some of the most common Silurian fossils. In Fig. 68, *1* to *6* show some of the characteristic shells of the period; 7^a represents a trilobite open, while 7^b represents the same species when curled up or closed; *8* and *9* are two of the simple coral forms, though the greater part of the coral of this formation was not of the branchy type, such as exists so commonly at the present day, but was more of the form shown at Fig. 69 (*d*), which represents a cup or horned coral, or at Fig. 69 (*e*), which represents a coral composed of long cells joined together in a series of chains, as shown. It was during this period that the form from which the modern nautilus and cuttlefish have descended first appeared. The nautilus has a shell composed of chambers, as shown at Fig. 69 (*a*), which represents the modern nautilus. The chambers are connected by a tube running from the animal's back through all the chambers, although the chambers themselves are empty. When the animal outgrows the forward chamber in which it lives, it

FIG. 68. SILURIAN FOSSILS

1, Orthis-Davidsonii; *2*, Pentamerus Knightii; *3* and *4*, Spirifer Cumberlandiæ; *5*, Pleurotomania agava; *6*, Murchisonia gracilis; 7^a and 7^b, Calymene Blumenbachii; *8*, Coral Fenestella; *9*, Coral Choetites; *10*, Graptolite; *11*, Orthoceras Duseri.

advances the shell and leaves another sealed chamber behind it. The first shell of this type was chambered in the same manner, but was not coiled as in the nautilus. In Fig. 68, *11* illustrates the shell, which was called the *orthoceras*. The shells are of considerable size in the Trenton limestone at Glens Falls, New York. Fig. 69 (*b*) represents a species of curved chambered shells that also came into existence before the end of the Silurian period.

Fig. 69. Silurian Fossils

(*a*), Pearly Nautilus; (*b*), Lituites cornu-arietis; (*c*), Crinoid; (*d*), Zaphrentis bilateralis; (*e*), Halysites catenulata.

Another important form of life that appeared during the Silurian period was the crinoid. This is illustrated at Fig. 69 (*c*). The crinoids were practically all attached to the sea bottom by long stems; the head of the crinoid was shaped considerably like a lily or flower, having five or more fingers or plates, which it could open or close while searching for food. In fact, the crinoid was a good deal like a starfish on the end of a stem. One very characteristic little fossil, found in the Silurian rocks, but not found above them, is shown at *10*, Fig. 68. This is called the graptolite, and is very common to the Utica shales near Glens Falls, New York. It is sometimes serrated on both edges, instead of one as shown.

GEOLOGY

(PART 3)

PALEOZOIC ERA—(Continued)

DEVONIAN PERIOD

1. Devonian Subdivisions.—The Devonian period is divided by Dana into three subdivisions; namely, the Lower, the Middle, and the Upper. These are further divided into four epochs; namely, the Oriskany, the Corniferous, the Hamilton, and the Chemung, which are again divided into stages. The Devonian rocks are sometimes termed the *Old Red Sandstone series*, from the rocks in Scotland. There is no distinct change between Upper Silurian and Lower Devonian rocks, the one gradually merging into the other; the latter, however, in Eastern North America, commences with sandstones, and is followed by a great continental limestone, termed the *Corniferous*. The rocks of this era show that there was considerable raising and lowering of the surface, so that at one time the land would be above water and at another time below. The seas contained, in general, invertebrate forms of life similar to those of the Silurian period, as well as vertebrates such as fishes—hence, the period is called the *age of fishes*. The trilobites were fewer, while corals and brachiopods were in large numbers, and new forms of cephalopods appeared.

LOWER DEVONIAN SYSTEM

2. Oriskany Epoch.—The rocks of the **Oriskany epoch** receive their name from the village of Oriskany Falls, New York, where the sandstone is about 12 feet thick. As it is traced south it increases in thickness until it reaches 700 feet in Pennsylvania, Maryland, and Virginia. A characteristic of the rock is the abundance of small cavities, which show in places where the rock is well developed. The rock is a coarse, porous, silicious sandstone, with a yellowish white color, and finds use in glass making. The cavities mentioned are due to solutions percolating through the rock, dissolving the fossils and leaving the casts of their shapes. It is sometimes a cherty limestone, a pebbly sandstone, and in part a shale, but its abundance of fossils and its semicalcareous character distinguish it from grits. The brachiopods shown in Fig. 1 are characteristic of the Oriskany.

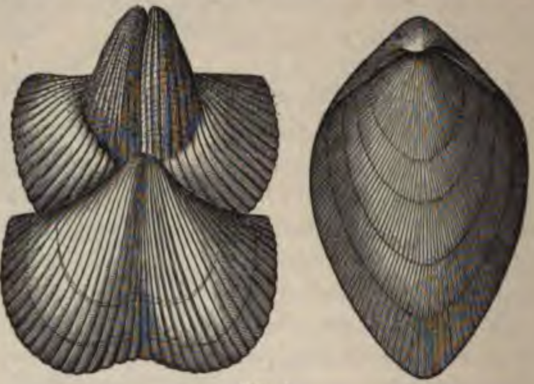


FIG. 1

3. Corniferous Epoch.—The **Corniferous epoch**, which is the second division of the Lower Devonian, is divided into three epochs by the United States Geological Survey. These rocks are widely dispersed, and the sandstones and limestones of this formation have been recognized in many places. The three subdivisions, beginning with the oldest, are the Cauda-galli grit, the Schoharie grit, and the Onondaga limestone. In Iowa, these members receive different names, and as they are changed in texture are known as Independence shale, Cedar Valley limestone, and Hackberry shale.

4. Cauda-Galli Grit. The **Cauda-galli grit** is a fine-grained drab or brownish calcareous and argillaceous sandstone. It receives the name of *Cauda galli*, or "cock's tail," from its peculiar markings, which bear some resemblance to a plume. Fig. 2 shows the markings of the fossil *Spirophyton cauda galli*, which is supposed to be the fossil remains of a seaweed. In New Jersey and Eastern Pennsylvania, it is a gritty slate which attains a thickness of 500 feet.


FIG. 2

5. Schoharie Grit.—The **Schoharie grit** is a fine-grained calcareous grit, naturally brown, but weathering to a drab color. The fossils are numerous and peculiar to the epoch. Its great number of gasteropods, one of which is shown in Fig. 3, give it a marked character. The name is derived from Schoharie, in New York, and the formation has a wide geological extension.


FIG. 3

6. Onondaga Limestone.—In the state of New York, the Onondaga epoch contains two members: the gray limestone below and the corniferous limestone above. The **Onondaga limestone** is recognized by its light gray color and its crystalline structure and toughness. It is a good building stone and resists the action of the elements; when wet it shows its characteristic fossils. The corniferous limestone, so called from the horn-like flint nodules embedded in it, alternates with the Onondaga, so that they are considered as one formation. The limestone is sometimes oolitic and varies from 50 to 250 feet in thickness. It is sometimes very prolific in shells and in corals, of the kind shown in Fig. 4. The rock carries petroleum at Enniskillen, Canada, and in Pennsylvania and Ohio.

FIG. 4

MIDDLE DEVONIAN SYSTEM

7. Subdivisions.—The Middle Devonian system is divided into four epochs by the United States Geological Survey; namely, **Marcellus, Hamilton, Tulley,** and **Genesee.** By Dana, however, the system is classed in two groups, the lower one being termed the Marcellus, and the upper the Hamilton. The latter group is named from the Hamilton group of rocks in Madison County, New York. The beds have a wide range and extend from New York westwards, appearing from time to time in various localities. The group attains a thickness of 4,000 feet in Monroe County, Pennsylvania, but is only about 20 feet thick at Louisville, Kentucky. At Gaspè, Canada, the beds are said to be 7,036 feet thick, and in the Eureka District, Nevada, 8,000 feet thick.

8. Marcellus Shales.—The lower part of the Marcellus formation is black, slaty, and bituminous, and contains pyrite and impure black limestone in irregular flattened masses. The shale resembles the Utica shale, and might be taken for it. There has been much unavailing search for coal in the Marcellus shales, although, according to Lesley, small coal beds do occur in Perry County, Pennsylvania. These are the oldest coal beds known.

FIG. 5

The few fossils in this formation—mostly cephalopods termed **Goniatities,** Fig. 5—are a foot in diameter and are found in a limestone of the same name near the bottom of the shales. The Marcellus shales sometimes attain great thickness (875 feet) and are a strong line of demarcation between the corniferous limestone and the sandy Hamilton beds.

9. Hamilton Epoch.—The town of Hamilton, in Madison County, New York, contains no other surface rocks and therefore affords a good opportunity for their examination. The epoch includes all the beds between the Marcellus shale and the Tully limestone, and varies in thickness and color. Chester, Green, and Albany Counties, New York, furnish the North River flagstones, while thicker layers known as *bluestone* are found in the same counties, as well as in Sullivan County and along the Delaware River. The strata have joints of great regularity. The beds consist of slate, shale, and sandstone of a dark blue or dark gray color, becoming olive or brown on exposure to the weather. Toward the western part of New York the beds become calcareous, with an increase of clay, and are separated into two parts by a thin layer of **encrinal limestone,** the upper bed being called **Moscow shale.** The rocks of this formation are often covered with ripple marks on the layers.

10. Tully Limestone.—The **Tully epoch** is sometimes wanting altogether, but wherever found it is recognized as the dividing line between the Hamilton and the Genesee. The limestone is impure, of a dark or blackish blue color, and at Tully, New York, is about 15 feet thick.

11. Genesee Epoch.—The **Genesee epoch** shows a great development of an even-grained black slate, which seems to weather much better than the Marcellus shales, but in the absence of fossils it would be difficult to distinguish the two. Its most prominent development is in the gorge of the Genesee River. Impressions of the remains of fishes are found in these rocks.

UPPER DEVONIAN SYSTEM

12. Upper Devonian Epochs.—The Upper Devonian system is divided by Dana into the Portage and the Chemung epochs; while the United States Geological Survey divides the period into the Chemung and the Catskill groups, with three epochs in the former. The dividing line between the Portage, Chemung, and Catskill is not well defined.

FIG. 6

13. Ithaca Group.—The **Ithaca group** of sandstones is prominently shown at Casadilla Falls, near Ithaca, New York. These sandstones abound in fossils, which are largely brachiopods, and bear a close resemblance to those of the Chemung and Hamilton species. As these rocks are overlaid with 500 to 600 feet of Portage sandstone, they are usually referred to the Portage epoch. Characteristic fossils are shown in Figs. 6, 7, and 8.

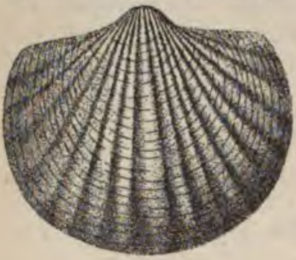


FIG. 7

14. Portage Epoch.—The rocks of the **Portage group** are named after the town of Portage, Livingston County, New York. They outcrop along a wide belt. The lower division of this group consists of green shale, thin flagstones, and sandy shale, which are known locally as the **Chasaqua shales** and the **Naples group.** The middle division consists of green and black slaty shales, with thin layers of fine flagstone known as the **Gardeau shales** and **flagstones.** The rocks of this part of the epoch form almost perpendicular walls on the banks of the Genesee River. This series is also called the **Oneonta sandstone of Vanuxem,** and in a measure resembles the Catskill beds. The upper part of the group consists of the Portage sandstones proper, which are thick-bedded and not very shaly. The sandstones are in alternate hard and soft layers, and on the Genesee River are about 1,000 feet thick. The fossils are not so numerous as in the Chemung group but contain various species of crinoids, brachiopods, and lamellibranches, as well as some fish and plant remains.

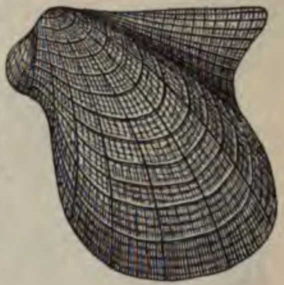


FIG. 8

15. Chemung Epoch.—To the **Chemung epoch** belongs part of the Ohio shales, which are 2,600 feet thick at Wellsville, in that state. These rocks are a series of thin-bedded sandstones and flagstones with intervening shales, and once in a while impure limestone. The whole series weathers to a brownish olive, but the original color of the shales is dark green, while the sandstones are brownish olive to light gray. Toward the upper part of the epoch, the shales are reddish, coarse, and fissile, and are sometimes taken for the Catskill above. The Chemung beds are more than 3,000 feet thick in some localities, such as in Perry and Monroe Counties in Pennsylvania. Seaweeds and land plants are more numerous in this epoch. Fig. 9 shows a


FIG. 9


FIG. 10

Lepidodendron primævum. Fig. 10 shows the *Cyclopteris Jacksoni*, and Fig. 11 shows the longitudinal sections of the wood of a conifer, as both were found in Bowman's Valley, Wyoming County, Pennsylvania. A fossil limestone supposed to be of the Chemung epoch is shown in Fig. 12.

FIG. 11

16. Catskill Epoch.—The first sign between the Chemung and the Catskill is an increase in the hardness of the rock and the red color. The group consists of light-colored gray sandstone usually hard (with a characteristic structure, the layers, 1 or more inches thick, being in oblique

FIG. 12

divisions that overlap); of fine-grained red sandstone, red slate or shale of a brick-red color; and of dark-colored slate and green shale, interstratified with red friable sandstone; these are succeeded by a reddish conglomerate rock. In this group are included the **Eureka shale** of Kansas and Missouri; and the **Cleveland, Erie,** and **Huron shales** of Ohio, which extend from Lake Erie to the Ohio River Valley. The Cleveland shale is at the upper part of the group, and affords many remains of fishes.

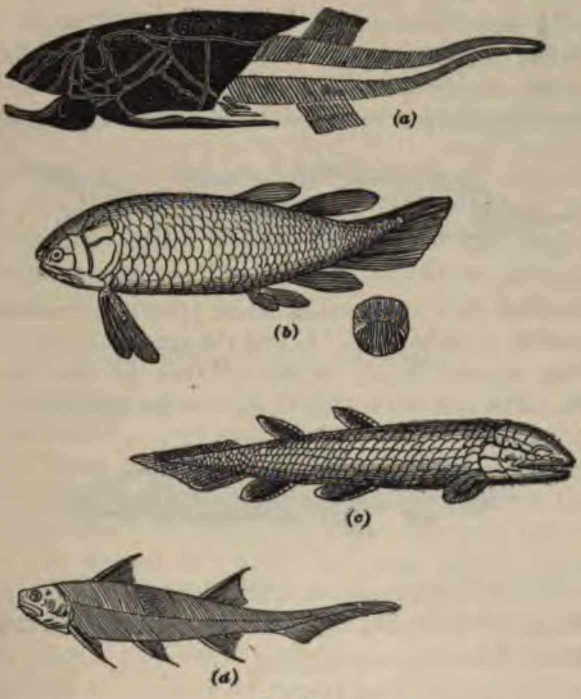


FIG. 13

Oil and gas are quite common in the Catskill rocks. The Devonian rocks are called the old red sandstone because of the color of the Catskill formation at the top of the epoch. The name Devonian was given to this formation because of the rocks outcropping in Devonshire, England.

17. The vertebrates of the Devonian age were nearly all of the fish species termed **ganoids**, although the teeth of sharks are found. The ganoids of this period are shown in Fig. 13 (*a*), (*b*), (*c*), and (*d*). The earliest forms of fishes did not have scales, but had instead horny plates arranged in regular order. Another species had the head and vitals covered with horned plates, and it is supposed that these fishes lived in holes in the mud, only dashing out and exposing their soft bodies when actually pursuing prey. The modern garpike, Fig. 14, and the sturgeon, Fig. 15, are about the nearest living representatives of the Devonian ganoids. The fish shown in Fig. 16 is an inhabitant of the River Nile in Egypt. It is evident from the fossil teeth found that Devonian fish had similar teeth to the sharks of the present day.

FIG. 14

FIG. 15

FIG. 16

DEVONIAN PERIOD IN GENERAL

18. The rocks of the Devonian system are, with one exception, sandstones and gritty shales, with here and there a subordinate layer of limestone. The rocks being sedimentary were formed under water, and are thicker in the Appalachian region than in the interior of North America. The corniferous limestone is an exception to the generality of Devonian rocks, and is one of the great limestones of the continent. The layers contain seams of **hornstone,** or flinty quartz—*cornu* meaning "horn"—and from this peculiarity the rock derives its name. Corals abound in the rock, and are exhibited in great numbers at the falls of the Ohio River near Louisville, Kentucky. The limestone is said to be full of microscopic plants. The land vegetation consisted of lycopods, or ground pines, and tree ferns, and of a low order of conifers. Brachiopods were numerous.

Both the Devonian and the Silurian rocks frequently contain pockets of graphite and pitch, or asphaltum, which seem to have been derived from organic remains of some kind. These organic remains may have been either seaweeds or animals. It is also probable that the natural gas and oil derived from these formations came from the slow distillation of these organic remains after the rocks had become buried under strata and the internal heat of the earth had an opportunity to act on the remains contained in the rock.

CARBONIFEROUS PERIOD

19. Subdivisions.—The Carboniferous rocks are in layers that show plainly that they are of sedimentary origin. Through these sedimentary rocks are found casts of plants, indicating that vegetation was abundant during the periods, for which reason the Carboniferous era has been termed the **Age of Acrogens,** or plants. In some places vegetation must have been very rank, for coal beds are found that have a thickness of 20 feet or more. These coal beds are supposed to have been formed by the compression of peat bogs, and from the very nature of the rocks it is evident that they have been submerged as each stratum was formed. During this era the tracks of amphibians appear in the rocks. These animals carried both lungs and gills and could breathe either air or water, and live either on land or in the sea. The system is subdivided into the Subcarboniferous, the Carboniferous, and the Permian period. The rocks are better defined and have been more thoroughly studied throughout the state of Pennsylvania than elsewhere.

SUBCARBONIFEROUS SYSTEM

20. Vespertine, or Pocono Sandstone. — Rogers divided the Subcarboniferous strata of the Appalachian Mountain region in the United States into Vespertine and Umbral. The former is known as the *Tenth Division* of rocks in the Second Pennsylvania Geological Survey and the lowest division of the anthracite measures; it is also termed **Pocono sandstone.** The name is derived from the Pocono Mountains near the Delaware Water Gap, where the series are coarse gray and yellowish sandstones and silicious conglomerate. These rocks become fine sandstones and dark olive and black shales to the westward. The color of Pocono sandstone readily distinguishes it from the red sandstone, shales, and conglomerate of the Catskill formation below. The Pocono sandstones can be distinguished from the Umbral of Rogers, because they are, in the main, coarse grayish conglomerates and sandstones, while the latter group consists of soft shales mostly of a red color. When red shale is encountered below coal measures it is useless to look further for coal.

21. Umbral, or Mauch Chunk Red Shale.—The **Umbral group** of rocks is the eleventh rock series of the Second Geological Survey of Pennsylvania. The rocks are almost entirely of soft red argillaceous shales, with some red clayey sandstones and limestones. At Mauch Chunk, in Carbon County, Pennsylvania, this group of rocks is 3,000 feet thick. The shales frequently show ripple marks, and crinoids are somewhat numerous in certain localities.

22. Mountain Limestone.—In the Southern and Western United States, the Subcarboniferous rocks are mostly limestones, which replace the Pocono sandstone and Mauch Chunk red shale. The limestone is termed *Mountain*, *Mississippian*, and *Subcarboniferous limestone*. To the west of Pennsylvania the rocks are described in groups, in order to prevent confusion; it must not be understood, however, that Carboniferous limestone is one unbroken mass of limestone in any one locality; on the contrary, it is interspersed with layers of shales, grits, fire-clay beds, and sometimes clay-iron ore.

ILLINOIS SUBDIVISIONS

23. Kinderhook Group.—The Kinderhook series of the Subcarboniferous receives its name from the Illinois subdivisions. It rests on Devonian black shale. The rocks consist of sandstones, grits, shales, and thin beds of oolitic limestone, and have a total thickness that varies from 100 to 200 feet. The **Choteau** and **lithographic** limestones and the **vermicular** sandstones and shales of Missouri are in this group, as well as the **Goniatite limestone** of Rockford, Indiana.

24. Burlington Group. — The **Burlington group** comes next above the Kinderhook. It consists of limestone with cherty layers at the top and nodules of hornstone throughout portions of the limestone. Much of this stone makes excellent building stone. The thickness of the group varies from 25 to 200 feet.

25. Keokuk Group.—The **Keokuk group** is the third from the Devonian. Along the junction with the Burlington limestone there are thin-bedded cherty limestones; the middle portion is a gray limestone, and the upper portion a shaly, argillaceous, magnesian limestone called the **geode bed,** because of the rock abounding in geodes varying from ½ inch to 20 inches in diameter. These geodes are often beautiful, being filled with quartz, calcite, and sometimes metallic mineral crystals.

26. St. Louis Group.—The **St. Louis group** is an evenly bedded limestone at Alton and St. Louis. At Alton, Illinois, the limestone is oolitic, as in Bloomington and in Indiana. At Warsaw, Indiana, the formation contains blue calcareous shales and arenaceous limestone. The celebrated Bedford limestone of Indiana probably belongs in this group. In Kentucky, the St. Louis limestone produces in places **onyx** marble.

27. Chester Group.—The limestone in the **Chester group** is in three or four beds, with intercalated shale and sandstone, and is sometimes 600 feet thick. It includes the **Pentremital** and **Upper Archimedes** limestones; the latter is also termed **Kaskaskia limestone.**

THICKNESS OF THE SUBCARBONIFEROUS

28. In Southwestern Illinois, the Subcarboniferous stratum is said to be 1,500 feet thick; near Chicago there is very little if any Subcarboniferous strata.

In Iowa, there are 175 feet of the Kinderhook beds, 190 feet of the Burlington limestone beds, 50 feet of Keokuk limestone, and 75 feet of St. Louis limestone, or a total of 490 feet.

In Missouri, the total Subcarboniferous limestone is 1,150 feet thick.

In Kentucky and Tennessee, the subdivisions observed in Illinois are not distinct.

In middle Tennessee, Stafford divides the Subcarboniferous into two groups; namely, the silicious and the limestone. The **silicious** from below comprises: (1) the **Protean series,** composed of cherty and argillaceous beds, with some limestone 250 to 300 feet thick; (2) the **Coral series,** containing impure cherty limestone, the equivalent of the St. Louis limestone, 250 feet thick. The limestone or second group is 400 feet thick on the northern border, and 720 feet thick on the southern border of the state. The upper member also extends into Mississippi and Alabama, where it consists of gray limestones, partly oolitic and partly cherty, with some shaly beds; in all, about 900 feet.

In Pennsylvania, the Subcarboniferous strata vary from 6,000 feet thick in the eastern part of the state to about 1,000 feet in the western part.

In West Virginia, the formation thickens in Pocohontas County to more than 2,000 feet, and includes the Big Elephant limestone 822 feet thick. In McDowell County, West Virginia, the formation is mostly sandstones, shales, and limestones, and from well-hole observations must be at least 1,500 feet thick.

The Michigan Subcarboniferous rocks are, according to Winchell, composed of 173 feet of grits and sandstones, called the **Marshall beds;** 123 feet of shales and sandstones, called the **Napoleon beds;** and 184 feet of shales, limestone, and gypsum, termed the **Michigan salt beds.** The gypsum rock, which is drab colored and massive, is made into plaster of Paris. The fourth member is the Carboniferous limestone, 66 feet thick. The Ohio Subcarboniferous is 640 feet thick.

OHIO SUBDIVISIONS

29. The **Waverly group** is the name given to the Subcarboniferous rocks in Ohio, and is subdivided, beginning at the bottom, into **Bedford shale, Berea grit, Berea black shale, Cuyahoga shale, Waverly conglomerate, Logan sandstone,** and **olive shales.**

SUBCARBONIFEROUS COAL BEDS

30. The Subcarboniferous rocks sometimes contain coal, but the beds are not persistent or as valuable as those of the coal measures proper. At Blacksburg, Montgomery County, Virginia, and in several other locations along the Blue Ridge and Alleghany Mountains in Virginia, a semianthracite is found. At Tipton, Pennsylvania, there is another coal deposit. The Pocahontas coal bed in Virginia and West Virginia is assigned to the Subcarboniferous period.

CARBONIFEROUS SYSTEM

31. Coal Measures.—The Carboniferous rocks do not always contain coal formations, for in the West there are no productive coal beds in the measures, although some of the most valuable silver, lead, and copper deposits are found in the limestones of this period that are adjacent to igneous or aqueo-igneous formations. The Carboniferous period in the East is subdivided into Millstone Grit, Lower Productive Coal Measures, Middle Coal Measures, Upper Productive Coal Measures, and Upper Barren Measures.

32. Millstone Grit.—The millstone grit is a mass of grayish sandstone highly silicious. It is the base of the coal measures proper, and rests on the Mauch Chunk red shale, or on the Carboniferous limestone. In the anthracite region of Pennsylvania, the rock is composed of water-rounded pebbles varying in diameter from $\frac{1}{4}$ to 1 inch or more and cemented together; in other coal fields, the grit is composed of angular quartz grains. The rock receives its name from the fact that it was once extensively used for millstones. The Pottsville conglomerate is the equivalent of millstone grit.

33. Lower Productive Coal Measures.—The **Lower Productive group** of sedimentary rocks contains good coal beds in the Eastern Middle States. The rocks consist of sandstone, slate, coal, and fireclay, the latter usually directly underneath the coal beds. The sandstones and slates contain fossil impressions of plants and trees.

34. Middle Coal Measures.—The **Middle Coal group**, while having all the rocks of the upper and lower coal measures, has few workable beds of coal, so that it has received the name of **Barren Coal Measures.** In Logan and Mingo Counties, West Virginia, these measures are quite productive.

35. Upper Productive Coal Measures.—The **Upper Productive Coal Measures** consist of alternate shale, coal, slate, fireclay, and sandstone rocks, and contain workable beds of coal. Probably they are more valuable from a commercial standpoint than the Lower Productive Coal Measures, as they contain the celebrated Pittsburg coal bed.

36. Permian, or Upper Barren, Measures.—The **Permian beds** are composed of shale, limestone, thin beds of coal, and sandstone. At Dunkard Creek, Green County, Pennsylvania, they are about 700 feet thick. The Permian epoch was one of transition between Paleozoic and Mesozoic times. Permio-Carboniferous rocks occur in Kansas, Texas, Indiana, and Mexico. The name is derived from Permia, a province in Russia. The coal measures of Kansas, Missouri, Illinois, Nebraska, Nova Scotia, New Brunswick, and Prince Edward Island are referred to the Permian. Permian beds have been identified in Colorado, Arizona, Utah, New Mexico, and California.

37. Economic Products of the Carboniferous Period.—The principal economic product of the Carboniferous period is coal, which varies from a poor quality to excellent coking coal, and ranges from bituminous shales to cannel coal. Anthracite, or metamorphosed coal, is best developed in Northeastern Pennsylvania, although there are beds of the mineral in Colorado and Utah. Underneath the bituminous coal beds there are beds of fireclay, which is useful for firebrick. The beds of sandstone split into layers, making it possible, whenever coking coal is found, to construct coke ovens at a small cost for building material. The building stones and variegated limestones make this era one of very great importance in architecture. Nor is this all, for in some formations the iron ore *siderite* is found, thus furnishing fuel, flux, and ore in the same locality. The great silver mines at Aspen and Leadville, Colorado, are in the Carboniferous limestone; while the copper mines of Cochise County, Arizona, are in the same formation. While some excellent coal beds exist outside of the Carboniferous, the most persistent, and as a rule the best, belong to this period.

DISTINGUISHING FEATURES IN CARBONIFEROUS ROCKS

38. Coal Flora.—The coal formations are distinguished by plant and shell remains rather than by rocks; nevertheless, any one accustomed to coal formations can distinguish Carboniferous rocks almost without fossil indications. To be an expert in paleontology, one must be able to separate the various families of fossil plants; and unless one is able to distinguish the plants of the Devonian from those of the Carboniferous, and the latter from the more recent, he will be no more certain of his strata than if he depended on rocks alone as a guide. The most common plant impressions in the sandstone and shales are those of trees and ferns. The impressions of the treelike fern stems termed **Lepidodendrons** are shown in Figs. 17, 18, and 19. Fig. 17 represents a **Lepidodendron aculeatum**, a variable species common in the lower coal beds. The fossil shown in Fig. 18 is found in the lower coal beds of Pennsylvania, Kentucky, Arkansas, and Illinois, and is termed **Lepidodendron modulatum.** Fig. 19 shows a fossil called **Lepidodendron obtusum.** There are various other species of tree-like fern stems, which at times attain a length of

FIG. 17

FIG. 18

FIG. 19

100 feet. They first appear in the Upper Devonian mixed with the calamites in the top Chemung-Catskill shales, and persist through the intervening strata to the Barren Coal Measures, where they disappear. The leaves of the Lepidodendrids shown in Fig. 20 are termed **Lepidophyllum**, and their cones, shown in Fig. 21, are called **Lepidostrobus**; they are both found in the same strata as the Lepidodendrons.

FIG. 20

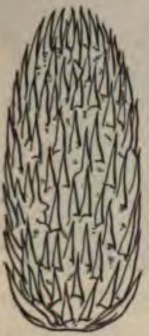
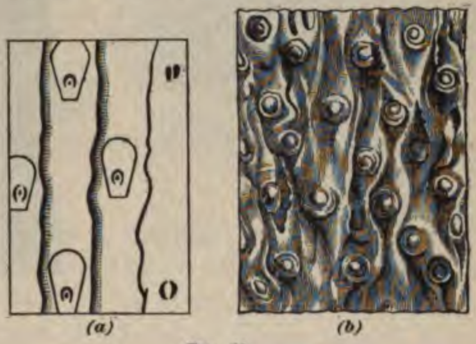


FIG. 21



(a) (b)

FIG. 22

FIG. 23

39. Sigillaria are species of Lycopods, and are similar in some respects to the Lepidodendrids, but differ in having the scars in vertical series, as shown in Fig. 22 (*a*) and (*b*). Sigillaria, Fig. 22 (*a*), and **Stigmaria**, Fig. 22 (*b*), were very common in the Middle Coal Measures, and are peculiar in that their markings on the outside differ materially from those beneath.

40. Calamites, or reeds, are found from the base of the Catskill formation in the Devonian up to the Barren Coal Measures. Fig. 23 illustrates this fossil plant, and there are many others, which assume at times the proportions of small trees. They can be readily distinguished by their reedlike markings.

41. The **Asterophyllites** were plants having leaves or rather little branches in whorls

FIG. 24

FIG. 25

around jointed stems, as shown in Fig. 24. This plant is characteristic of the Upper Coal Measures.

42. Ferns.—There was a large variety of ferns in the Carboniferous era. The most common kind in the Lower Productive and Barren Measures was similar to that shown in Fig. 25, and termed **Sphereopteris.** Another species termed **Neuropteris agustifolia** and shown in Fig. 26, is said to be the commonest fossil plant in the Pennsylvania coal measures—Upper and Lower alike.

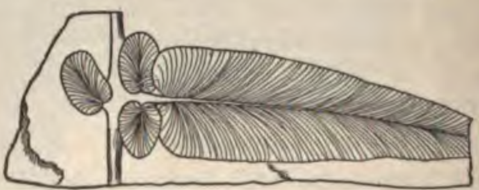


FIG. 26

FIG. 27

43. Trignocarpons are three- or six-sided nuts found in the coal measures, and resemble more nearly the fruit of the yew tree than any other known plant. In Fig. 27 is shown the **Rhabdocarpon,** which is plum-shaped and not three- or six-sided. This is another species of nut found in the Lower Productive Measures and in the highest coal measures, although they do not appear to be so numerous in the latter.


FIG. 28

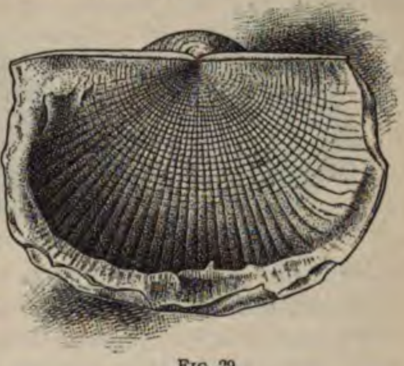


FIG. 29

44. Shells.—The fossils of the shellfish and corals of this period are abundant and fairly well preserved in the shales and sandstone. Fig. 28 shows the **Productus punctatus,** which is one of the best-known shells of the coal measures. It is found in the stratum from the Subcarboniferous to the Permian. There is another **productus,** which is widely known throughout European and American coal formations, and whose shell resembles that of a scallop


(a) (b)
FIG. 30

in that it has both longitudinal and transverse markings, as shown in Fig. 29. The **Spirifera camerata,** a vertical view of which is given in Fig. 30 (*a*), and a dorsal view at (*b*), ranges from the top to the bottom stratum of the coal formations, and is probably one of the most common species. The **Crinoids,** termed **Pentremites** and shown in Fig. 31, are found in large numbers in the Subcarboniferous formations. The **Pleurotomaria,** shown in Fig. 32 (*a*) and (*b*), are found occasionally in the Upper Coal Measures; but somewhat similar fossils are found in the Lower Coal Measures and the Subcarboniferous stratum.


FIG. 31

45. Trilobites are found in the Subcarboniferous strata, but they disappeared during this period. The **Orthoceras,** or straight-chambered cephalopod, disappeared with the end of the Paleozoic time, and became practically, if not quite, extinct during the Devonian age, although the curved or spirally chambered forms continue in great abundance. During the Carboniferous era, fishes became more numerous and attained a higher stage in the scale development than during the Devonian era. Before the end of the Carboniferous the first amphibians appeared. But the characteristic of the Carboniferous period was, as its name indicates, the great


(*a*) (*b*)
FIG. 32

abundance of vegetable life, which resulted in the formation of coal deposits. The vegetable life of the Carboniferous period was of the lower forms, such as our club mosses, ferns, etc. of the present day. There was none of the fruit trees or flowers of the present time, and the dense growth of vegetation in the swamps and on the low grounds resulted in great peat bogs, which finally became the coal seams of the present.

46. At the end of the Carboniferous period the thick deposits of sediment that were so long accumulating in the Appalachian regions were folded and forced up to form the Appalachian Mountains. At the same time, or very soon afterwards, the Utah Basin region was upheaved to form land, while the Nevada Basin region sank to become a sea. In fact, the Pacific shore line was transferred eastwards, but there still remained a narrow sea between the Appalachian Mountains and what are now the Rocky Mountains.

PERMIAN SYSTEM

47. The Permian period is usually classed with the Carboniferous period, but is in reality the transition period between the Paleozoic and the Mesozoic time. In North America, the transition between the two periods was marked by great changes in the continent. The Appalachian Mountains were forced up from the sea bed, and many extensive changes took place in the western portion of the country; hence, in most places the Permian is entirely wanting in this country, but is present in parts of Illinois, Kansas, Oklahoma, Texas Panhandle, and some other localities.

MESOZOIC ERA

48. **Subdivisions.**—**Mesozoic,** or medieval, time contains a single era only, and is termed the **age of reptiles.** It is divided by the United States Geological Survey into two periods; namely, the **Jura-Trias** and the **Cretaceous.** Foreign geologists, however, divide the time into three periods; namely the **Triassic,** the **Jurassic,** and the **Cretaceous.** In the United States, the three-bed period, or Trias, is not well developed, and the Jurassic—named after the Jura Mountains in Switzerland and France—make a continuous series not easily separated; hence the term Jura-Trias. At the time that the Mesozoic beds were forming, the Appalachian district was probably dry land, while to the west was an inland sea, and to the east the Triassic was formed from the Hudson River in New York to the Deep River in North Carolina. The rocks also appear in the Connecticut River valley, and at Newark, New Jersey. There is a Gulf border, and an Arctic area of these formations. The brownstones of Connecticut, Newark, New Jersey, and Manassas, Virginia, are of this formation. This stone is used largely for house fronts in New York City, but it does not always weather well. The rocks are mostly sandstones, conglomerates, sandy shales, and sometimes fine black shales and coal, together with thin impure beds of limestone. This stone is termed the **new red sandstone,** to distinguish it from the **old red sandstone** of the Catskill formation.

The Palisades opposite New York City are Triassic; that is, they are basaltic rocks that were forced from below through fissures in the Triassic formation. Wherever geological features of this description are discovered, the rocks are referred to as belonging to the age in which they were erupted.

JURA-TRIAS PERIOD

49. The Triassic formation is exposed in Northern Texas, Indian Territory, and Western Kansas. The formation exists about the Black Hills of Dakota, on the summit of the Rocky Mountains in New Mexico, Colorado, and Utah, as also in Wyoming, Montana, and Idaho. West of the Rocky Mountains over the Great Basin Plateau, and the plateau region of British Columbia, the strata have been observed. They are also found in Mexico and Honduras. Their existence in the eastern part of the United States has already been mentioned.

50. Jurassic rocks are reported at the base of the Black Hills in Dakota, along the base of the Laramie, Big Horn, Wind River, and other mountains in the chain. The Upper Jurassic, or **Rhætic,** in Colorado, Wyoming, and Montana contains the remains of large animals. The rocks are also found along the western slope of the Sierra Nevada, where they contain the auriferous slates of California. The Jurassic rocks seem to have been mostly fresh-water deposits. Numerous trap dikes have burst through the red shale and sandstone of the Jura-Trias since they were deposited.

CRETACEOUS PERIOD

51. Subdivisions.—The formations termed **Cretaceous,** from the Latin word for chalk, are divided in the United States and Canada into the Atlantic and Gulf area, the Interior area, and the Pacific Coast areas. These are subdivided locally in each district, and, while limited in area and thickness in the East, they cover a large area in the West, attaining 9,000 feet in thickness. The chalk rocks of England belong to this epoch, but chalk in this country seems to be limited to the vicinity of Trego, Kansas, where an area of 3,750 square miles is said to exist.

Besides fresh-water limestone beds, the formation contains coal deposits, which are mostly lignite. As stated, there is not much, if any, Carboniferous coal in the West; consequently, the Tertiary and Cretaceous formations are the sources of supply.

52. **Atlantic and Gulf Area.**—The **Potomac group** belongs to the Lower Cretaceous. It consists mostly of granitic sandstones and conglomerates, loosely aggregated and irregularly bedded, with clay beds in the upper portion. It extends from Delaware to Weldon, North Carolina, in a belt seldom over 10 miles wide.

The Northern Gulf border or the **Tuscaloosa group** is located in Alabama, and consists of clay and sand beds containing impressions of leaves.

53. The **Eutaw group** in Mississippi is also in this period, and is from 3,000 to 4,000 feet thick, and while generally of a similar character to the Potomac and Tuscaloosa groups contains some lignite. The Eutaw group consists of unconsolidated sands and dark-tinted clays. Above this is a fine micaceous sand of greenish tint, but sometimes with other colors (even an orange red), termed the **Tombigbee sand.**

The formation termed the **rotten limestone** has a thickness of 700 feet in the southwestern part of Alabama, but thins to about 100 feet at the Tennessee line. This is a white or yellowish white stone at the surface, but darkens with depth.

The **Ripley formation** is the topmost series of the Eutaw group. It is composed of a hard crystalline limestone, with the highest strata of bluish micaceous marls more or less sandy covered, with a gray calcareous clay.

UPPER CRETACEOUS SYSTEM

54. **Raritan Epoch.**—In New Jersey, along the coast, there are beds of green sand or marl interstratified with beds of common sand, clay, and occasionally marine shells. They are fresh-water beds, probably, since they contain plastic clay, fossil leaves, and lignite, and are supposed to be equivalent to the Dakota marine of the interior.

55. Western Gulf Area of the Upper Cretaceous. According to R. T. Hill, the Western Gulf area of beds extends from Arkansas westwards into the northeastern states of Mexico. The *Lower Cross Timber Sands* 300 feet thick are overlaid with the **Eagle Ford shales** 500 feet thick; then above the latter comes the Austin limestone 300 to 500 feet thick; and finally above these come the **Navarro** or **Eagle Pass beds** of green sand overlaid with chalk and marls. The **Laramie beds** of Western Texas are classed in this area.

INTERIOR AREA OF THE LOWER CRETACEOUS SYSTEM

56. The beds of the **Comanche series** are mostly marine, and reach a thickness of 5,000 feet on the Rio Grande. They extend from Kansas into Indian Territory and through Texas into Mexico. R. T. Hill divides them into the *Trinity*, *Fredericksburg*, and *Washita* epochs, with subdivisions. They consist mostly of limestones that are partly chalk, clays, and sands. The Comanche series are referred to the Texas area of the Lower Cretaceous.

57. Trinity Epoch.—The **Trinity group** of rocks consists at its bottom of sands with fossil leaves and lignite that are known as **Trinity sands.** Above the sands come the **Glen Rose beds,** which are sandy below and calcareous above. They contain some vegetable, reptilian, and marine fossils. Above these latter beds come the **Palway sands.**

58. Fredericksburg Epoch.—The **Fredericksburg group** begins with **Walnut clays,** followed by **Comanche Peak chalk,** and is topped with **Caprian** or **Austin limestone.**

59. Washita Epoch.—The lowest beds of the **Washita group** are termed **Preston** and consist of chalk (found at Duck Creek) and Kianutia clays. The **Fort Worth** or **Washita limestone** is next above the Preston, and above them come the **Denison sands,** clays, and limestones. The **School Creek** limestone is the topmost bed of the series.

INTERIOR UPPER CRETACEOUS SYSTEM

60. Dakota Epoch.—The **Dakota group** of rocks is placed at the base of the Interior Cretaceous period. These rocks are composed of clays, lignite, and sandstone beds, the latter below the lignite assuming the character of conglomerate. Fossil leaves are abundant, showing that the deposits were of fresh-water origin. The Bear River, Wyoming, coal beds probably belong to this group.

61. Colorado Epoch.—The lowest beds of the **Colorado group** are termed the **Fort Benton,** after the place of that name in Montana, where laminated clays and limestones are found that are said to have a maximum thickness of 1,000 feet. The **Coalville beds** of Utah, 1,500 feet thick, including the coal bed, are classed in this group by Stanton. The upper group of this epoch is termed **Niobrara** and attains a thickness of 2,000 feet; it consists of marls, chalks, shales, sandstones, and limestones.

62. Montana Epoch.—The **Montana group** of rocks reaches a maximum thickness of 8,700 feet. The lowest, **Fort Pierre,** group consists of clays, sand beds with limestone concretions, and marine fossils. The **Fox Hills beds,** which is the name given to the beds above the Fort Pierre, consist of sandstones and shales with marine fossils; their maximum thickness is given as 1,000 feet.

63. Laramie Epoch.—The **Laramie group** is divided into the Lower and the Upper Laramie. The length of the Laramie Interior Sea was nearly 2,000 miles, and another sea in the Mackenzie Valley area was 500 miles long, and probably opened into the Arctic Ocean.

Although the waters were generally fresh, still sea saurians and sharks ascended to Dakota.

64. The **Lower Laramie** consists of fresh-water cross-bedded sandstones, with clay beds; occasionally, there are fossiliferous brackish water and bituminous coal beds—there being, in some instances, fifteen to twenty coal beds in

1,000 feet. The maximum thickness of this group is given as 5,000 feet.

The coal beds of the West are nearly all of this group, Colorado alone having an area of 18,000 square miles; Utah, Wyoming, Montana, and New Mexico have also large coal areas. Fig. 33 is a cross-section of the Laramie Cretaceous coal measures under Pilot Knob Mountain, Colorado.

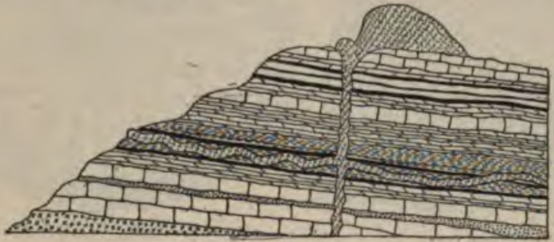


FIG. 33

65. The **Upper Laramie**, or **Denver group**, derives its name from its distribution about the city of Denver, Colorado; it overlies the Lower Laramie. Geologists seem to differ in regard to the location of these beds, some placing them in the Cretaceous period and others in the Eocene period of the Cenozoic era. The Denver group may probably be referred to the Cretaceous, and consists of the Arapaho and Denver fresh-water beds of sandstone and conglomerates, as well as of partly eruptive material, forming andesitic beds or old conglomerate, either with or without coal beds.

PACIFIC AND CANADIAN LOWER CRETACEOUS SYSTEM

66. The Lower Cretaceous beds of the Pacific Coast in the United States are marine; in British Columbia, they are partly of fresh-water origin. Dawson describes them as extending from Washington northwards to the Yukon district and then to the Arctic Ocean. They border the coast of California and Oregon, extending thence to Vancouver Island, and are found again far north on the shores of the Alaskan Peninsula. The beds in California are termed the **Shasta**

group, and are divided into the **Knoxville** and the **Horsetown beds.** The total thickness of this group in Tehama County is 26,000 feet. In Shasta County, where the Horsetown beds alone occur, the thickness is 5,200 feet. The Knoxville group has forms of mollusks of the **oyster** family shown in Fig. 34; while the Horsetown beds contain **Ammonites**, such as are shown in Fig. 35, that attain a diameter of $2\frac{1}{2}$ feet.

FIG. 34

FIG. 35

PACIFIC UPPER CRETACEOUS BEDS

67. The Pacific Upper Cretaceous beds extended originally from Lower California in a broad belt to the Queen Charlotte Islands. The Upper Cretaceous of California at present includes only the **Chico beds.** These beds, which are said to be 4,000 feet thick in Tehama County, California, are considered to be marine sandstones and conglomerates. In Canada, they are supposed to be correlative with the **Belly River group**, which contains fossil leaves and is a fresh-water deposit.

Correlative with the Chico beds are the **Nanaimo beds**, on the eastern side of Vancouver Island. **Tejon beds** are absent in California, and in Washington the **Puget group** underlies them. This latter group is non-marine in parts and contains coal beds. They extend from near Columbia to the Puget Sound region and are several thousand feet in thickness.

CENOZOIC ERA

TERTIARY PERIOD

68. Chronology.—The United States Geological Survey has divided the Cenozoic era into three periods. Dana divides it into two ages; namely, the Tertiary, or age of mammals, and the Quaternary, or age of man. The Tertiary system was divided by Lyell into three periods, which were named in proportion to the living and extinct species of shellfish they contained.

The term **Cenozoic** means "recent time" in the geological sense; the lowest subdivision of the era is termed **Eocene,** or the dawn of recent life. Either no species whatever or less than 5 per cent. of any of the species of the Eocene has persisted to the present.

The second period, termed the **Miocene,** meaning "less recent life," contained from 20 to 40 per cent. of the species living at present. The **Pliocene period,** meaning "more recent life," contains species of which more than one-half are now living. The Miocene and Pliocene are united under the term **Neocene,** when they are not readily separated, the term meaning "new and recent." The United States Geological Survey follows this method in its work, and to complete the Cenozoic era adds the **Pleistocene,** meaning "most recent." For the Eocene and Neocene, the Atlantic, Gulf, and Interior areas are described separately. The Tejon and Puget Sound groups have already been mentioned; but as they are supposed to be in part at least in this era they are repeated here.

ATLANTIC AND GULF EOCENE SYSTEM

69. Midway Epoch.—The lowest epoch of the Atlantic and Gulf Eocene system is termed the **Midway epoch,** and is represented by the calcareous beds near Midway, Alabama.

70. Lignitic Epoch.—The **Lignitic group** is represented by the lignite beds between the Mathews Landing clays and the Buhrstone of the Lower Claiborne epoch.

71. Lower Claiborne Epoch.—The **Lower Claiborne epoch** includes the Buhrstone of Alabama, Georgia, and South Carolina, and the silicious and calcareous Claiborne formation of Mississippi.

72. Claiborne Epoch.—The **Claiborne epoch** is the upper part of the Claiborne of Conrad, and occurs along the Alabama and Tombigbee Rivers in Alabama.

73. Jackson Epoch.—The white limestone near Jackson, Mississippi, represents, according to Conrad's subdivision, the **Jackson epoch.**

74. Vicksburg Epoch.—The **Vicksburg epoch** is named from the white limestone beds of Vicksburg, Mississippi. Correlative with the Jackson and Vicksburg epochs are the white limestones of the Ashley, Cooper, and Santee River beds.

LACUSTRINE AREA OF EOCENE SYSTEM

75. Lower Eocene.—In the interior of the United States, the Eocene period is represented by three groups, which are in turn subdivided. As the Arapaho and Denver groups have been described, they will not be repeated, although they are, by some, placed as the lower members of the Lower Eocene.

76. Puerco Group.—The **Puerco group** of rocks is named from the Puerco River in New Mexico. These rocks extend into Colorado and are located geologically just above the Denver group. The rocks are fine-grained sandstones, shales, and limestones, usually soft and fragile.

77. Wasatch Group.—The **Wasatch rocks** cover part of Utah, Wyoming, and Colorado. They are supposed to be correlative with the **Vermilion group** of King and the **Bitter Creek group** of Powell.

78. Middle Eocene.—The **Manti beds** of Cope, which occur in Sevier and San Pete Counties, Utah, are similar in character and fossils to those of the Green River basin, in Wyoming.

79. Amyzon Beds.—The **Amyzon beds** are difficult to correlate, some placing them between the Unita and the White River beds. They occur in Northeastern Nevada, in South Park, Colorado, and in Central Oregon. The Amyzon formations are largely made up of volcanic tufa, and are famous for their fossil insects.

80. Wind River Beds.—The **Wind River beds** are situated to the north of the Unita Mountains, in Wyoming, and consist of impure limestones and thin calcareous shales. The **Green River beds,** which are very nearly if not the same general formation as the Wind River beds, are situated mostly in Wyoming and cover an area of 5,000 square miles. Both formations have a thickness of about 4,000 feet, and are especially noted for their fossil fishes and insects. These beds are included, by King, in the Bad Lands of the Wasatch Mountains.

UPPER EOCENE SYSTEM

81. Huerfano Group.—The **Huerfano group** of rocks is to the east of the Front Range Mountains in Huerfano and Las Animas Counties, Southern Colorado.

82. The **Bridger group,** named after Fort Bridger, Wyoming, overlies the Wasatch group, north of the Unita Mountains. According to Marsh, this group contains the fossiliferous remains of the dinoceras, the skeleton of which is represented in Fig. 36.

83. Unita Beds.—The **Unita beds** are to the south of the Unita Mountains in Utah. They are the **Tapir beds** of Marsh, and include the **Brown's Park** group of Powell. The Unita basin has a height of 10,000 feet above sea level. The peculiarities of the Eocene period are: that its rocks

are confined mostly to the summit region of the Rocky Mountains; that the rocks are lacustrine, or formed in lakes; that their fossils are large extinct animals; and that their leaves, fishes, and insects are somewhat related to species of the present time.

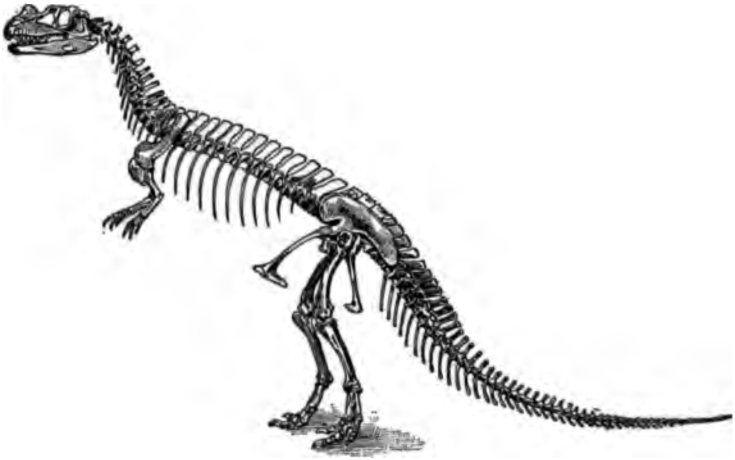


FIG. 36

ATLANTIC AND GULF AREA OF NEOCENE SYSTEM

84. Chattahoochee Epoch.—The exposures of the Neocene rocks are shown along the Chattahooche River in Southwestern Georgia and Northwestern Florida. They have a thickness of about 200 feet, and consist of clay, marl, and limestone. Correlative with these are the phosphatic oolite, ferruginous gravel, and green clays termed the **Hawthorn beds** of Central Florida, the **Tampa limestone** of Southern Florida, and the **Altamaha grits** of Georgia.

85. Chipola Epoch.—The beds of the **Chipola epoch** are named from an exposure on the Chipola River in Northwestern Florida. The Chipola sands are remarkable for their number of fossil shells, nearly 400 species having been found in a bed but 16 feet thick.

86. Yorktown Epoch.—The **Yorktown epoch** is that called the **Chesapeake** by the United States Geological Survey. This epoch, which derives its name from Yorktown, Virginia, lies above the Chipola. The **Ashley** marl bed containing phosphate nodules probably belongs to this group. Beds considered as belonging to this epoch are found in Eastern Maryland, New Jersey, and at Martha's Vineyard.

87. Floridan Epoch.—The beds of the **Floridan epoch** have now, by agreement, been termed the **Lafayette group.** They are probably a formation of the glacial period, containing marine deposits and phosphate bone deposits of animals whose skeleton fossils have been found in earlier rocks, as well as those found in later rocks.

LACUSTRINE AREAS OF NEOCENE SYSTEM

88. John Day Beds.—The beds known as the **John Day beds** were deposited in a great water body called Lake John Day which existed in Tertiary times between the Cascade and the Rocky Mountains, or that area now drained by the Columbia River. The rocks for the most part are of unconsolidated sand and clay, together with large quantities of volcanic dust. They have a thickness in some localities of 1,000 feet.

89. Columbia Lava.—Just below the John Day beds there is found the largest igneous overflow known. It covers a part of Washington, Oregon, California, and Idaho —an area, according to I. C. Russell, of 200,000 square miles—and has an average depth of 2,000 feet. The overflow is said to be basalt, and is termed the **Columbia lava,** by Russell.

90. Kittitas Coal Beds.—The **Kittitas coal beds** are found in a series of sandstones and shales below the Columbia lava, and rest on the oldest crystalline rocks. The system is well exposed, and may belong to the same group as the Laramie or Lignite beds to the east and south.

91. White River Group.—The **White River group** consists of variegated clays, together with sandstones and conglomerates. Above these are sandstones and nodulous clays, in all about 480 feet. These rocks have been formed by erosion, and are termed the Bad Lands of Dakota and Colorado in the White River basin.

92. Ticholeptus Beds.—The **Ticholeptus beds** outcrop on Cottonwood Creek, in Oregon. They are also found in Western Nebraska, and are known in Montana as the **Deep Creek beds** of the Deep Creek River valley near Helena. The beds are hard cream-colored clays overlaid with the loose beds of coarse and fine material of the Loup Fork beds.

93. Loup Fork Group.—The **Loup Fork beds** extend from the Loup Fork of Platte River in Central Nebraska southwards interruptedly to Mexico, occurring in New Mexico on the Rio Grande, Gila, and San Francisco Rivers. They contain the Philohippus of Marsh, although fossils are rare. These beds are conformable to the White River beds, so that it is difficult to tell them apart.

The **Blanco Cañon beds** of clays and sands, which are about 150 feet thick on the Staked Plains of Western Texas, are supposed to lie above the Loup Fork beds and to be the most recent of the Neocene period.

QUATERNARY PERIOD

PLEISTOCENE SYSTEM

94. Divisions.—The **Pleistocene** system is divided into two epochs; namely, the Glacial and the Post-Glacial. The Pleistocene system was attended with changes of climate and oscillations on the earth's crust, so that great sheets of ice came from the north and overspread the northern part of North America. There was more than one of these ice flows, and more than one period of ice melting and the formation of ice rivers. Some geologists, however, think that the continent was submerged, and that the ice marks and the drift left all over the northern part of North America are due to icebergs that came down from the north. Both theories are more or less founded on facts, for icebergs and glaciers are acting in the same way today, the latter bringing down, from the high mountains where they are formed, pieces of rock, and depositing them, thus forming drift deposits of terminal moraine. Icebergs carry their detrius out to sea, and in melting deposit it to form banks such as the Newfoundland Banks.

GLACIAL EPOCHS

95. Subdivisions.—The Glacial epoch is divided by the United States Geological Survey into three glacial epochs and two interglacial epochs. This is done because there are evidences that three glaciers spread over the land, and that deposits of alluvium took place between them.

96. First Glacial Epoch.—The limit of the glacier of the First epoch is marked by the moraine left especially along its eastern part. To the west it formed what has been spoken of as the **Lafayette beds** and **orange sands.** The extreme limit is best shown by the glacial marks left on the rocks. Fig. 37 is an illustration of a rock showing striations due to glacial action.

FIG. 37

The most eastern end of the glacier of this epoch is found at Cape Cod, Massachusetts, and from its markings and drift it is traced into Northeastern Pennsylvania, touching the southern border of New York; thence southwest through Ohio to the Ohio River; thence, crossing the Mississippi, it follows the Missouri River; and then passes into and through Montana into British America. Its rocks are the lower till of the interior and the extra-moraine drift of Pennsylvania and New Jersey. Part of the loess, yellow loam, and Port Hudson clays of Lower Mississippi, with the formation in the Eastern United States, is attributed to this epoch. While in places the moraine is quite thick, it is not so thick as that of later epochs. The glacial marks that are to be seen in the Lackawanna and Wyoming Valleys of Pennsylvania were probably formed at this time.

97. **First Interglacial Epoch.**—After reaching its limit, the ice sheet probably retreated to or beyond the Great Lakes. This epoch is marked by the buried forests of Iowa, Illinois, and other interior states, with old soils, nodules, and ferruginous accumulations; also by erosions toward the Atlantic Coast. The Wyoming Valley of Northeastern Pennsylvania has deep alluvium deposits in its basin, which probably accumulated at this time.

98. **Second Glacial Epoch.**—The second advance of the ice sheet is marked by a very distinct and nearly continuous moraine. In the eastern part, this second ice sheet is not distinguishable from the first, but in Ohio the two moraines divide. The second moraine is in a series of looping curves about the Great Lakes, through Iowa, thence northwards, through North Missouri and Dakota, into British America. The rocks are the upper till of the interior, with most of the loess of the Missouri and Mississippi Rivers, and the older glacial deposits toward the boundary between the United States and Canada.

99. **Second Interglacial Epoch.**—The retreat of the second glacier was slow, as is shown by the forest beds, buried soils, and alluvial deposits. The epoch is principally represented by erosion.

100. **Third Glacial Epoch.**—There seems to have been several smaller glacial advances and retreats; hence, they are placed under the heading of the Third Glacial Epoch. The terminal moraines and aqueo-glacial deposits of the Northern United States and Canada, as well as of the Rocky Mountains

and the Sierras, were supposed to have been laid down in this epoch. Probably the **Bonneville beds**—which were named after the explorer Bonneville, who visited the Great Salt Lake basin of Utah—belong to this period. These lake beds appear as a very perfect series of beaches on the adjacent mountain slopes. A similar lake, though smaller, that once occupied the low grounds of Nevada is known as **Lake Lahontan.** The deposits of this period, when not sand, were traventine marble, somewhat concretionary in structure and unlike the even-grained structure of ordinary marble. Lake Mono in the Great Basin probably belongs, at least in part, to this epoch.

POST-GLACIAL PERIOD

101. Champlain or Ice-Melting Epoch.—During the melting of the glaciers there was probably a sinking of the land; at least, all indications—such as old sea and lake margins, old river terraces, and old flood-plain deposits—point to such depressions. The inland beaches and deposits of the interior containing **Leda minuta** fossils were called by Dawson **Leda clays;** they are found in various parts of the continent, as are also the **Saxicava sands,** with various marine and lake beaches and deposits in Canada. Above these deposits are high alluvial plains and second bottoms in the North, with mud flats and clay deposits in the West. Marine and lake clays in the Hudson River, Champlain, and New England Valleys are also correlated with this epoch. The sands, gravels, and clays in the Champlain Valley are quite conspicuous, and give to this epoch its name.

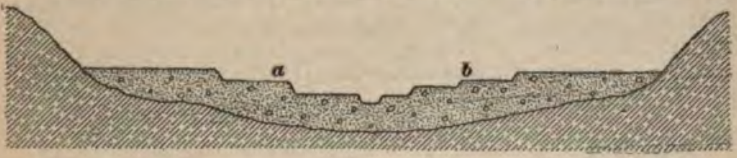


FIG. 38

102. Terrace Epoch.—As the ice retreated, the surface waters resumed their work, and many preglacial valleys were filled. As the waters continued to subside, terraces along river valleys were formed, as well as along lakes and seashores in higher latitudes. Fig. 38 shows the terraces *a* and *b* similar to those along the Connecticut River in New Hampshire, and presumably made during this period.

PSYCHOZOIC ERA

RECENT PERIOD

103. Rocks of Recent Formations.—The formations of the Psychozoic era are such as are now in progress of development over the land, along sea borders, or in the seas. They are: (1) of mechanical origin, such as are developed by seas, rivers, winds, glaciers, etc.; (2) of chemical origin, such as stalactites, stalagmites, hot springs, iron ore, etc.; (3) of organic origin, such as shell limestones, coral reefs, sponges, peat-bog deposits, etc.; and (4) of igneous origin, such as volcanic eruptions, igneous injections, etc. The formations enumerated are not always distinguishable from the Champlain epoch, but the remains of mammals, and especially the relics of man when present, afford assistance to their correlation.

104. Brute Mammals.—The mammals of the British Isles and Europe were of great size, and consisted of the mammoth, bear, rhinoceros, hippopotamus, deer, cave lion, cave bear, horse, hare, etc. The flesh-eating animals in America were not so numerous as in Europe, but were of large size. The mammals of North America were as large as the European, the mastodon in particular attaining a great size. The remains of this now extinct animal have been found pretty generally from Nova Scotia to Texas. The horse and other animals whose remains are found were of larger size than their kind of the present time. From the size and character of the fossil remains of the animals, it appears evident that the climate ranged from the warm temperate to an extreme cold temperature. From the fact that, at the present time in Siberia, mammoths are found frozen in the ice, it is presumed that the changes from temperate to extreme cold were very sudden—a supposition that is further borne out by many of the animals having long hair.

105. Human Relics.—Among the relics of prehistoric men found buried are human bones, stone arrowheads, lance heads, hatchets, and pestles; also arrowheads, harpoon heads, and other implements made of horn or bone from reindeer or other animals. There have been found bored teeth, bones, and shells; cut wood, bone, ivory, or stone with rude carvings on them suggesting animals, and fragments of charcoal and pottery—all of which may be termed relics of the **stone age.**

In later deposits, bronze implements occur, then iron, and with the latter coins, inscribed tables of stone, etc.; which have been buried in such cities as Nineveh and Pompeii. Civilization in the past, as in the present, depended on the natural resources of a country and the ability of the people of that country to make them useful. Those whose intelligence permitted them to make use of their natural resources overcame the less civilized nations, as they do today. At the present time, the civilization of a country depends on its mineral resources of coal, iron, and copper, and the ability of its people to work the metallic products into tools and implements, which not only add to the wealth of their own country but also to those of other countries. Geology is but one branch of the great civilizing industry of mining and metallurgy, on which all other industries depend.

106. Antiquity of Man.—Archeologists have divided the history of human civilization into three ages, which have been termed the **stone age**, the **bronze age**, and the **iron age.** The stone age was divided into the **old stone age** and the **newer stone age**, from the fact that in the old stone age only chipped-stone implements were used, while in the latter polished-stone implements were used. Still closer study has resulted in some considering that the stone age was contemporaneous with the mammoth and later on with the reindeer. The Mammoth age is supposed to be correlative with the Champlain epoch, but perhaps with the interglacial; while the Reindeer age is supposed to be still later, corresponding with the Second Glacial epoch. This carries man back to the Champlain epoch. Further back than this no reliable evidences of man's existence on the earth are to be found.

107. Mammoth Age.—In the terraces of the river Somme, chipped-flint implements associated with bones of the mammoth, rhinoceros, hippopotamus, hyena, horse, etc. are found. These fossils were in unstratified gravels beneath the river loam 20 to 30 feet. Supposing that the upper loam represents the full Champlain flood deposits, then that underneath would represent the earlier Champlain epoch. In the caves of Belgium and in Germany, human bones have been found associated with extinct animals. In a cave at Neanderthal, near Düsseldorf, Prussia, a very remarkable human skeleton was found. The limb bones are large and the protuberances for muscular attachments were very prominent; the skull was quite thick, very low in the arch, and very prominent in the brow. This has been supposed by some to be an intermediate form between man and the ape; according, however, to the best authorities, it is in no respect intermediate but truly human.

Recently, there have been found in a cave at Spy, Belgium, two nearly complete skeletons, which seem to be of the same type as the Düsseldorf skeleton, and hence are supposed to belong to a distinct and very early race. Several years ago, an almost perfect skeleton was found in a cave at Mentone, near Nice. It is that of a tall well-formed man with more than the average-sized skull. The antiquity of this man is undoubted, for his bones are associated with those of the cave lion, cave bear, rhinoceros, and reindeer, together with living species. The bones of the skeleton were all in place, and were surrounded with flint implements.

108. Reindeer Age.—During the Reindeer age man was associated with animals, especially the reindeer. The implements he used were well chipped and were much more neatly made. A sepulchral cave accidently discovered by a French peasant was found to contain seventeen human skeletons of both sexes and of all sizes, associated with the entire bones of extinct animals and with works of art. Outside the cave was found a deposit consisting of ashes and cinders mingled with burned and split bones of recent and extinct animals and with works of art. Among these animals were the carniverous and the herbiferous, the latter including the mammoth, rhinoceros, horse, Irish elk, and reindeer. From this it is evident that, in Europe at least, the earliest man was contemporaneous with a large number of extinct animals.

Several cases are reported of human bones and works of art having been found in the sublava drift of Double Mountain, Colorado. One specimen termed the **Calveras skull** and mentioned by Whitney was afterwards declared to be a hoax. From time to time, skeletons are found that are not classified; but it is evident that the first appearance of man in America seems to have been at about the same time as his appearance in Europe. On the Pacific Coast, his implements were found in great abundance in river gravels associated with the remains of the mammoth, the great mastodon, and the horse. The history of the American man can be traced onwards in refuse heaps and shell mounds, and in the great mounds of the so-called mound builders, which are scattered over the eastern part of the continent, but are especially abundant in the valley of the Mississippi. There are also relics of a class of people, now extinct, preserved in the cliff dwellings and buried cities of New Mexico and Arizona. Scientists have been endeavoring from time to time to connect the genealogy of man with the lower animals; but, although they have searched diligently, they have so far failed to find the missing link. There is no doubt, however, that very great changes both in the structure of the earth and in the animals inhabiting it have taken place since man appeared. The bronze and the iron ages are those of history. Recently, there has been found in the Lake Superior copper regions, tools made of copper that are supposed to belong to some extinct race.

PROSPECTING

(PART 1)

QUALIFICATIONS FOR PROSPECTING

INTRODUCTION

1. Prospecting is seeking for indications that denote the presence of minerals. The term suggests that a knowledge of the minerals sought is an essential qualification, in order that they may be recognized when found. The conditions of the minerals' formation and the kinds of rock in which it usually occurs should also be understood by the prospector. Prospecting involves labor; for, after a mineral is found, it must be sufficiently developed to determine whether it is valuable enough to warrant the expense of mining it. Besides the work of digging and drilling, the prospector is usually compelled to do his own blacksmithing and cooking. In short, while prospecting is generally a very healthful occupation and allows, at times, of hunting and fishing, at the best, it is hard work, for which reason many of those who engage in it are strong men inured to hardship.

One of the chief requisites to success in prospecting is good eyesight, so that any unusual condition or change in the ground will be instantly noted. This faculty of observation is largely a matter of habit; a skilled prospector has his eye so trained by experience that, in passing over the ground, anything unusual, no matter how slight, is sufficient to make him stop and investigate.

2. The Element of Chance in Prospecting.—Chance undoubtedly enters largely into prospecting; for many cases could be cited of men ignorant of ore deposits finding paying properties, while men thoroughly understanding the ores of similar metals have been unable to locate them. As a general rule, however, the man who is familiar with metalliferous ores will be most successful in the search for them. When a prospector, through a lucky chance, strikes a body of ore that is rich in immediate returns, he achieves a sudden notoriety; while the finding of an equally valuable ore body that is not so promising in quick results is frequently treated as of little consequence. Bonanzas are not plentiful enough to go round; what prospectors usually find are mostly low-grade ores, which require considerable development to prove their value and justify the expenditure of much labor and time on them. As low-grade ores are not easily detected, it is all the more important that the prospector have an educational equipment for his business—especially as the number of prospectors in the field is large.

3. Prejudiced Prospectors.—While miners are, from the nature of their work, particularly well seasoned for prospecting, as a rule they lack sufficient knowledge of minerals and geology. They may be well acquainted with the rocks surrounding the mines in which they have worked, and arguing from this standpoint they start out on a prospecting trip. If, for example, they have worked in a silver-lead mine, they will hunt for rocks similar to those with which they are familiar, and probably pass over ground that is rich in gold or some other valuable mineral. On the other hand, the gold miner may pass over silver or gold ore different from that which he has been accustomed to mine. The placer miner may pass over minerals of value, and hunt for the mother lode, expecting to find in that lode nuggets of gold similar to those found in the placer, when as a matter of fact such has never proved to be the case. Mining occupies an anomalous position, for, while it is one of the best of preliminary educations for prospecting, it is also one of the worst, if the miner is in any way stubborn or notional, or thinks he knows it all. Men who are free from prejudice and not always ready to jump at conclusions will probably make the best prospectors, provided they are properly equipped otherwise. There are many men prospecting who are absolutely unfitted for the work. Some cannot tell gold when they see it; others think they have found mineral every time the color of a rock changes; in fact, the majority of prospectors are pot hunters, expending their energies on useless work, in places where mineral in paying quantities could not exist. Mineral fiends that expend their time looking for minerals that they could not recognize if found, are in every locality. Men of this description always imagine that they have an abundance of valuable minerals, which on investigation prove to be worthless, or in quantities insufficient for mining purposes; and, in case they do stumble on a valuable proposition, they are unable to handle it to their advantage.

4. **The Study of Ore Deposits.**—A good plan for prospectors to adopt is to go from place to place where minerals are known to exist, and in that way become accustomed to geological conditions and mineral formations. However, before one can properly prospect, he must possess a general knowledge of useful minerals and their geology. The other qualifications that a prospector should have are perseverance and the physical ability to withstand sudden changes of weather, and fatigue, although many sick men have been made well by the outdoor air and rough living.

In selecting a district for prospecting, the geology of the region should first be studied. No attention should be paid to the fact that others have left prospect holes, for earlier prospectors often overlooked various good fields in searching for particular metals; for instance, Cripple Creek was passed by in making a search for silver, and the Comstock lode in Nevada was ignored in searching for gold. After getting a general idea of the character of the rocks under examination, the trained prospector can tell what minerals are likely to be found in them.

PROSPECTOR'S OUTFIT

5. The outfit for a prospector depends on the nearness of the prospected ground to mining camps or boarding places and on the mineral for which he is searching. If prospecting is to be carried on in the mountains away from habitations, it is best for two prospectors to join forces, as that makes work easier, and the combined judgment of two men is often better than that of one: moreover, two men can cover twice as much ground in the same time, and do more than twice as much work. The first part of a prospector's outfit, then, is a suitable partner. Of course, if a man is prospecting for magnetic-iron ore, copper ore, coal, or other useful mineral, he does not need a gold-miner's outfit, and his equipment should be reduced to the absolute necessities for properly carrying on his work.

6. Assay Outfit.—If the prospector intends to test his minerals, he should carry a blowpipe outfit, especially in the case of copper, gold, and silver; but it is not advisable to carry an assayer's outfit unless the prospecting party is large or assay offices cannot be reached within a reasonable time. Unless animals are used for transportation, it is hardly possible to carry, in addition to tools, a supply of provisions that will last more than a month at a time; hence, there must be a base of supplies, which, as it is usually the nearest town, will in all probability afford one an opportunity to get in touch with an assayer. Should, however, other conditions prevail, a portable assayer's outfit may be deemed desirable.

If the prospector is looking for placer deposits only, hammers and drills will not be necessary; in all other cases, they will probably be found useful.

7. Prospector's Tools.—The tools that should form a part of the metal prospector's outfit are: a pick; a long-handled, round-pointed shovel; a geologist's pick; a short-handled hand hammer—unless two are in the party, when a long-handled striking hammer will answer for both—three drills of assorted lengths; a scraper for cleaning out drill holes; a few pounds of rack-a-rock, or dynamite; two rolls of double-tape, waterproof fuse; and a box of detonators. A pole pick, Fig. 1, is better for prospecting among rocks than the ordinary two-pointed railroad pick, such as placer miners would require, since, in the hands of an experienced man, it may be used on gravel, as a sledge for cracking rocks, and as a bar, while the two-ended picks are heavier and cannot be used for so many purposes. In addition, the prospector should have a gold pan, a horn spoon, 1 pound of mercury, several clay pipes, and a small ax. The mercury should be carried in an iron or horn bottle, as glass is too easily broken.

FIG. 1

8. Prospector's Necessaries.—The prospector should provide himself with two heavy woolen blankets, a rubber sheet, a pair of heavy boots, two flannel top shirts, and a change of underclothing. As serviceability in clothes is a prime consideration, corduroy is a good material for trousers. A pair of brown-duck or khaki overalls and a jumper of similar material will be found serviceable, as they shed water and will be found cooler to work in than ordinary clothes. The prospector should be provided with a shotgun or rifle and ammunition, as well as with some fishing tackle. There are occasions when a gun is very handy to drive off wild animals; besides, it will furnish game food.

9. Transportation of the Outfit.—Whenever it is convenient, a burro or cayuse should accompany the party, unless the country is so devoid of vegetation that the animal cannot find food; ordinarily, however, the prospector knowing little of the vegetation to be found must trust to the country. The pack bags containing the equipment and provisions should be placed on the saddle and securely tied. To pack an outfit properly and keep it on the animal is quite a trick, and one that the new prospector should practice under the tutorage of an experienced packer.

The prospector's temporary camp should be fixed in some suitable location where he can obtain water and food for his animal, and return to this camp nightly. The cache, or hunky hole, of the prospector should be located close to the camp, and should be carefully planned and protected. If this matter is neglected, the prospector may find himself despoiled by marauders and be forced to cut his trip short or go hungry.

10. Food Economy.—As the prospector is usually compelled to do his own cooking, he should learn how to brew coffee, and to fry and stew. The art of making pancakes from flour and left-over corn and beans is a highly desirable accomplishment. A prospector may, of course, buy almost his entire food supply ready cooked; if, however, he carries bacon, beans, coffee, pepper, salt, baking powder, and flour, he should, with what game and fish he may secure, get along fairly well. If canned food is taken along, and some should be, it is well to bear in mind that a can opener is a utensil that is absolutely indispensable, as any person that has attempted to open a can without one can readily testify. A frying pan, a coffee pot, a tin cup, a fork, a knife, a spoon, matches, and a tin pail are all articles that are more or less necessary to man's comfort in the field.

11. The Prospector's Opportunities.—The usual idea of confining one's search to a particular metal or mineral is proper enough in the main; but, if large quantities of a useful mineral are observed during the hunt, they should at least be marked for future reference. In their search for gold, prospectors have very often passed over minerals that would pay them better; hence, as a knowledge of minerals is desirable, it would be a good idea to include a pocket mineralogy in the outfit, for recreation and practice, especially if a blowpipe is in the outfit. A small pocket compass, Fig. 2, with a clinometer attachment for finding the dip of the deposit, and a small aneroid barometer, Fig. 3, for giving heights will be found useful. With a compass, the prospector can also find his way about and relocate his find after leaving it for a time. Sketches and notes of the various geological peculiarities and the character of the ground should be made rather than entrusted to the memory. Such notes may prevent one's find being jumped during his absence, for courts generally recognize the usefulness of written descriptions, while verbal reports are not so impressive.

FIG. 2

12. Aneroid Barometer.—The density of the air varies with the altitude; that is, a cubic foot of air at an elevation of 5,000 feet above the mean sea level will not weigh as much as a cubic foot at sea level. Scientists have taken advantage of this phenomenon to measure elevations, by converting the changes in density of the atmosphere into mechanical movement, as evidenced by the **aneroid barometer** shown in Fig. 3. These instruments are made in sizes varying from that of a watch up to a 6-inch face. They consist of a metal cylindrical box, with a thin, elastic, corrugated-metal top, from which the air has been removed, so that, when the atmospheric pressure increases, the top is pressed inwards, and when it diminishes, the top expands by its own elasticity, aided by a spring beneath. These movements of the cover are transmitted and multiplied by a combination of delicate levers that act on an index hand and cause it to move, either to the right or left, over a graduated scale. Aneroid barometers are made self-correcting (compensated) for variations in temperature.

FIG. 3

Some are so sensitive that they are said to show a difference in the atmospheric pressure when transferred from the table to the floor. The mercurial barometer is the standard for comparison. At the level of the sea, the height of the mercurial column is about 30 inches; at 500 feet above the sea, it is 29.46 inches; at 1,000 feet above the sea, it is 28.9 inches; at 15,000 feet, it is 17.47 inches; at 3 miles it is 16.4 inches; and at 6 miles above the sea level it is 8.9 inches.

13. Two Classes of Mineral Deposits.—There are two classes of mineral deposits, the *loose* and the *solid*. In a new country, either class is worthy of examination, but it should be thorough and not casual. One will often hear in a mining country that a prospector that knows much about prospecting and minerals walked over a certain place time and again where another prospector not so learned has found rich mineral. Thus, one is told of men who walked daily over the rich Wilson lode in Idaho, afterwards known as the De Lamar mine, and of the miners who, when looking for the Comstock vein, threw away the black-looking stuff that formed the vein, until another man, wondering what the stuff was, had it assayed and found it very rich ore worth $3,000 a ton in silver and $186 in gold. The rich iron mines in Minnesota were discovered by ore clinging to the roots of overturned trees, while discoveries of coal and silver have been made in a similar manner. Many rich deposits of mineral have been discovered by making cuts for railroads and wagon roads. Gold and silver have been discovered where miners have made their camp fires. Whenever a prospector sees a specimen of mineral, the locality from which it came should be learned, if possible, as that may be made a field for exploration. The prospector must have an "eagle eye" and a "rabbit's ear," as well as a faculty for reasoning; since, if a mineral of value is found in one formation, it is likely to be found in a similar formation in some other locality.

14. Vein Changes.—From what has already been said, it will be understood by the prospector that he should not be too secretive concerning indications that may lead to a find; if he is, some other prospector may serve him in like manner, and make him the loser in the end. In prospecting, if the strike of the vein changes, the value of the mineral is likely to change. This phenomenon should be clearly understood, as well as that, where veins cross one another, the mineral will generally be richer, and that the cross-vein will usually contain a different kind of mineral or matrix. While the mineral is likely to be low grade in the case of wide veins, yet it does not always follow, and should moreover not be considered a drawback, for low-grade mineral deposits are in general much more lasting than bonanzas. As illustrations of low-grade deposits of value may be mentioned the Homestake mine of South Dakota, the Treadwell mine on Douglas Island, Alaska, and the Witwatersrand of South Africa, since they are probably the largest producers of that class of gold mines; but the mines of Gilpin County, Colorado, are examples of another kind of persistent low-grade deposits that are still producers, while richer mines have ceased to yield. One may lay it down as a fairly good rule that wide, long veins will extend to a greater depth, be more persistent in yielding, and in the long run, be more satisfactory to work, than narrow, short veins. Since, however, wide veins will be richer in one place than in another, several openings should be made before finally locating a claim.

PROSPECTING ALLUVIAL DEPOSITS

PRELIMINARY CONSIDERATIONS

15. **Placer Deposits.**—Alluvial deposits may contain metals, in their native state, oxides of tin or tungsten, and valuable sands and precious stones, either as placer or as river-bottom deposits. The term *placer* belongs properly to gold-gravel deposits; but it is here widened to take in gravel deposits containing valuable minerals of any description. River bottoms and beaches are also included in alluvial deposits; but the method of prospecting them is decidedly different from that of placers. In Arizona, New Mexico, Southern California, and Australia, there are said to be large areas of land that contain gold-bearing gravels termed *dry placers*, because there is no water to work them. Unless the ground should prove very rich, such deposits are not worth extended prospecting, since to obtain good results the miner must ordinarily have water to wash the gravels. If the ground seems to be in the bed of a dry river, it may be that water will be found in considerable abundance a few feet below the surface; for which reason, if rich mineral is found

in quantities, a test hole for water should be sunk before abandoning the prospect.

16. Prospecting for Placers.—Placers are deposits resulting from the decomposition and erosion of metal-bearing rocks and the concentration of the metallic fragments in beds, where they have been carried and deposited by water and glaciers. The principal minerals found in placer deposits are gold, platinum, and the associated platinum metals—oxide of tin, oxide of tungsten, monazite sands, and precious stones. These are of sufficient specific gravity, with possibly the exception of precious stones, to become concentrated by the action of water, and at the same time all are sufficiently insoluble to resist ordinary chemical solutions. As rocks are worn away, the liberated metals are carried down the mountain sides and hills by streams during freshets. The action of the water separates the valuable minerals, which, on account of their specific gravity, sink to the bottom, while the lighter worthless material is carried along by the stream to some point where the current is less swift, when it too is precipitated. The larger particles of minerals sink first, accompanied by coarser portions of the gravel, so that it would be unreasonable to expect coarse gold or other heavy minerals to be deposited at any great distance from the mother lode, except by glacial action, although the finer mineral particles may be carried great distances, particularly in streams having steep grades and high velocities. In exploring for deposits of this description, the prospector first finds gold colors that are not of much value but serve as a guide to placer deposits situated higher up the gulch or ravine. While following the stream up toward its source, the prospector takes a quantity of gravel from time to time and washes it to ascertain if the particles of gold are increasing in size; usually, if the deposits are not too thick, he goes to bed rock—that is, to the rock underlying the alluvial deposit, for in that place the heaviest particles of gold are likely to be found. The prospector continues in this way until he strikes a deposit that is rich enough to pay for the labor expended in working. In some localities, the prospector follows the ancient river beds through which water long ago ceased to flow. From his observations of modern streams, he is able to recognize places where there once was an eddy, or where the stream took a sudden drop from a ledge of rocks, or where it was whirled over the banks, leaving ledges of sand and gravel. Such places, the prospector should carefully examine, always going if possible to bed rock. Sometimes, it may be advisable to examine the cracks in the bed rock to ascertain whether there are any grains of gold hidden in the crevices. In some instances, the miner will notice dark streaks in an alluvial deposit, particularly if that deposit is quite thick; these consist usually of black sand or small particles of magnetite, which is a good indication of gold, since these particles are of a greater specific gravity than ordinary minerals and hence are naturally associated with gold and other minerals of placer deposits. Each of these streaks should be tested by the miner, for they represent a possible zone of pay dirt. In thick placers, there may be several such streaks; sometimes those above bed rock are more valuable than those at bed rock, but the latter are more likely to be the richer where the streaks have not been repeated. Placer deposits at times carry very fine gold, which, although it may scarcely be seen with the eye, may be well worth working, especially if the black sand contains gold and this sand is saved. It would hardly pay the placer miner to work such deposits; however, in machine mining with the aid of concentrators, the sand, in many instances, could be saved at a profit. At Flint Creek, Montana, gravel containing 1½ cents a cubic yard in gold is washed at a profit, under very favorable conditions. Gravel containing but 3 cents a cubic yard, has, according to good authority, been profitably handled by hydraulicking, and dredging is accomplished at 3½ cents a cubic yard.

17. Bed Rock.—The presence of bed-rock outcrops enables the prospector to follow the trend of the streams where alluvial patches are likely to have accumulated, since such outcrops act as dams and form obstacles to the further transportation of the gold by water; bed rock is not always productive, however. If the nature of the bed rock is, in general, soft, the harder parts will give it a wavy appearance; while, on the other hand, a hard rock will have cracks and crevices wherever joints and soft spots occur. In these rough places, the greater part of the gold is quite often retained. Where the wash has been especially heavy or has been semi-plastic in consistency, the gold has not been able to settle as far as the bed rock, which is, consequently, barren. As a rule, it may be expected that the gullies near the outcrops of auriferous-quartz veins will be rich in gold, and that farther away they will be poor; consequently, in looking for the richest ground, one is to be guided by the surface exposed. Some placers are more spotted than others, from possible shifts of the current made by obstacles in the stream; hence, the prospector should look for signs of eddies and for places where the banks of the stream may have caused a change in the direction of its flow.

Some placer miners believe that quartz gravel with quartz boulders is most likely to prove productive; others believe that slate and hard sandstone bed rocks are best for prospecting, since they are more likely to form natural riffles. This difference of opinion, however, is of little consequence, for one formation is just as likely to be as productive as the other. If, therefore, there are any signs of gold, only the most careful tracing will disclose it—whatever may be the character of the bed rock. Usually, black iron sand or oxidized iron that has colored the surface dirt is a good indication of gold, particularly in the region of eruptive rocks and metamorphosed quartz schists. When following up a gulch giving indications of placer mineral, attention should be given to the banks, in order that no outcropping vein be overlooked. The occurrence of a stray piece of quartz will be a guide for the miner in locating a lode, especially if it shows gold on panning.

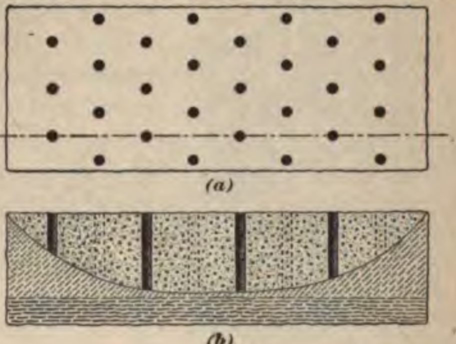
18. Panning.—In looking for gold, the prospector washes a pan of dirt from time to time, or at least whenever he suspects the presence of gold. As gold is heavier than dirt, it will, if mixed with water and agitated, sink to the bottom, where it will be retained when the dirt is removed; this operation is termed **panning.** The pan mostly used by the prospector is made from one piece of Russia sheet iron and is about 10 to 12 inches in diameter at the bottom, 16 to 20 inches at the top, and from 2½ to 3 inches deep. If coarse material is being sampled, the pan is filled; if the material is fine, the pan is not entirely filled, as it requires more agitation and more careful manipulation in order to prevent the loss of fine particles of gold—especially as it is the amount of the latter that guides the prospector in tracing up the gold. The placer miner cares little for colors after he has located a deposit, but he does depend on them to locate one.

FIG. 4

The pan, when charged, is carried to a stream near by and submerged, so as to loosen all gold from the larger rocks, which, when they are washed clean, are thrown out. All lumps of clay are next washed, and the pan moved about in the stream until the fine dirt has been washed away; the miner may assist in this operation by using his hands to break up the lumps. After the water in the pan has become comparatively clear, the pan is raised out of the stream, and by a quick motion, the heavier particles of sand and gravel are concentrated in one part of the pan. The coarser sand is then washed off, leaving the black sand and some quartz. If there is any gold, it will be seen in this mixture. As it is a difficult matter to separate fine gold from the black sands, even when the water is drained off, this operation is usually performed with the fingers (Fig. 4). The prospector takes out the gold and places it in a buckskin pouch that he carries for the purpose. If the miner or river prospector can obtain sufficient gold to pay for his labor, he is said to have *pay dirt;* if he has not, he should continue his search until he reaches a portion of the placer ground that will remunerate him for his toil. In some instances, a similar process is followed by prospectors in hunting for the lode from which the gold came.

19. In South America and in the Straits Settlements, wooden pans are made by the natives to take the place of the iron pan. The **batea** of South America and the **dulang** of the Chinese miners are turned out of one piece of wood, the sides being given a uniform slope from the center. The Mexican pans are made from pine logs 2½ feet long and 24 inches in diameter, the outside being fashioned to the required shape and the inside gouged out with a tool that looks like the back of a shoemaker's hammer. The batea in the rough is then buried in dry ground until the sap is all out, after which it is taken from the ground and smoothed with sandpaper or glass. The Chinese and South American miners are experts in the use of the batea and in gold panning.

20. Finding the Value of Placers.—After a placer deposit has been found, it is often necessary to test its average value and extent, particularly if it is to be worked by hydraulicking or placer-mining machinery. This testing may be done by test pits or by placer-prospecting machines. In some cases, it will pay to work ground containing but 25 cents in gold a cubic yard, provided that water is readily obtained and that the cubical contents of the deposit are large enough to warrant the outlay. To prospect such


(a)

(b)

FIG. 5

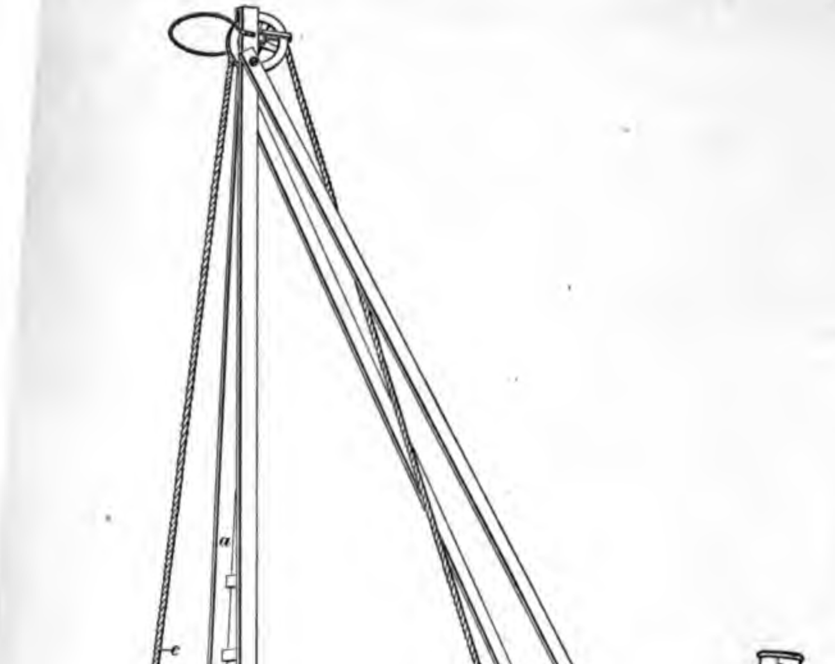


FIG. 6

ground, it is necessary, in order to ascertain its depth and extent, to make bore holes or test pits every 50 or 100 feet across and along the deposit and at the same time obtain the average value of the deposit, by panning the material excavated. The method of procedure is shown in Fig. 5, where (*a*) represents a number of test pits arranged in systematic order, say every 100 feet apart lengthwise and 200 feet apart across the deposits. As the dirt is removed from these pits, it is panned and (the number of the pit being recorded) the value of the ground per cubic yard at this point is ascertained. The depth is also noted, as shown in Fig. 5 (*b*), so that, after the width and length of the deposit have been ascertained, the cubic yardage may be computed; this, multiplied by the average value, will give the value per cubic yard of the deposit.

21. Cyclone Prospector.—Placer prospecting by the test-pit method is necessarily slow and expensive, for which reason the portable-drill rig has found favor. This, as shown in Fig. 6, consists of a derrick *a*, mounted on a truck with a boiler *b* and an engine *c*. The tools *d* are hung from the derrick by a rope *e*, and are moved up and down, from 90 to 100 times a minute, by the engine working a geared mechanism that turns a crank to which is attached a pitman *m* that raises and lowers a bell-crank *n*. On this bell-crank is a grooved pulley wheel *o* that alternately raises and lowers the rope *e* to which the tools are attached. The tools consist of an ordinary bit having a hole in the center, and having on each side holes that intersect with the center hole. The drill rod is hollow and has a ball valve at the

FIG. 7

coupling that joins the drill and bit. When the drill makes a down stroke, the cuttings are forced through the holes in the bit into the hollow drill rod; the valve opens as the drill descends and closes as it rises, thus forcing the cuttings to the top of the drill rod and out through the hose *h*.

FIG. 8

As the sludge comes to the surface it is panned with an automatic device worked by machinery; this saves the labor of two men, who are necessary for panning when digging test pits, and gives as close an approximation to the true value of the deposit as they could. The rapid strokes of the drill rod usually prevent the particles of gold from settling to the bottom of the hole; consequently, they are drawn up through the hollow bit and drill rod to the surface.

Fig. 7 is a cross-section showing this method of testing placer deposits. It will be observed that the casing pipe sinks, or is driven downwards, as the drilling progresses, thus making it possible to test the ground at any depth. The cuttings being brought to the surface from the bit *a* through the pipe *b*, and discharged, through the hose *c*, into a tank where they are automatically panned by machinery. The water that brings up the cuttings may be allowed to run back into the hole and, if necessary, used over and over again. The handle *d* is for the purpose of rotating the drill, and the entire drill mechanism is suspended by the swivel *e*.

22. Driving Casing Pipes.—In case the pipe does not follow the bit, it is driven down by the drive shown in

Fig. 8 (*b*). In drilling and driving, the block *e*, Fig. 8 (*a*), is bolted to the drill rod *a* in such a position that, when the bit is at the full stroke, or at the bottom of the pipe, the drive weight rests on top of the drive head *d*, thus preventing the bit *b* from going below the casing *c* unless it is desired to drill ahead through boulders or false bed rock before following with the pipe.

Fig. 9

23. Pipe Pulling.—As soon as one hole has been tested, the casing pipe is pulled and the machine moved and set up for another hole. It is very much easier to drive than pull pipe, the latter being quite a task if the pulling power must be applied through jack-screws. In Fig. 9, the driver *a* is made to pull pipe by placing a pulling plug *b*, on the driver stem *c*, underneath the drive head *d*. This strikes against the end of the drive pipe head and draws the pipe when the motion of the engine is reversed. When taking up slack rope, it is possible to hit the head a slight or a hard blow. By means of a worm-gear and a heavy drive head, a line of pipe can in most cases be readily started. As soon as one length of pipe gets above the ground it is uncoupled and the pulling plug inserted in the next section, and that pulled in a similar manner, and so on until the entire pipe is removed.

24. River Deposits.—Along various rivers there are gold-bearing beaches that may be worked by means of trenches or the costeaning method of prospecting; the practice adopted, however, varies in different countries. In the West, it is customary to prospect river beaches at low water by means of scoops. In the diamond districts of Brazil, the method of prospecting practiced by the natives is to drive a pole into the river bed and send down a diver, who scrapes a portion of the dirt into a bag, which is afterwards hauled to the surface.

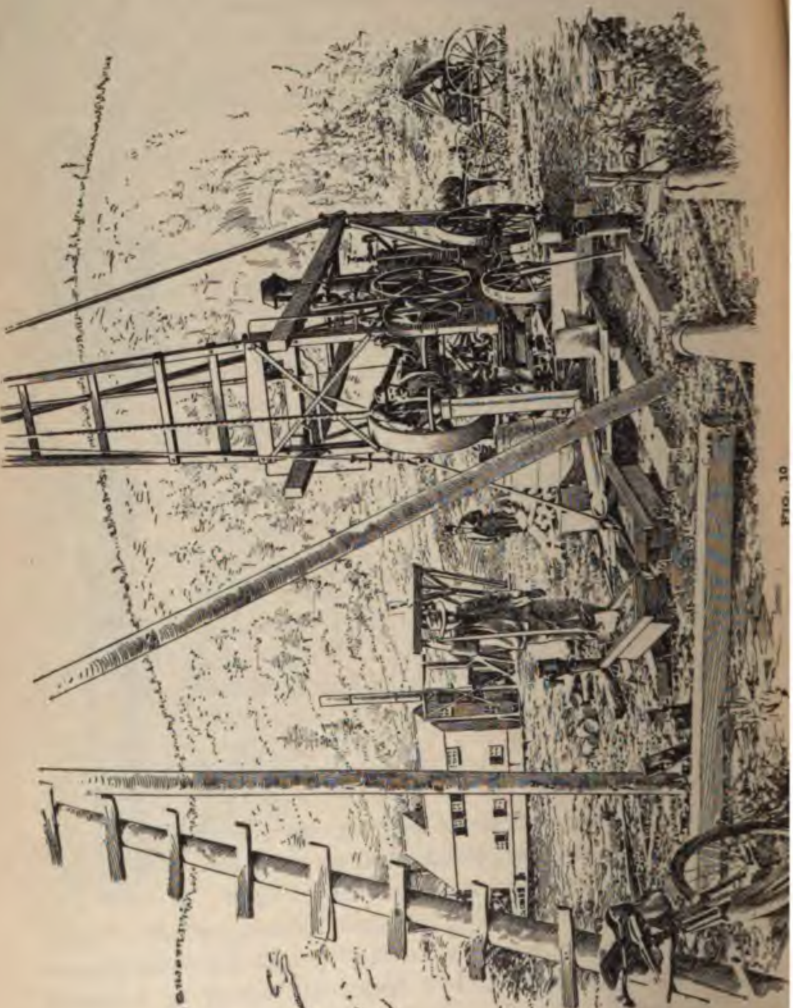


FIG. 10

In the United States, river gravels are now for the most part prospected by means of pumps.

Fig. 10 is a view of a Keystone prospecting outfit that is used to test river deposits. The boxes shown in the foreground contain the samples to be panned. To the left may be seen a dredging machine that excavates its own pond to float in, from the river inland, while dredging for gold.

Fig. 11

25. Prospecting River Benches.—It has long been known that some present river bottoms contain loose gold, but to test them and get some idea of their value has been a costly operation. The existence of gold in rivers may be ascertained by testing the river banks and dry bars by panning. The top of the placer may be very fine sand containing gold colors; the next layer may be gravel; and the lowest bench may consist of fair-sized boulders, among which may possibly be found coarse gold mixed with clay. Placers such as these are not difficult to test; but when the river beds are covered with water, the proposition assumes quite different proportions. To obtain values approximately correct from river beds, an apparatus similar to the prospecting machine described in Art. **21** should be used for drilling and sinking to bed rock, and a pump like that shown in Fig. 11 should be used for bringing up the ore.

26. Vacuum Sand Pump.—The **vacuum sand pump**, Fig. 11, consists of a sucker *b* that moves the whole length of the working barrel *a* when the sucker rod *c* is pulled out by the sand line attached to the pump at the eye *d*. When the sucker is rapidly lifted, a vacuum is formed, and the material below the bottom valve is drawn into the working barrel. If the material is not too coarse, the pump will often, because of the vacuum produced, sink 2 or 3 feet into the placer formation. One great advantage that this pump has over the common sand pump is thus made manifest; since, if gold or any other mineral is present, it will be drawn into the pump by the current of sand or mud. The efficiency of the vacuum sand pump depends on the rapidity with which the sucker is lifted; so that the sand reel must be operated with powerful friction gear. It may require a pull of 2,000 pounds or more to start this pump after it has partly buried itself in the river bottom.

DRY-PLACER DEPOSITS

27. The term **dry placer** is applied to all those placers that cannot be worked owing to the absence of the necessary water, as well as to those deposits where the supply of water is insufficient to work them at a profit. Dry placers occur in Arizona, Southern Colorado, New Mexico, and Lower California, where there are large areas of arid lands containing gold in gravel and clay. With even a limited water supply, however, dry placers may sometimes be successfully worked by steam shovels and other apparatus. In some localities where water is not abundant, sufficient for living purposes may be obtained by drilling from 30 to 50 feet below the surface, and it will not be long, where such conditions exist, before these placers become producers.

28. **Kinds of Dry Placers.**—Some localities may contain sufficient gold to make it worth while for the prospector to test them and stake off claims. In dry placers, the pay streaks are sometimes at or near true bed rock, but more often are found above bed rock, resting on layers of baked clay or cement that form false bed rocks. The gold occurs in narrow streaks, limited in depth and length, that are of irregular occurrence, and there is no way to predict where they will be found. One good guide, however, is the black magnetic sand, and the placers are as likely to be large as small in area, and may be crooked or straight. There are two classes of dry placers—one lies in the débris of sedimentary rocks; the other is in the débris of volcanic rocks.

When a pay streak is found, it is followed and, if deep, mined by shafts, tunnels, and rooms—the same as a nearly horizontal coal bed. When the streak is not deep, but is found at the grass roots, it will not in all probability extend to bed rock or grow richer with depth, because the conditions under which dry placers were formed were quite different from those that governed the formation of wet placers; however, as there are exceptions to all rules, a test in these cases is of more value than prior experience.

29. Prospecting Dry Placers.—If water is not available for panning and the ground, as is often the case, is baked quite hard, the dry-placer prospector is obliged to break up the dirt before panning, in order to loosen any particles of gold that may be encased in the dirt. The broken material is then put in the gold pan, and thrown up and down so that the wind will blow away the fine dust. After a while, the coarser particles are skimmed from the pan by the hand, care being taken that no pieces of quartz with gold adhering are thrown away. The material left in the pan is again tossed up and down until nothing but the heavier particles remains, and finally these latter are given a toss high in the air and allowed to fall on a sheet. The black sand and gold on the sheet are collected as a clean up, and, if possible, washed with water, when the gold may be picked out, or, if not too coarse, collected by using mercury as an amalgam.

LOCATING PLACER CLAIMS

UNITED STATES PRACTICE

30. Size of Claims.—The extent of ground that may be located as a placer is limited to 20 acres for one individual or person; a corporation is considered as an individual, regardless of the number of its incorporators. An association of a number of persons not incorporated may locate a claim in common not exceeding 20 acres to each individual, or 160 acres for the entire association; it requires at least eight bona-fide locators to lawfully claim 160 acres. Placer claims, where the lands have been previously surveyed by the United States, shall conform in their exterior limits to the legal subdivisions of the public lands, and all placer-mining claims shall conform as nearly as practicable with the United States system of public-land surveys and their rectangular subdivisions. This system allows for a claim of 1,500 ft. × 580.8 ft., 1,000 ft. × 871.2 ft., or 800 ft. × 1,089 ft.; but, where placer claims cannot conform to legal subdivision, the survey and plat shall be made as on all unsurveyed lands. In new districts on unsurveyed lands, it has been the custom to claim from rim rock to rim rock, regardless of the width of the gulch, within reasonable limits, and a sufficient length along the gulch to make the claim 20 acres, or such lesser area as might be the limit under local restricting laws, irrespective of bearings.

31. Discovery or Knowledge of Mineral.—For a valid location, it is necessary that the lands be known to have mineral value, either by discovery or by previous knowledge; and in the case of an association, a separate discovery is required on each 20 acres.

32. Location Claims.—United States laws, which are modified in many states, are practically the same for placer as for lode locations, except for shape and area, hence the location notice must conform to both state and local laws. In the case of lode claims, the local laws or regulations may also require the name or names of the locators, the date of the location, and such a description of the claim or claims located by reference to some natural object or prominent monument as will identify the claim. A location notice should give the course and distance that will serve to protect and fix the location of the claim and render it susceptible of identification. The United States laws do not require placer claims to be recorded, except that the miners of each district may make regulations not to conflict with the laws of the United States or the laws of the state or territory in which the district is situated, governing the location, the manner of recording, etc. Then the location notice must be filed for record in all respects, as required by the state or territorial laws, and the legal rules and regulations if any.

33. Staking Claims.—The dimensions of a claim instead of its total area are sometimes specified. In Idaho, posting must be done within 10 days after the discovery, and this feature should be looked into by the prospector in whatever state or territory he is prospecting. The locator is required to mark each angle he has claimed with a substantial post sunk into the ground at that point. When posts are not obtainable, the marks usually consist of stone mounds 3 feet high and 3 feet in diameter at the base. The monuments are referred by distances and direction to permanent monuments or natural landmarks, so that they can be readily located in case of controversy. The Idaho statutes state, for instance, that the post should be at least 4 inches square or in diameter, and that a mark must be hewn on the side facing the discovery. This has been held by the courts to mean that the posts must be large enough to square 4 inches and must be at least 4 feet high above the ground; they must therefore be larger than 4 inches in diameter.

34. To Hold Placer Claims.—The labor and the particulars necessary to hold a placer claim are the same as those for a lode claim: $100 worth of work must be done annually. This must be actual work in developing and improving the property. Where several claims are being worked as a group, all the work may be performed on any one of the group. The record of location must be placed with the recorder of the county and district in which the claim lies. The location notice and the record of location should not be confounded; the former indicates an expectation; the latter an assured fact.

BRITISH COLUMBIAN PLACER LAWS

35. Free Miners' Certificates.—The laws of the Canadian government in reference to placer mining are narrower than those of the United States. Miners or mining companies are obliged to take out **free miners' certificates** at an annual expense of $5 for individuals and $50 for corporations capitalized for $100,000 or less, and $100 for corporations with over $100,000 nominal capital, before they are entitled to the privilege of mining in Canadian territory. This certificate is an occupation-tax receipt, and also applies to lode mining. All miners that allow their certificates to expire are liable to a fine of $25 and costs, but any one may at any time within 6 months from date of such expiration obtain from the proper officers, on payment of the fee of $15, a special free miner's certificate. This special certificate—so far only as such title depends on the person having a free miner's certificate—has the effect of reviving the title of the person to whom it is issued to all placer claims that that person owned at the time of the lapse of his former certificate, except such claims as under the provisions of the Placer Mining Act may have become the property of some other person at the time of the issue of the special certificate, and operates as a free miner's certificate until midnight of the thirty-first day of May next after its issue. In the case of a joint-stock company, the fee for a special certificate is $300.

36. By *free miner* is meant any male or female over the age of 18, but not under that age, or any joint-stock company named in, and lawfully possessed of, a valid existing free miner's certificate, and no other. A free miner's certificate is not transferable, and only one person or one joint-stock company may be named in the certificate. The term *joint-stock company* means any company incorporated for mining purposes under a Canadian charter or licensed by the Canadian government. If any free miner's certificate is lost, the owner may, on payment of $2, obtain a true copy, which is marked *Substitute Certificate.* Every free miner has the right to enter, locate, prospect, and mine for gold and other minerals in the Yukon District, and no person or joint-stock company will be recognized, unless he or it and every person in his or its employment have unexpired free miner's certificates.

37. Size of Claims.—A **placer claim** is the personal right of property or interest in any placer mine; and in the term mining property is included every placer claim, ditch, or water right used for placer-mining purposes, and all other things belonging thereto or used in working thereof. Placer mines and diggings are synonymous terms.

The term **creek diggings** means any mine in the bed of a stream or ravine. The size of this claim is 250 feet square; provided the side lines are measured in the general direction of the watercourse or stream.

By the term **bar diggings** is meant any mine between high- and low-water marks on a sea, river, lake, or other large body of water. In bar diggings, a claim is: (1) A piece of land not exceeding 250 feet square on any bar that is covered at high water; or (2) a strip of land 250 feet long at high-water mark and in width extending from high-water mark to extreme low-water mark.

Dry diggings have reference to any mine over which water never extends. The size of such a claim is 250 feet square.

38. Discovery Claims.—If any free miner, or party of miners, discovers a new locality for the prosecution of placer mining, and such discovery is established to the satisfaction of the gold commissioner, placer claims of the following sizes will be allowed such discoverers; namely, for a single discoverer, 600 feet in length; for a party of two discoverers, 1,000 feet in length; and to each member of a party beyond two in number, a claim of the ordinary size only; provided that, where a discovery has been established in any locality, no further discovery will be allowed within 5 miles therefrom, measured along the watercourses. The width of such claims is the same as ordinary placer claims of the same class. A creek discovery includes all ground to the top of the hill on each side of the creek, provided that it does not exceed 1,000 feet in width.

39. Location Notice and Staking.—As nearly as possible, every placer claim must be rectangular in form and have its four corners marked with legal posts firmly fixed in the ground. On each post must be written the name of the locator, the number and date of issue of his free miner's certificate, the date of the location, and the name given to the claim. In timber localities, all boundary lines of a placer claim should be blazed and the underbrush cut so that the posts can be distinctly seen. On all boundary lines, also, the locator should erect legal posts not more than 125 feet apart. In localities where there is no timber or underbrush, monuments of earth or rock, not less than 2 feet high and 2 feet in diameter at the base, may be erected in lieu of the regular timber posts, except in the case of the four legal posts employed to mark the corners of the claim.

40. Recording a Claim.—Every free miner locating a placer claim must record it in the office of the mining recorder of the mining division in which the claim is situated, within 15 days after its location, if the claim is situated within 10 miles of the office of the mining recorder by the most direct means of travel. One additional day is allowed for every 10 miles additional or fraction thereof. The time allowed includes the day on which the location is made, but excludes the day of application for record. The application for such record must be under oath and in the form set out as provided for in the schedule to the Act.* A claim that has not been recorded within the prescribed period is deemed to have been abandoned.

41. Rerecording Claims.—Unlike the American practice, the Canadian law does not give the miner permanent ownership of the claim. Placer claims are recorded for a term of one or more years, and may be recorded for another term of years during the existence of a record to rerecord; the term may be extinct for one or more years, there being a fee for recording or extension.

42. Lay-Over.—When the supply of water is insufficient to work hydraulic or other placer claims requiring water, such claims may, through the gold commissioner, be laid over during the insufficiency; or, a notice of application

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*Bill No. 14, 1901, Part II, Art. 11, Section 23.

for a lay-over, which should bear the date of the cessation of work, must be posted on the claim, the owner must apply to the gold commissioner for the lay-over, which must be recorded and a notice thereof posted in the office of the mining recorder, as well as on the claim—within 3 days from the cessation of work if the claim is within 10 miles of such office, but with 2 additional days for each farther 10 miles or fraction thereof, the number of days being counted in the same manner as those allowed for recording a placer claim. During the time allowed for the cessation of work, and for obtaining, recording, and posting such lay-over, the claim will not be open for relocation by any other free miner.

43. Abandonment.—If, after recording a location and before the expiration of the record, a miner desires to abandon his claim, he is obliged to give notice of his intention to the mining recorder and pay at the same time the fee of $2.50.

YUKON DISTRICT PLACER LAWS

44. In the Yukon Territory, a creek claim is 250 feet long and as wide as the creek bottom. A hillside claim is 250 feet long, and must not exceed 1,200 feet in width. A bench claim is 250 feet square. In the Yukon District, the rules differ from those of British Columbia. An entry fee of $15 is charged the first year, and an annual fee of $15 for each following year. A royalty of 10 per cent. on the gold mined is levied and collected on the gross output of each claim; default in payment of such royalty, if continued for 10 days after due, is followed by cancelation of the claim. The sum of $2,500 is deducted from the gross annual output of a claim when estimating the amount on which royalty is to be calculated, but this exemption will not be allowed unless the royalty is paid at a banking office or to a gold commissioner or mining recorder. Every free miner is entitled to the use of as much of the water naturally flowing through or past his claim, and not already lawfully appropriated, as shall, in the opinion of the mining recorder, be necessary for the proper working of his claim, and is entitled to drain his own claim free of charge.

ORE DEPOSITS

PRINCIPLES OF ORE DEPOSITS

45. The Earth's Zone.—The outer crust of the earth has been divided by recent geologists into three zones, termed *the zone of fracture*, *the zone of flowage*, and *the zone of fracture and flowage.*[*]

The **zone of fracture** is near the surface; in it, the rocks are deformed by fracture, due to the earth's cooling and to dynamic forces. The ruptures that occur in this zone are those of faulting, jointing, differential movements between the layers, fissility, and brecciation. The so-called folds in the zone of fracture are chiefly the result of numerous parallel-joint fractures across the strata with slight displacements at the joints, giving each block a slightly different position from the previous one, and thus as a whole making a fold.

The **zone of flowage** is the name given to that state in which deformation occurs by granulation or recrystallization, no openings except those of microscopic size being produced.

The **zone of combined fracture and flowage** lies below the zone of fracture, for the reason that the strength of rocks varies considerably, and that various other factors enter into the problem; such as rapid deformation, variation in the temperature at which deformation occurs, the amount of moisture present, etc. It follows, therefore, that fissures in this zone will gradually disappear at different depths below the surface, depending on the hardness of the rock in which they occur. Illustrations of the disappearance of fissures are numerous; it is stated on good authority that, in the gold belt of Nevada City and of Grass Valley, in California, many small fissure veins close up with depth.

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[*] The system followed is that of Prof. C. R. Van Hise in the United States Geological Reports.

Fissures may not only die out below, but may also disappear above, the fault line either not having reached the surface or else having been replaced by a flexure in the overlying stratum. This phenomenon has been described by Rickard, who showed how faulted fissures in sandstone and limestone disappeared above at the place where shale is encountered, which accommodated itself to the fractures below by monoclinal flexures. This is shown in Fig. 12, in which *a* is a gentle arch of impervious shale, which begins where the feeding fissure *b* ends.

FIG. 12

46. Grouping Ore Deposits.—Geologists have divided ore deposits into three groups, as follows: Ore deposits of direct igneous origin, which are probably of limited extent; ore deposits that are the direct result of the processes of sedimentation; and ore deposits that have been derived from underground waters.

47. Igneous Ore Deposits.—Certain basic igneous rocks have been worked as iron ores. The magnetic iron-ore bodies of the Appalachian Mountains seem to have been plastic magmas, and are coarsely crystallized. Vogt considers the sulphide ores of various metals in Norway to be a direct segregation from a magma. Emmons has also favored the idea of a first concentration at least of the metallic contents of the ore by some process from igneous rocks, more particularly basic rocks. In many cases where ore deposits, and especially sulphides, are supposed to be igneous, the question arises as to how much these deposits may be due to magmatic differentiation, and how much to the second and more important concentration that is performed by underground waters. Igneous ore deposits are found in the older and, in most cases, the aqueo-igneous rocks.

48. The **ores of sedimentation** were mentioned in connection with placer deposits, but they include others that may have been formed by mechanical concentration; such as monazite sands, stream tin, magnetic sands, and some diamond and other gem deposits. Usually, such deposits are near the surface, although they may be found covered to a considerable depth by recent alluvium.

49. Chemical Deposits.—The deposits that are of most interest to the lode miner are those formed, probably, by underground waters; hence it is in these above all others that the prospector looks for gold, silver, and copper. Such deposits must occur in the zone of fracture, for in the zone of flowage there are no crevices through which underground waters can circulate. The water may collect some mineral in its downward course; then, gradually becoming heated, collect another mineral; and, finally, when in a proper condition or degree of saturation, deposit the minerals so collected on the walls of the crevices through which it circulates. The water that collects the minerals increases in temperature with depth, and in this condition can take other minerals into solution, thereby creating solutions that will dissolve still other minerals. The journey of underground water is at first downwards through small openings, then lateral, and finally upwards through larger openings. Of course, where large openings are available for downward-moving waters, they will be utilized; but it is thought that on the average the larger openings are more extensively used by the upward-moving waters, the smaller fissures acting as feeders to the larger.

50. Chemical Action.—Chemical action may take place between gases and gases, gases and liquids, gases and solids, different liquids, liquids and solids, and different solids. So far as the deposition of ores is concerned, the reactions in connection with underground liquid solutions are by far the most important. Water that holds substances in solution may combine with substances to form hydrates; it may part with its hydrogen in exchange for bases—especially the alkalies and alkaline earths—thus at the same time changing the composition of the rock and taking into solution the bases replaced; or it may deposit substances from solution. Chemical reactions may be caused by different substances being taken into solutions at different times, by different solutions coming together, by solid material coming in contact with water having substances in solution, and by a changing temperature and pressure. In all these changes and interchanges, the materials pass through a state of aqueous solution, which may be alkaline, acid, or neutral.

51. Underground Aqueous Solutions.—The quantity of a solid that can be dissolved in liquid depends on the number and nature of the compounds present, on the pressure, and on the temperature. When a salt is placed in a liquid, it forms a homogeneous mixture of salt and liquid. This statement applies also to the minerals of nature; that is, they are salts that are soluble in water; it even applies to quartz and the most refractory silicates, as Barus has shown that water at 185° C. attacks with astonishing rapidity the silicates composing soft glass. At 180° C., various zeolites can be dissolved in pure water, the material crystallizing out on cooling. Lemberg shows that water at 212° C. slowly dissolves anhydrous powdered silicates. It is therefore apparent that in the lower part of the zone of fracture water is a chemical agent that has a dissolving power that may be increased by one of the salts it contains helping to dissolve another salt; for instance, the presence of alkaline sulphides is very favorable to the solution of sulphides of the heavy metals, such as copper, silver, and gold. The temperature influences the rate of solution as well as the quantity of material that may be held in solution; that is, for most substances, a moderate increase of temperature gives greater capacity for solutions; while for many substances a temperature exists at which there is the maximum capacity for solution, and the amount of material that may be held in solution at a higher and lower temperature is less than this maximum. In the lower part of the zone of fracture, increase in temperature with depth may exceptionally lessen the average amount of a substance that may be held in solution; but an increase in the pressure with an increase in the depth promotes solubility.

52. Precipitation From Aqueous Solutions.—Since the precipitation from solutions is the cause of fissures becoming filled with minerals that are termed *veins*, it is necessary to view the different methods by which the phenomena may be accomplished. The necessary condition for precipitation is that the solution should be supersaturated, when precipitation may result in various ways—such as changes in temperature and in pressure, and reactions between aqueous solutions, between aqueous solutions and solids, or between gases and solutions.

53. Belt of Weathering.—The division of the zone of fracture, known as the **belt of weathering**, extends from the surface to water level, and possibly beyond this point. In this belt are various gases (the most important being carbon dioxide and oxygen) and a great variety of solutions and solids, thus involving gases, liquids, and solids in the reactions set up. Furthermore, organic bodies act on inorganic bodies, making the chemical reactions in the belt of weathering extraordinarily complex; the most important are carbonation, hydration, oxidation, and solution. The process of *carbonation* is quite extensive in the belt of weathering, producing abundant quantities of the carbonates of the alkalies, alkaline earths, and iron, and, but less abundantly, the carbonates of other metals.

While *hydration* is usual in the belt of weathering, yet, under some conditions, and especially those of great aridity and high temperature, *dehydration* may occur. *Oxidation* is also very general in the belt of weathering, but *deoxidation* may occur in regions of very luxuriant vegetation where there is an unusual quantity of reducing material of an organic nature. If all the compounds produced by weathering remained where they were formed, the volume of the rocks would be greatly increased by these changes; but simultaneously with these reactions, *solution* is taking place on a great scale, and the quantity of material dissolved is more than sufficient to counterbalance the increase in volume due to chemical changes. In connection with the chemical changes, mechanical action is continually subdividing material.

54. Belt of Cementation.—In the division of the zone of fracture, known as the **belt of cementation,** hydration, carbonation, oxidation, and deposition occur. Hydration and deposition are the characteristic reactions, while carbonation and oxidation are subordinate. The reactions take place by metasomatic changes within many of the original minerals, and by deposition of material within the openings. Many of the minerals produced are strongly hydrated. The cracks and crevices produced by mechanical action—such as faults, joints, bedding partings, and fissility—and the openings or spaces in sedimentary rocks between particles are slowly but surely filled by the action of ground water, and the rocks are thus cemented. The belt of weathering is where solution takes place; the belt of cementation is where deposition takes place. Of the substances deposited in the belt of cementation, quartz is undoubtedly the one that predominates. Prof. C. R. Van Hise shows that one of the deep-seated dominating reactions is the process of substituting silica for carbon dioxide, with the simultaneous liberation of carbon dioxide. This process takes place at moderate depth, especially under dynamic conditions; the carbon dioxide liberated joins in part the underground waters. Such carbonated waters are capable of taking into solution the salts of metals, alkalies, alkaline earths, and iron that may reach the surface. Other issuing waters may, in addition to carbon dioxide, contain chlorhydric, sulphydric, sulphuric, and other acids. Thus, by various processes, the larger openings are filled with deposits; but, where one of these openings contains metalliferous ores in sufficient quantity to be of service to man, the remainder of them will be found barren—that is, filled with quartz, calcite, dolomite, and other gangue minerals.

APPLICATION OF PRINCIPLES TO ORE DEPOSITS

55. Introduction.—There have been endless discussions as to whether ore deposits are produced by descending, lateral secreting, or ascending waters. Prof. C. R. Van Hise, whose arguments are being followed because he harmonizes theories with well-known scientific facts, says that, "instead of the old ideas being contradictory, as many suppose, they are mutually supporting, because, when combined, they furnish a more satisfactory theory than any of them alone." It is now probably clear that the deposition of the greatest group of metalliferous ores is accomplished by underground waters, which may be ascending, descending, or lateral in their movements.

The water that performs the first work moves downwards, then laterally; that is, for a given fissure, the waters entering it do so from the top and sides, but not from the bottom. The waters do not enter the fissure at a single place, but at numberless points along the course, from the deepest parts to the surface. Somewhere, the water that enters a fissure must flow from it, and this place may be at the surface of the ground or at a considerable depth below the level of ground water. The quantity of water that enters a fissure laterally, decreases with depth, but in all probability the amount of mineral per unit volume increases; and if the rocks with which the deeper water comes in contact can. furnish metalliferous materials, such waters should be heavily loaded. Even if the amount of water furnished is small, yet during its long life it may contribute from the country rock mineral material in solution that is more than sufficient to fill a fissure entirely. It appears, therefore, that lateral-moving waters find their way to fissures, and that lateral secretion is an essential in the first concentration of ore deposits.

56. Vein Formation.—Ore deposits are found in fissures, which are the main streams for circulating waters in the latter part of their courses. The underground waters when they reach this channel begin their ascent; and the quantity of water gradually increases in volume from the lower depths to the point where it escapes. The varieties of the solutions become more numerous, for each stream entering this channel probably differs in its salts, and the pressure and temperature are also lessening, thus making the conditions favorable for precipitation. Ascending waters coming in contact with various kinds of wall rocks and with various solutions precipitate minerals probably to a wider extent than the descending and the lateral-moving waters. The ascending waters may vary in the quantity and kind of material they transport, so that the material filling a fissure may differ from time to time, thus forming a banded mineral vein, such as is shown in Fig. 13, which has diminished the width gradually until the cavity has become filled. It will be noticed that the filling nearest the walls of the cavity is calcite, the next quartz, the next metallic minerals, and the center a gangue with mineral in its mixture. From the reasoning followed, the upper lateral streams contained lime, which was deposited as calcite, and thus closed up lateral fissures leading into the main channel; silicious deposits next formed from lower depths; and then metallic deposits from still lower; and so on until the vein was filled.

Fig. 13

57. Irregularity in Vein Deposits.—It is well known that *veins* vary in richness in an exceedingly irregular manner. At a place in a vein where a metal is abundantly found, the explanation in many cases would be that near that place a stream emptied that either carried the precipitated metal or contained an agent capable of precipitating the metal already in solution. For instance, it is believed that, where the great bonanza of the Comstock lode in Nevada was found, solutions rich in gold and silver met other solutions, there or near there, that were capable of precipitating this gold and silver.

58. Ore chutes, or **chimneys** of ore, of exceptional richness are occasionally found; these are sometimes parallel with the dip of the strata, and at other times pitch to the right or left of the dip. Some of these deposits are in the necks of extinct volcanoes; but the explanation of their filling is probably—in some instances, at least—that a cross-fracture or joint existed, through which waters entered, carrying either metalliferous material or solutions capable of precipitating the metalliferous mineral near the place where the lateral streams of water entered. The lead and zinc deposits of Missouri, according to Jenney, are larger where two fissures cross than elsewhere; the silver-lead deposits of Aspen, Colorado, also show rich ore bodies where two faults intersect, the explanation offered being that, by the mingling of solutions that had previously flowed along different channels, the precipitation of metallic sulphides was brought about. It is frequently the case that, where veins cross, one carries minerals that are different from those in the other; probably the rich chutes of gold ore in the Sierra Nevada are due to mingled solutions. Penrose observes that many of the rich ore chutes at Cripple Creek occur at cross-fissures.

59. Reactions Due to Wall Rocks.—The principal influences of wall rock on circulating waters in fissures are three in number, as follows:

1. A solid, when placed in contact with a liquid, may precipitate some compound held in solution, part of the solid

going into solution at the same time. This is a sort of replacement of minerals, such as occurs, according to Foster, in the tin mines of Cornwall, as shown in Fig. 14, where replacement of mineral particles has taken place forming ores in the altered country rock.


FIG. 14

2. The wall rock may furnish precipitating solutions, which will precipitate the metals already in the solution. This probably is more noticeable in lead-ore deposits, as shown in Fig. 15, where lead ore is deposited in magnesian limestone; probably most contact deposits are of this description, although some deposits indicate that they are due to displacement.

3. The wall rock may furnish metalliferous material for the ore deposit, and this may be precipitated when it reaches the fissure by the mingling of solutions.

Any or all of these factors may work together. Thus, the position of lead in limestone may be partly explained by the reactions that occur with the solutions


FIG. 15


FIG. 16

in the fissure and the limestone; or, the reactions resulting in the precipitation of the lead may be partly the results of solutions in the channel and the solutions in the limestone. The waters in the fissure may be acid; then alkaline solutions from the limestone will immediately react on such solutions and precipitate lead sulphide. The ready solubility of the limestone furnishes the openings, giving a receptacle for the lead, as shown in Fig. 16, and the lead itself may come from the limestone.

Near Morristown, Tennessee, there are deposits of galena and blende in limestone; below these deposits there are caves, the walls of which are incrusted with zinc carbonates and, at times, lead carbonates. Sometimes galena is incrusted with lead carbonates. Usually, the lead and zinc carbonates are deposited in entirely different places, showing that the points where the materials are found were more suitable to one than to the other metal salt, although derived originally from the same deposit.

Another precipitation resulting from the influences of solids is the occurrence of metallic copper about grains of magnetite, and in the openings of the sandstones, conglomerates, and amygdaloids of Keweenaw Point, Michigan. Where the copper surrounds the magnetite, it seems perfectly clear that the oxide of iron in the magnetite was the reducing agent that precipitated metallic copper. The metallic copper between the particles was doubtless precipitated by ferrous solutions furnished by the wall rocks.

60. Compounds Deposited by Ascending Waters. The most important metalliferous ores are iron, copper, lead, zinc, silver, and gold. These are deposited by ascending waters, mainly as sulphides or, in the case of gold, associated with sulphides and tellurides. The cause for this precipitation is that downward-moving water is deprived of its oxygen by ferrous compounds or organic matter of ascending water. Sulphides do not always appear above water level in old fissures, on account of downward percolating waters; and oxidation seldom occurs below water level.

61. Source of Metals.—The rocks that furnish metallic salts are to a great extent igneous. The frequent occurrence of workable ores in regions that have been disturbed has led some geologists to believe that the igneous rocks furnished heat to assist in the solution. While igneous rocks are undoubtedly the source of a large portion of metallic deposits, it is equally certain that another large part is derived from sedimentary, metamorphosed, and partly metamorphosed rocks. The mistake is often made of stating that some one formation, sedimentary or igneous, is the sole source of the valuable metals.

62. Source of Sulphur.—Metallic sulphides seem to be the original constituents of igneous rocks, and it is probable that sufficient sulphur was present to satisfy all the sulphur compounds in ore deposits. The sulphides in the belt of weathering are oxidized to sulphates, and these are taken in solution and into underground waters, where they may come in contact with buried organic matter and be converted into sulphides. This would be especially likely to happen where the ores are disseminated through beds bearing carbonaceous material. Cazin mentions a Vermont copper mine as a case where ores are mingled with organic matter. Rickard enumerates a number of similar cases. Lindgren states that pyrite occurs in the carbonaceous slate, but not in the quartz of one gold vein in Grass Valley, California. Two springs of ascending waters in the latter district show the presence of sulphates in considerable quantities. Pyrite is also common in coal beds. On Bowan's Creek, in Wyoming County, Pennsylvania, chalcocite and chalcopyrite occur in sandstone and shale that also contain the organic remains of Devonian flora.

Sulphates and sulphites could be reduced to sulphides by ferrous iron in the rocks, particularly in basic rocks that are altered or in scoriaceous basic rocks, and this reaction, which is advanced by Professor Van Hise, would account for the deposition of sulphides in rocks where carbonaceous material is not available.

63. Solutions of Sulphides.—Sulphides of the valuable metals are somewhat freely soluble in alkaline solutions, and especially so in alkaline sulphide solutions. Bicarbonates of the alkalies and alkaline earths holding an excess of carbon dioxide are favorable for the solution of sulphides. Probably sulphides are rendered more soluble by the presence of various other compounds in underground solutions; Doelter has shown that to some extent they are soluble in pure water. Whatever the source of sulphides may be, these ores are generally deposited in fissures by ascending waters.

64. Source of Carbon Dioxide.—Besides sulphuric acid, another acid of great importance in the deposition of ores is carbon dioxide; this is the dominant acid contained in issuing underground waters. Where vegetation is abundant, carbon dioxide is concentrated in the soil; a large part is retained in the belt of weathering by the carbonation of the silicates, but another part joins the sea of underground waters. Considerable carbon dioxide is sometimes obtained from rocks that contain microscopic, and sometimes larger, cavities filled with the gas.

One of the deep-seated dominating reactions is the process of silication of the carbonates, that is, the substitution of silica for carbon dioxide; thus, deep waters are ever receiving contributions of carbon dioxide, which makes them more capable of taking metals in solution. At the Geyser shaft in Custer County, Colorado, the superficial waters are said to contain ten times as much silica as the deep-seated waters. In the deep waters, the carbon dioxide is greatly in excess of that contained in the waters near the surface.

65. Precipitation by Ascending and Descending Waters Combined.—In regions where mining is going on, denudation had, previous to the discovery of the mines, decreased the depth of the veins, so that in many cases only a small portion remains to be worked. From this, it may be surmised that in the past the waters in the large fissures were probably ascending during the time that the first concentration of sulphurets and other products took place. But, as a result of the downward migration of the belt of weathering and the downward movement of the water in that belt, alteration and secondary concentration of ore deposits have taken place. This secondary concentration may explain the frequently greater richness of ore deposits near the surface than exists lower down.

The changes at the surface may cause three zones of mineral, as follows:

1. Above water level, there is a zone of mineral composed largely of oxides, carbonates, chlorides, and associated products, which not infrequently contain rich sulphides.
2. Above and below water level, there is a belt composed of sulphides rich in such metals as gold, silver, copper, lead, and zinc, which, however, contain subordinate amounts of oxidized products.
3. Deeper down is a belt of lean sulphides, bearing small amounts of the more valuable sulphurets, which commonly pass into iron sulphide. It is evident that, if the sulphides are equally abundant, the sulphide that is most easily oxidized will disappear first, and that the order of oxidation will be iron, copper, silver, zinc, and lead. During oxidation, the sulphides are largely altered to sulphates, which are taken into solution and carried away. The sulphides are not all oxidized to sulphates; part of them is converted into sulphur dioxide and oxides of the metals. A part of the oxides unite with carbon dioxide to form carbonates. Finally, the oxides and oxidized salts react on unaltered sulphides producing richer sulphurets. The reactions may be between an oxide or a salt of a metal and its sulphide, as, for instance, the oxide or the sulphate of copper on the sulphide of copper; thus,

$$6CuS + 2Cu_2O = 5Cu_2S + SO_2$$

and

$$6CuS + 2Cu_2SO_4 + 3H_2O = 5Cu_2S + 2H_2SO_4 + H_2SO_3$$

The reaction may be between the oxide or the salt of one metal and the sulphide of another metal; thus,

$$FeS_2 + Cu_2SO_4 = FeSO_4 + 2CuS$$

LEAD, ZINC, AND IRON DEPOSITS

66. In order that the relations of lead, zinc, and iron as they occur together in ore deposits may be understood, the known facts concerning their occurrence should be noted. In the upper Mississippi Valley and the Appalachian Mountains, limestones and dolomites contain lead and zinc minerals as sulphides. These sulphides are sometimes spangled through magnesian limestone in such a manner that it is almost impossible to obtain a first-class concentration mechanically, but nature has taken these metals into solution in many places and deposited them, wherever there was iron in sufficient quantities, as zinc carbonate or zinc silicate. The order of occurrence is usually as follows: Above water level, the predominant minerals are galena and sphalerite; the latter is oxidized more readily than the former and is then changed to carbonates and silicates. There is also some cerusite and anglesite. The carbonates and silicates may extend 15 or 20 feet below water level; but at a greater depth these oxidized products disappear. Below the oxidized minerals, galena and sphalerite are found in connection with iron sulphides. In these deposits, there has evidently been two concentrations: the first concentration is probably the result of ascending waters that concentrated the sulphides; the second concentration is probably the result of downward waters holding the minerals in solution. In some cases, such as may be observed at the Clark and Bertha zinc mines, in Virginia, no other explanation is possible than that descending waters held the minerals in solution.

67. **Precipitation of Galena From Solutions.**—During the process of oxidation, sulphates and carbonates of lead are formed; and these, in solution, sink downwards and react on the other sulphides present, and reprecipitate the lead as galena. The chief reactions, supposing that the lead is a sulphate in solution and meets the iron sulphides FeS or FeS_2, are as follows:

$$PbSO_4 + FeS = PbS + FeSO_4$$

or

$$PbSO_4 + FeS_2 + 2O = PbS + FeSO_4 + SO_2$$

Or, if the lead is in solution as lead carbonate,

$$PbCO_3 + FeS = PbS + FeCO_3$$

or $$PbCO_3 + FeS_2 + 2O = PbS + FeCO_3 + SO_2$$

Lead carbonate can be formed by some such lead-sulphate solutions coming in contact with calcium carbonate; thus,

$$PbSO_4 + CaCO_3 = PbCO_3 + CaSO_4$$

It may be possible that the following reactions are set up, in case zinc sulphide and lead sulphate or carbonate are brought together:

$$PbSO_4 + ZnS = PbS + ZnSO_4$$

$$PbCO_3 + ZnS = PbS + ZnCO_3$$

68. Precipitation of Zinc Minerals From Solutions. Zinc holds to sulphur less strongly than lead, but more strongly than iron. The sphalerite is concentrated in the zone below the galena, the reactions being similar to those producing the galena. The reactions with iron sulphides may be formulated as follows:

$$ZnSO_4 + FeS = ZnS + FeSO_4$$

$$ZnSO_4 + FeS_2 + 2O = ZnS + FeSO_4 + SO_2$$

and $$ZnCO_3 + FeS = ZnS + FeCO_3$$

$$ZnCO_3 + FeS_2 + 2O = ZnS + FeCO_3 + SO_2$$

The formula for calamine is given by Dana as $Zn_2H_2O_5Si$, and any series of formulas that will explain such complex compositions will require that silica be taken into the solution by an alkali; consequently, the reaction advanced is not absolute, but merely illustrative:

$$2ZnSO_4 + CaSiO_3 \cdot 2H_2O = Zn_2H_2O_5Si + CaSO_4 + H_2SO_4$$

Electric calamine is found in beds of limonite, where it is supposed that the precipitation is produced by an electric or galvanic current set up between the metals in solution and the iron oxide, although an interchange of elements could be the cause. The calamine in the Clark mine seems to have formed from the bottom up, as if deposited from a saturated solution of zinc silicate.

COPPER AND IRON COMPOUNDS

69. First Concentration of Copper Ores.—In dealing with copper deposits, both first and second concentrations may be considered. It is assumed with first concentration that the deposits are due to the fact that the ascending waters held salts of the metal in solution. Mining has proved that, deep down in the vein deposits, iron sulphides predominate, for which reason, as the deposit nears the surface, different grades of the more valuable metals are met. It is possible and often demonstrated in mining that chalcopyrite increases in richness toward the surface until it predominates over pyrite. The reactions between copper sulphate and iron sulphides may be written as follows:

$$CuSO_4 + 2FeS = CuFeS_2 + FeSO_4$$

or $$CuSO_4 + 2FeS_2 + O_4 = CuFeS_2 + FeSO_4 + 2SO_2$$

either of which gives the mineral chalcopyrite.

Where the iron sulphide is pyrrhotite, the reactions may be expressed by combining the above equations in proper proportions and using the sulphide, Fe_7S_8.

In passing upwards from the lowest level in which chalcopyrite appears, this mineral may steadily increase in quantity until the iron sulphide is subordinate, when bornite is likely to appear. This may possibly occur according to the following reactions:

$$Cu_2SO_4 + CuSO_4 + 3FeS = Cu_3FeS_3 + 2FeSO_4$$

or

$$Cu_2SO_4 + CuSO_4 + 3FeS_2 + 6O = Cu_3FeS_3 + 2FeSO_4 + 3SO_2$$

Bornite, however, could be produced by the reaction of the copper salt on chalcopyrite. Passing now to still higher levels in the deposit, chalcocite, Cu_2S, will probably be encountered which may be produced by the reaction of cuprous sulphate on iron sulphides, as follows:

$$Cu_2SO_4 + FeS = Cu_2S + FeSO_4$$

or $$Cu_2SO_4 + FeS_2 + O_2 = Cu_2S + FeSO_4 + SO_2$$

Chalcocite may be produced by the reaction of the sulphates either on chalcopyrite or on bornite. Chalcocite is usually found in copper deposits near the water level, and is a very rich copper ore. At still higher levels in the deposit, carbonates may appear with the sulphurets; while at still higher levels, especially above water level, carbonates predominate, since in this situation rich sulphurets in ascending solution have been directly acted on by oxygen or carbon dioxide. The oxidation of the sulphur and copper may be simultaneous, or the sulphur may be oxidized first, forming metallic copper. A series of transformations can occur in this zone, which would result in cuprite, Cu_2O; tenorite, CuO; azurite, or blue copper carbonate, malachite, or green copper carbonate; and chryscolla, a hydrous copper silicate.

70. Second Concentration of Copper Ores.—In the first concentration of the copper deposits, it has been assumed that the deposits were formed by ascending solutions; in the second concentration, it is assumed that sulphides have been oxidized in the zone of weathering, and the concentration has been accomplished by descending waters holding salts of the metals in solution. Such secondary concentration will naturally diminish in richness with depth. In secondary copper deposits, the top of the deposit is usually a poor iron ore known as *gossan;* below this, at the level of ground water, there is usually found a rich deposit of chalcocite of varying thickness; below this is bornite; and still deeper chalcopyrite is found, which gradually loses its percentage of copper until it shades into pyrite. The secondary concentration occurs only as deep down in the deposit as water level. The gossan may carry high values in silver and gold. Thus, at Bûtte, Montana, the increase in silver and gold in the oxidized zone is quite noticeable when compared with the material below water level. To account for these high values in gold and silver above water level, one must suppose that this belt has received contributions of those metals from the upward extension of the vein that is now removed by erosion. The many illustrations of sulphide deposits that have been oxidized at the surface point almost conclusively to a secondary concentration.

SILVER DEPOSITS

71. Silver is a metal that has great affinity for sulphur and its original forms are generally sulphides, sulphantimonites, sulphantimonates, sulpharsenites, and sulpharsenates. Ordinarily, silver is not sufficiently abundant to constitute the main mass of an ore deposit; hence, in lead-zinc-iron compounds, it is found most abundantly with lead, less abundantly with zinc, and least abundantly with iron. The rich silver compounds—native silver, cerargyrite, $AgCl$; argentite, Ag_2S; proustite, Ag_3AsS_3; pyrargyrite, Ag_3SbS_3; and stephanite, Ag_5SbS_4—may be abundantly found in the upper parts of the veins, but frequently decrease in quantity in passing into the zone of sulphides, and sometimes entirely disappear, the products being wholly argentiferous lead, zinc, copper, and iron; if, with increase of depth, the ores become poorer in lead and zinc, they are also likely to become poorer in copper; the silver will also ordinarily decrease in amount. As an illustration of second concentration in the belt of weathering, suppose that the silver sulphide was oxidized to silver sulphate; this salt would then pass downwards in solution until it reached chalcocite, when it may be assumed that the silver would be precipitated as argentite, according to the equation:

$$Cu_2S + Ag_2SO_4 = Ag_2S + Cu_2SO_4$$

In a similar manner, various other reactions could be written for the salts of silver and the sulphides of copper, lead, zinc, and iron.

In the Leadville, Colorado, ores, the galena is much richer in silver than the cerusite. This discrepancy may be explained by the reaction of the oxidized silver salts on the galena, producing a galena richer in silver than originally existed. Above the level of ground water, the silver occurs to some extent in native form, but more largely as horn silver, as that compound is not easily oxidized; and if not precipitated as cerargyrite the upper part of the silver veins in the belt of weathering may be greatly depleted in silver as the result of the leaching. If there is a deficiency of chlorine in the solutions, silver chloride will not be formed; but should there be silver chloride in solution, argentite could be formed when brought in contact with copper sulphide, thus:

$$Ag_2SO_4 + 2NaCl = 2AgCl + Na_2SO_4$$

or, for the second case,

$$Cu_2S + 2AgCl = Ag_2S + 2CuCl$$

The oxidized portions of the Cripple Creek tellurides carry free gold, but are deficient in silver; while the original tellurides contain a certain amount of silver below the oxidized zone, which fact would indicate that silver has been leached out from the oxidized zone.

PROSPECTING FOR GOLD

72. Gold-Vein Deposits.—In some veins—particularly at the oxidized outcrops—gold is found in its native form; more often, however, it is found associated with sulphides or tellurides. In the form in which it occurs in oxidized vein outcrops, gold is a secondary product of concentration; in the other cases, it is usually in the first-concentration stage. Below the level of ground water, the most common associates of gold are the sulphides of the base metals. In such cases, where the sulphides are plentiful the gold is more abundant, and where deficient the gold also is lacking. It is probable that the original sulphide solutions contained gold, which would account for the deficiency when the sulphurets are not abundant. Gold is frequently deposited with the telluride minerals *petzite* and *sylvanite*—according to some, as a telluride of gold; according to others, in its native state and associated mechanically with tellurium. Dana states that this occurrence of gold with tellurium is a chemical combination; other equally good authorities claim that it is merely a mechanical association.

Gold is known to be soluble in some solutions and especially in alkaline sulphides, which are sure to occur in underground waters. Moreover, gold combines with iodine and chlorine, and both compounds are soluble. Gold is said to be soluble in ferric sulphate, $Fe_2(SO_4)_3$, and alkaline iodides are capable of dissolving gold. Since underground solutions of gold are exceedingly dilute, it is probable that gold is kept ionized or in the free state. It would be kept in the ionic state, not by one but by all of the free acids present. Metallic gold has been found in sedimentary rocks bearing organic matter, and in veins where they cross carbonaceous shales. Away from the carbonaceous shales, the quartz vein is said to be absolutely barren. Gold could be precipitated from solutions that have come in contact with ferrous oxide, such as magnetite, or from solutions bearing ferrous or cuprous salts, which are abundantly produced underground. It may be possible that the alkaline solutions that dissolved the quartz of veins and brought them into solution, also collected and transported the gold, since quartz is nearly always a gangue rock of gold. In some cases where wire gold occurs, silication and carbonation may have furnished carbon dioxide for precipitation; in fact, numerous speculations may account for the precipitation of gold from solutions.

That gold ores are sometimes richer at the surface than lower down may be due to the concentration by the action of weathering, and certain it is that oxidized products are due to that cause. A peculiar fact to be noted is that, in some mines where the ores contain silver and gold, the two metals increase in abundance in about equal proportions, also that this enrichment of the vein occurs at somewhat regular intervals on both the strike and the dip. This would suggest that solutions capable of precipitating the metals entered at these particular places. Selective agency may have had much to do with the concentration of minerals; for, since the solutions must have been very weak, it can be imagined that, where a crystal started to form, a mineral of the same kind in solution would add to its size.

73. Gold Deposits.—Gold veins have most frequently been discovered where oxidized outcrops occur, because in such locations the gold is often visible to the eye. It has, however, been found by the examination of rusty quartz—that is, quartz that has been stained with the iron from the oxidized pyrite. In the latter case, the gold may or may not be visible to the naked eye, and its determination must be accomplished by assay. Most gold found in the native state contains from 5 to 13 per cent. of silver, but whether the silver is always alloyed with gold or exists separately in the ore it is not possible to say positively; it is known, however, that placer gold is alloyed with silver. There are many instances where gold and silver are associated with copper, lead, zinc, and iron minerals, but in such a fine state that its detection can only be determined by assay. Tetrahedrite, mispickel, and other combinations of mixed sulphides also contain gold in a form not visible to the eye. The tellurium minerals sylvanite, nagyagite, and petzite usually contain gold in their composition, and are worked extensively in Boulder, Custer, Teller, and San Miguel Counties, Colorado, as also in the Mercur district of Utah.

While gold is widely distributed, in small quantities, in rocks of all geological systems, it is only once in a while that it is found concentrated in bonanzas. Neither gold nor quartz, with which it is usually associated, is readily acted on by the elements, but when the quartz is decomposed, the gold remains near by unless transported by rapid streams or glaciers. Gold is a constituent of sea-water, but in such minute quantities that it cannot be recovered at a profit, although frequently, in the past, men with more imagination than wisdom have attempted it. The black sands of placers, rivers, and sea beaches often contain gold.

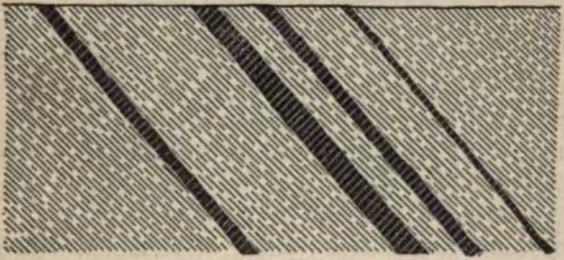


FIG. 17

The African gold fields that have been developed are in Rhodesia and the Transvaal. The Witwatersrand, termed Rand for short, is the largest gold field so far discovered. The gold is in quartz, conglomerate beds, occasionally broken by faults or dikes. The geological structure is very simple, compared with other fields, and, as shown in Fig. 17, a cross-section of the Glencairn property is quite regular. The beds are termed *reefs*, and the conglomerate is a mass of quartz pebbles cemented together with a quartz cement in which pyrite and free gold are found. These ores are not exceedingly rich in gold, but are easily worked and the gold recovered by amalgamation followed by cyaniding. From the description given of this field, its geological position would approximate the Carboniferous period.

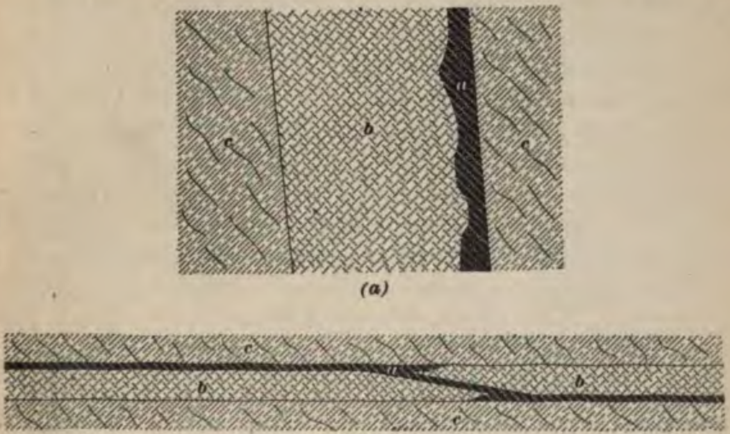
The gold deposits of New South Wales, Victoria, Queensland, and Tasmania are also called reefs. The peculiarity of these fields is the anticlinal saddle reefs shown in Fig. 18, in which the black area represents the gold ore. In the slates at Tambaroona, New South Wales, both anticlinal and synclinal reefs occur, according to Watt. Some of these reefs are in sedimentary rocks bearing organic matter.

FIG. 18

In the Eastern United States, termed the Appalachian Region, gold was discovered in North Carolina as far back as 1799. It is found in quartz that is encased in slates; schistose gneiss; schists; and clays derived from these rocks, which are relics of the Archæan and are probably Cambrian. In some cases, the gold occurs in quartz veins that stand above the surrounding slates and altered gneiss and schists. It has not been concentrated to any great extent, appears, in many instances, to be pockety, and is usually of a refractory nature. Development has not been extensive, but in some cases the ores are worked at a profit. In Gilpin

County, Colorado, gold is found in fissure veins that are in granite or gneiss. At the surface, the ores are free milling, but with depth they become sulphurets; the veins are very persistent and extend to great depth. The Clear Creek County gold ores are similar in formation and character. In Boulder County, Colorado, the gold is associated with tellurium minerals, in small veins, along fault fissures in granite or gneiss sometimes associated with porphyry. In Lake County, Colorado, the gold is found in veins through granite, in porphyry dikes, and in limestone associated with porphyry. Leadville is in this district; but, although it furnishes gold, it is more of a silver than a gold camp. In Teller County, Colorado, particularly in the Cripple Creek district, tellurides containing gold are found in fissures near phonolite dikes in eruptive rocks.

Fig. 19 (*a*) is a cross-section of the Elkton mine, Cripple Creek, in which *a* is the vein; *b*, the dike; and *c*, the eruptive country rock. Fig. 19 (*b*) is a horizontal section of the same mine, showing the relation of the vein *a* to the dike *b* and the country rock *c*. It will be noticed that the vein cuts through the dike from one wall to the other. In this location, the walls of the veins as well as the veins themselves



(a)

(b)

Fig. 19

are very irregular, and show apparently that the veins were filled by ascending solutions. The San Miguel and San Juan Districts of Colorado have fissure veins containing gold in tellurium minerals.

In Deer Lodge County, Montana, there are quartz veins in granite that contain gold with a large percentage of silver associated with it. Lewis and Clark County has similar veins in granite, and also quartz veins in slate. The rocks at Mercur, Utah, are said to be Carboniferous sandstones and limestones. Here, the tellurides are deposited in contact with altered limestones and thin intruded porphyry sheets, but sometimes they are found in the porphyrys themselves and in the limestones immediately above them. It is believed that these deposits were formed by ascending mineral solutions.

The Comstock lode in Nevada is a great quartz vein, having diorite and diabase for country rock, in which silver predominates in the proportion of two parts of gold to three parts of silver. The ore is sometimes found in rich masses or bonanzas.

A gold belt in California, known as the mother lode, extends through Amador, El Dorado, Calaveras, Toulumne, Mariposa, and Madera Counties. It is not one continuous mineral vein, but a series of parallel veins that are sometimes unbroken for a long distance. The rocks are complex and have been cut through by fissures and overlaid with eruptive material. The fissures contain dike-like masses of diabase, diorite, serpentine, and other intrusive rocks, which were thrust, from below, through the overlying rocks. The rocks in the formations are slates, quartzites, and greenstones, which are due to the alteration of crushed diabase combined with metamorphism. The walls sometimes differ; there is a greenstone foot-wall, then slate with the quartz gold vein, next a gouge, and a black slate hanging wall. The greenstone is sometimes the hanging wall. The gold is found in the quartz adjacent to the slates. The Mariposa beds, in which the central, or mother, lode of this gold belt is associated, has clay slates that were considered an essential feature; in fact, in former times the immediate contact or close proximity to Mariposa clay slates was deemed indispensable to pay rock. Later developments show that fissures in the clay slates of the Mariposa beds are barren, and that the productive vein fissures are approximately parallel. The impression also existed that a paying mine must be in contact with greenstone and black slate, but late developments show that some of the best-paying ore chutes are in amphibolite schists. Investigation has shown that slates of the ore deposits are the result of an alteration of diabase, and may be distinguished by their pitted appearance from the clay slates of the Mariposa beds. The ore deposits seem to be independent of contact with slates and massive greenstone, but the black slates and the quartz keep together with regularity. The gold deposits in the Black Hills of South Dakota consist of schists in Cambrian sandstones, granite, and igneous rock. The largest gold mine in the United States is located here, and while the gold is not concentrated in bonanzas it is fairly uniform in large rock masses that are easy to work and from which the gold is easily recovered. The average value of the ore does not exceed $4, but the dividends from this mine have so far amounted to more than $15,000,000.

The Alaska-Treadwell mine on Douglas Island, Alaska, is a somewhat similar formation, the wide granite lode having been shattered and then cemented with quartz solutions containing gold. The foot-wall is slate, the hanging wall greenstone.

The foregoing examples show that, while the prospector is more likely to find gold in mountainous mineralized zones than in other regions, there is no definite limit to its existence elsewhere. Gold in all probability comes from the interior of the earth in solutions, but it is so indestructible that the original veins that held it may have been weathered long ago, and the gold again become encased in other rocks of a sedimentary character. There is one instance in the anthracite fields of Northeastern Pennsylvania where, in the Upper Devonian formation, gold, silver, and copper are found in micaceous sandstone, nor is there any dike in the vicinity; but the sandstone is shattered by deformation due to dynamic agencies.

74. Gold in Other Ores.—Gold is often a by-product of silver-lead mining, and, in some instances, of copper mining. It may be found in the residues after pyrite has been burned for sulphuric acid; consequently, its production is not confined to gold mining alone. In Mexican silver mines, the gold usually increases as the proportion of silver increases. If a quartz vein has been discovered but no gold found, the prospector need not feel disheartened, but should try the same vein in another place—in fact, several other places. Success may in the end reward his search. After finding the lode, the prospector should take out from 4 to 5 tons of the ore in different spots along the vein, and have an average sample crushed separately and panned for gold. He should not attempt to take the best of this ore, as otherwise he will deceive himself; on the contrary, in order to obtain a good assay or average value, he should take an average sample, or vein matter that carries mineral as well as some that is not mineral bearing.

75. Tracing Veins.—The search for mineral veins carrying gold requires a thorough knowledge of rocks, for the gold will not always be visible. In a new country, quartz ledges should be first examined, and some of the rock crushed and panned. If no signs of mineral are found, the vein should be traced until some oxidized pyrite is observed, when another panning should be undertaken. It may happen that the mineral is so fine that it cannot be detected; hence, if the quartz is much stained and pitted, a sample should be assayed. The vein prospector must work hard and be a close observer, otherwise he will meet with indifferent success. All slates near the quartz vein should next be examined and panned for mineral, particularly if they are quartz slates; in this case, sulphide mineral is an indicator if found in the pan. In the Atlantic coast states, chloritic quartz schists often carry gold. If the prospector is in a location where veins cross different kinds of rock, he should examine the vein in each rock, and particularly the intersection of cross-veins. If there is a fissure where contact occurs between two kinds of rock, the filling to the fissure may contain the valuable metal, especially where eruptive and sedimentary rocks are in contact. Unless the prospector knows that he is in a mineralized zone, he should look for indications of mineral—that is, examine the float or vein matter that has become detached from the parent lode by natural agencies. Such fragments are found in gulches, on benches of rock, or along watercourses; in fact, the prospector should examine every place where mineral would naturally lodge, either when rolling down hill or when being transported by avalanches, ice, or water. Sometimes mineral blossoms have been transported considerable distances from the lode, and at the same time a large quantity will be barren while only a small percentage shows mineral; but the latter is an indicator that the vein is mineralized and should be traced. Gold float is usually rusty quartz stained reddish brown, native gold, or quartz containing some sulphide not easily weathered. There may be other vein minerals, such as barite and calcite, that will bear examination if in quantities, although such gangue minerals are more likely to be with silver-lead minerals. The quartz may be stained greenish from the oxidation of copper pyrite; but care should be taken to examine such stains, as vegetable matter will also stain quartz green. In prospecting mountain spurs, the quartz veins will likely be prominent if the wall rocks are easily weathered. Where there are no outcrops, the streak-like depressions on the surface should be closely examined, for in them mineral veins are sometimes found. The first operation should be to wash out some of the digging surface. If only a trace of quartz gold is obtained, a vein is likely to exist in the neighborhood; trenching should therefore be undertaken—that is, ditches should be dug in the soil to look for float or to uncover mineral veins. These trenches should be systematically followed up, but their selection, or site, must be left to the judgment of the prospector, who should be guided by his knowledge of the country being prospected and of the mineral that he is hunting.

76. Determination of Fine Gold.—Coarse particles of gold are readily distinguishable by the eye, either in the quartz or after crushing, but there are instances where the particles of gold are so fine that they are not discernible, and other instances where they are so wrapped up in other minerals that they cannot be distinguished. In order to test for the presence of such gold, Darton advises the following method, which he considers trustworthy in such cases and very useful to prospectors, in that, in all probability, it will save them considerable money and labor. Small pieces of the rock to be tested are finely powdered and well mixed; then, about $\frac{1}{8}$ ounce of the powder is placed in a large test tube, together with a solution made by dissolving 20 grains of iodine and 30 grains of iodide of potassium in about $1\frac{1}{2}$ ounces of water. The mixture is then thoroughly agitated and heated, and, after it has settled, a piece of pure, white Swedish filter paper is dipped into it and allowed to remain for a few moments. The paper is then taken out, drained, and dried over a spirit lamp, after which it is placed on a piece of platinum foil and heated to redness over the flame, the foil being held with pincers. After the filter paper has been consumed and the carbon burned off, the residue on the foil is allowed to cool and is then carefully examined. If the residue appears at all purple, gold is present in the ore and the relative amount may be approximately deduced. The whole operation takes but little time.

If the prospector desires to confirm the presence of gold, he should take some of the ash remaining and treat it with a few drops of aqua regia. Evaporate the solution to dryness at a gentle heat and dissolve the residue in water. The solution is then poured into a breaker that is placed on a sheet of white paper. Another solution is now prepared by adding ferric chloride to stannous chloride until a prominent yellow color is produced. This solution is diluted with water and a glass rod dipped first into it and then into the gold solution; if a bluish-purple streak appears in the track of the rod, it is positive evidence of the presence of gold.

77. Ohler's Method of Determining Gold.—A new method of detecting the presence of a small quantity of gold has been recently discovered by Doctor Ohler. By this method, the presence of quantities as low as 77 centigrams per ton may be established. The operation is as follows: A quantity of finely powdered ore, say 120 grams, is introduced into a flask. To this an equal volume of the tincture of iodine is added, and the mixture well agitated. It is then left for an hour, being agitated from time to time, and is finally allowed to stand. When the solids have settled, a piece of filter paper is saturated with the solution and then allowed to dry. The operation is repeated five or six times in succession, in order to completely saturate the paper. After it is calcined, the ash, when gold is present, has a purple color. This color should disappear quickly if the ash is moistened with bromine water. The test may be modified in the following manner: Cover a quantity of the powdered ore, say 120 grams, with bromine water and filter the solution after it has been agitated for about an hour. On adding chloride tin, the solution, if gold is present, will turn a purple color, which is known as the Purple of Cassius. In the case of sulphides, the ore should be previously roasted, and when the mineral contains a considerable proportion of carbonate of lime, it should be calcined in the presence of ammonia carbonate.

78. Hushing.—When the prospector finds the rock of the hillside that he wishes to examine covered with a layer of drift, it may be possible to remove the earth and expose the rock by the process called **hushing**. This is really ground sluicing to remove the earth. The water is either confined in a reservoir near the top of the gulch, and suddenly released to plow its way down the valley, and so carry much of the earth with it, or else a ditch is dug from some creek and carried along the hillside until it gains a sufficient height above the valley, when it is allowed to flow down over the hill. Frequently, the earth in the course of the water is loosened with a pick and the stream made to carry it away.

Under favorable circumstances, a man can move more earth in a day by hushing than he could in several weeks with a pick and shovel; but it is seldom that this system is practiced, unless the prospector is sure he has gold and wishes to mine rather than prospect.

LOCATING LODE CLAIMS

UNITED STATES PRACTICE

79. Public Lands.—If, as the result of investigation, the prospector considers the deposit a promising one, he proceeds to locate it according to the laws of the district in which the property lies. All valuable mineral deposits in lands belonging to the United States, both surveyed and unsurveyed, are free and open to exploration and purchase, except land in Michigan, Wisconsin, Minnesota, Missouri, Kansas, and Alabama. All lands so excepted are open to exploration and purchase, according to legal subdivisions, in tracts of not more than 160 acres, as agricultural lands. All other lands situated on the public domain are subject to exploration, location, and purchase as mineral lands. The locators of all mineral lands have exclusive right of possession and enjoyment of all the surface included within the limits of every location, and of all veins, lodes, and ledges throughout their entire depth, the top, or apex, of which lies inside of such surface lines. Lode locations are the withdrawal of surface area from the public domain, with underground rights to all the area within the surface lines; hence, valid locations cannot overlap in law, and the area in conflict must be excluded from one or the other of the conflicting locations. The lode may be followed beneath the side lines and the surface ground of a prior location, provided the lode does not, in its course, intersect with a lode that has its apex within the surface ground of the prior location, in which case it may be followed only to the point of intersection.

80. Size of Claim.—The mining laws of the United States limit the dimensions of a lode claim to 1,500 feet along the course of the vein by 600 feet wide, horizontal distance—300 feet on each side of the center of the vein at the discovery shaft. In Colorado, the State Legislature has fixed the legal width of a claim at 300 feet, except in the case of Gilpin, Clear Creek, Boulder, and Summit Counties, where the limit is 150 feet. In all other states and territories, the dimensions specified by the act of Congress of 1872—1,500 feet by 600 feet—hold, and can under no circumstances be exceeded for individual claims. Under the United States laws, no local laws are allowed to curtail the length of a claim, though the width may be reduced to not less than 25 feet on each side of the middle of the vein at the surface. The only provision in the United States mining laws in regard to the shape of the claim is that the end lines must be parallel. The side lines may run in any direction so long as they are nowhere more than the legal distance apart, and the location will still hold. They are usually surveyed parallel to the center line, however, and at the maximum legal distance from it, when such a course will not bring them in legal contact with other properties.

81. Discovery Shaft.—To render a location valid in Colorado, Idaho, Wyoming, New Mexico, Arizona, and Montana, a shaft, or equivalent opening, that will expose the ore body to a depth of at least 10 feet below the lowest point of the surface at the opening must be made. In those states in which the depth of the discovery shaft is not fixed by law, an exposure of the vein is all that is necessary, and if the vein outcrops on the surface no digging is required. The **discovery shaft** is not necessarily the opening by which the lode was discovered, but merely a condition of a valid location, subsequent to discovery, and may be sunk at any point along the vein. The statutes of Idaho require that any excavation that will cut such veins 10 feet from the lowest part of the rim and will cover 160 cubic feet in extent, shall be considered a compliance with this provision. The claim must be staked within 10 days of the notice of discovery. The discovery shaft must be included in the location, and any change of boundaries that includes the discovery shaft renders the location invalid.

82. Location Notice.—The location notice for lodes is the same as that for placers. The manual of instructions issued by the General Land Office for surveyors-general and deputy mineral surveyors, issued by authority as "in strict conformity with the United States mining laws and the decisions thereunder, with which the prospector will be expected to strictly comply," gives the following forms for placer and lode location certificates. Idaho's additional requirements are given in parenthesis.

LOCATION CERTIFICATE

Lode Claim

State of ____________ }
County of ____________ } *ss.*

Know all men by these presents, that ________ the undersigned [a citizen of the United States (or has declared his intention to become such) of the age of 21 years], has this ________ day of ________ 190__, located and claimed, and by these presents does locate and claim, by right of discovery and location, in compliance with the mining acts of Congress, approved May 10th, 1872, and all subsequent acts, and with local customs, laws, and regulations, ________ linear feet and horizontal measurement on the Birthday lode, vein, ledge, or deposit, along the vein thereof, with all its dips, angles, and variations, as allowed by law, together with ________ feet on the ________ side and ________ feet on the ________ side of the middle of said vein at the surface, so far as can be determined from present developments, and all veins, lodes, ledges, or deposits and surface ground within the lines of said claim, and ________ feet running N 48° 46′ E from center of discovery shaft; said discovery shaft being situate on said lode, vein, ledge, or deposit, and within the lines of said claim, in Wild Horse Mining District, county of ________ and state of ________, described by metes and bounds as follows, to wit: Beginning at corner No. 1, whence corner to Secs. 17, 18, 19, and 20, T. 14 S. R. 69 W bears S 27° 28′ E 393.26 feet, thence N 17° 38′ E 831.34 feet to corner No. 2, thence N 48° 46′ E 661.7 feet to corner No. 3, thence S 41° 14′ E 300 feet to corner No. 4, thence S 48° 46′ W 578 feet to corner No. 5, thence S 17° 38′ W 929.04 feet to corner No. 6, thence N 41° 14′ W 350.48 feet to corner No. 1, the place of beginning (and that I intend to hold and work said claim in accordance with the laws of the United States and of the State of Idaho).

(Dated on ground ________ 190)
Date of certificate ________ 190 __
(Filed ________ 190__)

Discovered ________ 190__
(Located ________ 190__)
(Recorded ________ 190__)

The placer-location certificate, when the location is on unsurveyed ground, is to be substantially like the lode certificate.

83. Staking Lode Claim.—Having decided on the course of his claim, the prospector must mark its boundaries. by means of stakes, or, if these are not obtainable, by monuments of stone or earth. (A stump or boulder properly marked fully answers the purpose of a stake.) The stakes should be at least 4 inches square and 3 feet long, and should be set 18 inches in the ground. One such stake, blazed on the side toward the claim and marked with the name of the lode and the number of the corner, is set at each corner of the claim. When the center line of the claim is straight, a similar stake is set in the middle of each side line, blazed on the inside, and marked. When the center line is broken, stakes are set at all angles of the side lines and numbered continuously around the claim, starting with one of the corner stakes, as No. 1. Only the stakes at the angles are numbered, center stakes, when present, being merely marked as such. In the Dakotas and in Arizona, a stake is required in the middle of each end line.

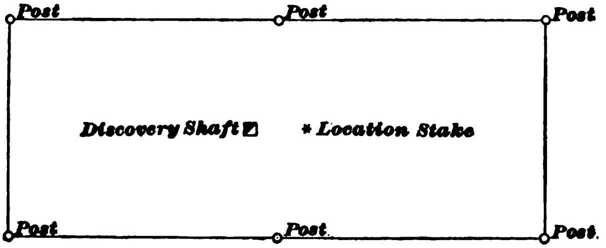


FIG. 20

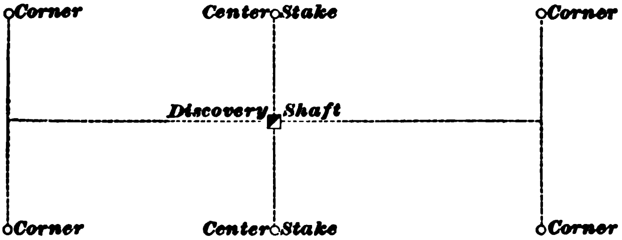


FIG. 21

Fig. 20 is a diagram of a lode correctly located under the present law in Colorado and most of the other mining states and territories. Fig. 21 shows the lines that it is necessary to run for the prospect survey.

When a stake cannot be driven, on account of bed rock, it should be fixed in a pile of stones. If, on account of precipitous ground, it is impossible to set the stake where it belongs, a witness stake should be set at the nearest available point along one of the lines of the survey, and suitably marked to designate the position of the corner.

84. Rights of the Locator.—Having properly located the claim and recorded the location with the recorder of the county or district, the prospector is entitled to all veins apexing within his boundaries that are not already claimed, and may work such veins on their dip, to their full depth, for the distance between the parallel vertical planes of the end lines; under no condition, however, can he follow the vein outside of the vertical planes of the end lines. If the vein, in its dip, turns and crosses the end line, he loses all right to follow it on its dip beyond where it crosses. Thus, he may follow the lode indefinitely if, as in Fig. 22, it remains

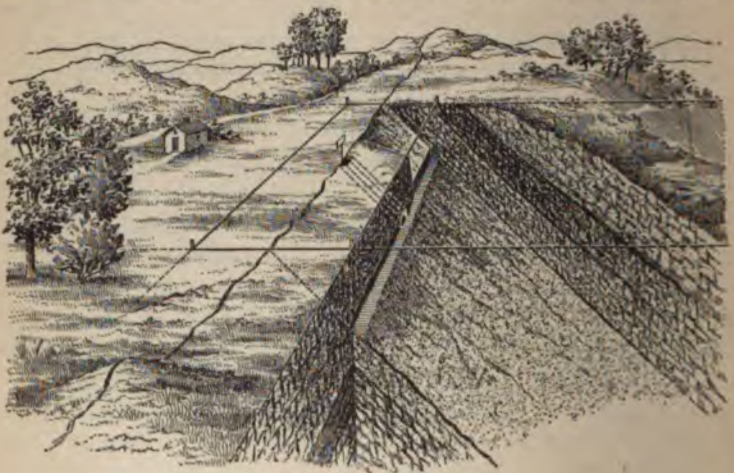


FIG. 22

within the end lines; but if it turns and passes out through either end line, as in Fig. 23, he has no claim to any portion of the lode beyond the end line.

The terms *apex* and *outcrop* must not be confounded. Flat, stratified deposits—such as coal beds, the zinc-ore beds of Missouri, or even blanket veins—cannot fairly be considered to have an apex, or highest part, though they may have a well-defined outcrop.

In the cases of coal and zinc beds and stone quarries, no extralateral rights are ever granted, the locator being entitled to that portion of the bed vertically beneath his surface location. The case of flat veins and blanket deposits, though coming under another statute, would appear analogous, and is generally so considered by the courts. A location on the outcrop of a vein with a dip of 8° was held to give the locator no extralateral rights, and subsequent locations made on the dip of the same vein were held to be valid, with the same restrictions.

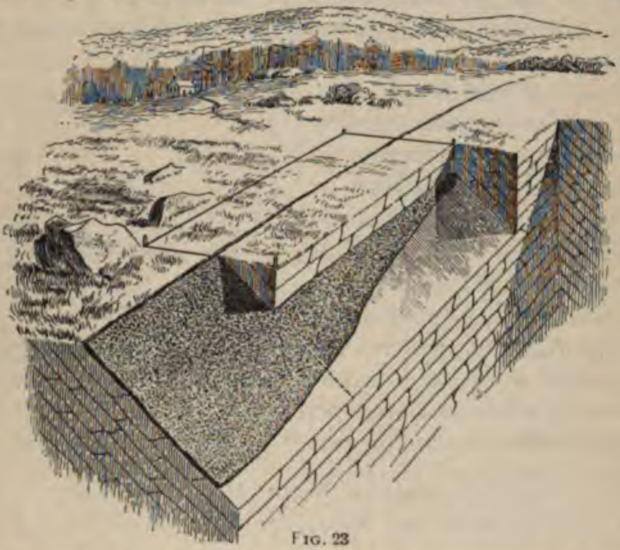


FIG. 23

85. Apex and Side Line.—If the apex crosses one side line, as in Fig. 24, the courts have decided that the point *a* of departure of the vein becomes in effect one point of an end line *a b* parallel to the other end line, beyond which the locator has no rights on the vein.

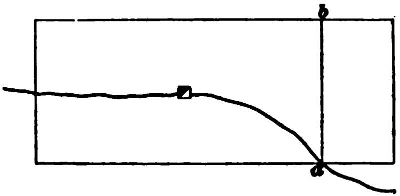


FIG. 24

86. Apex and End Lines.—If the apex crosses both side lines, the same rule usually holds, each end line being moved to the nearest point of intersection of the vein with the side line, as indicated by the dotted lines in Fig. 25; or the court may fix through these points end lines at right angles to the strike of the vein. If, however, the apex intersects the side lines at a high angle, as in Fig. 26—in the words of the ruling, "substantially at right angles"—so that the distance between the end lines, if moved in, would be less than the legal width of the claim, the side lines become in effect end lines and the rights of the locator are limited by the vertical planes of both side and end lines.

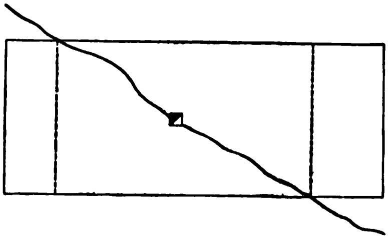


FIG. 25

87. Court Decisions Regarding the Apex.—If the apex departs from one side line twice, as in Fig. 27, the locator is entitled to only that portion of the vein within the vertical planes of his side lines. Such cases as these, however, are more or less in the hands of the courts, and mining cases are always in doubt until the final decision of the highest court has been made. The construction that a court may put on certain phrases and conditions of the

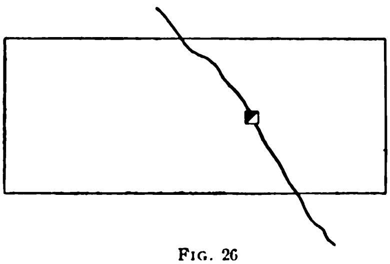


FIG. 26

statutes is frequently totally unexpected and without precedent, so that the prospector in locating his claim should exercise the utmost care to have it incontestable so as to avoid future trouble.

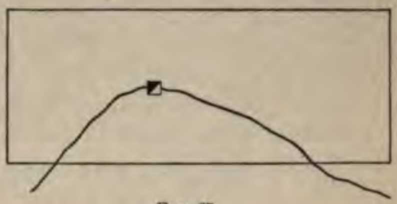


FIG. 27

88. The Form of a Mining Claim.—The form of the mining claim does not have to be rectangular, but may be laid out as shown in Fig. 28, in which case the line *AefB* is supposed to approximately follow the vein, but its length must not be over 1,500 feet. The end lines through the points *A* and *B* cannot be over the full width of the claim, as allowed by law, and must be parallel to each other; that is, the line *ab* passing through the point *A* must be parallel to the line *cd* passing through the point *B*. The side lines are parallel to the center line, and in no place should the perpendicular distance between them be over the allowed width of the claim. These angular claims are used to overcome the difficulties illustrated in Figs. 24, 25, 26, and 27. The stakes are numbered as in the case of rectangular claims, and may start from the point *a*, and be numbered in order, as shown in Fig. 28.

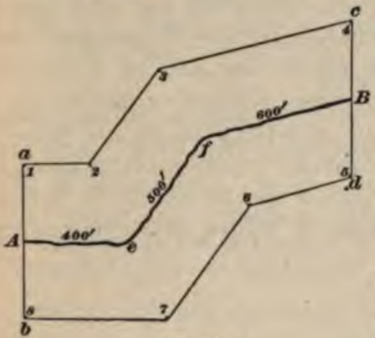


FIG. 28

89. Location Survey.—For the location notice, it is not necessary that the survey of the claim be tied to a special government monument, patent corner, or section corner. It is considered sufficient if it is tied to some natural landmark or to a monument that can easily be identified. When the claim is finally surveyed for patent, the survey must be tied to a government monument or section corner.

90. Annual Labor.—To hold a claim until it is patented, the locator, or owner, must, each calendar year, perform at least $100 worth of labor in actual development of the property, or make improvements of that value, such as buildings, machinery, etc., until the total sum amounts to $500. Where a number of claims are worked as a group, provided the ownership of the claim is a common one and the claims are contiguous and the work done develops or benefits each claim of the group, the work may be done on any one claim of the group.

91. Locating Minerals in the Eastern and Southern Portions of the United States.—In the eastern and southern portions of the United States, the discoverer is not allowed to stake out a claim, as in the West, but must purchase the land on which the mineral occurs from the government. If the land is owned by private parties, he may purchase it from them, or obtain the privilege of mining the mineral by paying a royalty on a definite lease. In these regions, the mining must be confined to the vertical planes passing through the boundaries of the property; in other words, the miner is not allowed to follow his vein under another person's property.

BRITISH COLUMBIAN PRACTICE

92. Size and Shape of Claim.—A mineral (lode) claim, according to the mining laws of British Columbia, may be, but cannot exceed, 1,500 feet square. All angles must be right angles; that is, the claim must be rectangular. Two sides of the claim must be, as nearly as possible, parallel to the general course of the vein.

93. Discovery of Vein.—To make a location valid, ore must be discovered in place, as in the American laws, but there are no regulations as to openings. A discovery post must be placed as near as possible to the point of discovery. This must be the ordinary legal post described under British Columbian Placer Laws (see Art. **39**).

94. Staking.—Besides the discovery post, the Canadian prospector is obliged to set only two other posts (see Fig. 29); these are set along the line of the vein, not more than 1,500 feet apart. They must be legal posts, and numbered separately No. 1 and No. 2. On No. 1 posts there must also be written the words "initial posts," the approximate compass bearing or direction of No. 2 post, and a statement of the number of feet the locator claims on each side of the line between the two posts, known as the *location line*. Thus:

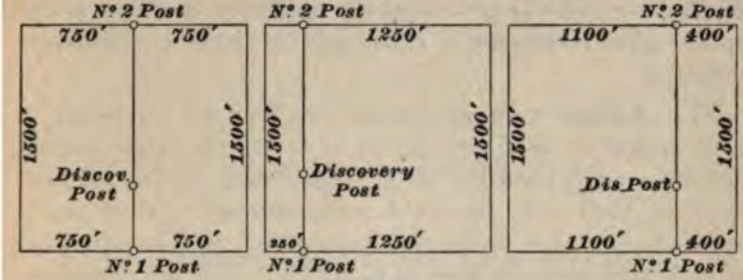


FIG. 29

> Initial post. Post No. 2, 1,500 feet northeasterly. 900 feet of this claim lies on the right and 600 feet on the left of the line from No. 1 to No. 2 post.

The location line should be marked in such a way that it can be plainly seen. If the country is timbered, the trees are to be blazed, and the underbrush removed along the line; if it is open, legal posts, or monuments of earth or stone are to be set up not less than 2 feet high and 2 feet in diameter at the base, so that the line can be easily traced.

Once set and recorded, No. 1 post cannot be moved or tampered with in any way. If the distance between No. 1 and No. 2 is found to be more than 1,500 feet, the Provincial land surveyor can move No. 2 in to the proper point; if, however, the distance is less than 1,500 feet, it cannot be changed after the claim is recorded.

95. Recording.—The prospector is given 15 days from the date of location in which to record a claim, if within

10 miles of the recorder's office, and 1 additional day for each 10 miles or fraction thereof beyond that distance. A claim not recorded within the time prescribed will be considered abandoned.

96. Abandonment.—The law regarding abandonment is the same as for placer claims, except that it is not necessary to work claims continuously in order to hold them. Without a written permit from the gold commissioner, a free miner cannot relocate a claim that he has abandoned or forfeited.

97. Annual Labor.—Work must be done on the claim or in proximity to it, with intent to develop it, to the amount of $100 a year, from the date of recording, and an affidavit must be filed with the gold commissioner, setting out a detailed statement of the work done, before the expiration of each year from the date of record. Unlike the American law, surveying done on the claim within 1 year from the date of record, to an amount not to exceed $100, is counted as development work. Two or more miners may work their claims as a group, after having filed a notice of such intention, and all the work for the group may be done on one claim.

PROSPECTING

(PART 2)

TUNNEL LOCATIONS

PROSPECTING BY TUNNELING

1. Mining Through Tunnels.—In 1872, about the time the Sutro tunnel was driven to unwater the mines of the Comstock lode, in Nevada, a tunnel fad was introduced. Tunnel sites were located in various parts of the West wherever there were deep cañons between mountains that were known to contain rich veins of ore, the object of the tunnels being to cross-cut a rich vein of ore that appeared at the surface and possibly to discover other veins that showed no surface outcrop. Enterprises of this nature are wholly speculative, unless their purpose is to unwater mines or to tap a vein known to extend to the depth of the tunnel level. Moreover, they are expensive undertakings, as the cost of tunnel driving approximates $25 a cubic yard, and since the excavation must, to a considerable extent, be made in barren ground, the economy to be established by their construction is a subject requiring more than a passing thought.

2. Value of Tunnels.—The mining tunnels excavated without some definite object in view have so far proved unremunerative; since, while a cross-cut tunnel may find a lode, it does not determine its value without the expenditure of additional exploration work and ultimately the sinking of shafts from the surface. Unless the vein has been worked to a depth equal to that of the tunnel level, there is no certainty whatever that the vein will be met by driving a tunnel. While the advantage to be derived from cheaper transportation through a cross-cut tunnel is not ordinarily enough to warrant the expenditure necessary for its construction, yet, at a large mine, the advantages of drainage—with or without the incidental saving in transportation and gain in ventilation—may warrant such an outlay. The value of the tunnel, however, depends entirely on the amount of water to be handled, which—like all other factors determining the advisability of the long tunnel—can only be known after the development of the mine or mines to be benefited has progressed considerably. According to Doctor Raymond, it is as absurd to run a cross-cut tunnel after blind lodes as it is to sink a shaft haphazard in dead rock. Unless there is some income, such as tunnel royalty due to unwatering several mines in one location, the enterprise is likely to prove disastrous financially. Some of the large number of tunnels driven have been total failures, while probably not one, the Sutro tunnel included, ever did or ever will repay its cost.

3. Tunnel Rights.—Section 2323 of the Revised Statutes of the United States in regard to tunnel rights reads as follows:

> Where a tunnel is run for the development of a vein or lode, or for the discovery of mines, the owners of such tunnel shall have the right of possession of all veins or lodes within 3,000 feet from the face of such tunnel on the line thereof, not previously known to exist, discovered in such tunnel, to the same extent as if discovered from the surface; and locations on the line of such tunnel of veins or lodes not appearing on the surface, made by other parties after the commencement of the tunnel, and while the same is being prosecuted with reasonable diligence, shall be invalid; but failure to prosecute the work on the tunnel for 6 months shall be considered as an abandonment of the right of all undiscovered veins on the line of such tunnel.

4. Definition of Tunnel.—In civil engineering, the word *tunnel* is used to indicate an excavation made through a hill and having two openings—one at each end. In mining engineering, this meaning has been perverted, and any excavation made in a hill is termed a tunnel, and is so considered in law. If the tunnel is driven through barren ground, with the object of reaching a real or an imaginary ore deposit, it is termed a *cross-cut tunnel;* if it is excavated in a deposit, it is called an *adit drift*, or, simply, a *drift tunnel.*

5. Tunnel Face.—Every rectangular tunnel has five walls; namely, two sides, a roof, a floor, and a face. *Face* and *breast* are synonymous terms, meaning the end within the tunnel farthest removed from the entrance, and where the work must be carried on to extend the excavation. If Section 2323 of the Revised Statutes were to be taken literally, the owners of the tunnel, as that excavation advances, would always have a right to own 3,000 feet beyond the tunnel face; as this, of course, would be intolerable, and give tunnel owners rights to which they were not entitled, the Land Office has construed the term *face* to be the first working face formed in the tunnel, and to signify the point at which the tunnel actually enters cover, it being from this point that the 3,000 feet is to be measured.

6. Making a Tunnel Location.—Regarding tunnel locations, the regulations of the United States mining laws, relating to Section 2323, Revised Statutes, are as follows:

> To avail themselves of the benefits of this provision of law, the proprietors of a mining tunnel will be required at the time they enter cover as aforesaid (Art. 5), to give proper notice of their tunnel location by erecting a substantial post, board, or monument at the face or point of commencement thereof, upon which should be posted a good and sufficient notice, giving the names of the parties or company claiming the tunnel right; the actual or proposed course or direction of the tunnel; the height and width thereof, and the course and distance from such face or point of commencement to some permanent well-known objects in the vicinity by which to fix and determine the locus in manner heretofore set forth applicable to locations of veins or lodes; and, at the time of posting such notice, they shall, in order that miners or prospectors may be enabled to determine whether or not they are within the lines of the tunnel, establish the boundary lines thereof, by stakes or monuments placed along such lines at

> proper intervals, to the terminus of the 3,000 feet from the face or point of commencement of the tunnel, and the lines so marked will define and govern as to the specific boundaries within which prospecting for lodes not previously known to exist is prohibited while work on the tunnel is being prosecuted with reasonable diligence.

It will be noticed that the boundary lines of a tunnel are to be established by stakes and monuments at proper intervals from the face to the terminus of the 3,000 feet of length. The law mentions only the line of the tunnel, and, as this line could be sufficiently shown by monuments along the axis, there seems to be no reason for staking out a parallelogram 3,000 feet long and 8 feet wide.

7. Line of a Tunnel.—According to Doctor Raymond, there is some reason to believe that the original idea of the framers of Section 2323, Revised Statutes, was that a tunnel locator might lay out a tract of land 1,500 feet wide—that is, 750 feet on each side of the tunnel by 3,000 feet long—as the area within which every other location should be invalid while he continued to work. Some Colorado adventurers that entertained this view of the law undertook, by marking off tunnel locations side by side along the foot of the mountain, tó monopolize a large amount of mineral ground. Public indignation aroused by this attempt resulted in a hasty retreat from the position they had taken, and a letter from the Commissioner of the General Land Office, September 20, 1872, declared:

> That the line of the tunnel is held to be the width thereof and no more, and upon this line one prospecting for blind lodes is prohibited, while the tunnel is in progress, and that the right is granted to tunnel owners to 1,500 feet of each blind lode, not previously known to exist, which may be discovered in the tunnel; but that other parties are in no way debarred from prospecting for blind lodes or running tunnels so long as they keep without the line of the tunnel as herein defined, the said line being required by our regulations to be marked on the surface by stakes or monuments placed along the same from the face or point of commencement to the terminus of the tunnel line aforesaid.

8. Lode Discovered in a Tunnel.—With regard to the location of a lode discovered in a tunnel, the land office has held that no patent can be issued without a surface location, and that this surface location must include the apex. The United States Supreme Court has ruled that a failure to mark on the surface the boundaries of a claim will not destroy the right of the tunnel owner to veins discovered in the tunnel, provided that he posted proper notices at the mouth of the tunnel and filed them in the Land Office as required by the local statutes.

9. Filing a Tunnel Claim.—Regarding the filing of a tunnel claim, the provisions of the United States mining laws are as follows:

> At the time of posting notice and marking out the lines of the tunnel as aforesaid (Art. 6), a full and correct copy of such notice of location defining the tunnel claim must be filed for record with the mining recorder of the district, to which notice must be attached the sworn statement or declaration of the owners, claimants, or projectors of such tunnel, setting forth the facts in the case; stating the amount expended by themselves and their predecessors in interest in prosecuting work thereon; the extent of the work performed, and that it is bona fide their intention to prosecute work on the tunnel so located and described with reasonable diligence for the development of a vein or lode, or for the discovery of mines, or both, as the case may be. This notice of location must be duly recorded, and, with the said sworn statement attached, must be kept on the recorder's files for future reference.

10. Assessment Work.—The tunnel owner's rights of possession date by relation back to the time of location of the tunnel sight. Section 2324 of the Revised Statutes was amended, in 1875, to read as follows:

> Where a person or company has or may run a tunnel for the purpose of developing a lode or lodes, owned by said person or company, the money so expended in said tunnel shall be taken and considered as expended on said lode or lodes, whether located prior to or since the passage of said act; and such person or company shall not be required to perform work on the surface of said lode or lodes in order to hold the same as required by said act.

In regard to the facts discovered in the tunnel, Doctor Raymond says that the preponderance has been given to the principle of discovery over the principle of the apex law; and the result in many cases is going to be one of confusion. For instance, the locator on the surface is by law given rights in all lodes apexing within the location, whether they are blind lodes or not. Such a location, if made before any tunnel was commenced, would undoubtedly be valid against the tunnel. If a blind lode first struck in the tunnel should prove to have its apex within such a prior and varied surface location, and therefore to have been withdrawn from the public domain before any tunnel rights existed in the premises, the tunnel owner cannot claim it.

11. Tunnel Claims.—The United States Supreme Court has ruled that the location of a claim to a vein discovered by a tunnel may be taken the full length of 1,500 feet allowed by the United States Statutes (Section 2320) on either side of the tunnel, or in whatever portion of it on either side that the locator may desire; and the claim is not limited to 750 feet on each side of the tunnel on account of a failure, when the tunnel is located, to indicate what particular 1,500 feet would be claimed. This permits the tunnel owner, by simply locating his tunnel, to fix the date of his title to property that is undiscovered, without making it necessary, until the property is exactly discovered, that he decide on where he will locate his claim. Doctor Raymond thinks that this law should be repealed or a new law substituted, for the reason that, under such conditions, no one can safely go into a tunnel zone until the tunnel locator has made his discovery and exercised his option. Moreover, it seems to follow that, even after a tunnel has passed through the course of an intersecting vein without discovering it, a tunnel owner, guided by developments made by surface explorers outside, can go back, make another search, find what he is looking for, and date his discovery back so as to gain possession of the bonanza that has been rightfully discovered by others.

ORE DEPOSITS

12. Plutonic-Rock Theory.—According to the Plutonic theory, the interior of the earth was a fiery mass, and those who hold that the older rocks, like granite, are of fiery origin are said to belong to the Plutonic school. The Plutonic rocks are those which have probably cooled slowly, that is, at great depths, and the name is used to distinguish them from volcanic rocks, which cooled quickly and at the surface. Some geologists go so far as to assert that ore deposits have been formed by the agency of fire. Doctor Hutton was a strong advocate of the Plutonic theory of ore deposits, which is that metals originated at great depths under the influence of heat, where they were sublimed, to be later deposited in the colder cracks near the surface. He says, "Ask the miner from whence has come the metals in his veins of ore. Not from above nor from the strata which the vein traverses; these do not contain one atom of the mineral now considered. There is but one place from whence those minerals may have come, and that is the bowels of the earth—the place of power and expansion, the place from whence has proceeded that intense heat by which loose materials have been consolidated into rocks, and the enormous forces by which the regular strata have been broken up and displaced."

13. Hydrous-Rock Theory.—Directly opposed to the Plutonists are those who assume that at a great depth, rock material is in a plastic state, owing to heat and pressure, the degree of plasticity depending on the intensity of the heat and the amount of the pressure. These rocks are known as aqueo-igneous rocks, because, in order to explain their peculiar crystalline structure, it is assumed that water entered into their formation as well as heat. On this assumption, the theory of magmas is based. **Magmas** are defined as molten masses within the earth's crust and as the source of igneous eruptions. This definition is, by some mineralogists, changed to read (because it is probable that no fire entered into the formation of some magmas) that magmas are soft, more or less viscid masses, formed by heat and the water of crystallization. This definition corresponds to the accepted term of aqueo-igneous fusion.

14. Formation of Magmas.—It is assumed that at a certain depth the pressure on a rock due to the rocks above it is sufficient to crush the rock, and, with the aid of water present, to convert the mass into a paste. When heated and under pressure, water will dissolve most rock materials much more effectually than when cold. The heat at the point where materials are made plastic may be above that necessary to produce a fiery mass at the surface and yet be able to dissolve and hold the mass in a fluidal state, without the presence of fire; again, the heat may not be sufficient to produce a fiery mass at the surface, and yet be able to hold the minerals in a fluidal state. If magmas are formed by aqueo-igneous fusion, then all volcanic rocks may be considered as slags in which crystallization is lacking.

15. Hydrous Theory of Ore Deposits.—Those who accept the hydrous theory of ore deposits are directly opposed to the Plutonic theory of ore deposits, and are also at odds with each other. The theory is that mineral deposits in veins were formed solely by the agency of water, which, according to one school, is of atmospheric origin, and, according to another, is of oceanic character. The atmospheric school contends that rocks contain minerals that circulating waters dissolve and redeposit in cracks and fissures.

The balance of opinion seems to favor the hydrous rather than the Plutonic solution of the intricate problem, and decides further that the former agency derived its waters from ocean currents and not from the atmosphere. This view is held because some geologist discovered in galena ore distinct signs of the fossilized existence of what were once living creatures that thronged the sea in prehistoric ages. The fossils are supposed to support the theory that lead deposits are of marine origin; this hypothesis, however, can hardly sustain a universal theory, since lead deposits have been found in granites and quartz veins as well as limestones.

16. Van Hise Theory of Ore Deposits.—Prof. R. H. Van Hise attacked the subject from a new standpoint. He took the underground circulation of water as one connected manifestation of natural activity, and emphasized the fact that, in the formation of ore deposits, it may at different times play a part. Two conclusions, however, he insisted on; namely, that sulphide ores are generally deposited by ascending waters, and that a secondary enrichment of such ores is affected by the agency of descending waters. Professor Van Hise is right in some of his conclusions, at least, and his theory is added to the magmatic theory from the fact that, if not entirely correct, it has circumstantial evidence in its favor.

17. Saturated Solutions.—When a liquid will dissolve no more of a solid, it is said to be *saturated*. Some liquids when heated will dissolve more of a certain substance than when cold, and will moreover dissolve the substance in less time. Some liquids, under heat and pressure, will dissolve more of certain solids than when cold and not subjected to pressure. When a liquid is saturated and can absorb no more, a slight decrease in the quantity of liquid due to evaporation will cause *supersaturation* of the solution, and a solid will be deposited. The best example of this is the evaporation of salt brine to produce salt. Some substances, such as borax and sugar in solution, will, on cooling, crystallize out from solutions. Some minerals, owing to affinity, will crystallize out from weak solutions. The freezing of salt water illustrates the action that might occur when a magma cools. The substance that first freezes out from salt-water solutions has not the exact composition of the solution, as the salt concentrates in the unfrozen part or mother liquor. As freezing progresses, and more ice freezes out, the mother liquor becomes richer and richer in salt until the proportion of salt reaches 23.6 per cent., beyond which concentration refuses to pass. From this point freezing is unselective, and that which freezes out has the composition of the mother liquor; the mother liquor, however, in freezing, splits into distinct crystals of ice and distinct crystals of salt.

18. Metallic Minerals in Magmas.—All rocks formed from magmas have a crystalline or cryptocrystalline structure, and crystallized metal minerals are sometimes found incorporated in them as a component part of their structure. Frequently, one finds that a rock is more prolific in one kind of mineral than another; and, when such a mineral is of metallic origin, the locality where it is found is said to be a *mineralized zone.*

In some cases, the metallic minerals have so increased as to saturate the magma, and this, with selective action, has grouped some minerals into masses, such as the magnetite, pyrrhotite, and pyrite deposits in the Appalachian Mountains and elsewhere. In other cases, one will find pyrite, galena, and sphalerite spangled through a crystalline limestone; again, pyrite and chalcopyrite or other metal minerals may be spangled through a mass of crystalline rock of the aqueo-igneous variety, which may also contain gold and silver. From such aqueo-igneous magmas, ore deposits have probably originated. It is known that rocks will weather, and that during the weathering process solutions will be formed containing metallic minerals, and that these minerals will be precipitated from these solutions. It is, of course, natural that such solutions would move downwards through any crevices or openings in their vicinity. Again, when such aqueo-igneous magmas are deep-seated, circulating waters could dissolve out their minerals, and, rising up through cracks and fissures, deposit these minerals on the walls of the fissures or in adjacent openings.

19. First Concentration.—The first concentration is that of magmatic masses, such as described for magnetite in the older formations. These masses are lenticular shaped, and in some cases show unmistakably that they were doughy and capable of being molded to conform to the bed rock. The gangue that usually accompanies magnetite deposits is feldspar, which likewise shows selective agency; that is, the feldspar is grouped in masses surrounded by magnetite, thus making a complete separation of the two minerals. Unfortunately, apatite seems, in some deposits, to have had difficulty in separating out from magnetite mother liquors until the supersaturation limit was reached, when it separated and crystallized in between the crystals of magnetite. Deposits containing apatite require crushing and magnetic concentration before the two minerals are properly separated.

With the exception of magnetite and iron and copper sulphides, no ores have been formed by first concentration into masses; mineralized magmas, however, are sometimes capable of being worked at a profit, and then they may be considered as the product of first concentration.

20. Quartz Deposits.—There are two kinds of quartz found in nature: one is formed by being deposited from solutions, the other is formed by the agency of heat. Quartz deposited from solutions may be crystallized in six-sided prisms that have striation marks; or it may be massive (in fact, it is usually white and massive) and be stained pink, red, brown, and, but infrequently, black. This kind of quartz is vitreous, but is not vitrified; it has a splintery fracture, and a specific gravity of 2.6.

Quartz formed in a dry way or by fire fusion has a specific gravity of 2.2. It is vitrified glass, as found in obsidian and on the surface of basalt flows. As granite is a typical magma and contains water-formed quartz, it follows that it was an aqueo-igneous magma. If a magma is coarse-grained, it has solidified slowly; if fine-grained, it has solidified quickly. This assumption is based on the fact that cast iron will form in fine crystals when chilled or hastily cooled, and in coarse crystals when slowly cooled. Vitrified quartz is found in slags, but it is not crystalline. In silica, this difference marks the dividing line between aqueo-igneous and igneous rocks. Among the former, one may expect to find ore deposits; among the latter, one need not expect to find them, for the reason that the heat necessary to convert silica into glass would also change metal minerals into metals that would separate out from the silica, or else would alloy with the silica as a slag.

21. Upward Secondary Concentration.—It is well known that some ore deposits are formed by aqueous solutions and obtain their metal from magmatic rocks. The metal sulphides are the most common form of metallic minerals, and in most cases, when the minerals are in another form, their origin may be traced back to sulphides. Metallic sulphides are slightly soluble in alkaline sulphides, and quite soluble in hyposulphites of calcium and sodium (as are gold and silver); and these are often found associated with alkaline carbonates in hot springs. Such waters, if they ascended through fissures, would deposit their minerals both by cooling and by relief of pressure. Then, too, alkaline sulphide waters that hold metallic sulphides in solution could have their alkalinity neutralized, and so deposit the sulphides. It may be assumed, therefore, that all sulphide deposits originated from magmas, and that, when found in veins, they have ascended in solutions and been deposited.

22. Downward Secondary Concentration.—Metallic sulphides—particularly of iron, copper, zinc, and lead—can be oxidized by the weather in the order named. When so affected, they are taken into solution and deposited in another form. Sometimes, they are concentrated by this means, particularly if the rock magma from which they are derived is also weathered. The process may be slow, but it is a sure one.

Sedimentary rocks—particularly lime rocks in the vicinity of eruptive rocks—have, in some instances, been acted on by acid or alkaline sulphide solutions holding metallic minerals in solution, and thus an ore deposit has been formed.

Both of these kinds of ore deposits may, when they are oxidized products, be ascribed to descending solutions.

23. Third Concentration.—There is no doubt but that a third concentration can occur—as, for example, in the case of oxidized ore in veins, or in the formation of the brown iron ore called *limonite*, or in the formation of manganese, etc. A third concentration is also illustrated by placer deposits and stream tin deposits, where the vein rock of the second concentration has been eroded and washed away, while the mineral itself has been concentrated in placers.

24. Rocks as Guides to Ore Deposits.—A general knowledge of the more common rocks is necessary for intelligent prospecting. The prospector must be able to distinguish aqueo-igneous from igneous rocks, and both from sedimentary and metamorphic rocks. Many rocks, being a local mixture and hence relatively unimportant, may exhibit signs of minerals, and warrant therefore a careful examination, especially if they are in a mineral zone. It is advisable, wherever possible, to assign the rocks to some particular geological system, as in that case one can better determine what minerals may be expected to occur. Ores of the first concentration will be found in the magmatic rocks; ores of the second concentration will be found in veins in aqueo-igneous rocks, and in masses and veins in sedimentary rocks; and ores of the third concentration will be found in the loose rock matter of the present time. Some magmas may be mineralized sufficiently to work at a profit; others may simply indicate a mineral zone; in either case, the subject is of interest to the prospector, for veins in such zones will probably carry paying minerals.

25. Fissures in the Earth's Surface.—Various agencies have been named as the cause of rents in the earth's crust; but, as this is a subject that belongs to dynamic geology rather than to prospecting, it will not be discussed here further than to say that the fissures formed have been healed and filled with vein material brought into them by solutions or as aqueo-igneous magmas intruded from below. Some of the fissures are mere cracks filled with material known as *gouge*, or *selvage*, which may or may not be valuable. If there has been a movement of the country rock along the walls of a vein or dike, and either side is mineralized, the gouge will probably be mineralized also; if, however, there has been no such movement, the gouge will be merely fine powdered rock or a sediment carried down from the surface by water.

When a decided fissure appears that has been healed by mineral matter held in solution, then a vein is established.

Dikes are wide fissures through which magmas have been forced, completely filling them. Dikes may themselves be fissured and contain veins parallel to or across them, and, on the other hand, dikes may appear subsequent to the formation of the vein. Several cases are on record where dikes have become mineralized.

Reefs are rocks, composed either of aqueo-igneous or of metamorphosed sedimentary rock matter, that have become shattered by dynamic forces and then healed with solutions. Such rocks are at times mineralized sufficiently to be worked at a profit.

26. Fissure Veins.—While a vein is a fissure that has become filled with mineral matter, it must be borne in mind that the earth's surface has been considerably changed since the original fissure was formed and filled, and also that erosion has probably decreased the depth and length of the vein enormously. Under such adverse conditions, investigation only can determine to what depth a vein will extend; but from the following illustrations it may be argued and to some extent proved by experience that a wide long vein will extend to a greater depth than a short narrow vein.

Let it be assumed that, in Fig. 1 (*a*), the central lines bound a fissure that had its commencement at *a* and its ending at *b*. If the miner nears either end, the fissure gradually pinches out until it disappears in a mere crack. Suppose that the original deposit had a height shown by the dotted line *e*, Fig. 1 (*b*); then the fissure must pinch out below, for, since its length is limited, its depth also must certainly be limited, and the pinching out will be downwards, as shown at (*c*). To determine how much of the vein has been eroded is impossible; and to determine how much remains below the surface is a problem that can be solved by actual sinking only.

27. Fissure or Vein Filling.—Veins are filled by solutions, dikes by intrusions—thus, there are granite dikes and quartz veins. Fissures that have been filled with magmatic rock material that has evidently been plastic and injected into them are properly termed dikes. While rocks of this nature may be metal-bearing, the metal is not usually concentrated sufficiently to mine. Vein fissures have in the majority of cases been healed by quartz solutions, either wholly or in part; but the greater number of quartz veins are barren. The gangue or barren material of ore deposits is not always quartz; it may be calcite, fluorspar, feldspar, heavy spar, wolframite, or mixtures of these minerals.

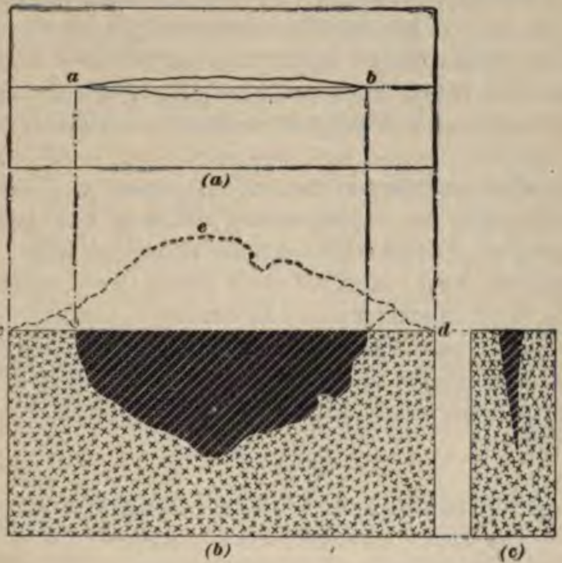


FIG. 1

28. Association of Metals.—In most ore deposits, particularly sulphide deposits, one metal is found associated with another. This association is sometimes such as to form a definite chemical compound; sometimes such as not to form a definite mineral but a separate individual compound. Because gold and silver are usually found associated, it is believed by some mineralogists that all native gold contains some silver. Platinum is frequently found in gold placers, and platinum has at times associated with it palladium, iridium, osmium, and certain other rare metals. Lead and silver are usually associated to such an extent that some claim that no lead ore is entirely free from silver. Copper, silver, and gold are often found associated in the same ore deposit. Lead and antimony, lead and zinc, cadmium and zinc, copper and lead, nickel and cobalt, iron and nickel, nickel and chrome iron ore, iron and tungsten, copper and iron, iron and manganese, tin and wolframite, and several other combinations are all known to exist. Where ore deposits have been derived direct from magmas, or where a third concentration has occurred, the association of metals is not so noticeable. Arsenides, antimonides, tellurides, and sulphides of various metals are found associated in such a manner as to make bad combinations for the metallurgist.

29. Relationship of Metals: Gangue and Country Rock.—The rocks through which underground waters circulate are the sources of gangue materials as well as the ores. If the gangue is mostly silica, the supposition is that the solutions traversed through acid magmatic rocks and that gold may be present. If the gangue is silica and feldspar, it may be assumed that the solutions traversed magmatic rocks, and, that gold, silver, copper, and iron sulphurets may be present. If the vein material is mostly calcite, with subordinate quantities of other gangue minerals, the supposition is that the solutions circulated through limestone or dolomite, and that lead-zinc, lead-silver, or silver-lead ores may be present. There are many cases where secondary enrichment of a vein has occurred after it had been formed. This seemingly is due to crustal movements that have shattered the veins and to solutions bearing metals that have healed them anew.

30. Acid Rocks.—The term *acid* refers to rocks in which silica is the predominent element. The acid aqueo-igneous rocks that occur massive are granite and syenite. The acid aqueo-igneous rocks that occur as dikes and overflows are granite, syenite, porphyry, felsite, rhyolite, trachyte, and phonolite. If a vein in acid rocks has been closed by acid solutions, it is likely to be barren of metals; but, if basic gangue is also present, one may expect to find metal minerals, probably as sulphides, etc. Veins in such rocks have been known to be barren until they encountered basic or organic rocks.

The volcanic acid rocks are scoria, pumice, and obsidian, with basalt where it has cooled in contact with the atmosphere. These rocks have not been known to contain ore.

31. Basic Rocks.—Rocks containing comparatively little silica are termed *basic*. The basic aqueo-igneous rocks that occur massive and as dikes and overflows are diorite, gabbro, diabase, andesite, and basalt. These rocks are also ore bearing when conditions are favorable for the deposition of minerals from ore-bearing solutions.

32. Mineralized Zones.—As the aqueo-igneous rocks seem to be the parent rocks of matallic minerals, it would naturally follow that metamorphic sedimentary rocks and sedimentary rocks in their vicinity would be ore bearing. This is sometimes, but not always, the case, for aqueo-igneous rocks may not be prolific in metal minerals in all spots, and suitable conditions may not prevail in order to deposit minerals. If the rocks are magmatic, whether eruptive or otherwise, and are mineralized, the prospector in a mineral zone should examine every kind of rock for evidence of precious metals, and veins in particular. Formerly, it was held that the granite rocks of the Archæan age contained the best gold veins; where, however, the Archæan rocks are exposed, erosion has taken place and in all probability the veins are not deep.

In the Rocky Mountains, which are supposed to have been formed during the Tertiary period, the granitic rocks have been fissured, and these fissures are deep in some instances but not in others. The veins in dikes that were formed during the Tertiary period are, as a usual thing, deep.

33. Auriferous Slates.—Quartz veins carrying gold are found in the Jura-Trias and Cretaceous slates in California. These slates have evidently had their leaves parted or broken by dynamic influences, and into the fractures thus formed solutions carrying quartz and gold have been injected. These slates are now metamorphic, and it may be noted that ore deposits are most common in regions where dynamic forces have caused upheaval and folding, which produced this class of metamorphism. This condition does not apply to all fissures that have occurred in the Tertiary period, as some of the deepest fractures and richest ores intersect non-metamorphic rocks of this period. Cambrian chloritic schists in the Eastern United States and Canada are impregnated with quartz and carry gold.

34. Contact Deposits.—When hot aqueo-igneous magmas were forced to the surface and brought in contact with sedimentary rocks, solutions were carried up with the magmas that contained minerals, which were deposited in the sedimentary rocks. This, of course, has not always been the case, for in some instances the solutions seem to have eaten into the sedimentary rock and dissolved mineral that was previously deposited; where no mineral was present, the solutions simply changed the character of the rock. The solutions that were instrumental in forming this class of ore deposits seem to have come from below through the crevice between the aqueo-igneous and the sedimentary rock; and wherever there was an opening in the latter they entered and filled it with mineral matter.

A second class of contact deposits was formed by acid solutions coming from the magma and entering crevices in the sedimentary rock, which they enlarged and in which metallic minerals were subsequently deposited.

Contact deposits have afforded some rich lead-silver and copper deposits.

35. Bed Impregnations.—There are some beds of stratified rocks—such as sandstone, shale, and clay—that have become mineralized. An example in point is the deposits in Utah, which contain horn silver. In this instance, salt lakes abound in the locality, and it is likely that ascending waters carrying silver in solution had the silver deposited by water carrying salt in solution. There are many other kinds of deposits, most, if not all, of which can be traced to the origin of magmas and the mineral solutions acting on them. Hence, it is important that the prospector ascertain first of all whether the rocks he meets are in a mineralized zone.

36. Ore Masses.—With the exception of a few iron carbonates of the Carboniferous period, and the oolitic hematite of the Clinton measures of the Upper Silurian period, no metallic-ore deposits are regularly formed strata. Most metallic minerals are found in bunches and pockets, the base metal ores being in larger masses than the precious metals; and it is just this condition of affairs that makes gold more valuable than iron. Bodies of iron ore are larger than bodies of lead or copper ore; bodies of silver ore are of less size than lead, zinc, or copper; and gold ores that are extremely rich are very rare. One may find a vein that will contain rich patches of ore, and then become barren for a considerable distance, or at least be very lean in comparison with the rich bunches. The same phenomena occur also with depth; hence, it is well for the prospector, before staking out a claim on a newly discovered vein, to follow up the vein until the samples taken have proved its worth. Most prospectors are rich in poor claims, because they have not yet realized that all quartz veins are not bonanzas. While most metal ore bodies are in masses, some are in larger pockets than others; the prospector, therefore, should ascertain the size of his deposit on the surface, for if it is not large on the surface, it is not likely to increase in size with the depth.

37. Tracing Outcrops.—Having found a vein, the prospector should follow it along the outcrop to ascertain if it is continuous. A long strong vein is usually a deep one; while a small short vein is probably the pinching out of a former strong vein that has been eroded. Where the vein is not covered too deeply with dirt, the prospector should put in a little labor to ascertain if the vein is continuous. While this work may seem rather unnecessary, especially when the outcrop is seen above the ground some distance farther on, still there are good reasons for making the test. If the outcrop is covered with soil, it may be that at this point a chimney of rich ore will be found, for rock containing rich mineral will usually decay sooner than barren vein rock, and it is known that some veins are richer in one place than another.

Erosion may have eliminated the length of the fissure, so that between one outcrop and apparently the next outcrop there may be no mineral vein, and unless this is ascertained by uncovering the vein at intervals along the crop all expectations may prove void. There are sometimes plant indications, and at other times surface indications, such as depressions, that will aid in tracing the outcrop. The prospector should not become excited over every little vein he finds, unless it is exceptionally rich; nor should he get the idea that it will improve with depth. By this it is not to be presumed that the outcrop should not be traced to ascertain the length and width of the vein, but rather that, if the vein does not widen out, the prospector had better not expend further labor in examining it; for it is exceptional to find any vein worth working that does not give a first-class showing, either in quality or quantity, at some place along its length at the surface. If a ravine or gulch crosses the vein, the prospector should find out whether or not the vein has increased in width or richness with the depth; if it has not, he should abandon the work and go elsewhere. If the vein crosses the general trend of rocks, it is more likely to be a deep vein than where it is parallel with them, but this does not signify that the vein will be a rich one. Only inconsequential movements will occur to fracture a bed along its length—movements of this description being slips rather than openings termed fissures. There are, however, exceptions to all rules, and sometimes strong veins will run parallel with the deposit in dikes, or with slate seem to be a part of the formation, as in the Mother lode of California. When the vein cuts across the formation, it indicates a fissure caused by contraction of the rocks.

In case the deposit is a contact, it should be followed along its outcrop; but, if covered in places, it will be necessary to locate the outcrops only of the rocks on each side of the contact, and confine the search to the space between them. This may be done by trenching in, between the rock outcrops, to a depth that will uncover the rock and the vein if it exists. If the vein is a contact deposit and a second outcrop exists at a short distance, both outcrops may be fairly considered as the same lode, which, if not continuous at the surface, will in all probability join below the surface; of two such outcrops, however, the more mineralized outcrop is the proper one for the prospector to sink on. The same remarks will apply to a vein formed on the wall of a dike; but, as the vein will sometimes jump from one wall to the other, it is not the length altogether, but the richness also of the vein, that is of importance.

38. Value of Mineral Deposits.—When mineral has been discovered, the prospector should proceed to ascertain its value. In order to do this properly, the deposits should be opened in one or more places. In case unoxidized mineral is encountered on the outcrop, particular care should be used before jumping at the conclusion that the deposit is valuable; for, if it is a vein formation, the chances for its continuance downwards are not good, but if the deposit is a reef or dike, the chances for low-grade and paying deposits of ore are excellent. It should be borne in mind that oxidized outcrops are not always prolific; but the fact that they are oxidized is a fair indication that more mineral is below and that the deposit is worthy of examination, for it permits solutions to percolate to some underground watercourse. It is a common occurrence to find a deposit of free milling gold whenever the outcrop is oxidized; but with depth the character of the deposit will change to sulphurets, provided that the deposit goes below water level.

39. Selling Claims.—If the prospector intends to sell his claim, he must have his titles clear, and have conformed strictly to the law, if no patent has been granted. He must also have enough development work done to show the price asked and a little more. There was a time when speculation in gold mining was such that, to find a purchaser, the prospector needed only to announce his discovery, but conditions now are changed and the purchase of mines and prospects is made on a business basis. The intending purchaser hopes, of course, to realize a profit on his investment, and it is not likely that he will take chances and pay for more than he can see. Moreover, the cost of mining and milling the ore in sight is no inconsiderable item, for which reason the prospector had much better underestimate rather than overestimate the value of his claim or working.

40. Developing Claims.—To develop a prospect costs labor, time, and money. If the prospector can show a reasonable deposit, and can make a profit on his investment of labor, time, and money, he should sell out; otherwise, he had better wait until he has developed more values. It is of course a trying moment to a man when he is offered a small sum for a property that has cost him much time and hard work; however, if he is in need of money, it may be well to part with the property and look for a new deposit elsewhere. When a prospector has found a rich deposit that does not, at the outset, require money for mill and machinery, he should keep it and work it himself, for the money to be gained is as useful to him as to any one else, and each foot of development and each cubic foot of reserve ore adds to the value of the mine.

41. Opening the Prospect.—In opening a prospect, the best plan to follow, when the ore does not crop out on a side hill, is to sink a shaft on the vein. When this shaft has reached a depth of, say 150 feet, a level should be started toward the side-hill outcrop first if that exists; otherwise, it may be run in the direction of the vein that shows the most mineral. In every case, the prospector should follow the ore, no matter how crooked the vein may be, and every change in the character of the ore should be carefully noted so that advantage may be taken of the knowledge gained for future development work. If the ore excavated is rich enough to ship, the returns will aid in further development; but no ore should be shipped until it has been carefully sampled and the sample assayed—otherwise it may not pay the freight and smelter charges, in which case the shipment would be a loss rather than an asset. While a hole for testing purposes may be run in from the outcrop on a side hill, a shaft must ultimately be sunk for ventilation purposes; hence, it may be advisable to sink the shaft first and drive the tunnel later.

42. Opening Prospects With Cross-Cut Tunnels. It is not considered good practice to drive a tunnel through barren rock unless the excavation happens to be short and the vein is known to extend to a depth equal to the level of the tunnel opening below the outcrop. Should water be encountered in the shaft, the probabilities are that a cross-cut tunnel may be needed to reach the deposit. In this case, however, unless an actual survey is made, the tunnel may be driven so as to gain a little depth on the vein; while, as a usual thing, it is desirable to gain all the depth possible in order to drain the prospect. The natural slope of the banks and dumps is about 32°, thus giving a fall of about 62 feet in 100 on the slope. To obtain the inclination of the surface, the clinometer may be used, as illustrated in Fig. 2, and the distance measured from the vein to the point where it is proposed to open the cross-cut tunnel; then the length of the cross-cut may be obtained by multiplying the sloping distance by the natural cosine of the slope angle. The depth from the outcrop at which the tunnel will cut the vein, provided that the latter is vertical, can now be found by multiplying the length of the tunnel by the natural tangent of the angle of slope. In case cross-cut tunnels are to be driven in the hanging wall or the foot-wall, to reach a vertical shaft, the better location will probably be the hanging wall, especially

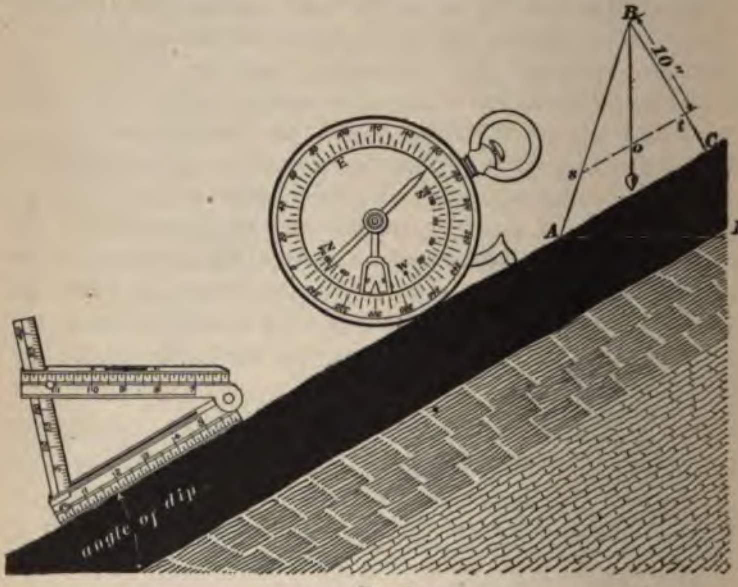


FIG. 2

if the tunnel is to be driven a considerable depth below the outcrop. The reason for this is that, if the lode dips away from the vertical, the tunnel must be made longer; while, on the other hand, when the vein dips toward the tunnel, it will be shorter. As a matter of fact, however, the ground is usually not so arranged that the prospector can choose on which side of a vein he will open his tunnel, so that he must take the best offered; but he should know the distance that he must drive the excavation.

43. Cross-Cutting Underground Explorations.—All work done on a prospect should be thoughtfully planned, and partners should carefully consider every detail, especially of assessment work and underground exploration. It is frequently necessary to drive cross-cuts to find new bodies of ore or to discover the lost mineral part of a vein; for the ore is not always in clean-cut fissures, and the vein is liable to be crushed or the wall rocks decayed; besides, in dikes and wide veins, the mineral part of a vein is likely to shift. Sometimes, in wide veins, parallel ore bodies are found that are even richer than the one worked; again, when the ore becomes lean, it may increase decidedly in richness in some other locality in the vein. It is advisable, also, when prospecting in metalliferous deposits where the values are in patches, to cross-cut the vein, and if the wall rock shows signs of decay or traces of mineral the cross-cut may be continued to solid rock. The circulating waters that carry the mineral will permeate soft wall rock and crushed areas, and in so doing may deposit the mineral. There are a number of examples where such phenomena evidently occurred; in fact, nearly every vein shows sheets of barren and productive stuff at intervals along the strike and on the dip, for which reason it is not unreasonable to assume that the same phenomena will occur across the vein or parallel with it. Every miner has known the mineral to jump from the hanging wall to the foot-wall, and then again to be in the center of the vein. They have also probably noticed that the mineral will sometimes be concentrated, and then again separated, throughout the vein matrix; hence, by reasoning from these occurrences, one can believe that, if there are parallel crevices or cavities in the vein walls that will permit of mineralized waters circulating through them, mineral deposits may have accumulated. That this is the case has been proved many times by actual tests.

44. Position of Ores in Veins.—Different ores are usually accompanied by different gangue minerals; for example, gold is associated with quartz veins; lead with calcite;

barite or zinc with calcite; tin with wolframite; magnetite with feldspar; etc. This peculiarity, however, does not prevent any or all of the other gangue rocks from being present at times in the same vein; and it is evident, from the examination of ribbon veins, that the solutions carrying minerals have been charged at one time with one mineral and at another time with another mineral. This would suggest that the country rocks through which waters circulate or come in contact have a direct influence on the minerals that will be dissolved and deposited. Assume, for example, that there is a contact vein between an acid eruptive and a basic sedimentary rock, and that the mineral solution was acid; then the prospector will not find ore on the eruptive-rock side of the vein, but on the basic-rock side. In some localities, it has been observed that, where quartz veins were wholly in acid rocks, they were not productive; although, if the same vein continued into sedimentary or organic rocks, it became productive. The same observation might apply to basic rocks, provided that the solutions were alkaline, and then productive portions of the vein could be looked for in acid rocks.

45. **Frozen Veins.**—In some veins, one wall may be well defined while the other graduates into the country rock in such a manner that one cannot tell in some instances where the two begin or leave off, as no defined wall is discernible. A vein in this condition is said to be **frozen**, and the value of the mineral will peter out on the frozen side. The vein may be frozen to slate or some other rock differing materially from it in composition; but usually the best ore is found on the side that has a defined wall. In case the vein is frozen to both walls, it is considered a positive certainty that the vein will not be deep, but heavy clay seams or gouges are taken as evidence of a deep-seated fissure.

46. **Lost Veins.**—The subject of faulting belongs properly to mining, although it has some bearing on prospecting. The prospector has been advised to trace the outcrop to

ascertain the length of his vein. It is possible that the vein he is following will be cut off by a fault fissure and a part of the vein lost. As there are no underground indications to follow, all examinations tending to show in which direction the vein has been heaved are made at the surface. Before searching for the lost part of a vein, the rock surfaces must be exposed, the wall rocks thoroughly studied, and the greater angle made by the intersection of the vein and the slip fault followed. If the prospector has been fortunate enough to find the lost part, he has achieved something that will be of value should it ever happen that the deposit is worked as a mine.

47. Development Work.—An excavation made to determine the extent and value of a deposit is termed **development work.** Such work is confined at first to tracing the deposit, and next to ascertaining its depth and value. It should be conducted systematically, with a view of future mining, and of showing how much mineral can be depended on. There is little stoping done, unless the vein is rich, in which case the owner may work the property as he sees fit; but, even then, ore reserves should be left as pillars, and the levels, winzes, etc. run for further development.

Pinches and horses, where the vein walls are intact, are not to be taken seriously, as such matters are frequent in nearly every vein and are merely local. Sometimes, the veins will widen out abnormally, and the mineral may be so scattered through the gangue as to make the deposit too lean to mine profitably. In such cases, the vein is merely tunneled through until it narrows and becomes richer; but before this is done the prospector should make sure that his vein is lean, as there are exceptions to all rules.

PROSPECTING FOR COPPER

COPPER ORES

48. Rocks Containing Copper.—Copper is found in aqueo-igneous rocks, such as diabase, diorite, rhyolite, gneiss, and granite; and is at times found associated with gold, silver, iron, nickel, and cobalt. Oxidized copper ores have been found in carboniferous limestone with granite contact; in lime and sandstone contact; in limestones; in sandstone conglomerates; and in shales and sandstones with fossil plants.

49. Copper Minerals.—Copper is a widely distributed metal, and it occurs also in large quantities. The copper minerals are as follows:

1. **Native copper,** Cu, is found in the United States in the neighborhood of Lake Superior, in China, Japan, Siberia, and Sweden.

2. **Chalcocite** ($Cu_2S = Cu, 79.8 + S, 20.2 = 100$) is a black earthy-looking mineral.

3. **Chalcopyrite** ($CuFeS_2 = Cu, 34.6 + Fe, 30.5 + S, 34.9 = 100$), also called *copper pyrites*, is a brass-yellow mineral that tarnishes on exposure to the air. Silver and gold are sometimes found associated with it.

4. **Bornite** ($Cu_3FeS_3 = Cu, 55.58 + Fe, 16.36 + S, 28.06 = 100$) is a deep yellow or reddish-brown brittle metal that tarnishes when broken. The proportions of elements in this mineral vary, and give it at times a peacock display of colors.

5. **Cuprite** ($Cu_2O = Cu, 88.8 + O, 11.2 = 100$) is a deep red, earthy-looking mineral.

6. **Tenorite** ($CuO = Cu, 79.85 + O, 20.15 = 100$), sometimes called *black copper*, is a steel- or iron-gray, earthy, black mineral.

7. **Melaconite,** CuO, is an earthy variety of tenorite, and occurs as a scaly, black, or grayish-black mineral. It yields about 65 per cent. of copper.

8. **Malachite,** or *green copper carbonate*, has the composition $Cu_2CO_4 \cdot H_2O$, in the proportion of 19.9 per cent. of carbon dioxide, 71.9 per cent. of copper oxide, and 8.2 per cent. of water.

9. **Azurite,** or *blue copper carbonate* ($Cu_3C_2O_7 \cdot H_2O$) is composed of cupric oxide 69.2 per cent., the remainder being carbon dioxide and water. The percentage of copper that this mineral contains is 55.22.

10. **Chrysocolla** is a lustrous, clear, greenish-blue mineral. It varies much in composition, on account of impurities, but contains about 36.1 per cent. of copper, the remainder being silica and water.

50. Coloration of Rocks by Copper.—As the ores of copper are usually weathered at the surface, the coloration or stain given to the rocks by this oxidation is sometimes valuable as a guide to the location of copper deposits. While the blue, green, and red colors are not to be overlooked as a possible source of metal, it is not a foregone conclusion that there is a large copper deposit where they are discernible, for the probabilities are that no large deposits of this description will be found except in limestone formations near igneous rocks. In granite and older rocks, copper pyrite may be found that will prove productive when developed; but in such instances the outcrop will not have the same copper coloration as in other rocks. Copper stains are probably as good indications of ore bodies as of merely isolated copper minerals; however, there are other minerals, and at times vegetation, that will color rocks.

51. Native Copper.—At Keweenaw Point, Michigan, native copper is found in veins that traverse both sedimentary and intrusive rocks, and is also found in beds of conglomerate, sandstone, and interstratified diabase. The copper at times carries native silver, and sometimes, in the form of wire and sheet metal, binds the pebbles of the conglomerate together. The diabase is interstratified between the other rocks in thin sheets of amygdaloid as well as massive structure. The amygdaloids have in some cases been filled with copper. The sandstone supposed to be Potsdam is sometimes impregnated with copper, and there are contact deposits between the sandstone and the diabase. Native copper in sandstone in contact with diabase is found at Arlington, New Jersey.

Native copper occurs also in Green County, Virginia, in a greenish rock that resembles diabase. The rock has been shattered and healed by quartz. According to Weed, the deposits are superficial, and the rock is an epidote. At Cape D'Or, Nova Scotia, there is an extensive deposit of native copper on one side of an extensive trap dike that is probably 50 feet wide. Adjacent to the mineralized side of the dike is a dark green soft epidote that is amygdaloid in character. The cavities in this case are filled with calcite and coated with copper stains. No impurities, such as antimony, arsenic, bismuth, and sulphur, are found associated with this copper, so that it is easily concentrated and refined.

Amygdaloid diabase is found in British Columbia and Oregon in which traces of copper are present; however, but little native copper has so far been discovered in the rock.

52. Chalcocite.—**Chalcocite**, known also as *copper glance*, *vitreous copper*, and *redruthite*, is an oxidized product of copper precipitated from solutions as a massive blackish-gray mineral by a sulphur salt in solution. It is also found crystallized. When copper is leached from pyrites in the upper part of a deposit, and carried downwards to water level, chalcocite is precipitated and concentrated. The ore above this deposit is known as *gossan;* while below, the pyrite is generally poor in copper. The gossan at the Anaconda mine, Butte, Montana, from which the copper has been leached, is rich in gold and silver. At this place, the chalcocite was about 200 feet thick; while at Ducktown, Tennessee, it was about 10 feet thick. Other chalcocite deposits have been found, which, as the depth increased, turned into bornite. Deposits of chalcocite are, as a rule, found in veins that are situated in aqueo-igneous magmas. The veins are almost dikes in width, and in some respects resemble magmas. The Ducktown deposit is cupriferous pyrrhotite; the deposit at the Anaconda mine is chalcopyrite.

53. Chalcopyrite.—While chalcopyrite mineral is composed mostly of iron, it is frequently found in large masses, so that the secondary products of copper derived from its weathering are quite important. Unless the iron-copper sulphides contain more than 3½ pounds of copper per hundredweight of ore, they are not of commercial value. Large bodies of such sulphides have been weathered and leached so as to form gossan, a poor iron ore, near the surface, and possibly in some locations they are the original source of iron-ore deposits. Such deposits produce chalcocite and bornite as explained, and are the original source of the oxidized copper ores found in Arizona, New Mexico, and possibly elsewhere.

54. Copper in Pyrite.—Large pyrite and pyrrhotite deposits containing some copper and other metals are found at Sudbury, Canada; Davis, Massachusetts; Pulaski County, Virginia; Ducktown, Tennessee; and in North Carolina. These deposits are either in syenite, granite, or gneiss, or adjacent to intrusive magmas, as in New Hampshire, Vermont, Virginia, and Massachusetts, where they occur in argillaceous schists adjacent to gneiss. In California, chalcopyrite occurs in auriferous slates in contact with diabase. Copper pyrite easily oxidizes, and is converted into sulphates of iron and copper that are soluble in water. When chalcopyrite does not show weathering, it is a fairly good indication that there is no concentrated deposit, but that the mineral is disseminated through the vein or magma. If, however, there are sedimentary rocks near, particularly limestone, there may be secondary deposits of great value. Fissure veins of chalcopyrite will at times show depressions on the outcrop, and water will flow from them at water level. Sometimes, the heat arising from the chemical reactions due to oxidation will melt snow above them at the outcrop. Beds of iron-copper sulphides, associated with chert in magnesian limestone of the Cambrian system, occur at St. Genevieve, Missouri. In this case, there are two horizontal beds of ore.

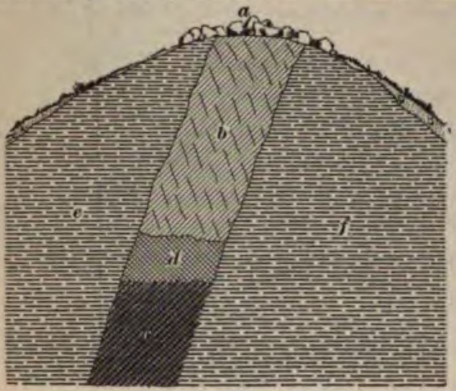


FIG. 3

Fig. 3 is an illustration of an iron-copper-sulphide deposit. The outcrop *a* shows the impure limonite boulders; *b* shows the gossan or iron hat; *d* shows the secondary copper deposit of chalcocite, bornite, etc.; while *c* shows the unaltered sulphides. The country rock is represented by *e* and *f*.

55. Copper Oxides.—Bodies of copper oxides occur in limestones near by aqueo-igneous rocks, and also in kaolinized porphyry and sandstones. Carl Heinrich concluded that there were three classes of these deposits in Arizona, where the most productive copper-oxide bodies are found.

56. Contact Deposits.—According to Heinrich, contact deposits occurred in kaolinized porphyry (that is, altered porphyry composed partly of kaolin resulting from the decomposition of the feldspar in the rocks), between a bluish fine-grained limestone and solid porphyry. Many such ore bodies, and probably the largest of them, are directly in the limestone, as azurite, malachite, cuprite with some metallic copper, and melaconite (tenorite or black copper) in a gangue composed chiefly of limonite.

FIG. 4

57. Replacement Deposits.—Replacement deposits,
cording to Heinrich, were found in limestone that seemed
have been formed by the circulation of copper-bearing
lutions along crevices in the rock. Wherever such solu-
ons permeated the limestone they reacted on the calcium
d in part replaced that with copper, thus forming car-
onate* and oxide ores. Fig. 4 illustrates the method by
hich replacement deposits are formed.

58. Impregnations.—**Impregnations** of copper,
cording to Heinrich, are found in porphyry in the form of
eets and in pockets in the solid rock. A rock to be
npregnated by solu-
ons must be porous,
d the mineral is de-
osited in the pores of
ch rocks. The de-
osits here under con-
deration are oxidized
the surface, pass into
alcocite with depth,
en into bornite, and
ally into unaltered
alcopyrite. The im-
egnated porphyries are at present the chief ore supply in
rizona, as the former carbonates worked near the surface
ve been replaced by sulphides at greater depths.

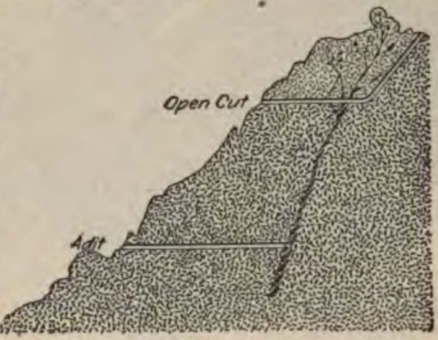


FIG. 5

From the preceding discussion and the accompanying
gures, it is evident that the original copper-bearing minerals
ere in magmatic rocks; but the Connecticut and Pennsylva-
a sandstones have small copper deposits in some localities
here they are in contact with gneiss. Copper carbonates
d chalcocite, which is a secondary formation, are found in
e Jura-Trias sandstones of Texas, and the Tertiary of
ew Mexico and Utah, as well as in the Upper Devonian in
ennsylvania and Nova Scotia. The sandstones are either

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*All ores not containing sulphur are spoken of as *oxidized ores*.
his term is general, and includes carbonates and silicates.

metamorphosed or adjacent to aqueo-igneous rocks. With the exception of one or two cases,* the sandstones, schists, and shales have not been very productive.

The copper found in the Devonian, Carboniferous, Jura-Trias, and Cretaceous formations seems to have been precipitated from copper solutions coming in contact with organic matter, either in limestone or in sandstone. As an illustration, Fig. 6 is a sandstone containing a large number of fossil imprints, one to the middle right being particularly noticeable. The rock is partially metamorphosed, but not sufficiently to have obliterated the fossil leaves and ferns. The solutions that found their way through the sandstone carried copper, which was precipitated by the organic remains.

FIG. 6

59. Looking for Copper.—The copper stains that will often be found on rocks are not necessarily criterions by which to judge the size of a deposit, but are indications that

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*At the Schuyler mine, near Arlington, New Jersey, probably the first copper mine in this country was opened that was worked at a profit, for Philip Schuyler imported a Watt engine to pump the water from the mine. This is said to have been the first steam engine erected in this country.

copper pyrite is to be found in the vicinity. If the pyrite is found—either in rocks of aqueo-igneous origin, like diabase porphyry, etc., or in metamorphic rocks—a contact deposit should be looked for in the vicinity, either in sandstone or in limestone. It is not likely that large copper-iron sulphide deposits will be found that show these minerals at the surface, but gossan in the form of a reddish-brown rock is an indication of such deposits. Springs issuing from hills are also indicators of copper deposits; and, if old tin cans, shovels, or pieces of iron are left in springs that carry copper sulphate in solution, copper will be deposited on them. A quicker method of testing springs is to put some of the water in a test tube and add a little ammonia water when, if copper is present, a blue coloration will be observed. An acid solution of copper will have a blue coloration when ammonia is added to it, provided that it is allowed to stand a few moments. Usually the color shows at once, but sometimes iron prevents it; and again, if organic matter is present, as in some forms of chalcocite, the blue does not appear quickly.

PROSPECTING FOR LEAD

60. Lead Minerals.—Fifty-three lead-bearing minerals are known, and it is probable that there are more. Not all of these minerals are mined for the lead they contain. Many of them are sought for their value as fluxes, and for the more valuable minerals that are associated with them. Some of the more important lead minerals are as follows:

1. **Altaite** ($PbTe = Te$, $38.3 + Pb$, 61.17) is a tin-white telluride of lead.

2. **Anglesite**, $PbSO_4$, is a lead sulphate, highly lustrous, nearly colorless and tinged with yellow, gray, green, or blue. It contains nearly 73 per cent. of lead.

3. **Boulangerite** ($Pb_3Sb_2S_6 = Pb$, $58.7 + Sb$, $23.1 + S$, $18.2 = 100$) is a massive, metallic, bluish-gray sulphide of antimony and lead.

4. **Cerusite**, $PbCO_3$, also called *white-lead ore*, *carbonate of lead*, or *dry bone*, is an adamantine white to grayish-black mineral, and contains 68.3 per cent. of lead.

5. **Clausthalite** ($PbSe = Pb, 72.4 + Se, 27.6 = 100$) is a granular, metallic, lead-gray, opaque selenide of lead.

6. **Cotunnite,** $PbCl_2$, is a soft, white, native lead chloride containing 74.5 per cent. of lead.

7. **Crocoite,** $PbCrO_4$, is a yellow chromate of lead. It has a bright red color, with orange-yellow streaks running through it. It contains 69 per cent. of lead, and 31 per cent. of chromium trioxide.

8. **Descloizite** ($Pb_2V_2O_7$ = vanadium pentoxide 29.1 + lead oxide 70.9 = 100) is a bright red through brown to black lead vanadate.

9. **Galena,** PbS, or sulphide of lead, is of a lead-gray color with a shining metallic luster. It contains 86.6 per cent. of lead, and 13.4 per cent. of sulphur.

10. **Leadhillite,** called, also, *Susannite*, is a pearly, resinous, white, lead sulphato-carbonate of varying composition.

11. **Linarite,** $PbCuSO_4 \cdot H_2O$, is a deep azure-blue lead-copper sulphate, composed of sulphur trioxide 20 per cent., lead oxide 55.7 per cent., copper oxide 19.8 per cent., and water 4.5 per cent.

12. **Mimetite** is a lead-arsenate crystal. In color, it ranges from a pale yellow to brown. Its composition is approximately as follows: arsenic pentoxide 23.20 per cent., lead oxide 74.96 per cent., and chlorine 2.39 per cent.

13. **Nagyagite** is a foliated, metallic, blackish lead-gray lead-gold sulphotelluride. It contains about 54 per cent. of lead, 32 per cent. of tellurium, and 9 per cent. of gold.

14. **Pyromorphite** is a bright green to brown lead phosphate of varying composition that crystallizes in the hexagonal system. It contains about 82 per cent. of lead and 15.7 per cent. of phosphorus.

15. **Stolzite** ($PbWO_4$ = tungsten trioxide 51 + lead oxide 49 = 100) is a green, gray, brown, or red lead tungstate, crystallizing in square prisms.

16. **Vanadinite** is a resinous, orange to red crystal of lead chlor-vanadate. It contains 19.36 per cent. of vanadium pentoxide, 78.90 per cent. of lead oxide, and 2.5 per cent. of chlorine.

17. **Wulfenite,** $PbMoO_4$, is a tabular, resinous, yellow lead molybdate.

61. Lead Ores.—Most of the minerals named have little importance from a commercial standpoint, as they are not usually found in such quantities that they can be termed ores, and hence for the most part are interesting only as lead indications and as rare minerals.

62. Galena is the mother ore of lead, but sometimes it has been oxidized or taken in solution, and the minerals anglesite and cerusite been formed by deposition. While galena is the chief ore of lead, little of it is mined, in this country, for lead alone, owing to the large output of the metal that results from base-bullion smelting and the lead obtained as a by-product from zinc mining. Galena has associated with it gold, silver, zinc, iron, copper, nickel, and cobalt, as well as arsenic and antimony. With its property of easy fusibility, and its power of concentrating the more valuable metals gold and silver, it is almost a necessity in gold and silver smelting—that is, base-bullion smelting or lead smelting. A gold ore that carries less than 7 per cent. of galena or lead in some fusible form is termed a *dry ore,* and cannot be smelted alone; but, by the addition of galena having a little gold and silver, both ores can be smelted at a profit. Lead minerals that contain arsenic and antimony are not so desirable in smelting operations as other ores, and must contain silver and gold in considerable quantities to warrant smelters in handling them.

63. Cerusite was mined by the Omaha and Grant Smelting Company years ago, when they were unable to obtain sufficient argentiferous galena for flux. Their mine was near Silver Cliff, Colorado, and was known as the Terrible. This mineral and anglesite are found in considerable quantities near galena deposits, but probably the Terrible mine has been the only large deposit found and worked in this country. It is scarcely to be expected that large deposits of this mineral will be found, but small ones are indications that galena is in the vicinity, and, as already stated, may carry the precious metals if located in veins near by or in aqueo-igneous rocks.

64. Lead Deposits.—In order to systematically describe lead-ore deposits, they are divided into three classes: lead, lead and zinc, and lead silver. The Terrible mine is located as a vein in a limestone that is surrounded by eruptive rocks. In Tennessee, cerusite is found in limestone caves and in cracks in red-colored slates or shales. It is also sometimes observed as an enclosing shell and as a crust about galena. Galena is found in granite, gneiss, slate, sandstone, and limestone, with associated minerals. When in veins, the gangue is quartz and calcite, with other minerals, such as barite and fluorite subordinate. Galena is also found in veins in granite, gneiss, sandstone, limestone, and slate in the Appalachian region, as well as in the West. In the Middle West, it occurs, in the states of Illinois, Iowa, Missouri, and Wisconsin, in bedded deposits or in cracks in limestone. In Southeastern Missouri, near Fredricktown, galena is associated with cobalt and nickel chalcopyrite. The deposits are found in Trenton limestone and Utica shales both of which contain organic matter that may have been the cause of the galena being deposited where it is. In Missouri, sink holes in the soil that carry calcite and barite as float minerals, are considered to indicate the presence of lead, and in Illinois fluorite is considered to be an indication of galena. In the Eastern, Southern, and New England States, galena is found in bunches that are usually mixed with zinc. Both sulphides are in dolomite or magnesium limestone.

In many cases, zinc and lead sulphides are found in magnesium limestone as a constituent part of the rock. This limestone, termed *galena limestone*, is a part of the Lower Silurian formation, and is situated just above the Trenton limestone. The assumption is that this limestone was the source of the galena deposits in the Trenton limestone; and the theory is that descending solutions carrying lead in solution met, in the cracks of the limestone, ascending solutions that were able to precipitate the lead as sulphide wherever there was organic matter. Lead sulphide has been produced artificially, it is said, by suspending a bag containing sulphate of lead in water that has been saturated with carbon dioxide, and in which putrid fermentation is kept up. Lead sulphide is also at times a furnace product. The La Motte sandstone below the Trenton limestone rests on granite, porphyries, and diabase in the Missouri and Wisconsin lead sections, and, as they are aqueo-igneous, it is probable that they furnish the ascending solutions.

In Southeastern Pennsylvania, galena is found in contact with Archæan gneiss and Triassic sandstone. The Carboniferous sandstones in Northeastern Pennsylvania are highly metamorphosed; and, on two occasions, galena, in combination with quartz, feldspar, and pyrite, has been found,—but only in very limited quantities.

65. Lead Zinc.—Deposits of lead-zinc sulphides are found in magnesian limestone in Kentucky, Virginia, and Tennessee, as well as in vertical and more or less horizontal cavities in the galena and the Trenton limestone of Southwestern Wisconsin, Eastern Iowa, Northwestern Illinois, and Southeastern Missouri. The Kentucky deposits are said to be in the St. Louis limestone, which is synonymous with mountain or sub-Carboniferous limestone. The Kentucky zone includes several counties south of the Ohio River and east of the Cumberland River. While limestone forms one of the walls of these deposits, sandstone of an undetermined age forms the other. In Southwestern Virginia and Eastern Tennessee, zinc-lead sulphides are found in the magnesian limestone of the Lower Silurian, but not as separate deposits, as is the case in Wisconsin, Illinois, and Missouri. In the latter states, galena is found in cavities above the sphalerite; while in Virginia and Tennessee the sulphides are in bunches or else are disseminated through the rock. The Missouri sulphides seem to be the products of second concentration, while the others are products of first concentration, the magnesian limestone being the magma.

66. Lead-Silver Deposits.—The quantity of lead in lead-silver deposits is many times in excess of that of silver. At the present time, most lead-silver ores come from the Rocky Mountain mines and from Mexico. These ores occur in limestone that is associated with aqueo-igneous rocks. Fig. 7 is a cross-section showing the rocks at Leadville, Colorado; *a* is white porphyry; *b*, blue limestone; *c*, ore; *d*, gray porphyry; and *e*, white limestone. These ores are oxidized at the surface—a fact that the prospector should bear in mind. While anglesite appears rusty and dirty at the surface, it is adamantine when not stained; with a white to a gray-green color, and a conchoidal or a basal fracture. Cerusite is likely to be dirty at the surface, but a fresh piece will be milk-white, almost like porcelain—or else an adamantine whitish gray—with conchoidal fracture. Its easy fusibility is another distinguishing feature. Below water level, the sulphide lead-silver ores appear.

FIG. 7

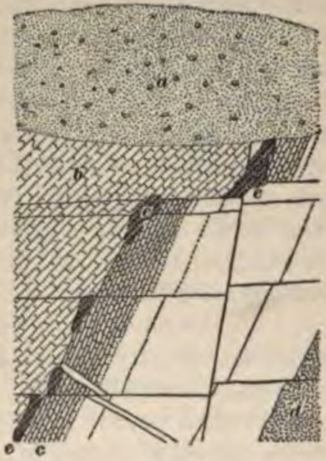

FIG. 8

At Aspen, Colorado, the ores are sometimes similar to those of Leadville, and are nearly always in limestones in contact with such eruptive rocks as porphyry or near aqueo-igneous rocks.

Fig. 8 is a section, by J. E. Spurr, of the Bushwacker mine at Aspen, Colorado. Alluvial drift is seen at *a*, Carboniferous limestone at *b*, dolomite at *c*, eruptive rock at *d*, and ore bodies at *e*. The rocks are faulted. Another section by Spurr gives, from the bottom up, granite, Cambrian quartzite, Silurian dolomite, Devonian quartzite (thin), Carboniferous limestone (with a contact fault in which ore bodies are found) and finally shales, porphyry, and drift.

The lead-silver ores in the Eureka, Nevada, district are said to be in fractured Cambrian limestone; while similar ores are found in the Carboniferous limestones of Utah. Mexico is rich in lead-silver ores.

PROSPECTING

(PART 3)

ORE DEPOSITS—(Continued)

PROSPECTING FOR SILVER

SILVER-ORE DEPOSITS

1. Distribution of Silver Ores.—The rocks that contain silver are not limited to any age or formation, nor are the ore deposits limited to veins alone, for rich silver deposits are found in beds, in veins, and in crushed-rock areas. The gangue rocks accompanying silver deposits are quartz, calcite, barite, feldspar, and fluorite. The metals that are almost invariably associated with silver are lead, copper, and gold with subordinate quantities of zinc.

The elements associated with silver to form compounds are sulphur, antimony, arsenic, bismuth, chlorine, bromine, and iodine, and occasionally some other subordinate elements. Gold is usually associated with silver in ore deposits, but the widely marked variations in geological formations and situations render it impossible to give a list of all the conditions under which they occur.

As most silver is found in the form of sulphide, it may be assumed, by analogy, from the silver deposits known to exist, that the original mineral was a sulphide in an aqueo-igneous magma. Silver sulphides are readily oxidizable, and any silver taken in solution could, in circulating through rock crevices, be deposited by precipitation as sulphide, chloride, antimonide, and arsenide, and probably also in some other form, such as native silver. Galena appears to be the most prolific source of silver for secondary concentration; next in order comes either native copper or copper pyrite; finally pyrite and, at times, sphalerite contains silver.

2. **Silver Deposits.**—While silver occurs in veins and beds—both of the older and of the more recent formations—there are three distinct kinds of deposits whose origin can be traced to solutions derived from aqueo-igneous magmas, either of the Archæan or of the more recently disturbed and eruptive magmas.

These classes of deposits are as follows:

1. The first class of deposits is made up of fissure veins that have become filled by ascending solutions bearing minerals. This kind of deposit may have been shattered, and secondary concentration have resulted by downward mineral-bearing solutions.
2. A second class of deposits is found in sedimentary-rock beds, either in horizontal or in vertical joint planes. Similar deposits are found in contact veins. These deposits are probably all of secondary concentration, and are found in contact with or near by eruptive rocks or older aqueo-igneous formations. There are indications that a third concentration has occurred in some deposits of this nature.
3. The third class of deposits is found in rocks that were shattered by dynamic disturbances and reunited by deposits from mineral solutions. This kind of deposit is not confined to aqueo-igneous rocks, but is found in slates and sedimentary rocks that have been metamorphosed. Where the rock has been shattered and healed, the deposits are termed **stockwork**; and where the slates have had their leaves opened and mineral solutions injected, the deposits are said to be **impregnations.**

3. **Native Silver.**—Silver is seldom found native, unless it is associated with some other metal, such as gold or copper, or has been precipitated from solutions by

rbonaceous material. Gold is seldom found free from lver—even placer gold contains a certain amount. In the ake Superior copper mines, silver is found attached to ative copper—sometimes in large masses. The present utte, Montana, copper mines were first worked for silver nd gold, the pyrites containing those metals having been xidized and leached to a considerable depth. At the muggler mine, Aspen, Colorado, native silver is found at is the product of third concentration, the steps being alena to silver sulphide, and the latter to native silver.

4. Argentite.—Argentite, known also as *silver glance, itreous silver*, and *silver sulphide*, contains 87.1 per cent. of ilver and 12 per cent. of sulphur. It is sometimes found rystallized, but more often it is amorphous. The mineral an be cut with a knife, has a lead-gray color, and will give silver button when melted on charcoal by the blowpipe. hen in quartz veins, argentite is probably the product of rst concentration from solutions that ascended the fissure. he associated minerals in such cases are galena, blende, yrite, and chalcopyrite, with gangue of quartz. With other angues there may be other minerals, such as sulphides, rsenides, antimonides, and tellurides. When oxidized, lver sulphide may be converted into other silver minerals r even into native silver.

At the Ontario silver mine, Summit County, Utah, there is fissure vein that averages 8 feet in width for 6,000 feet in ngth. At the surface, the fissure is in quartzite, but at condeerable depth it comes in contact with porphyry. At the aly-West mine in Utah, one wall of the vein is limeone, and associated with the argentite are galena, PbS, phalerite, ZnS, and tetrahedrite, $Cu_8Sb_2S_7$. From the xidation of silver sulphides, insoluble silver minerals such s cerargyrite, $AgCl$, bromyrite, $AgBr$, embolite, $Ag(ClBr)$, nd iodyrite, AgI, are formed.

5. Pyrargyrite.—Pyrargyrite, called also *ruby silver* nd *dark red silver ore*, contains less silver and more sulphur han argentite, and has in its composition antimony as well.

When powdered, the mineral has a purplish-red color and gives a red streak, although in its native state it is black-looking with a reddish tinge. Its luster is metallic, and its fracture conchoidal; and, on account of the antimony present, it is quite easily fused. The mineral is attacked by nitric acid, leaving a white residue of antimony that will disappear if dried and heated on charcoal before the blowpipe.

In some localities the pyrargyrite is sufficiently abundant to be classed as an ore, but it is usually subordinate to some other silver mineral. At the Poorman mine in Idaho, at the Tonopah mines, Nevada, and at the Ruby Silver mine near Butte, Montana, it is quite abundant. The altered products of the mineral such as cerargyrite, and possibly secondary sulphides, would form under proper conditions, as well as native silver and haloid silver compounds.

6. Stephanite.—**Stephanite**, Ag_5SbS_4, called also *brittle silver* and *black silver*, is, as its common names would suggest, a black and brittle mineral, and is composed of 68.5 per cent. of silver, 15.3 per cent. of antimony, and 16.2 per cent. of sulphur. Usually, stephanite is associated with pyrargyrite, both minerals, when in veins, being probably the product of first concentration, and, when in beds, of secondary concentration; in either situation, both minerals seem to be subordinate to polybasite. Both the streak and the color of stephanite are iron-black—peculiarities that distinguish it from pyrargyrite.

When stephanite is heated, antimony fumes are given off, thus showing the presence of that element; when stephanite is placed in a solution of nitric acid, the silver is dissolved out, its presence being detected by the fact that a bright piece of copper becomes silver-plated when immersed in the solution.

7. Polybasite.—**Polybasite** is a mineral that somewhat resembles stephanite, but differs from the latter in that it has arsenic and copper in its composition, in addition to sulphur and antimony. It seems to be a secondary product derived from argentiferous galena. The famous silver mines of Aspen, Colorado, have a deposit of this mineral adjacent to galena, the gangue being barite. At Neihart, Montana, rich pockets of polybasite occur in quartz veins associated with galena and sphalerite, but even in this case the deposits seem to be of secondary origin. As a rule, all bonanzas are either secondary or tertiary concentrations, and polybasite is the preeminent silver bonanza mineral.

8. Cerargyrite.—Cerargyrite, $AgCl$, known also as *horn silver* and *silver chloride*, is, when pure, translucent, sectile, resinous in luster, resembles somewhat wax or horn in appearance, and varies in color from pearl-gray to violet-brown. The composition of cerargyrite is silver 75.3 per cent., and chlorine 24.7 per cent., the combination being an insoluble compound in water and nitric acid. It is not an uncommon mineral for it is found in various localities, particularly in California, Nevada, and Utah, where areas of salt water are found. This, however, does not limit its extent, as it is also found in Arizona, Idaho, Montana, and Colorado, and probably elsewhere. In Nevada, there are quartz veins containing silver chloride that cut granite, slates, and quartzites in the order named. At Silver Reef, Utah, native silver, cerargyrite, and argentite impregnate Triassic sandstones, and often replace organic remains. There are two silver-bearing strata at this place, with beds of shale between. When above water level, the beds carry cerargyrite; when below water level, they carry argentite. At times, no ore is noticeable in the sandstone; nevertheless, it sometimes assays $30 a ton.

9. Proustite.—Proustite, Ag_3AsS_3, or *light ruby silver*, is light red in color, and differs in other respects from pyrargyrite, for instance, in that it contains arsenic. The luster of proustite is adamantine; its streak, scarlet red; its tenacity, sectile to brittle; and it is easily fusible. Sometimes, antimony is entirely wanting; at other times, there is a little present in addition to arsenic. The percentage composition of the mineral is given as silver, 65.5 per cent.; arsenic, 15.1 per cent.; and sulphur, 19.4 per cent. When treated on charcoal before the blowpipe, the antimony fumes are not copious, their place being taken by the garlic odor of arsenic.

Another silver mineral—having an adamantine luster, a fire-red color, a pinacoidal fracture and in groups of delicate crystals—is **pyrostilpnite,** which, though resembling proustite, is not likely to be confounded with it.

HINTS ON SILVER PROSPECTING

10. Output of Silver.—There are few mineralized zones—especially copper and lead deposits—that do not contain some silver, for which reason indications of such deposits are not to be overlooked when prospecting for silver. The greatest quantity of silver produced in the United States results from copper refining; next, from base-bullion refining; and lastly, from silver-gold mining. In this country, few silver mines are worked for silver alone; as lead-silver propositions, however, they are worked extensively, since gold is frequently found associated in such mineral combinations. When the silver contents of an ore increase, it frequently happens that the tenor in gold also increases. While silver minerals are for the most part dark colored, the silver compounds of chlorine, bromine, and iodine are light colored.

What has been stated in regard to veins and deposits near or in aqueo-igneous rocks applies also to silver.

11. Colorado and Montana Silver Deposits.—At Aspen, Colorado, the Carboniferous limestone is in two beds. The division between the blue and the brown limestone is termed the *contact fault;* in it, silver lead is found. Between the blue limestone and the shales above it, another ore sheet is found, called the *silver contact.* This sheet is quite rich in silver, particularly where cross-faults occur.

At Butte, Montana, silver occurs in the gossan above the copper. The country rock there is granite that has been fissured in some manner, and the fissures have been filled with pyrites. Fissure veins, with quartz gangue and argentiferous galena, also occur in granite. Ruby silver, associated with gold, is found in veins that have gray granite country rocks.

12. Nevada and Idaho Silver Deposits.—The Comstock lode in Nevada carries gold and silver in quartz gangue, the lode being in diorite. In the Eureka district, the oxidized lead-silver ores with some gold are irregularly distributed through veins in Cambrian limestone and shales.

The ores in the Coeur d'Alene district, Idaho, are argentiferous galena with siderite gangue occurring in folded schists and quartzites as country rock. The veins are near syenite and basalt dikes. The principal minerals are quartz, siderite, galena, zinc sulphide, and pyrite; but, at the surface, carbonates, iron and manganese oxides, and native silver occur. The Bunker Hill lode cuts anticlines and synclines for a length of 6,000 feet. All the mineralization is said to be on the hanging-wall side of the fissure next to the quartzite. For from 100 to 300 feet in the shattered quartzite, the joints and seams have been filled with galena, quartz, and iron carbonate.

13. New Mexico, Utah, and Arizona Silver Deposits.—New Mexico furnishes silver-lead ores that are found in Paleozoic limestones. In Beaver County, Utah, a fissure vein is found in trachyte associated with argentiferous galena, sphalerite, and barite. Quartz veins that carry argentiferous galena also are found in trachyte. In the Tombstone district, Arizona, horn silver, associated with galena, free gold, pyrite, and lead carbonate, is found in a porphyry dike that is 70 feet wide. The gangue is quartz, and the porphyry has been altered and faulted, making the present deposit of a secondary nature.

The Bull Domingo mine, at Silver Cliff, Colorado, and the Bassick mine, at Rosita near by, are apparently the necks of ancient volcanoes. These necks, called *chimneys*, are found in gneiss country rock, near dikes of granite, syenite, and andesite. They contain boulders of granite, gneiss, and syenite, which are coated with silver sulphides carrying gold and associated with galena, sphalerite, pyrite, and chalcopyrite. At Silver Cliff, porous rhyolite contains small fissure veins carrying chloride of silver and black manganese minerals.

14. Conditions Under Which Silver is Found. When the various conditions under which silver is found are grouped, it will be noticed that in nearly every case the veins are in or near aqueo-igneous eruptive rocks, and that deposits are in sedimentary rocks adjacent to eruptive rocks. If the solution is basic and carries metal minerals, then the deposit is in acid rocks or on the acid-wall side of the vein, with usually a basic gangue; again, if the solution is acid, it will deposit its minerals in basic rocks and on the basic-wall side of the vein. There are numerous instances where veins cross, and at the junction of such fissures the mineral is quite rich, probably because basic and acid solutions have met. It is noticeable that, in such instances, the character of the mineral and that of the vein rock change on the opposite sides of cross-fissures. The Penoles mine, at Mapimi, Mexico, is a good illustration of veins crossing. The veins are in limestone at the Ojuela mine, where for a depth of 1,900 feet the mine was dry. With the exception of galena and antimony sulphide, the ore was oxidized; at the depth of 2,100 feet, water was encountered, when the ores changed to sulphides, antimonides, and arsenides. Near by the limestones were dikes of porphyry and other eruptive rocks. The deposit at the junction of the veins was quite wide, making it possible to mine several hundred tons of ore daily.

PROSPECTING FOR GOLD

GOLD DEPOSITS

15. Distribution of Gold.—Gold is said to be wherever one finds it, since it is widely distributed in small quantities in nearly all formations. Gold is seldom found in large quantities, and seldom in paying quantities—outside of placer deposits—unless associated with other metals. The original gold deposits seem to have been deep-seated magmas, which contracted on cooling and so became fissured. The solutions that closed the fissures were mostly quartzose carrying sulphide minerals and gold. In time, when these rocks and veins were eroded, placer deposits were formed. It is from the erosion of rocks carrying gold that the prospector traces float gold up to the original deposit. The prospector will find gold in the newest as well as in the oldest rocks, and probably always associated with quartz, whether the metal is in slate, limestone, granite, or alluvial rock.

Table I shows the geological distribution of gold.

TABLE I

GEOLOGICAL DISTRIBUTION OF GOLD

Period	Rock	District	Region
Quaternary	Andesite	Monte Cristo	Washington
Tertiary	Eruptive	Cripple Creek	Colorado
Cretaceous	Green porphyry	White Oaks	New Mexico
	Gray porphyry	Parsons	New Mexico
	Green porphyry	Santiago	Cuba
Jurassic	Amphibolite schist	Mariposa	California
Triassic	Limestone	Raibl	Carinthia
Permian	Conglomerate	Stupna	Bohemia
Carboniferous	Shale	Gympie	Queensland
Devonian	Conglomerate	Witwatersrand	Transvaal
	Shales	Bowman's Creek	Pennsylvania
Silurian	Slate and sandstone	Bendigo	Victoria
	Eruptive	Montgomery County	Virginia
Cambrian	Slate and quartzite	Waverley	Nova Scotia
	Chlorite schists	Farquier County	Virginia
	Chlorite schists	Randolph County	North Carolina
Pre-Cambrian	Schist	Homestake	South Dakota
	Hornblende schist	Kola Gold Fields	India
Archæan	Granite and schist	Lake of the Woods	Ontario

16. Modifying Conditions.—There are cases where silver-lead ores or silver-copper ores carry small quantities of gold, and then the gangue may not be quartz entirely, as the deposits are of secondary concentrations. There have been fissures in rocks up to the Cretaceous formations, and through them aqueo-igneous magmas have been intruded as dikes. These aqueo-igneous magmas have sometimes been mineralized, and fissures in them have been filled with rich minerals. There are also slates and sandstones that have been dynamically distorted so as to furnish cracks and crevices through which mineralization has taken place, particularly near by dikes of eruptive rocks. The gold-bearing slates of California and the Cambrian schists of the Appalachian Mountains are of this class. In some cases, the rocks have been shattered, and through the shattered zone minerals have been distributed.

PROSPECTING FOR IRON ORE

IRON-ORE DEPOSITS

17. Origin of Iron Ores.—The various iron-ore deposits in different parts of the country are proofs, evidently, of different modes of formation. Most of them are secondary formations, while the more recent deposits are tertiary concentrations. The original iron was probably derived from magmas of the aqueo-igneous variety, such as the granite and gneiss of the Archæan. This magma produced the mineral magnetite, while such eruptive aqueo-igneous magmas as are found in the great outburst of Virginia and in various other parts of the country produced the great iron-sulphide deposits. From such deposits, it is probable that all secondary deposits of iron ore are derived.

18. Distribution of Iron Ores.—Iron ore is found in the rocks of all ages, but in the United States the most important deposits are in pre-Cambrian rocks. The Clinton limestones and the Oriskany sandstone are quite productive iron-bearing rocks, but their ores are not so valuable from a commercial standpoint. There are black-band ores in some states and large deposits of siderite that are not worked because of better iron ores being obtainable. In England, France, and Germany, the chief iron ore is the carbonate, and for making mixtures the better kinds of iron ore are imported from Spain, Italy, and Algeria.

The iron ores of Spain, Cuba, and San Domingo are of Bessemer quality, and find a ready market in foreign countries.

19. Iron is seldom found native, except as in meteorites and in other rare cases. The chief iron ores are all oxides of iron, with the exception of iron carbonate. It would seem as if pyrite should be included in the list of iron ores, but, as it is used in the manufacture of sulphuric acid, and not in the manufacture of iron, it is properly termed a sulphur ore. A brief description, however, is given of iron pyrites in another place (Art. **50**).

20. Appalachian Iron Ores.—Rich magnetite ores are found in the pre-Cambrian rocks (usually granite or gneiss) from Lake Champlain to Cranberry, North Carolina. The hematites of the Appalachian range are found in the Clinton limestone, at Clinton, New York, in Tennessee, and in Alabama. There is a poor deposit of this ore in Tazewell County, Virginia.

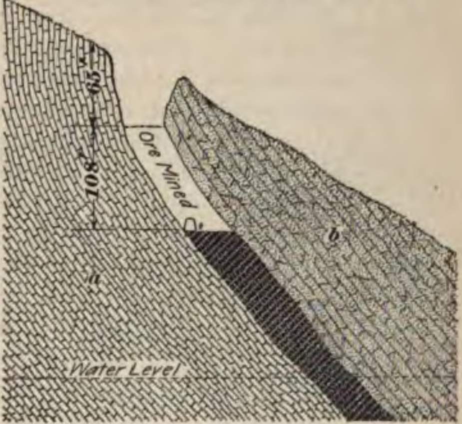

FIG. 1

The Appalachian Mountain region is also prolific in limonites that are of more recent age. These ores are found in contact with limestones of the Carboniferous, Devonian, and Silurian periods. Fig. 1 shows a section of Ritch Patch Mountains in Alleghany County, Virginia. The limestone *a* is considered to be the Upper Helderberg of the Upper Silurian period; while the sandstone *b* is considered to be the Oriskany of the Devonian period.

21. **Lake Superior Iron-Ore Region.**—The best ores from a commercial standpoint are those found in Minnesota and Michigan in what is termed the Lake Superior region. The rocks in this section are Archæan and pre-Cambrian. The iron ores of Lake Superior are found in certain rocks that have been termed the iron-bearing formations in that section. These rocks are as follows: (1) cherty iron carbonates; (2) ferrous-silicate rocks; (3) pyritic quartz rocks; (4) ferruginous slates; (5) ferruginous cherts; (6) jaspilites; (7) amphibolic schists; (8) iron-ore deposits; and (9) detrital ferruginous rocks derived from the foregoing. The rocks have been disturbed, and dikes, igneous-rock flows, etc. are frequently in evidence. The ores are found in relatively impervious rock, usually an altered igneous dike—now hornblendic and dioritic, but originally composed of diabase.

22. **Impurities in Iron Ores.**—Most iron ores contain impurities, and those that contain sulphur, phosphorus, or titanium in considerable quantities—for instance, 1½ to 2 per cent.—are not suitable for the manufacture of some classes of pig iron. Sulphur makes iron brittle when hot, and destroys its welding properties; while phosphorus makes iron brittle and hard when cold. Titanium is said to make iron cold short; little, however, is known in regard to this element and its effect, except that it makes iron hard and more difficult to smelt in the blast furnace.

Ore for making Bessemer pig iron should not contain more than .05 per cent. of phosphorus. Manganese, although an impurity, is sometimes desirable, since, when it is in sufficient quantity, ferromanganese may be made.

OXIDES OF IRON

23. Magnetite.—**Magnetite**, or *magnetic iron ore*, contains 72.4 per cent. of iron and 27.6 per cent. of oxygen. It is black, and gives a black streak. It is almost infusible before the blowpipe, but when fluxed with borax in the reducing flame gives a yellow glass bead. It attracts the magnetic needle, and on account of this property has received the name of *lodestone*. Unlike most other iron ores, it is attracted by the magnet before roasting. When concentrated in beds, magnetite appears as a mass of crystals cemented together. Workable beds of magnetite are found in New York near Lake Champlain, in the counties of Putnam, Orange, and Rockland, and elsewhere in the eastern part of the state. It is also found in the counties of Warren and Sussex, New Jersey. In the latter state, at Franklin Furnace, a magnetite deposit containing zinc and manganese occurs, which is called *franklinite*. These deposits are lenticular shaped, and peter out at each end, as well as with depth, into the country rock. Some of the New Jersey mines are very deep, although in all probability they are not veins. While many rocks containing magnetite will not prove sufficiently concentrated to be a mining proposition, yet such indications of mineralization may lead to ore deposits.

24. Sources of Magnetite.—The older aqueo-igneous rocks, such as granite, seem to be the parent rocks of magnetite, although many eruptive rocks contain the mineral in fine particles. Magnetite, termed *black sand*, is nearly always present in placer deposits, and many consider that it is an indication of such deposits when in a mineralized zone. Unlike other iron ores, magnetite is not weathered or decomposed by atmospheric agencies. Magnetite—particularly if it contains sulphur—may be converted into hematite by roasting.

25. Origin of Magnetite Deposits.—Metallic minerals are incorporated in aqueo-igneous rocks as a constituent part of their structure, increasing in quantity here and there as do other minerals not metallic. In some localities the quantities have so increased as to saturate the magma, and this, with selective action, has grouped the metallic minerals into masses, which are termed the *products of first concentration*. If the principle involved in the freezing of salt water were applied to the magnetites of New York and New Jersey, it would account for these deposits, for they show in some instances unmistakable signs of having been plastic magmas that were capable of being molded to conform to bed rock. The gangue that accompanies these deposits is usually feldspar, which also shows selective tendencies; that is, the feldspar and magnetite while in the same bed are not mixed, but occupy separate places, where they are concentrated in masses apart from each other. Unfortunately, apatite seems to have had greater difficulty in separating from the mother liquor until the saturation limit was reached, when it separated and crystallized in between the crystals of magnetite in such a manner that they cannot be separated without crushing and magnetic concentration.

FIG. 2

26. The Dipping Needle.—Indications of magnetite are found in rocks, in beds of streams, and in lake sands. An ordinary horseshoe magnet will usually determine this mineral, although chromite is also magnetic. When magnetite is under cover, the deposits may sometimes be found by the dipping needle shown in Fig. 2. The needle is a steel magnet pivoted at the center so as to move in a vertical plane. When there is no attraction, the needle will be horizontal; but, as soon as the needle comes within a magnetic field, it will be drawn from this position. The upper surface of magnetic rocks invariably attracts the north end of the needle and repels the south end, from which it is inferred that the upper part of the deposit is the south end, or negative side, while the lower side, or the deeper side from the surface, is the north end, or positive side. From this, it is presumed, with a fair degree of certainty, that these deposits are magnetic owing to the earth's induction.

27. Utility of Dipping Needle.—While the dipping needle will show magnetite, it does not follow that the deposit will be commercially valuable. For instance, while a certain prospect shaft was being sunk, the needle, instead of pointing downwards as at the surface, assumed a horizontal position, and, as depth increased, pointed more and more in a vertical direction, thus showing that the deposit had been passed through. From this fact it is inferred that all rocks that attract the needle do not necessarily contain large deposits of magnetite. While thin deposits do not exercise so great an attraction as thick deposits, yet, as attraction or repulsion varies as the square of the distance, the areas immediately surrounding the needle will have greater attraction than a thicker but deeper deposit. The area of the thin deposit, however, is likely to be less than that of a deep-seated and thicker one, and thus give a shifting attraction, while the larger deposit, notwithstanding its depth.

Fig. 3

will furnish a steady attraction. The dipping needle shown in Fig. 2 is known as the *Norwegian*, and has a sort of universal joint. It is not considered so good a needle for magnetite prospecting as one that is allowed to swing in one plane only, as shown in Fig. 3. The south end of the needle is weighted with a rider, to balance the earth's vertical attraction—either wholly or in part. Usually, the rider is so arranged that the north end will dip about 10° from the horizontal.

28. Prospecting With the Dipping Needle.—When prospecting for magnetic-iron ore, the ordinary surveyor's compass and the dipping needle may be employed. Fig. 4 shows the manner in which the ordinary compass needle would behave in passing about a body of magnetic ore situated at *a*. If a prospector were to start at *b*, the compass, instead of pointing due north, would be deflected slightly toward the ore body *a*; and, as he advanced toward the position *c*, the deflection would become greater until it reached the maximum opposite, or nearly opposite, the ore body *a*; and after he passed this point, the attraction would become less. Similarly, in passing from *d* to *e*, the compass needle

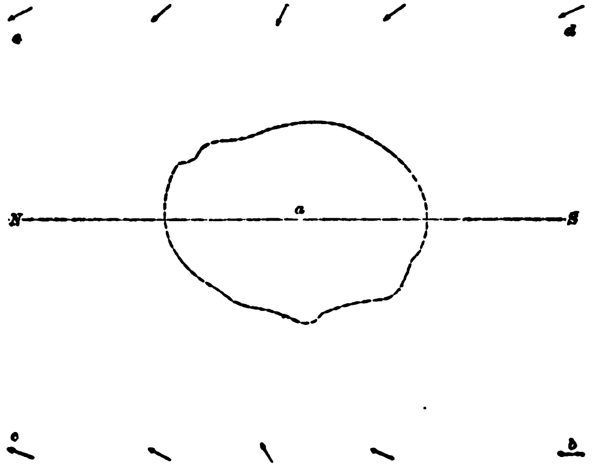

FIG. 4

would be deflected toward the ore body *a*. After having passed over the ground with an ordinary compass needle, and obtained some conception of the position and extent of a deposit, the prospector uses the miner's compass, or dipping needle, to locate the deposit definitely.

Assume that Fig. 5 is a vertical section on the line *NS* of Fig. 4. If the dipping needle were taken from the point *S* toward the point *N*, the dip would vary until the needle pointed directly downwards when over the center of the deposit, and then after passing the center it would be inclined less and less in the opposite direction.

29. Limitations of Dipping Needle.—If the ore dips away from the needle, the degree of attraction will not be so gradual as when the ore is dipping toward the approach of the needle. After the strike of an ore body has been determined, it is usual, in order to determine its width and dip, to survey the ore body at stated distances along the strike, the surveyor moving at right angles to it. If the readings of the needle are recorded, a map of the deposit can then be made, and the proper locality for testing the deposit, either with a shaft or with a diamond drill, can be determined. Some rocks that are prolific in black magnetic or ilmenite sand may afford sufficient attraction to cause the prospector to be misled, unless he understands the nature of the rocks in which magnetite occurs in concentrated masses. Again, magnetic iron ores carrying sulphur, phosphorus, or sand will afford as much attraction as richer ores; and, of course, deposits under thick surface covers will show poor attraction.

FIG. 5

30. Appalachian Magnetite Deposits.—There is a series of magnetic-ore deposits that extend from Lake Champlain to Cranberry, North Carolina. Most of these lenses are evidently magmas formed by selective agency from the aqueo-igneous rocks, granite and gneiss. Extending for 20 miles or more—from Rockland County, New York, to Green Pond, New Jersey—there is a series of magnetite-ore beds carrying sulphur. These beds are in the same rocks and are parallel with the magnetic-ore bodies mentioned; in fact, on the Sterling Iron & Railway Company's property, the Redback mine is between magnetite deposits that are devoid of sulphur.

31. Pennsylvania Deposit.—A deposit of magnetic ore occurs at Cornwall, near Lebanon, Pennsylvania. This deposit carries about the same amount of sulphur as the Redback and Green Pond mines, but rests on a dike of diabase that cuts the Siluro-Cambrian series. The ore, according to E. V. d'Invilliers, dips below the limestone. Since similar deposits are in aqueo-igneous rocks, and are evidently derived from those rocks as magmas, it is probable that these deposits have a similar origin. Much has been written on this subject of the origin of magnetic-iron deposits. Some mineralogists believe that they were formed from limonites that have become metamorphosed into magnetite. As this is something that has not been accomplished artificially, it would appear that the magmatic theory is a more practical solution of the question. The extent of the deposits has not been fully established.

32. Deposits of Virginia and New Jersey.—In Patrick County, Virginia, there is a bed of magnetite that evidently is of sedimentary origin, the particles having been concentrated as are the beach sands off Block Island, near Rhode Island. Sand is mixed with this deposit, which is probably of the Silurian formation, with near-by metamorphosed schists and shales. A similar deposit exists at Rocky Mount, in Franklin County, Virginia. At Franklin Furnace, New Jersey, there is a deposit of franklinite ore that consists mostly of magnetite with some zinc and some manganese. It is in a crystalline limestone that is white and pure, but carries a little graphite. The deposit is evidently a magma, having differently associated minerals from the others. Titaniferous magnetites occur in New York, New Jersey, and North Carolina—most of them as magmas, and located near magnetite magmas that do not contain titanium.

33. Lake Superior Magnetites.—The magnetites of the Lake Superior region are subordinate in quantity to the hematites, and occur in the Archæan formation of the Marquette region. In the Penokee-Gogebic district, magnetite is found in schists that are not productive, and are probably of sedimentary origin, or, at least, are in sedimentary rocks.

34. Western Magnetite Deposits.—In Colorado, numerous magnetite deposits have been found, but they have not, except where the foot-rock is syenite, proved very satisfactory. In California, magnetite is reported from Sierra, Placer, San Bernardino, and San Diego Counties, and always in conjunction with metamorphic rocks or aqueo-igneous syenite. In Iron County, Utah, near the southern end of the Wasatch Range, the largest beds of magnetite in the West are said to exist. The ore forms projecting ridges that are locally called "blow-outs." The ore lies between quartzite and granite, and this arrangement occurs at the Sterling mine, at Sterling Lake, Rockland County, New York.

35. Hematite Deposits.—The mineral **hematite,** Fe_2O_3, is the most widely distributed and important iron ore in the United States. The color of hematite varies from blue to iron-black, but its streak is red. It is sometimes slightly attracted by the magnet, and in its natural location has a disturbing influence on the compass. The varieties of hematite are as follows:

1. **Specular iron** ore is a variety of hematite having a bright metallic luster.
2. **Micaceous iron** ore has a foliated structure.
3. **Red hematite** is a submetallic mineral with a brownish-red color.

4. **Red ocher** is a soft earthy mineral that often contains clay.

5. **Red chalk** is a chalk colored with ferric oxide, and is firmer and more compact than red ocher, besides being of a finer structure.

6. **Clay ironstone,** or *clay iron ore*, is the oxide or carbonate of iron mixed with clay. It is a jaspery silicious clayey ore. The name is also applied to siderite.

7. **Oolitic red ore** is a mineral in which the ore appears as if composed of numberless rounded grains.

8. **Martite** is an iron-black submetallic ferric oxide crystallizing in octahedrons. The ore is considered by some mineralogists to be derived from the oxidation of magnetite.

Hematite, when pure, is composed of 70 per cent. of iron and 30 per cent. of oxygen.

36. Origin of Hematite.—It is fairly well established that hematite is the product of secondary concentration. The original iron was probably contained in aqueo-igneous magmas as magnetite pyrrhotite or pyrite. The Cornwall magnetite in Pennsylvania is roasted to expel sulphur, during which operation the ore is converted into hematite. Magnetite without some impurity is difficult to oxidize; while magnetite containing sulphur or pyrite is readily oxidized by air and water. The limonite ores of Southwest Virginia are probably due to the oxidation of the pyrites from the great outburst and other sources. The Clinton hematites of the eastern part of the United States are considered by some to have originated from the weathering of Clinton limestone; by others they are said to be due to iron being deposited from solutions. The oolitic character of the ore is ascribed to iron replacing organic substances; to concretionary layers of iron about sand; and to the particles of iron after formation being water rounded. The ore is evidently of sedimentary origin, rather than the result of metasomatosis or alteration in place. The hematite of Minnesota is thought by Van Hise to have been precipitated from iron solutions, and then to have been metamorphosed and anhydrated as now found.

37. Appalachian Hematite Deposits.—In the eastern part of the United States, there are beds of hematite in the Oriskany sandstone of the Devonian. This ore is quite high in phosphorus—at least in Pennsylvania, West Virginia, and Virginia. The most important hematite in this section of the country is the *dyestone*, or Clinton ore. Beds of hematite are found in the Clinton limestone of the Silurian from Canada to Alabama; at the latter place it forms the chief iron ore. This ore is high in phosphorus and somewhat low in iron oxide, but is extensively used for pig iron. A hard hematite ore at Iron Mountain, and a hard specular hematite at Pilot Knob, Missouri, are said to occur in porphyry.

38. Geology of Lake Superior Iron District.—The iron-ore deposits so far discovered extend in a belt reaching from Marquette, Michigan, on the east to the Vermilion Range, in Minnesota, on the west. Between these extremes is the Penokee-Gogebic district of Wisconsin. The iron-bearing rocks that contain iron in the Vermilion district are considered to be Archæan, and have been locally called the *Soudan* formation. The iron-bearing rocks of the Penokee-Gogebic district are Upper Huronian, and are called by Van Hise the *Ironwood* formation. The Marquette district is in the Lower Huronian. The rock series containing the ore beds has been termed the Negaunee. There are six ore-bearing districts in the Lake Superior district; namely, the Marquette district, to the northeast; the Menominee district, south of the Marquette; the Crystal Falls district, to the west of the Menominee district, and comprising part of Michigan and part of Wisconsin; the Penokee-Gogebic district, north west from the Crystal Falls district; and the Mesabi district, southwest from the Vermilion district in Minnesota.

39. The Marquette District.—The Negaunee formation, which contains the chief iron-ore beds in the Marquette district, is between the Goodrich quartzite containing detrital ores at its base and the Siamo slate containing interstratified amygdaloid. The maximum thickness of the Negaunee formation is between 800 and 1,500 feet, varying in different locations. It is made up of cherty iron-bearing carbonates, ferruginous slates, ferruginous cherts, jasperlites, magnetite schists; detrital ferruginous rocks, and ore bodies. The ores are chiefly soft red hematites; but there are also some hard specular hematites and subordinate deposits of magnetite and limonite.

40. **The Menominee District.**—The iron ores in the Menominee district are principally gray, finely banded hematites, and, to a subordinate extent, dense flinty black hematites and siliceous black and gray banded hematites. The ores are in what is termed the Vulcan formation of the Upper Huronian. It consists of three members in the descending order here given: The *Curry member* is about 170 feet thick, and rests on the Brier slate, which is about 330 feet thick. Above the Curry is the *Hanbury slate*, the lower portion of which carries siderite and iron oxide. The *Traders member* of the Vulcan formation is below the Brier slate and above the Randville dolomite of the Lower Huronian. It is ore-bearing, and has a thickness of about 130 feet.

41. **The Crystal Falls District.**—The structure of the Crystal Falls district is very complicated, and the iron-bearing members of the Upper and Lower Huronian are probably both present. The only iron formation that has been largely developed is the Groveland, or the upper member of the Michigamme formation of the Upper Huronian. The ores obtained from this district are soft red hematite and brown limonite.

42. **The Penokee-Gogebic District.**—In the Penokee-Gogebic district, the ore deposits are in the Upper Huronian. The Ironwood formation is between the Tyler slate above and the Palms quartz-slate formation below. Most of the ore is somewhat soft; but in places it is hard blue slaty ore. The main belt of this formation averages 850 feet thick, and comprises cherty iron-bearing carbonates, ferruginous slates, ferruginous cherts, and jasperlites.

43. **The Mesabi District.**—The ore in the Mesabi Range of Minnesota is below the Virginia slate and above

the Pokegama quartz-slate formation, in what is termed the Biwabik formation. These three members constitute the Mesabi series, or the Upper Huronian. The discovered workable ore deposits are mainly hematites, west of Mesabi railway station. The cross-section (Fig. 6) shows, according to Professor Winchell, the usual manner in which iron ores occur in the Mesabi Range. In the figure, *a* is glacial drift; *b*, ore; *c*, limestone; *d*, quartzite; and *e*, granite.

FIG. 6

44. The Vermilion District.—In the Vermilion district, the Soudan formation contains the ores. Above the ore are granites, porphyries, and greenstones, supposed to be intrusive; and below is an igneous greenstone. The ores of this district are hard blue and red hematites, partly massive and partly brecciated.

45. Limonite.—The mineral **limonite**, known indiscriminately as *limonite*, *brown hematite*, *brown ore*, *bog-iron ore*, etc., is an iron oxide containing water, silica, alumina, and other impurities. To be of value, it must be low in phosphorus and sulphur, and contain from 45 to 59 per cent. of iron. The pure mineral contains 59.92 per cent. of iron and 14.4 per cent. of water. Limonite-ore deposits are found widely distributed in the eastern United States and in the Rocky Mountain regions. They are all secondary deposits and, in the East, are much mixed with earthy material. In treating the limonite ores of New River, Virginia, it is necessary to wash about 5 tons of material in order to secure 1 ton of limonite that will assay 40 per cent. of iron. These proportions are varied somewhat, according to conditions, but they are probably a fair average. Limonites usually contain phosphorus, but not always in quantities great enough to prevent their use as Bessemer-iron ores. Limonites carry also manganese, and in some cases are a source of ferromanganese. Usually they are high in aluminum and low in silicon.

46. Origin of Limonite.—Limonite originates from iron pyrites through oxidation, leaching, and precipitation. Bog-iron ore is being formed in swamps at the present time, and limonite also, in various sections of the country. In the Three River district of Canada, limonite is being deposited from Laurentian rocks. In Oregon, limonite is being deposited in basalt due to aqueous solutions leaching amygdaloid basalt or diabase that carries pyrite and clayey-looking iron in the amygdaloids. The limonites in the East are associated with limestones, and in the Lake Superior regions with jasperlites and siliceous rocks. The Colorado deposits are important as a source of iron ore. The gossan resulting from the oxidation and leaching of pyrite ores in Virginia has been used for pig-iron manufacture; but the quantity is limited because of the fact that the percentage of sulphur becomes greater as the depth increases. Through the Shenandoah Valley and Southwestern Virginia, limonite is widely distributed—sometimes in workable beds, but more often in nodules of hematite occurring as boulders and geodes over the surface. The same condition exists in Eastern Tennessee, along the Appalachian Mountain range. The ore is being formed, at the present time, in many swamps all over the country.

CARBONATE AND SULPHIDE OF IRON

47. Siderite.—Carbonate of iron, $FeCO_3$, contains, when pure, 62.1 per cent. of iron protoxide and 37.9 per cent. of carbon dioxide. It often contains some manganese, magnesia, or calcium oxide, which replaces some of the iron. Carbonate of iron is known as *spathic iron*, and *chalybite*, and some varieties as *clay ironstone* and *black-band ore*. The last two varieties are argillaceous, and are found in or near the coal measures. The clay ironstone exists as concretionary balls in beds of considerable extent and as regular as the coal measures themselves. The black-band ore contains bituminous and earthy matter, as well as iron carbonate. Clay ironstone is found in some of the regular Carboniferous formations in the eastern part of the United States. The Triassic and Cretaceous coal formations of the Wyoming and Colorado districts are said to have black-band ores. Crystalline siderite is found at the Burden mines near Hudson, New York, between slates and calcareous sandstones of the Silurian known as the Hudson River group. There are other deposits of siderite in shales of the Marcellus stage of the Devonian across the Hudson River from the Burden mines.

48. Occurrence of Siderite.—Siderite occurs in gneiss in fissure veins throughout New York and New England, and also as a gangue rock in some of the fissure veins of the West. The ore is not much used in the United States on account of an abundance of better ores. *Mesitite* is an iron-magnesium carbonate. *Ankerite* is something like mesitite, but contains, in addition, a large percentage of calcium. The decomposition of ankerite in dolomitic limestones is said to be a source of limonite. Professor Van Hise believes that much of the hematite ore in the Lake Superior iron-ore region is derived from limestones by the decomposition of this mineral.

49. Pyrite.—Beds of pyrite, FeS_2, are found in the older formations, such as the Cambrian or the Huronian. The most usual rocks for large masses are Archæan gneisses and Cambrio-Silurian schists and slates. Many of these deposits are in fissures or in dikes. Pyrite sometimes carries copper, and often gold. It is an associate of gold in quartz veins—in fact, when not present it is considered a rather unusual occurrence. *Sulphurets*, as auriferous pyrite is called, may contain copper, silver, nickel, and cobalt.

50. Near Charlemont, Massachusetts, in Pilleys Island, Newfoundland, in Virginia at Mineral City, in North Carolina, and in Colorado, pyrites are mined extensively for the purpose of making sulphuric acid and sulphur. There is a considerable demand for pyrite for making sulphuric acid; and, as pyrite often contains gold, nickel, copper, silver, and arsenic, such deposits should be carefully examined and assayed by the prospector.

In some localities, sulphide ores, such as galena, sphalerite, chalcopyrite, etc., are roasted in order to obtain sulphuric acid for copper-leaching purposes.

51. Nature of Pyrite Deposits.—Some pyrite deposits are lenticular, seemingly favoring magnetites in this respect and suggesting that they are of aqueo-igneous origin. Again, they are found in fissure and impregnation veins, which would indicate that they were deposited from ascending aqueous solutions. Not infrequently, pyrite is found disseminated through rock as one of its constituent parts, which suggests that they were part of the magma (as, for instance, in granite) and were due to metamorphism when in dolomite and metamorphosed rocks. Pyrite is frequently found in coal beds and slates.

PROSPECTING FOR ZINC

ZINC-ORE DEPOSITS

52. Origin of Zinc Deposits.—The Franklin, New Jersey, ore deposit contains willemite and zincite in subordinate quantities to manganese and magnetite. The ore is crystalline, and is evidently the product of an aqueo-igneous magma from which it has separated. In Southwestern Missouri, the zinc is found in masses as sphalerite. The supposition is that it was leached from dolomite containing both lead and zinc, and that the solutions carrying the minerals down through crevices and bedding planes deposited first the galena and below this sphalerite, as the latter is in a lower horizon than the galena. In Virginia, Tennessee, and possibly other localities, the solutions that carried the zinc when passing through limonite deposited calamine and smithsonite, owing to changes that occurred in the solutions. Similar deposits are found in the Saucon Valley, near Friedensville, Pennsylvania, and elsewhere. There is a similarity in all oxidized zinc deposits, namely, that they all rest on limestone.

53. Ores of Zinc.—The ores of zinc are the following:

Sphalerite, ZnS, commonly called *zinc blende*, or *black jack*, contains 67 per cent. of zinc and 33 per cent. of sulphur.

Zincite, or *red zinc ore*, ZnO, contains 80.26 per cent. of zinc. It is distinguished from some zinc minerals by its color, and from others by its cleavage and mineral associates.

Franklinite is a variable mixture, with iron predominating in about the following proportions: iron, 51.8 per cent.; manganese, 7.5 per cent.; and zinc 5.54 per cent.

Willemite is a zinc silicate that contains, when pure, 58.5 per cent. of zinc and 27 per cent. of silica.

Calamine is a hydrous zinc silicate côntaining about 54.2 per cent. of zinc and 25 per cent. of silicon. It has a creamy color.

Smithsonite, or *zinc carbonate*, contains about 52 per cent. of zinc. In color, it ranges from a greenish white to brown. It effervesces with acids, and is thus distinguished from willemite, which gelatinizes in hydrochloric acid, and from calamine, which gelatinizes in sulphuric acid. As it is infusible before the blowpipe, it can be distinguished from lead carbonate, which it resembles.

54. Distribution of Zinc.—Although zinc is widely distributed in rocks, fissures, and beds, there are a few localities where it is found concentrated, so that it may be worked alone at a profit. The original zinc rocks seem to be aqueo-igneous magmas or limestones that have been crystallized. Zinc sulphide is found in magnesian limestones as a constituent part of the stone, although it is subordinate to the other elements composing the stone. It is usually associated with galena. It is also found in vein formations associated with galena, and often in sufficient quantities to make it a nuisance. Geologically, blende belongs to the Lower Silurian limestones, particularly of the Trenton period. It is found, in the Chazy limestone, in Pennsylvania, and in the galena limestone, which is a member of the Trenton series, in Missouri, Iowa, Illinois, and Wisconsin.

55. Franklinite.—At Franklin Furnace, New Jersey, there is a peculiar mixture of magnetite, zinc, and manganese called **franklinite.** This is a crystallized magmatic body of ore that is probably in Huronian rocks, although there is a white graphitic limestone adjacent that some assign to the Cambrian formation. In Virginia, Tennessee, and Kentucky, zinc blende and galena are spangled through magnesian limestone. Where this rock has weathered, secondary oxide formations of zinc have sometimes been concentrated. Deposits of zinc, supposed to be in Silurian limestone, are found in caverns in New Mexico. The zinc deposits of Joplin, Missouri, are found in galena limestone, but are concentrated in cavities. The oxidized zinc deposits of Virginia occur in limonite beds adjacent to limestone and usually resting on limestone. Unless zinc-lead-sulphide deposits are in large crystals, and are more or less separated, it is very difficult to separate them and make them pay. Much time and considerable money have been lost by men that did not understand the zinc-lead difficulties in concentration.

Zinc is volatile, and, when it is associated with limonite and cadmium, and the limonite is made into pig iron, the cadmium will usually deposit in the throat of the offtake, while the zinc will be deposited as oxide in the stoves of the furnace. The deposit of zinc oxide is quite large in some of the Virginia iron furnaces—as much as 100 tons a year in the Ivanhoe furnaces—and is a source of revenue.

PROSPECTING FOR MERCURY (QUICKSILVER)

56. Ores of Mercury.—**Cinnabar,** *HgS*, is the principal ore of mercury, containing 86.2 per cent. **Guadalcazerite,** *HgS*, is similar in appearance and composition to cinnabar, but is different in crystallization.

57. Distribution of Mercury.—Minerals containing mercury occur in veins, irregular masses, and impregnations, confined to no particular age or kind of rock. The principal deposits so far discovered occur in regions of great disturbance and zones of former igneous activity, making them of later formation than the enclosing rocks. Mercury deposits seem to be of the contact order, deposited from solutions containing mercury or by sublimation. The cinnabar deposits of Almaden, Spain, are in Silurian slates and sandstones, which stand nearly vertical. These are, at present, the most important quicksilver deposits in the world. The next most important deposit is at New Almaden, California. This ore is cinnabar, with some native quicksilver, associated with a gangue of quartz, calcite, and dolomite. The deposits are found as stockwork in shattered metamorphic rocks of serpentine and sandstone. Further south, at New Idria, California, the ore is deposited in shattered metamorphic rocks of the Lower Cretaceous, and is accompanied by bitumen. North of San Francisco, cinnabar is found in serpentine rock and altered sandstone. In Southwestern Texas, cinnabar occurs in massive limestone in silicious shale and as a white earthy clay-like rock. The age of the nearest determinable rocks is that of the Lower Cretaceous.

At Idria, in Austria, cinnabar is found in Triassic schists, limestones, and sandstones; the gangue material is spathic iron, and is the chief source of profit, mercury being a by-product. The mercury is obtained from bunches of tetrahedrite carrying both silver and mercury.

In the Vallalta region of Italy, cinnabar is found in Triassic rocks in contact with quartz porphyry. In Peru, it is found in Jurassic rocks.

PROSPECTING FOR NICKEL AND COBALT

58. **Occurrence.**—Nickel and cobalt are mentioned together, because they are usually associated in nature. They occur in *mispickle*, a mineral composed of arsenic and sulphur; with sulphur compounds such as pyrite and pyrrhotite; and as oxidized ores with silicates related to serpentine. Of the various ores, nickeliferous pyrrhotite is the most important—in the United States at least. Pyrrhotite occurs in the older formations, usually in gneiss, serpentine, or metamorphic rocks. The Sudbury nickel mines of Canada are said to be in Huronian granites and gneisses, which grade almost imperceptibly into *norite*, a variety of gabbro in which rhombic pyroxene is important. The ore bodies have rusty gossan outcrops, consisting of limonite in cellular masses. Copper is also mixed with the pyrrhotite. In Douglas County, Oregon, irregular deposits of hydrated silicates of nickel and magnesia are found in serpentine rocks, with limonite, quartz, and chromite as invariable associates, and with clay and other products of alteration.

Olivine seems to be the parent rock from which the nickel silicates of Oregon and North Carolina are derived. Green crusts of oxidized nickel are guide marks for the prospector, and such discolorations are not uncommon in serpentine-rock districts. The outcrops of nickel deposits are usually oxidized, the ore passing in depth to sulphides. In Missouri, near Mine la Motte, nickeliferous pyrite is found in Cambrian sandstone, and in Salina County, Arkansas, millerite is found in black shales with a quartz gangue. In New Caledonia, considerable nickel is found in serpentine rock associated with ferric oxide and manganese oxide. From the analysis given, no cobalt is found in connection with it; otherwise, the formation is the same as in the foregoing cases.

59. **Ores of Nickel.**—Nickel is associated with pyrrhotite, pyrite, and marcasite.

Pentlandite, $(FeNi)S$, is the most important nickel-bearing mineral in the Sudbury, Ontario, district. An analysis gave its composition as follows: nickel, 34.23 per cent.; cobalt, .85 per cent.; iron, 30.25 per cent.; and sulphur, 33.42 per cent. Pentlandite is found in pyrrhotite and other iron sulphides.

Millerite, NiS, contains 64.4 per cent. of nickel, and 35.6 per cent. of sulphur. It is rare, and is found crystallized in hair-like forms or in slender prisms of a brass-yellow color. It is found sometimes in pyrrhotite.

Polydymite, Ni_3FeS_5, is gray, very easily tarnished, and very soft. It quickly decomposes, and loses its metallic luster. It is found in connection with chalcopyrite, and contains 41.96 per cent. of nickel.

Nickelite, $NiAs$, called also *niccolite* and *kupfernickel*, is one of the richest nickel minerals. It has a pale copper-red color and a metallic luster. The silver-cobalt-nickel mines near Lake Temiscamingue, Ontario, are often rich in this mineral.

Gersdorffite, $NiSAs$, is an arsenide containing about 35 per cent. of nickel. It is white to steel gray in color, and is found in the Sudbury mines, Ontario.

60. Relations of Ore to Rock.—Prospectors for nickel recognized a peculiar rock called *norite* as being generally associated with nickel deposits in the Sudbury district. On the surface, pyrrhotite is not found, but in its place is gossan; and every patch of rock showing gossan has been taken up as a claim. Gossan does not in every case mean a deposit of workable size, although a large area of gossan has nearly always been found to indicate an ore body worth developing.

Thomas W. Gibson, in his report* on the Sudbury districts, says that the nickel ores are in basic rocks that pass by insensible gradations into acid granitic rocks. The ore is found in the basic norite, and not in the acid granitic rocks. He considers the Sudbury nickel-bearing rocks eruptive.

61. Origin of the Sudbury Deposits.—Mr. Coleman favors the magmatic segregation theory, for the following

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*Report Vol. XIV, Part III, 1905: The Sudbury Nickel Field.

reasons: (1) The ores are everywhere associated with norite. (2) Norite and ore are mixed in every degree from rock enclosing scattered particles of ore to pyrrhotite-norite, in which ore and rock are in equal amounts. Norite spotted with ore is sometimes found in bands a long distance from the nearest ore body. (3) There are secondary deposits, due to the action of water circulating along fissures and dissolving nickel, which was deposited some distance away from the magma.

62. Cobalt-Nickel Deposits.—The cobalt-nickel-arsenic-silver deposits near Lake Temiscamingue are comparatively recent finds. Although they have been known for some time, it has only been since W. G. Miller made a report, in 1905, to the Ontario Bureau of Mines that anything approximating definite information has been available. The cobalt ores are found in the Lower Huronian rocks, which consist of conglomerate, breccia, quartzites, and graywacke slate. The veins or fissures are nearly vertical, and cut across the slightly inclined rocks. The outcrops of the veins show native silver and cobalt bloom, the latter being of a rich pink color that is apt to be confused with iron oxide. If the bloom, however, is carefully heated, it will turn blue. If fused with borax, it will turn a beautiful blue, but so will aluminum, and this must not be confused with cobalt. The native silver at the outcrop will be tarnished, but its color can readily be determined by cutting; its weight is also another indication. Bismuth when cut with a knife has a silver color, but it soon tarnishes to a reddish color. Argentite is another silver mineral that occurs in this locality, and might be mistaken for lead, as it is readily cut with a knife. Native nickel associated with iron has been found in several localities and in meteorites.

PROSPECTING FOR MANGANESE

63. **Manganese** is found in all geological horizons, the original source, according to Kemp, being ferromagnesian igneous rocks. It is not so widely distributed as some other elements, Vogt placing it as forming from .1 to .01 per cent. of the earth's crust. Most of the deposits in the United States are found above the Potsdam sandstone of the Cambrio-Silurian, but frequently manganese is found—particularly in the West—in conjunction with magnesian limestone. In Virginia, and in Cartersville, Georgia, manganese deposits are found in pockets above the Potsdam sandstone covered with a clay in which hardly a pebble is found. At the Huston mine, near Nace, Botetourt County, Virginia, a pocket of manganese was found below a bed of limonite ore, resting against limestone. All the Virginia manganese is found in pockets in clay, and in thin impure limonite streaks in rocks. There are four classes of ores produced in the United States, as follows: (1) manganese ores for chemical purposes, which are nearly pure minerals; (2) manganiferous iron ores, which are used for making spiegeleisen; (3) manganiferous silver ores, which are used in the West as a flux in lead-silver smelting; (4) manganiferous zinc residuum, resulting from the distillation of zinc found in franklinite, and used in the manufacture of spiegeleisen.

At Batesville, Arkansas, the ore is braunite, and is found in masses of stiff clay, which seems to be due to alterations in the St. Clair limestone of the Lower Silurian. Considerable manganese occurs in some Lake Superior iron ores and in the Santiago de Cuba iron ore. Manganese iron ores are found in the Leadville, Colorado, sub-Carboniferous strata, as well as in the sub-Carboniferous limestones of New Brunswick and Nova Scotia. Manganese is also found in residual clay on the Isthmus of Panama. Spain and Chili seem to be the only countries where there are stratified deposits of manganese. At Franklin Furnace, New Jersey, there is a deposit of franklinite from which manganese is obtained after the zinc has been extracted.

PROSPECTING FOR TIN

64. Distribution of Tin.—Alluvial tin deposits are found in various countries. At present, however, stream tin is worked mostly in the Straits Settlements, where the deposits apparently come from granite rocks overlaid in most places by limestone. They occur in three forms: (1) The first kind of deposits is termed *surface alluvial* deposits and carries payable tin from the grass roots down. These deposits seldom exceed 15 feet in depth. (2) The second kind of deposits is termed *shallow alluvial*, the tin-bearing gravel being from 15 feet to 20 feet deep, and under from 15 feet to 20 feet of overburden. Sometimes there are two layers of wash dirt, from 10 feet to 20 feet thick, with ore-bearing gravel underneath. (3) The third kind of deposits is termed *deep alluvials;* that is, they have from 30 to 50 feet of overburden. Gold is frequently found in these deposits, and, with the tin, is washed out by panning, unless a regular system of mining is followed. The tin of this field is usually the black oxide. Stream tin also exists in the northeastern part of Tasmania, but owing to the scarcity of water in that locality it is not worked. In Australia, on the northern coast of New South Wales, alluvial deposits occur in sand dunes that are from 200 to 300 feet wide and from 10 to 20 feet high, and that run in parallel rows for several miles inland. This wash is characterized by its dark, almost black, color, its high specific gravity, and the fineness of its particles, the material frequently passing through a screen with 3,000 holes to the square inch. The wash has a complicated composition, but its principal constituents are ilmenite, zircons, quartz, cassiterite, garnets, gold, platinum, and the platinoid metals.

65. Cassiterite.—The principal ore of tin is **cassiterite**, or *tin oxide*, which contains when pure about 78.67 per cent. of metallic tin. This mineral occurs in small stringers and veins on the borders of granite knobs and in granite. A favorite rock for the ore is the so-called *greisen*, which is a mixture of quartz and muscovite or lithia mica. Topaz, tourmaline, and fluorite are associated minerals, as are also wolframite and scheelite.

In the Black Hills of Dakota, cassiterite is found disseminated in masses of albite and mica associated with crystals of spodumen in granite rock. The tin found in Mexico is in small veins, the country rock being rhyolite; the veins are not large enough to be productive. The tin lodes of Cornwall, England, are considered by some to have been formed by the alteration of granite, there being no distinct vein walls, as in most other mineral deposits. The tin of Gaston County, North Carolina, and of Alaska is found in greisen rock, the quartz and mica being coarse and jumbled. The appearance of the rock is such that it can be easily recognized.

PROSPECTING FOR PLATINUM

66. Occurrence.—The world's supply of platinum so far has come from alluvial deposits, situated in various parts of the world. The chief source of supply, however, is Russia. The method of prospecting for platinum does not differ from that of gold. The prospector looking for gold should examine any heavy particles of white metal in his pan, to see if they are not platinum, since that metal is as valuable as gold. The metal is easily distinguished from native silver, on account of the fact that it is not attacked by a single acid. Platinum is usually found in scales and rounded granules, but microscopic particles predominate. There are other metals found with platinum that are sometimes termed *platinum metals*. They consist of iridium, osmium, ruthenium, and palladium. Pure grains of iridium are extremely rare, but a metal alloy of iridium and osmium called *iridosmium* is frequently found associated with platinum. In New Zealand, the platinum deposits are found with black magnetic sands that carry gold as well as platinum; these deposits have a bed rock, which is mainly igneous. The Russian deposits seem to have been produced by glacial action, and the platinum is found in connection with peridotites. The gravels in which platinum is found seem to have come from the disintegration of gabbros and of peridotites, although the bed rock is limestone with a corrugated surface, which seems to form a natural riffle for saving platinum and gold. The thickness of the alluvial beds does not average more than 4 feet, and their average value is about 40 cents a cubic yard. Such deposits do not, of course, pay the prospector to work, but at times these placers are exceedingly rich, running in one district in Russia as high as 48 pennyweights per ton of dirt. In recent years, considerable platinum has come from Brazil, and some has been saved when working the placer deposits in the northwestern part of the United States. The domestic production of platinum was obtained at the San Francisco mint from parting and refining gold from certain localities in Trinity, Shasta, and Plumas Counties, California, and from British Columbia. There are also beach mines in Oregon that have yielded platinum in commercial quantities, but usually these bed deposits are too poor to be worked by ordinary miners. In all instances, platinum has been found with gold and magnetic sands, and seems to be more of a by-product from placer mining than a regular business. Platinum sands are also found near New Plymouth in New Zealand, as well as in Oregon, and in British Columbia. So far, all platinum finds have been in basic rock.

67. Ores of Platinum.—Sperrylite, $PtAs_2$, is a platinum arsenide, and was probably the first natural platinum compound to be discovered. It is found in the Vermilion and Victoria mines in the Sudbury, Ontario, nickel district. This mineral is distributed through the gossan outcrop and the solid ore. Platinum in this locality seems to favor the copper rather than the nickel minerals. It is a tin-white metallic-looking mineral in tiny crystals belonging to the isometric system and showing many of the planes found on pyrite. The specific gravity is 10.6. Platinum is found at Grand Encampment, Wyoming, in covellite, a rare copper sulphide. Gold, rhodium, and palladium are also found with sperrylite.

PROSPECTING FOR GEMS

68. Gem Deposits.—Very few gems have been found in what is considered their original formation, the greater number so far discovered being in the secondary formations from older rocks, and in the present gravels or sands of streams and rivers. The prospector looking for placer gold can examine the gravel for precious stones, which will show plainly, on account of their brilliancy if the water in the pan is clear. If, however, a person intends to prospect exclusively for gems, a special outfit is desirable. The particular qualities of precious stones are hardness, beauty of color, and rarity; so that their value is largely a matter of fancy and fashion.

69. Gem Prospector's Outfit.—The following has been recommended as an outfit for a person searching for gems; it is of course subject to change, and may require additions, such as hammers and drills, powder, caps, and fuse.

The tools are: a pick, a shovel, an ax, and two sieves, one having three meshes to the linear inch, and the other twenty or more meshes to the linear inch, the sieves being so arranged that the coarser sieve can be fastened on top of the finer. In addition to these appliances, the prospector needs a tub of sufficient size to enable him to submerge the sieves in water during the washing process; an oilcloth on which to sort the gravel; several stones to determine the hardness; a large hand magnifying glass; a pocket magnifying glass; and a dichroscope, or a tourmaline lens. The rest of the outfit will depend on the distance that the prospector intends to go into the mountains or the wilderness, and on his nearness to a base of supplies.

70. Practical Gem Prospecting.—Having discovered, by means of *shoding*—that is, panning river beds, bars, and alluvial deposits—that precious stones may be expected, the prospector fills a tub with water, fastens the coarse sieve on top of the fine one, and places in it a shovelful of the material to be examined. The sieves are next immersed in water, and the clay and finer material are worked by hand through the upper sieve, on which the coarser material remains. The upper sieve is removed after this operation, the stones examined, and, unless attractive, thrown away; but, if attractive, further examination should be made. The material in the lower sieve is next washed free from clay and fine sand; then, by raising and lowering the sieve in water, the coarser and heavier stones will arrange themselves on the bottom of the sieve with the lighter stones above. The sieve is next removed from the water and allowed to drain, then it is turned over on the oilcloth, so as to bring to the top of the pile the material that was at the bottom. The prospector now examines the stones with his magnifying glass, and those that are attractive he removes for further examination as to their identity, their hardness, and their freedom from flaws. Few of the precious stones are sufficiently heavy to cause them to concentrate into decided deposits, as in the case of gold, tinstone, and some other heavy minerals; nevertheless, they are usually somewhat concentrated. Garnets are frequently found in pockets on the bed rock or in patches, where they have been carried by eddies or other disturbances in the flow of the streams. The presence of garnets is considered a good indication of the possible presence of more valuable gems.

DIAMONDS

71. Classification.—The mineral known as the **diamond** is pure carbon, and is classified under three heads; namely, gems, carbonados, and borts. Only the gems have sufficient brilliancy to be used for ornaments, although the others have lately come into prominence for gem cutting and diamond-drill boring. To determine whether the stone under investigation is a diamond, a chip diamond should be used for the scratch test. One diamond will slightly scratch another, although the person may have to look closely to see the scratch; if, however, a diamond will not scratch another stone, it is safe to assume that the latter is a diamond.

72. Occurrence of Diamonds in the United States. Diamonds have been found on the eastern slope of the Alleghany and the western slope of the Cascade and Sierra Nevada Mountains, in loose gravels that are probably derived from the disintegration of crystalline rocks. Diamonds have also been found on Plum Creek, Pierce County, Wisconsin, in sand that contained, besides, gold, quartz, grains of magnetic iron, titanic iron, almandite, garnet, and monazite.

The rocks of the Blue Ridge and the Alleghanies are Archæan and Cambria-Silurian, as are those of Wisconsin, but the Sierra Nevada rocks were metamorphosed much later. In each instance, the discovery of diamonds resulted from prospecting for gold. There is no doubt that, in the quest for gold, very many valuable diamonds have been destroyed or overlooked by prospectors. The American diamond-bearing localities are for the most part granitic or highly metamorphosed rocks. The Dewey diamond found near Richmond, Virginia, is probably the largest diamond that has ever been found in the United States, but whether it was found in itacolumite, or flexible sandstone, which is popularly stated to be an indication of diamonds, is not known, although this peculiar stone occurs in the Richmond formation. Itacolumite also exists in the North Carolina diamond belt, and is therefore considered an indicator for diamonds.

73. Brazilian Diamonds.—The diamonds of Brazil are gems, carbonados, and borts. The **carbonados,** or black diamonds, have no regular crystallization or cleavage plane, hence their value for diamond-drill work and for polishing other diamonds. They are black outside, but inside are of various shades of gray.

Borts are semitransparent diamonds, similar in appearance to the rough brilliant, but are of different crystallization. They are usually spherical in shape, and are said to be softer than either the gem or the carbonado. The Brazilian diamonds are found mostly in stream deposits, but also in ground that consists of the weathered and decomposed remains of metamorphic rocks. The diamonds are frequently found held fast in a conglomerate or pudding stone cemented by iron oxide.

74. Distribution of Diamonds.—Diamonds in British Guiana are found in a formation consisting of sandy clay that is mixed with rounded and subangular pebbles of ironstone and quartz; with ilmenite, or titanic-iron, sand; or with small pieces of light-colored corundum and topaz. Digging in this section has been carried to 7 feet below the surface; and, from 15 cubic yards, more than 1,000 small-sized stones were extracted, the largest weighing perhaps 2 carats, or 6.336 grains. In another locality, 100 cubic yards yielded more than 1,000 stones. These gravels were removable from the large quartz crystals free from erosion.

Fig. 7

The diamond-bearing rocks of India are all in two deposits south of the Ganges. The pre-Cambrian diamond beds are conglomerates derived from earlier rocks; the other deposits are recent stream deposits derived in part from the conglomerates.

Borneo diamonds are found in schists and granites, and in river gravels derived from them.

The South African diamond fields are in the neighborhood of Kimberly. The rocks of this field are Carboniferous black shales with a peridotite dike or blue ground in which the diamonds are found. The blue ground is quite hard, but is readily weathered, and from it the diamonds are picked out. A section of the Kimberly mine, which is the most prolific mine of all, is shown in Fig. 7. The blue ground *a* is in a huge dike that cuts through dillage *b*, basalt *c*, black shale *d*, porphyritic augite-andesite termed *melaphyre e*, quartzite *f*, and shale *g*.

GARNETS

75. The precious garnet is **almandite,** which is composed of silica, alumina, and iron protoxide. Several minerals are included under this head; the finest of them come from India. The fire-pyrope, composed of silica, magnesia, and alumina is found in the Kimberly diamond mines. Garnets have various colors and names, and are quite different in chemical composition, but crystallize in the isometric system. Some of the **essonites** have a red, hyacinth, or yellow color, a hardness of 7, and a specific gravity of 3.68. **Grossularite** is a pale-green or yellowish variety of essonite, and, like it, is a lime-alumina-silica compound.

Almadine garnets vary in color from violet to deep red. The scarlet and crimson varieties, when cut in a half-oval manner, are called **carbuncles.** They have a hardness of 7.5 and a specific gravity of 3.45. **Ouvarovite** is of a brilliant emerald-green, has a hardness of 8, and a specific gravity of 3.45. **Demantoid** is a green garnet with a very high refractive power by artificial light. Its hardness is about 5, and its specific gravity is 3.85. Garnets are found in various places in the United States; but, except in Virginia and North Carolina, none have been discovered of sufficient brilliancy to make them particularly valuable. Pyrope garnets have lately been found on the Navajo Indian Reservation, in New Mexico, associated with olivine and chrome pyroxene.

CORUNDUM

76. Sapphire, Oriental Ruby, Oriental Emerald, Etc.—The mineral **corundum** is composed of oxide of aluminum, and is found in several colors due to small amounts of metallic oxides. The **sapphire** is blue, the **Oriental emerald** is a green sapphire, the **Oriental ruby** is a red sapphire, the **topaz** is yellow, and the **Oriental amethyst** is purple. All these gems have a hardness of 9. The main source of supply has been Burma, Ceylon, and Siam, where they are found as crystals in limestones or in soil derived from these limestones.

Corundum occurs massive in a number of colors in North Carolina, as also in New South Wales. Emeralds have been found as crystals near massive corundum, in alluvial deposits, and in stream-tin drift. Recently, sapphires were found in the beach gravels of Yogo Creek, Montana, and were traced up 5 miles to the parent rock, which proved to be a trap dike cutting through limestone rocks. The material of the dike varies from a hard igneous rock to a soft yellow clay. These gems are of such good quality and brilliancy that they find a ready market for jewelry.

77. Beryl.—**Aquamarine, emerald,** and **oriental cat's-eyes** are varieties of **beryl**, each crystallizing in the rhombohedral system, almost always in a six-sided prism, and having a hardness of about 8. They differ somewhat in color, due to slight traces of other compounds than their regular composition, which is quite complex, but largely silica, alumina, and beryllium oxide. Their color varies from green, blue, and yellow to pink. They occur in isolated crystals, and in geodes in clay slate, in Brazil, Hindustan, Ceylon, and Siberia.

The emerald variety of beryl is one of the most remarkable of American gem minerals. In North Carolina, beryls are found with quartz, rutile, dolomite, muscovite, garnet, apatite, etc., all in fine crystals. Stones of their description are found in Colorado and Maine. The largest beryls so far found were from Grafton and Acworth, New Hampshire.

Phenacite, another beryl mineral, has been found in Maine, and on Pike's Peak, Colorado, in granite associated with smoky quartz, topaz, and muscovite. The **peridot,** which is the chrysolite, or olivine, of the mineralogist, is found in Colorado, Arizona, and New Mexico.

78. **Opal.**—**Opals** are found in various localities. The opal is a silica-like quartz, with a varying amount of water. Fire-opal from Mexico is valued highly as a gem. Similar gems have been found in isolated districts in the West and also in the South. The color is grayish-white, and the colors have considerable play with reflected light. The agates, carnelian, jasper, onyx, cameos, and silicified wood are in the same family as opal. The opal has a hardness of from 5.5 to 6.5, and a specific gravity of 1.9 to 2.3. It is vitreous, resinous, and pearly at times. It occurs as a filling in cavities, fissures, and seams in igneous rocks, porphyry, and some metallic veins. It is also found embedded in limestone and argillaceous beds, and is formed from the siliceous waters of hot springs.

79. **Turquoise.**—**Turquoise** is supposed to be a hydrous phosphate of aluminum with some iron and copper. It is found in thin seams in Arizona, New Mexico, Mexico, Colorado, and possibly other localities in the western hemisphere. Usually, the rocks in which it is found are igneous. The color is from sky-blue to greenish-gray. Oriental turquoise comes from Persia and Egypt. The Egyptian turquoise turns from blue to green; and possibly all stones of this description will change color according to the person wearing them and the care with which they are handled, as the stone is susceptible to fatty acids. It is possible to mistake this gem for the copper mineral malachite, or chrysocolla, and hence neglect it, thinking that the copper streak was too narrow to promise any great value. Turquoise is found near copper mines in Arizona and New Mexico. In Persia, there is a vein 6 inches wide; but usually the mineral is in irregular patches in brecciated porphyritic trachyte and clay slate.

PROSPECTING WITH MACHINES

THE DIAMOND DRILL

80. Testing Bog or Lake Bottoms.—The method of testing placer deposits might be used to test bog or lake bottoms were it only necessary to go to bed rock; but, since the bed rock must be penetrated, other methods have to be adopted. There are deposits, located as in Fig. 8, where the ore body is below a swamp or lake. The outcrop at *a* indicates that the ore body exists; but the miner must know to what extent, in order to calculate his expenses and returns.

FIG. 8

The nature of the ground is such that a diamond or calyx drill may be used, when the surface is frozen, by driving a stand pipe through the soft material and then drilling as if no soft material was over the deposit. Drilling has been done from the frozen surface of lakes, and valuable discoveries made. If possible, a better plan is to build a scow, in the swamp, large enough to hold the drill rig, and then to drill from this during the warm months. To test such deposits by means of shafts would be expensive under normal conditions; and, when one has such a doubtful proposition, it is always good practice to employ the most economical means for prospecting.

81. Fan Holes.—In some instances, it is possible to sink shafts around the edges of a swamp or lake that shows indications of an ore deposit beneath, and from the bottom of these shafts to drill holes in various directions. Three

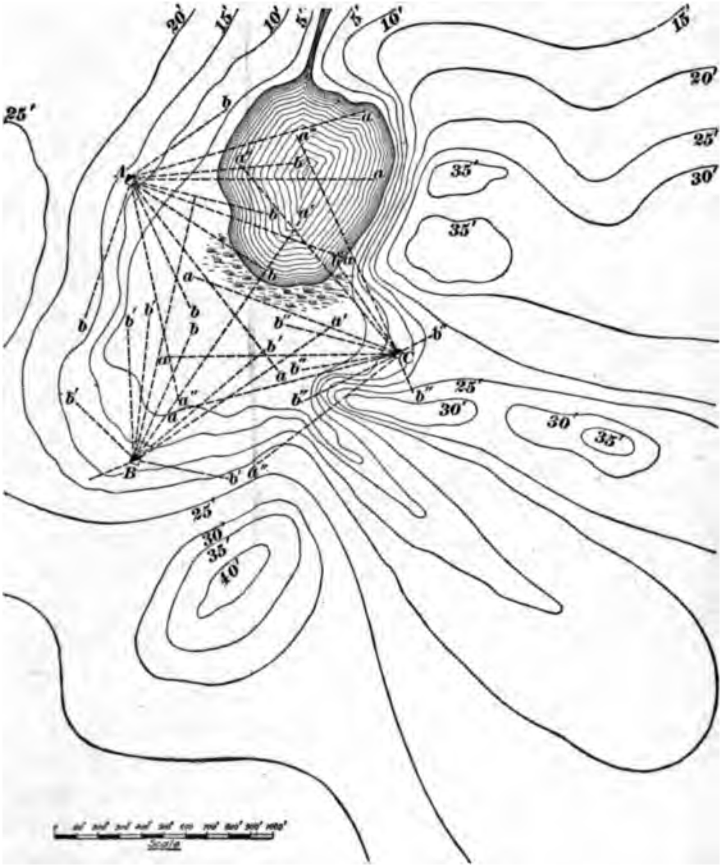

FIG. 9

sets of these **fan holes** are shown in Fig. 9 as radiating from the test shafts *A*, *B*, and *C*, located on low ground near the swamp and pond. The long lines *a*, *a'*, *a''*, etc. represent holes drilled at a comparatively flat inclination; while the shorter lines *b*, *b'*, *b''*, etc. represent holes drilled at greater inclinations. The shafts *A*, *B*, and *C* are sunk at points where the ground is firm, and where the diamond drill can penetrate the strata and cover most effectively the area to be tested. The use of a barge or scow for holding the drill will probably prove as effective and much cheaper than this method of test pits and fan holes.

82. Inclined and Vertical Drill Holes.—When the dip of a rock formation is unknown, the ground to be prospected should be blocked off into approximate rectangles. The holes may be drilled at such inclinations that they will cross one another—thus, possibly, locating small irregular deposits as well as the larger deposits—or the holes may be drilled vertically.

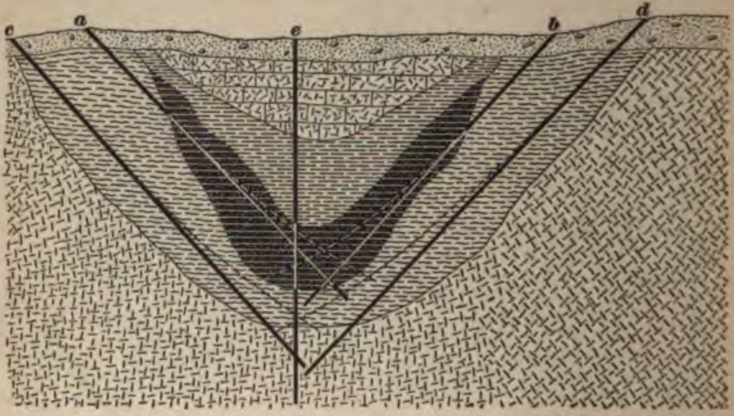

FIG. 10

Fig. 10 shows a body of ore occupying a trough or depression as in the case of Lake Superior iron ores. If the drill holes had been put down in the positions *a*, *b*, a wrong conception of the deposit would be had; and if they had been drilled as at *c*, *d*, no ore would have been encountered. In such cases, it is best to drill a series of holes such as *e* across the deposit each way, and thus obtain a fairly definite idea of its extent and value. Besides the fact that the inclined holes may give one a wrong conception of the deposit, they are liable to drift from the inclination at which they were started, as shown by the dotted lines.

83. Determining the Dip of Inclined Strata.—It is often advisable, when prospecting with a diamond drill, to ascertain the dip of the deposit. Generally, but not always, the rock cores will furnish the dip; and, in case there is no outcrop, it is a matter of importance to ascertain the dip, in order that a shaft may be located through which the deposit may be worked.

A single hole drilled through a formation, as in Fig. 11, will not give the dip unless there is an outcrop; for the core is liable to, and probably will, turn in the core barrel, so that, while the dip shows in the core, it cannot be told in which direction it is. If the next hole should be put down either to the right or left of the one shown, the dip could be determined; for the one to the right would not be so deep, while that to the left would be deeper to strike the deposit. From the various depths obtained, the inclination can be plotted. In the case of vertical deposits such as veins, holes might be drilled to an indefinite depth on either side of the deposit without obtaining valuable information; for which reason, deposits of this description are seldom explored from the surface by the diamond drill.

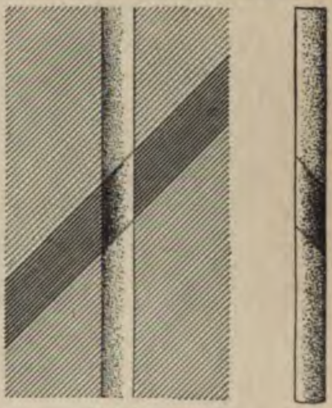
FIG. 11

84. Irregular Deposits.—Fig. 12 shows an irregular deposit and a number of test holes put down in various directions and close together. There is no good reason why holes should be put down in this manner, except it be due to lack of surface facilities for setting up the drill and obtaining the necessary supply of water. The cost of setting up several times is not more than drilling one hole; while a less number of holes than were drilled at *c* would have thoroughly tested the deposit. In the figure, the hole *a b* has passed through a small detached body of ore. The hole *c d* has passed through a thin portion of a large body of ore, but did not strike the smaller body. A vertical hole halfway between *a* and *c* would have answered the purpose fully as well. If a vertical hole had been put down at *e*, and then another hole had been put down halfway between *c* and *e*, the irregularity of the ore bed would have been determined; so that, with five holes, as much information of importance would have been gleaned as with the fourteen holes illustrated.

By the careful and systematic exploration of bedded ore deposits with drills, it is possible to obtain all the data necessary for laying out a mine or attacking a new portion of a deposit. Diamond-drill holes have been put down about 5,000 feet in the Transvaal, and proved that the gold ore worked nearer the surface reached that depth.

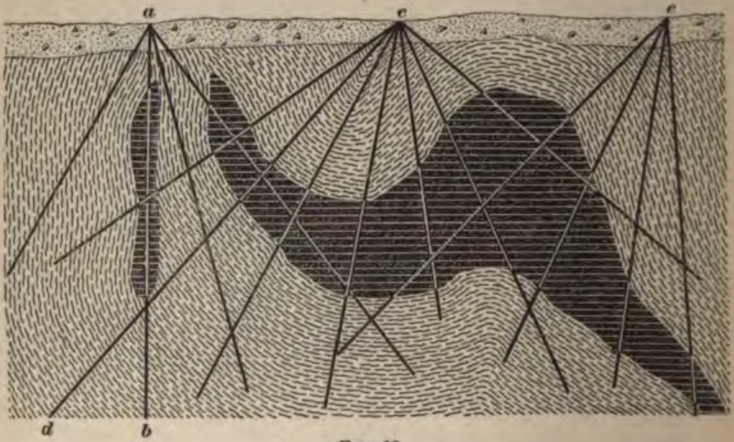

FIG. 12

Much exploration work has been done in the Lake Superior iron-ore districts with the aid of diamond drills. Unless there are geological features at the surface that are indications of ore, such exploration is entirely speculative. Even in known mineral sections, a large percentage of the holes will be barren, as is the case in oil-well drilling. To put down a drill hole in a country where no mineral shows or has been found, with the hope of striking some, is the height of folly and extravagance.

85. Advantages and Disadvantages of Bore-Hole Prospecting.—One advantage of prospecting with diamond drills is that several holes can be drilled for the price that one shaft would cost. Then, if it is desired to attack a deposit by means of a tunnel, a diamond-drill hole in the deposit will prove whether the mineral extends to the depth of the proposed tunnel.

The disadvantages of prospecting with diamond drills are that, in case of veins, if the drill is put down on the vein and the vein changes, there is nothing definite to determine whether the vein has turned to the right or to the left or has petered out. Then, since the hole is small, if it comes within an inch of a deposit, there is nothing to show that a deposit has just been missed. Another disadvantage is that the drill must go in a straight line and cannot follow the sinuosity of a vein along its course—a matter very necessary in vein mining, particularly where values jump from one side to the other. In bedded deposits of copper, lead-silver, and zinc ores, diamond drills are very successfully used below ground for prospecting purposes. In the Joplin zinc districts, it would seem in some instances that they could be used to great advantage from the surface.

86. Analysis of Drill Cores.—When prospecting with diamond drills, all cores should be carefully examined with a magnifying glass; and, if they show metallic minerals, their nature should be determined by blowpipe or wet assay, while their value should be ascertained by quantitative assay.

In testing for lead, zinc, and coal, a large bit is preferable to a small one, because of the abrasion the core undergoes by the bit and core barrel revolving.

If it is desired to make a determination for iron from a core obtained from a hematite-ore deposit, the iron worked from the bit and core barrel must be separated from the crushed mineral by means of a magnet; otherwise, the analysis will prove wrong. Before this method is adopted, the ore should be tested to ascertain whether it is magnetic; for some hematites are partly magnetic and can be attracted by the magnet. If the ore is magnetic, the result would be wrong either way when a magnet was used. There are times when diamond-drill cores of hematites give a lower percentage of phosphorus than the ore when mined. It is presumed, therefore, that the wash water floats away the phosphorus mineral. This is correct, for it has been noticed that porous ores near the surface are often quite free from phosphorus, while deeper down they are prolific in that mineral. As phosphorus is seldom in equal proportions throughout an iron-ore bed, it may be that the drill passed through a good portion of a bed low in that impurity.

87. Value of Drill Cores.—With regard to diamond drilling, all ore bodies may be divided into three classes:

1. Bodies of material may have a uniform composition and a low value per ton and may depend on the existence of large masses for their market value, such as iron ore, salt, gypsum, coal, etc. The diamond drill furnishes an excellent means of prospecting for any of the materials that come under this class.

2. Bodies of material may have a somewhat less uniform composition and a higher value per ton, and usually may be associated with more or less gangue, such as the ores of lead, zinc, copper, etc. The value of the diamond drill in prospecting for such formations varies inversely as the amount of the precious metals contained in the ore. That is, if a deposit is mined for lead, zinc, or copper, the ore must be of a somewhat uniform nature; while, if it is mined mainly for the precious metals, the value may and usually does vary from point to point, and in places the vein may be cut out entirely by horses or barren portions of rock. The liability of the diamond drill passing through abnormally rich or through barren portions of the vein is thus very much increased.

3. Bodies of material may consist of rich veins of sulphurets, etc. In prospecting for this class of material the diamond drill is of very little use, the valuable material being often so soft and friable that it is liable to become ground to a powder and washed away by the drilling water, thus leaving no record of its existence, and such veins are so erratic that the drill is liable to cut them either in barren portions or to follow a rich seam, thus giving indications very much above or below the true value.

From the foregoing, the following general rule may be derived: *The value of the record furnished by the diamond-drill core varies inversely as the value per ton of the deposit sought.* Or, stated in different words, the value of the record furnished by the diamond drill is greater when prospecting for low-grade uniformly distributed ores than when prospecting for high-grade irregularly distributed ores.

The diamond drill has been used with great success in prospecting rich deposits of the precious metals, which occur in well-defined pockets or large masses. If the diamond drill encounters native copper, the metal clogs the space between the diamonds, thus preventing the boring, or it may even block the bit entirely, causing the rods to twist off. The diamond drill has been used very successfully in prospecting for low-grade gold deposits, such as the blanket reefs of South Africa.

PROSPECTORS' ASSAY OUTFITS

FIRE-ASSAY OUTFIT

88. The entire result of a gold-silver assay or any analytic determination is dependent on the accuracy of the weighing, both of the ore charge and, more particularly, of the button or the other product resulting from the assay. No matter how well the rest of the work is done, an error in weighing either the charge or the button will render the result, as a quantitative analysis, worthless, as the amounts to be weighed are so small that a very slight error will multiply itself enormously when the results are reduced to the basis of ounces of metal in a ton of ore. Ores containing less than $3 in gold per ton are, in some instances, profitably worked, and much smaller proportions than this of gold can be recovered by the fire-assay, and the buttons accurately weighed.

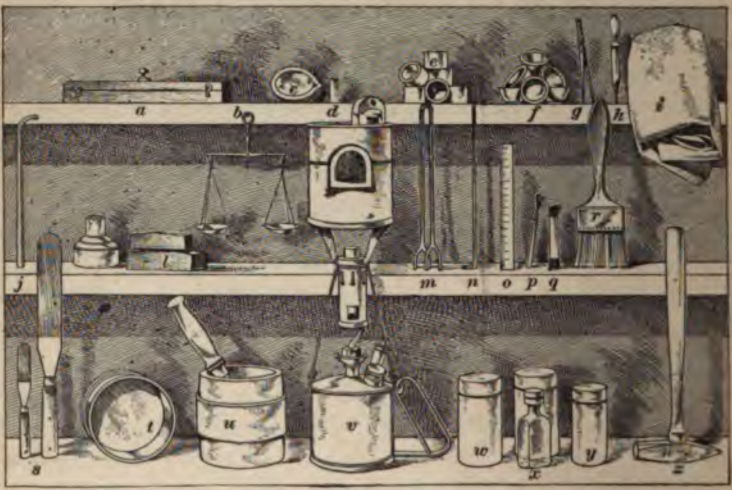

Fig. 18

In Fig. 13 is shown a fire-assay outfit that may be considered typical of the best portable outfits manufactured. At *a* is shown a button balance enclosed in a case having a rider attachment not shown, with which device all the more delicate and higher-priced balances are equipped. The riders are set astride of the beam of the balance, which is graduated like the beam of a steelyard. At the end of the other side of the beam, a small depression serves as a pan for the buttons. The beam is of aluminum, with steel knives and bearings. Forceps are provided for handling the riders. The best types of these portable assay balances are readily sensitive to $\frac{1}{20}$ milligram.

At *b* is shown an ore balance, with which weights are furnished. At *c* is shown a porcelain dish; *d* is a lead and borax measure; *e* and *f* are cupels and scorifiers, which are of special construction, the former being 1½ inches and the latter 1 inch in diameter. A pair of forceps is shown at *g*; *h* is an acid dropper; *i*, an oilcloth; *j*, a blowpipe; *k*, a spirit lamp; *l*, charcoal slabs; *m*, tongs; *n*, a rake; *o*, an ivory scale; *p*, a small camel's-hair brush; *q*, a button brush; *r*, a large flat brush; and *s*, a large and a small spatula. The sieve *t* and the mortar, pestle, and anvil *u* are all of special construction. The mortar is 5 in. × 5 in. in size, and is equipped with an extra-heavy pestle. The bottom of the mortar is smooth, and serves very well as an anvil. The sieve is made of brass, with frame and bottom of the same material, and fits over the end of the mortar.

The furnace, which is shown at *v*, is equipped with two muffles. The heat for the furnace is generated from kerosene of any specific gravity. The advantage of this is apparent, as kerosene can be obtained anywhere. The muffles are each about 4 inches long, 1¾ inches wide, and 1¾ inches high. The door of the muffle has a circular opening at the top, which is closed with a removable plug. The door has also a rectangular opening, with a plug at the bottom. At the top and back of the furnace, there is a diagonal opening leading into the muffle, through which the operations going on in the muffle may be observed without opening the door. The muffle may be removed, and in its

place a crucible support used that can accommodate a 2¾" × 2¼" (5-gram) crucible. At *w*, *x*, *y*, and *z* are shown a test lead box, a nitric-acid bottle, a borax-glass box, and a hammer, respectively. In addition, the outfit includes some lead and silver foil, a pair of scissors, and a magnifying glass.

BLOWPIPING OUTFIT

89. A well-appointed blowpiping outfit omits nothing that is needful and includes nothing that is not absolutely necessary, as the prospector would soon become tired of carrying around articles not needed for finding and determining minerals. Briefly, the prospector, in starting out from camp, should take with him the following tools and appliances: a blowpipe, with one or two candles and some fluxes; a horn spoon for panning; a compass to find his way about, and ascertain in which direction his vein points; a 2-foot folding rule, or a small tape measure; a small bar or horseshoe magnet; a magnifying glass; a small streak plate; and a geologists' hammer. The blowpiping outfit can be packed in a cigar box and the acids carried in screw-top cases. Stannous chloride, when added to a solution of gold, gives a purple color, hence a little of this solution might be included in the outfit. The acids will be found useful in testing rocks as well as minerals. A little ammonia water, ½ dozen test tubes, a diamond mortar and pestle, and an agate mortar and pestle should also be taken along. Sometimes, under exceptional circumstances, some of these articles may be omitted; but it is better to err a little on the side of overcaution than be caught in the field insufficiently equipped. Whatever else is left out, however, the prospector should be sure to take with him the charcoal and fluxes.