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SOME CAUSES OF ORE SHOOTS.

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GENERAL STATEMENT.

The subject of ore shoots is so closely connected with that of the origin of ore deposits, that the one cannot be intelligently discussed without more or less reference to the other; but the intention in the present article is to confine the discussion as much as possible to the causes that lead to the concentration of certain valuable materials in rich spots in ore deposits, and not to discuss the original sources of the materials of the ore. Moreover, the following remarks relate largely to ore shoots in fissures and other more or less deep-seated positions.

In most ore deposits, the ore and the gangue vary in degree of

admixture from places where the deposit is largely ore with a little gangue to places where it is largely gangue with a little ore. It is rare that ore of even approximately uniform character occurs throughout a deposit, and the richer material is generally in bodies of varying size, continuity and shape. When small, these bodies are known as "nests," "bunches" or "pockets," but the larger or richer ones are called "ore shoots," sometimes also "ore courses" or "pay streaks." When conditions have been unusually favorable, we have those large and immensely valuable ore shoots known to the miner as "bonanzas," which have produced the wealth of many of the world's famous mines.

In its most restricted sense, the term ore shoot applies to a part of a deposit richer in certain metalliferous¹ contents than the adjoining parts, the latter being composed of gangue with perhaps more or less disseminated ore. The term, however, is equally applicable to the not unusual occurrence of an isolated body of ore, more or less steeply inclined in a fissure or other position, surrounded simply by country rock, with no other gangue materials adjacent. Such bodies are often known as "chimneys," "pipes" or "necks." Among miners the term ore shoot is also often applied to places where there is a widening of the deposit and the ore is more abundant than elsewhere, though not necessarily of higher grade.

The typical ore shoot is of a more or less columnar shape, dipping vertically or at a steep angle; but most shoots are less regular in form and some are strikingly irregular, protruding and receding on all sides, thinning down in some places to a narrow neck, in others widening into great dimensions and throwing out long arms from the main body. Some ore shoots instead of dipping steeply, lie almost horizontally or meander up and down. These forms are especially characteristic of those shoots resulting from superficial alteration, as described later. Some ore shoots which originally dipped steeply have been tilted by the folding of the enclosing rocks, and now occupy various posi-

¹The term shoot is generally applied to metalliferous deposits, but there is no reason why it should not also be applied to non-metallic deposits.

tions of incline. Some shoots form lenticular masses, following a fissure for many feet along its course, and finally thinning out at either end into leaner ore or gangue. In fact sometimes a whole vein is composed of rich ore, and in such a case it is, in a sense, as much an ore shoot as the forms already described; but the term is usually applied to a more or less circumscribed body of ore, and it is this conception of its circumscribed character, in addition to the greater value of its contents as compared with the enclosing materials, that distinguishes an ore shoot from a whole vein of rich ore.

Ore shoots may crop out at the surface or may be found at a greater or less distance below the surface. In depth they may continue for great distances, or they may terminate at less depths and may or may not be succeeded by other shoots below. Where several parallel veins intersect a certain stratum in a formation which encourages ore deposition, such as a limestone or other stratum to be discussed later, an accumulation of ore in a shoot may occur at the point where each vein intersects this special stratum. Thus the shoots in the different veins will occur along the line of the strike of that stratum. In the same way if several parallel veins cross a certain fissure which promotes ore deposition, as explained further on, the shoots in the different veins will occur along the line of that fissure. This form of symmetry in the occurrence of shoots is known among miners as "ore against ore."

The occurrence of ore shoots is due to the varying chemical and physical conditions in different places at the time of ore deposition. Van Hise¹ classifies them in three groups, those "largely explained (A) by structural features, (B) by the influence of the wall rocks, and (C) by a secondary concentration by descending waters." Irving² classifies ore shoots as "shoots of

¹C. R. Van Hise, "Some Principles Controlling the Deposition of Ores," *Trans. Am. Inst. Mng. Eng.*, Vol. XXX., pp. 27-177.

²J. D. Irving, "The Localization of Values in Ore Bodies and the Occurrence of Shoots in Metalliferous Deposits," *ECONOMIC GEOLOGY*, Vol. III., 1908, pp. 143-154.

variation" and "shoots of occurrence," the former being shoots that vary from the enclosing material only in relative richness in ore, and the latter class being shoots occurring in isolated positions with no other ore of any kind about them. Winchell¹ classifies ore shoots as "paragenetic shoots," or shoots developed mostly at the time of the original formation of the ore deposit enclosing them, and "postgenetic shoots," or shoots developed mostly after the original formation of the enclosing ore deposit.

The great difficulty in classifying ore shoots is that many totally different causes have often combined to produce any one shoot, and the evidence of some of these causes may have been much obscured or even obliterated since that time, so that the determination of just what cause has been uppermost in influence is often impossible. Thus a given shoot may clearly owe its presence, in part at least, to the replaceable character of the wall rock, but if the structural features in the same spot were also favorable to ore deposition, it might be difficult to decide which influence had been the more important. If in addition to this, the shoot had been clearly enriched by later alteration from above, the complication would be still further enhanced. In the present paper, instead of classifying ore shoots, the various influences tending to produce them will be grouped under separate headings.

A most important point, however, must be made clear before going on with this discussion, and this is that the influences to be described as sometimes causing ore shoots, do not always operate in this way. As a matter of fact, most of these influences seem to be practically without effect in far more cases than they have effect, and in some cases they have actually been injurious to the quantity or quality, or both, of the ore. In the cases where they have been favorable to the unusual concentration of ore, however, their effect has often been so very marked that it cannot be doubted.

¹H. V. Winchell, "The Localization of Values in Ore Bodies and the Occurrence of Shoots in Metalliferous Deposits," *ECONOMIC GEOLOGY*, Vol. III., 1908, pp. 425-428.

INFLUENCE OF MAGMATIC SEGREGATION.¹

Many bodies of ore occurring in more or less irregular masses in rocks of igneous origin, are supposed by some geologists to have been formed by segregation during the cooling of the magma in which they are found. Other geologists believe that a tendency to such segregation may have occurred during the cooling, but that the ore-bodies as now found are not altogether due to magmatic segregation, and have been at least assisted in their formation by the later action of vapors and hot waters. The theory of the magmatic origin of certain classes of ore deposits has been gaining much strength in recent years and in many cases is now very generally admitted.

Professor Vogt,² of Kristiania, Norway, has for years advocated the magmatic origin of various basic segregations, including many deposits of titaniferous magnetite and other ores, in Norway, Sweden and elsewhere. Among other deposits now generally supposed to have had a similar origin, may be mentioned the titaniferous iron ores of Cumberland in Rhode Island, those in the gabbro of the Adirondacks and of Minnesota, the native iron in the basalt of Greenland, perhaps some of the copper and nickel deposits of Sudbury in Canada and the nickel deposits of Lancaster Gap in Pennsylvania, as well as many other similar occurrences.

Deposits of this kind are very different from deposits of more clearly aqueous origin. The ore is generally in more or less irregular pockets, bunches or larger bodies enclosed on all sides by country rock, not dependent on the presence of a fissure, a contact, an easily replaceable rock or any of the other usual positions favorable for ore deposition. In such respects they represent a distinct class of ore shoots. Some geologists even

¹The class of shoots represented by magmatic segregation is small compared with the deposits formed by the various processes of aqueous concentration to be described later, but they are mentioned first because, in some cases, they may have been one of the sources of supply of metalliferous materials in later aqueous concentrations.

²J. H. L. Vogt, "Zeitschrift für praktische Geologie," numerous papers from 1893 to present time.

believe that certain gold-bearing quartz deposits occurring in fissures, were formed from the siliceous residue of magmas out of which most of the basic materials had previously crystallized.¹

INFLUENCE OF LOCAL EMANATIONS OF ORE-BEARING SOLUTIONS.

One of the most common modes of occurrence of ore is in fissures, yet the existence of a fissure by no means indicates the presence of ore. Most all regions, especially those that have been subjected to orogenic movements, are more or less fissured, and sometimes intensely so; but the fissures that have become the receptacles for any important quantities of ore are the rare exceptions and not the rule. The other fissures may be filled with calcite, quartz, silicates, fluorite, barite and other common gangue minerals, or they may be empty or partly filled with clay selvage and other products derived from the rubbing and the decay of their walls, or they may be lined along the walls with films of siliceous, calcareous, ferruginous or other incrustations.

When the barren fissures are younger than the ore-bearing fissures, the absence of ore may be because they were not formed until ore deposition had ceased; but in many cases the barren fissures are as old or older than the ore-bearing fissures, and moreover fissures frequently carry ore in some parts and are barren in other parts. It seems probable that the presence or absence of ore is often determined by the presence or absence of conditions suitable for its precipitation from ore-bearing solutions, but undoubtedly it is sometimes due to the ore-bearing solutions following only certain channels and not others. They probably often rose as fumaroles or thermal springs, spreading along some fissures and not others, and even in the same fissure often rising along narrow chimney-shaped channels, while elsewhere other waters circulated.

In many regions of both cold and thermal springs at the present time, a characteristic feature is the occurrence, in close

¹J. E. Spurr, "Ore Deposits of the Silver Peak Quadrangle, Nevada," U. S. Geol. Survey, Professional Paper, No. 55. Also, "A Theory of Ore Deposition," *ECONOMIC GEOLOGY*, Vol. II., pp. 781-795.

proximity to each other, of waters heavily charged with one kind of mineral matter and waters heavily charged with another kind, as well as waters carrying very little mineral matter of any kind. Such a condition is especially characteristic of regions of subsiding igneous activity, and in it we see a reason why the vents of some extinct springs should be filled with mineral matter of varying kinds and others should carry little or none.

FIG. 5. Stereogram showing ore shoot at Anna Lee Mine, Cripple Creek, Colorado, after R. A. F. Penrose, Jr., 16th Ann. Rept. U. S. Geol. Survey, 1894-5, pt. II.

Where the mineral matter in the spring was ore-making material, an ore shoot might be formed; where it was gangue-making material, a deposit of gangue minerals might result, and between these extremes all degrees of admixture might occur. These various conditions offer a possible reason for the occurrence of ore in shoots along certain narrow limits, such as are represented by the channels of thermal springs.

A typical case of a shoot filling a purely local channel is seen in the long columnar ore body at the Anna Lee mine in Cripple Creek, which varied from 12 to 15 feet in diameter and was followed down almost vertically for some hundreds of feet (see Fig. 5). At Kalgoorlie in West Australia, several mines, including the Brown Hill, Oroya Brown Hill, Oroya North Block and Iron Duke, are located on a large chimney of gold ore which may have been formed in a somewhat similar manner. This shoot, when seen by the writer in 1904, was from 30 to 50 feet in width and had been followed on the incline for some 3,000 feet, corresponding to a vertical distance of about 1,000 feet. This deposit differs from the other gold deposits in the Kalgoorlie district, most of which partake more of the nature of veins in fissures. Again the Silver King mine in southern Arizona, is located on a chimney shaped body of quartz with seams of ore radiating off from it into the country rock.

In some places small volcanic necks or vents have been filled with igneous materials which have later been impregnated with ore, forming chimney-shaped ore shoots. A notable case of this is the old Bassick mine¹ (see Fig. 6) near Rosita, Colorado, which is a volcanic vent filled with fragments of andesite, granite, gneiss, etc., all more or less cemented and encrusted with sulphides. The ore was probably deposited from hot solutions which followed the subsidence of the igneous activity that produced the vent. The Etta tin mine in the Black Hills of South Dakota belongs to a somewhat similar class. It is an intrusive granitic neck which has been later impregnated with cassiterite and other minerals, probably by fumarole action. The diamonds of South Africa occur in somewhat similarly shaped necks, locally called "pipes," filled with a brecciated mass of igneous material.² The Cripple Creek district of Colorado is on a volcanic vent

¹ S. F. Emmons, "The Mines of Custer County, Colorado," 17th Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 405-472. Also, Whitman Cross, "Geology of Silver Cliff and the Rosita Hills," 17th Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 263-403.

² R. A. F. Penrose, Jr., "The Premier Diamond Mine, Transvaal, South Africa," *ECONOMIC GEOLOGY*, Vol. II., pp. 275-284.

FIG. 6. Section showing ore shoot at the Bassick mine, Colorado, after S. F. Emmons, 17th Ann. Rept. U. S. Geol. Survey.
a-a = ore shoot intersecting igneous materials. *b-b* = subordinate ore shoot.

filled with breccia, which in turn is honeycombed with gold-bearing veins; but in this case the vent is so large that the chimney character is not so noticeable as in narrower necks.

INFLUENCE OF GASEOUS EMANATIONS.

The presence of large quantities of gases in coal mines is a generally recognized matter, but the occurrence of gases in metalliferous mines has been much less studied, probably because the gases are in smaller quantities and are less apt to be dangerous; yet in some metalliferous mines they often cause much inconvenience and sometimes danger. They are found issuing from different vents in underground workings, often with considerable force, and consist most commonly of carbonic acid and hydrogen sulphide, but not infrequently of sulphur dioxide, methane (marsh gas), nitrogen and sometimes other gases.

Where these gaseous emanations occur in mines in igneous rocks, they are probably often the remnant of the fumarole or hot spring action that produced the ore deposit, just as the fumaroles were the remnant of the subsiding igneous activity that produced the rocks of the region. Gases are, therefore, less apt to occur in ore deposits where long intervals have elapsed since their formation than in deposits of younger age. In the older deposits, carbonic acid gas is the most common one found, while in younger deposits various other gases also may occur. Gases may also occur in some ore deposits from chemical decomposition of certain minerals, unassisted by any igneous influences.

Certain gases may have a precipitating effect on an ore-bearing solution, and where a jet of such a gas occurs in the path of a solution, a shoot may be formed, while beyond the limit of the effect of the gas, deposition might cease. Gaseous emanations, when evolved with sufficient strength, may also have considerable influence during the formation of an ore deposit in forcing the ore-bearing solutions along certain courses and not along others, so that the solutions pass upward within only certain narrow limits. By such action they may often have much to do with the position of fumaroles and springs, and hence with the formation of shoots.

Emanations of carbonic acid gas are notably abundant in some of the mines of Cripple Creek in Colorado, of the Thames or Hauraki district of the north island of New Zealand and many other regions. In the mines of Sulphur Bank in California, in addition to carbonic acid gas, there are hydrogen sulphide, marsh gas, nitrogen, etc., while at Steamboat Springs in Nevada the gases are mostly carbonic acid and hydrogen sulphide.

INFLUENCE OF THE STRUCTURE OF FISSURES.

As explained on page 114 a fissure may differ much in character as it passes from one rock to another, yet even in the same rock its character may vary from spot to spot, both on account of the nature of the movement that produced it and on account of the structural condition of the rock. A fissure passing through a horizontal or regularly dipping rock may have a very different, and generally much more uniform character than in the same rock much disturbed and folded. A fissure, therefore, whether intersecting different rocks or the same rock, may in one place be a clean cut break, in another a zone of brecciation, or a series of parallel fissures, or a series of more or less shattered areas connected by comparatively regular breaks, or may assume various other more or less complicated forms. When there has been a fault movement of greater or less extent along a fissure, different parts of the rock may be brought into juxtaposition, leaving cavities separated by places where the walls are close together.

In these various ways numerous cavities may be formed, which may influence the position of ore shoots, not only because they offer the physical space for deposition, but because they afford a better chance for admixture with other solutions which may cause precipitation,¹ and also because they produce a slackening of speed in the ore-bearing solutions that enter them, and may thus cause a deposition of ore which might not occur where the solu-

¹ On the other hand, open spaces may be unfavorable places for deposition when they happen to be the channels for waters which have no precipitating action on the ore-bearing solution, and which simply dilute the latter and thus tend to impede or prevent deposition.

tions were rapidly moving. In brecciated areas, ore shoots are apt to occur not only because of the open spaces, but also because there is better opportunity for replacement than in the solid sides of the fissure.

Obstructions, as well as openings, in a fissure may in some cases have an influence on the position of ore shoots. Obstructions may occur where the walls are locally pressed tightly together, or where the fissure makes a curve or is faulted, or where the decay and rubbing of the walls produce clay selvage, or gouge, which collects and forms obstacles, leaving other parts of the fissure open. Obstructions may also be found in a fissure in cases where the gangue comes from a different source than the ore, perhaps from the adjacent rocks, and partly fills the fissure before ore is deposited in the remaining space. Obstructions may also occur where the fissure passes from a rock in which it has caused a pronounced break to a more plastic rock in which it has had very little effect, or even has disappeared, as described on page 114.

Any of these obstructions may influence the formation of ore shoots by locally checking the speed of the ore-bearing solutions that come in contact with them, thus encouraging deposition, or by forcing them into other parts of the fissure not obstructed and thus confining deposition to circumscribed positions, or by forcing them into the wall rock, forming local accumulations of ore either by replacement or by filling interstices and cracks.

A notable case of the different aspects of a fissure in different parts, is seen in the great faults on which the Ontario silver mine and other mines at Park City, Utah, are located. The principal fissure in the Ontario mine intersects chiefly limestones and quartzites, with some shale, in the vicinity of an igneous contact. The fissure is sometimes a clean cut break, sometimes it forks and comes together farther on, enclosing great "horses" of rock, and sometimes it is represented by a zone of intense brecciation. In some places the walls come close together and but little ore intervenes, in others they widen out and larger bodies of ore occur; while very characteristic features are zones of brecciation varying from a few feet to many feet in width, and

impregnated with ore. In some places the ore cements this zone into a solid mass, in others it occurs in thin seams meandering through it and separated by areas of loose breccia, forming an open porous vein filling. The fragments of the breccia are mostly limestone and quartzite and both materials have been more or less replaced by ore, as have also the walls of the fissure and the "horses" of rock. In places the ore runs out from the main vein for some distance along lines of bedding in the country rock, forming collateral shoots, and gradually tapering out.

The Comstock lode at Virginia City in Nevada is another case where the varying character of a great fault fissure affects the quantity of ore from place to place; and in fact many of the important mines of the world illustrate similar phenomena. On the other hand, the Butte City copper mines and some of the silver-lead mines of the Cœur d'Alene district of Idaho represent conditions in fissures in which there has been but little displacement and where the ore shoots are mostly replacements of wall rock.

In some places the folds in rocks offer structural conditions that influence the position of ore shoots, even where there is no well defined fissure. Thus at Bendigo in Australia, the gold ore has accumulated in the crests of anticlinal folds, in sandstone strata immediately underlying slate, in bodies known to the miners as "saddle reefs."¹ The sandstone, perhaps more or less shattered by the folding, has offered a pervious channel, and the overlying less pervious slate has confined the ascending solutions to it. Under favorable conditions, ore may also accumulate in a similar manner in synclinal troughs. The latter, however, are better adapted for the accumulation of ore from descending solutions, and some of the iron deposits of the Lake Superior region are accumulations in such positions, due to downward moving solutions meeting an impervious base,² instead of upward moving solutions meeting an impervious roof, as at Bendigo.

¹ T. A. Rickard, "The Origin of the Gold-Bearing Quartz of the Bendigo Reefs," *Am. Inst. Mng. Eng.*, Vol. XXII., pp. 289-321.

² C. R. Van Hise, "The Iron Ore Deposits of the Lake Superior Region," 21st Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 305-434.

INFLUENCE OF INTERSECTING FISSURES.

There is a popular impression among miners that ore shoots are especially likely to occur where one vein intersects another, and sometimes this is true; but as with most conditions under which ore shoots may be formed, the actual occurrence of the shoot is the exception and not the rule. Nevertheless important ore shoots sometimes do occur at vein intersections; and moreover they also sometimes occur where a vein of ore is cut by a vein of gangue material or by a barren fissure containing no mineral matter other than rock débris. It is noticeable that this enrichment is not confined to places where strong well-defined fissures cut the ore-bearing fissures, but that it occurs also where smaller cracks or even joint planes intersect them.

The occurrence of a shoot at the intersections of two ore-bearing veins may be due to the fact that the rock was more shattered than usual at such positions¹ and permitted a more ready and copious supply of ore-bearing solutions than elsewhere, or it may be due to the fact that where solutions in two fissures meet, their speed is slackened and a deposition of ore may occur which would not have taken place from more rapidly moving solutions. In the same way, if one fissure is faulted by another, deposition of ore may occur as the result of the checking of the progress of the solutions at the fault.

When a shoot occurs at the intersection of a fissure that carries ore and one that is barren or carries only gangue minerals, the latter may have acted as a channel for certain solutions different from the solutions in the main fissure, and of such a character as to cause a precipitation of mineral matter from the solutions in the main fissure, which might not otherwise have occurred. In other cases the influence of the cross fissure may have been purely mechanical, deflecting the metalliferous solutions and confining or guiding them to advantageous positions of deposition. Sometimes cross fissures, instead of supplying solutions, may act

¹ This action is most apt to occur where the fissures meet at low angles, thus forming wedge-shaped bodies of rock which are more easily shattered on their edges, than the blocks formed by fissures coming together at high angles.

as channels through which the ore-bearing solutions in the main channel are carried off into the country rock, depositing "stringers" of ore which gradually taper out at a short distance. Where a number of cross fissures intersect the ore-bearing fissure and also each other, they form blocks of country rock in the walls, which may be replaced by ore in much the same way as the "horses" of rock described on page 108.

FIG. 7. Section showing the occurrence of ore shoot at the intersection of veins at the Moanataeri mine, New Zealand, after T. A. Rickard, *Trans Amer. Inst. Mng.*, Vol. XXXI. A-B = vein. C-D = vein.

An effect similar to that caused by a cross fissure is sometimes produced where the main ore-bearing fissure crosses an especially well marked line of stratification in sedimentary rocks, this line having often the same influence as a cross fissure.

The favorable influence of intersecting veins and fissures on ore shoots is seen in many well known mining districts, such as Aspen and Cripple Creek in Colorado, the gold regions of California, the Mississippi Valley lead and zinc regions, Freiberg in Germany, the Hauraki district of New Zealand and many other places. Even in such regions, however, the intersections do not always have this effect, and it is the exception and not the rule to find it. Much more often they have no effect, and sometimes they have a bad effect, perhaps due to the fact that they may allow the leaching of some of the normal ore contents of the

FIG. 4. Longitudinal section showing ore shoot at the intersection of fissures in the C. O. D. mine, Cripple Creek, Colorado, after R. A. F. Penrose, Jr., 16th Ann. Rept. U. S. Geol. Survey, pt. II. *a* = surface débris; *b* = ore shoot; *c, c, c* = cross fissures.

vein. When, however, the influence has been favorable, the result is often so very striking that this cause of ore shoots must be considered one of the most important of all causes¹ (see Figs. 7, 8 and 9).

Frequently cross fissures intersect a vein after it has been

¹ Where several parallel veins are intersected by a cross fissure that has promoted deposition of ore, the shoots in each vein occupy a position in line with the cross fissure, producing the effect known among miners as "ore against ore" (see page 99).

formed, and may cause an enrichment of the original deposit by the influx of fresh ore-bearing solutions, just as in the case of veins fissured longitudinally by later breaks (see page 129).

FIG. 9. Longitudinal section showing occurrence of ore shoots in the Ida May mine, Cripple Creek, Colorado, after R. A. F. Penrose, Jr., 16th Ann. Rept. U. S. Geol. Survey, 1894-5, pt. II. *a, a* = ore shoots; *b* = surface debris. Scale: 1 inch = 100 feet.

INFLUENCE OF THE WALL ROCK OF FISSURES.

In many regions of fissure veins, the wall rock has a marked effect on the quantity of ore present, and sometimes on the nature of the ore, thus greatly influencing the distribution of ore shoots. A fissure intersecting different rocks may carry an abundance of ore in one rock and little or none in another, or may carry a certain ore in one rock and a different ore in another. These occurrences were once used by the strict lateral secretionists as arguments that the ore had been derived from the rocks immediately adjacent, and in some few cases, perhaps, this argument may have force, but in most cases the effect is probably due to the action of the wall rock, or the waters draining from it, on the ore-bearing solutions. The quantity of ore is the feature

most generally influenced under these conditions, but some notable cases occur where different metals are found in different parts of a fissure, the change being coincident with a change in wall rock.

INFLUENCE OF THE PHYSICAL CHARACTER OF THE WALL ROCK OF FISSURES.

A given rock may be more open and porous than those associated with it, and if cut by a fissure, it may offer a better opportunity for the infiltration of ore-bearing solutions than the others, thus encouraging the formation of shoots. Moreover, a fissure intersecting different rocks often has a very different character in one than in another. In one rock it may be a single, sharp, clean-cut break, in another it may fade out and disappear, in another it may be shattered and brecciated, and in still another, it may separate into a number of more or less parallel fissures, forming a zone of fissuring; or many other forms may be developed, depending on the varying physical character of the different rocks.

The more irregular and broken fissures offer better channels for percolating solutions than the clean cut fissures with the two sides pressing close together, and, therefore, the rocks that produce the former conditions are frequently more apt to contain ore than the latter. On the other hand, if a fissure breaks up into a number of small fissures and the rock is not subject to replacement, the ore may sometimes be too much scattered to be of value.

Excellent examples of the change in the physical character of fissures as they pass from one rock to another are seen in Cripple Creek, Colorado, where fissures are often well marked in certain rocks, while when they pass into more plastic materials they become much smaller or even disappear.¹ Somewhat similar cases are described by Irving and Emmons² in the Black Hills

¹ R. A. F. Penrose, Jr., "Mining Geology of the Cripple Creek District, Colorado," 16th Ann. Rept. U. S. Geol. Survey, Pt. II., p. 144.

² J. D. Irving and S. F. Emmons, "Economic Resources of the Northern Black Hills," U. S. Geol. Survey, Professional Paper, No. 26, pt. 2.

of South Dakota, by Rickard¹ at Rico in Colorado, by Purington at Telluride in Colorado,² by Spurr in the Mercur district of Utah,³ by Beck⁴ near Freiberg, Germany, by De La Bêche⁵ in Cornwall in England, by Von Cotta⁶ at Przibram in Bohemia.

INFLUENCE OF THE CHEMICAL CHARACTER OF THE WALL ROCK OF FISSURES.

The chemical character of the wall rock of a fissure often has far more influence on the deposition of ore than the purely physical character, and frequently determines the existence or non-existence of ore in a fissure, thus influencing in a marked manner the distribution of ore shoots. The rock in which a certain ore is abundant may have caused precipitation by a direct chemical effect on certain constituents of the ore-bearing solutions; or waters draining from this special rock and impregnated with the substance of it, or with other materials, may have had a similar effect. The rock may also have been susceptible to replacement by certain materials in the ore-bearing solutions, thus encouraging the concentration of ore by giving space for its accumulation. This replacement may have gone on by the removal of certain ingredients of the rock by the ore-bearing solutions and the substitution of certain other ingredients from the same solutions, practically simultaneously, and in this case the process represents that form of metamorphism known as metasomatism. In many cases, however, the replacement has gone on by the removal of certain ingredients of the rocks by one solution and the later substitution of other ingredients by the same or another solution. In this latter process, the change may

¹ T. A. Rickard, "The Enterprise Mine, Rico, Colorado," *Trans. Am. Inst. Mng. Eng.*, Vol. XXVI., pp. 976-977.

² C. W. Purington, "Ore-Horizons in the veins of the San Juan Mountains, Colorado," *ECONOMIC GEOLOGY*, Vol. I., pp. 129-133.

³ J. E. Spurr, "Economic Geology of the Mercur Mining District, Utah," 16th Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 452-454.

⁴ R. Beck, "The Nature of Ore Deposits," Weed's translation, Vol. I., pp. 119-120.

⁵ H. T. De La Beche, "The Geological Observer" (Philadelphia, 1851), pp. 640-641.

⁶ B. Von Cotta, "A Treatise on Ore Deposits," Prime's translation, p. 48.

progress particle by particle, in a very minute manner, or cavities of larger size may be formed, and even great chambers may result from the dissolving solutions, and may later become the receptacles for ore.¹

Limestone.—Many rocks have an influence on ore deposition, but some have much greater influence than others, and of all rock, limestone, including dolomite, has the most generally marked effect. Its influence is due both to the metasomatic replacement of calcium carbonate by materials from the ore-bearing solutions, and to the leaching out of cavities in the limestone and substitution of other materials in the spaces thus formed. Its influence may perhaps sometimes be further increased when, under the action of certain solutions, the calcium carbonate is decomposed chemically, setting free carbonic acid, which may add greatly to the power of the solutions to dissolve limestone, thus increasing the number and size of the cavities available as receptacles of ore.

In a fissure crossing a series of interbedded limestones, sandstones, slates, etc., or limestones cut by igneous rocks, the preference of ore for the limestone rather than for the other rocks is often very marked, and large ore shoots often occur where a fissure passes through this rock, while where it passes through other rocks the ore body is often much contracted. If a number of limestone strata separated by other strata occur, we may find a series of alternating wide places and narrow places in the deposit. The ore shoots in the limestone are often especially large at the contact of that rock with a less easily affected rock, a fact due probably to the slackening of speed and to the enforced accumulation of ore-bearing solutions at such places (see Fig. 10).

Examples of the influence of limestone on ore deposition are seen at many places in the world, especially in silver, lead, copper and iron, and sometimes gold and other deposits. Among such

¹Where several parallel veins cross a formation that encourages ore deposition, the bodies of ore in each vein occupy a position in line with that formation, producing the effect known among miners as "ore against ore" (see page 99).

instances are Leadville and the San Juan region in Colorado; Bisbee, Clifton, Globe, and Tombstone in Arizona; Silver City and Lake Valley in New Mexico; Park City and Eureka in Utah; Eureka in Nevada; Sierra Mojada in Mexico; various districts in British Columbia, and many other parts of North America. Similar occurrences are seen at Cumberland and Derbyshire in England, and many places in Chile and other parts of the world. Among the more common metals, many iron deposits are due to a replacement of limestone, as seen in some of the lower Paleozoic deposits in the Appalachian Mountains, at the Calumet and

FIG. 10. Sketch section showing occurrence of ore shoots in limestone at contact of overlying shale at the Bremen mine near Silver City, New Mexico, by R. A. F. Penrose, Jr. *a, a* = limestone; *b, b* = shale; *c, c, c* = ore.

the Orient mines in Colorado, and the Bilbao mines in Spain, at some of the mines of the Island of Elba and many other places.

When limestone strata have been turned on end, and fissuring follows the strike, the formation may become so open and porous that large and extensive cavities are formed by the downward percolation of surface waters or the upward percolation of deep seated waters, thus affording ready receptacles for ore shoots. A remarkable instance of such leaching is seen at Eureka, in the Tintic district of Utah, where a steeply dipping limestone is

impregnated along its strike for a width of sometimes over 500 feet with mineral matter (see Fig. 11). Many noted mines such as the Eureka Hill, Bullion Beck, Gemini, Centennial, etc., are located on this zone of mineralization. In one place on it, in 1894, the writer saw in the underground workings an open natural chamber, formed by leaching, between 200 and 300 feet in length, ten to fifteen feet in width and over 100 feet in depth. This was formed after the deposition of ore, but similar chambers

FIG. 11. Sketch section showing a typical occurrence of ore at Eureka, Utah, by R. A. F. Penrose, Jr. Dotted parts indicate ore; the enclosing rock is limestone; on the left is an igneous mass. Scale: 1 inch = 50 feet.

may have been formed before ore deposition and later may have acted as receptacles for ore, in addition to the ore deposited by metasomatic replacement.

Though limestone has, more than any other rock, been instrumental in the formation of ore shoots in various parts of the world, yet like most influences affecting shoots, its action is not universal, and there are many districts in which such rocks appear to have had no influence, while in others they appear to have been actually detrimental to the accumulation of ore. As a rule, however, unless limestone has been proved to have been inert or to have had a negative effect, it is always well to investigate its possible favorable influence on ore deposition.¹

Siliceous Rocks.—Under the action of certain ore-bearing solutions, siliceous rocks may be extensively replaced, thus forming ore shoots, though such results are not so generally marked as with calcareous rocks. At the principal silver-lead mines in the Cœur d'Alene district in Idaho the ore deposits are mostly a replacement of quartzite and other siliceous rocks by siderite and argentiferous galena, with other minerals in small quantities.² Again in the iron districts of the Lake Superior region, Van Hise³ has shown that many of the rich iron deposits were formed from low grade ferruginous materials and that this concentration progressed largely by the replacement of silica by iron ore. In this case the replacement has occurred on an enormous scale.

In some cases certain silicates in crystalline rocks may be replaced more easily by ore than other silicates or other constituents of the rock, thus influencing shoots in certain rocks containing the replaceable materials.⁴

Organic Matter.—When a vein crosses a formation highly impregnated with organic matter, ore shoots often occur, and

¹ Any rocks containing calcium carbonate, like calcareous sandstones, calcareous shales, etc., tend to have an influence somewhat similar to limestone, on account of the ease with which ore-bearing solutions act on the calcium carbonate in them.

² F. L. Ransome and F. C. Calkins, "The Geology and Ore Deposits of the Cœur d'Alene District, Idaho," U. S. Geol. Survey, Professional paper No. 62.

³ C. R. Van Hise, "The Iron Ore Deposits of the Lake Superior Region," 21st An. Rept. U. S. Geol. Survey, pt. 3, pp. 305-434.

⁴ See W. H. Weed, "Influence of Country Rock on Mineral Veins," *Trans. Am. Inst. Mng. Eng.*, Vol. XXXI., pp. 634-653. Also, "Geology of the Little Belt Mountains, Montana," 20th Ann. Rept. U. S. Geol. Survey, Pt. III., pp. 418-420.

this is probably due to the action of the organic matter on ore-bearing solutions, causing precipitation by its reducing action or by other chemical means. Such occurrences are seen in some of the lead and zinc regions of the Upper Mississippi¹ and of Missouri,² at Bingham³ in Utah, and in parts of the mother lode region of California. In northern New Mexico,⁴ wood, branches of trees, leaves, etc., are found converted to copper minerals, showing the effect of vegetable matter on copper bearing solutions, and similar occurrences are seen in northern Texas,⁵ as well as in many other places in America and Europe. At Freiberg⁶ in Germany veins crossing graphitic schist are richer than elsewhere, and at Mansfield⁷ in Germany the copper ores are notably rich in bituminous formations. Organic matter is supposed to have had marked effect on ore deposition at Ballarat, Victoria, where a very thin but quite persistent stratum of black slate appears to have caused an increase in ore where veins cross it, and hence is locally known as the "indicator."⁸ A similar influence of organic matter is seen at Bendigo in Victoria and at Gympie in Queensland.

Sulphides.—Any rocks heavily charged with iron pyrites or

¹ T. C. Chamberlin, "Geology of Wisconsin," Vol. IV., pp. 547-549. Wm. P. Blake, "The Lead and Zinc Deposits of the Mississippi Valley," *Trans. Am. Inst. Mng. Eng.*, Vol. XXII., pp. 630-631.

² W. P. Jenny, "The Chemistry of Ore Deposition," *Trans. Am. Inst. Mng. Eng.*, Vol. XXXIII., pp. 445-498.

³ J. M. Boutwell, "Genesis of the Ore Deposits at Bingham, Utah," *Trans. Am. Inst. Mng. Eng.*, Vol. XXXVI., pp. 541-580.

⁴ F. M. F. Cazin, *Engineering and Mining Journal*, Vol. XXX., p. 381.

⁵ E. J. Schmitz, "Copper Ores in the Permian of Texas," *Trans. Am. Inst. Mng. Eng.*, Vol. XXVI., pp. 97-108.

⁶ B. Von Cotta, "A Treatise on Ore Deposits," Prime's translation, pp. 46-47.

⁷ Von Cotta, *op. cit.*, p. 166.

⁸ T. A. Rickard, "The Indicator Vein, Ballarat, Australia," *Trans. Am. Inst. Mng. Eng.*, Vol. XXX., pp. 1004-1019. The "indicator" also contains large quantities of iron sulphide, and some authorities claim that the influence of the "indicator" was due to the action of this on the ore-bearing solutions and not to the action of the carbonaceous matter; but Rickard believes that the carbonaceous matter caused the deposition of the iron sulphide, and that, therefore, it has been, either directly or indirectly, the cause of the increase of ore in the veins crossing it.

other sulphides may have an effect on ore-bearing solutions on account of the precipitating action of the sulphides. This action is analogous to that of sulphides in veins on later ore-bearing solutions, and is further discussed on page 129.

Igneous Rocks.—Many ore deposits in regions of igneous rocks are directly due to the various influences of subsiding igneous activity; but there is a class of ore deposits, and of ore shoots in these deposits, which have been caused simply by the chemical and physical action of certain mineral constituents in igneous rocks on ore-bearing solutions, in a manner analogous to the way certain sedimentary rocks, already described, affect such solutions. Thus in the Lake Superior copper region, the copper occurs with basic volcanic rocks and is supposed to have been precipitated by the action of ferrous compounds in these rocks on copper-bearing solutions.¹ Frequently the copper has more or less replaced the country rock, especially in some of the volcanic conglomerates, in which the open structure allowed a free percolation of metalliferous solutions. In the San Juan region of Colorado, according to Purington, the ore in different strata of andesitic breccia is more abundant in those strata which carry large quantities of basic minerals than in other strata.²

These processes of replacement in igneous rocks are often greatly hastened when more or less of the original heat and other accompanying phenomena of subsiding igneous activity still remain. Such may have been the case at the time of deposition of some of the ore at Cripple Creek, Col., where an andesitic breccia, and sometimes other igneous rocks, have been extensively replaced, often forming large ore bodies in the wall rock along very narrow fissures.³ Again in the tin deposits of Mt. Bischoff,

¹R. Pumpelly, "Geology of Michigan," Vol. I., Pt. III., p. 43. R. D. Irving, "The Copper-Bearing Rocks of Lake Superior," Mon. U. S. Geol. Survey, No. 5, pp. 420, 425-426.

²C. W. Purington, "Ore Horizons in the Veins of the San Juan Mountains, Colorado," ECONOMIC GEOLOGY, Vol. I., p. 133.

³R. A. F. Penrose, Jr., "The Mining Geology of the Cripple Creek District, Colorado," 16th Ann. Rept. U. S. Geol. Survey, Pt. II., 1894-5. Also, W. Lindgren and F. L. Ransome, "Geology of the Gold Deposits of the Cripple Creek District, Colorado," U. S. Geol. Survey, Professional Paper No. 54, 1906.

Tasmania, extensive replacement of an igneous rock, probably under conditions of heat, has taken place. The ore occurs not only in fissure deposit, but also extensively as a replacement of quartz-porphry.¹ The writer visited this mine in 1904, and at that time large quantities of the igneous rock partly replaced by cassiterite were being mined as ore. Many other similar cases of extensive replacement of igneous rocks under conditions of heat might be mentioned.

Contact Deposits.—The subject of the increased chemical activity of underground waters near igneous rocks, leads up to that large and important class of ore bodies known as contact deposits, lying at or near the contact of the country rock with dikes or other igneous masses. This subject, however, involves more the study of the varied effects of hot igneous rocks on the general geological and chemical conditions of the region, than the direct action of a rock on the character or quantity of ore within it, and though of great scientific and industrial importance, it is beyond the scope of this paper. Suffice it to say here that the occurrence of contact deposits near igneous rocks is probably due in most cases to the fact that the latter are manifestations of past igneous activity, and ore-bearing solutions are generally recognized as being especially abundant and active under such conditions; while in some cases the presence of the ore may be due to a source from the igneous rocks or to the adjoining presence of an easily replaceable rock, or to the fact that the intrusion of the dike has caused fissuring favorable for ore deposition, or to all these causes combined and many others. Such deposits are so numerous as hardly to require illustrations, but it may be said that the silver mines of Leadville and many of the gold mines of Cripple Creek, Col., many of the copper mines of Globe, Clifton and Bisbee in Arizona, the copper mines of Rio Tinto in Spain, and many great mines elsewhere represent contact deposits.

Different Ores in Different Rocks.—The influence of the wall rock of fissures on shoots, already described, relates largely to the effect on the quantity, rather than on the nature of, the ore.

¹ W. von Fircks, *Zeitschrift der deutsch geol. Gesell.*, 1899.

In some places, however, the nature of the ore is affected, and a fissure passing through different rocks may contain one ore where it intersects one rock and another ore where it intersects another rock.

At the Dolcoath mine in Cornwall, England, the ore body was rich in copper near the surface, where it intersected slate, and rich in tin lower down, where it intersected granite. The writer visited this region in 1901, at which time the mining for copper had long ceased, but tin was being actively produced from a depth of over 3,000 feet. The ore of the mine had been copper down to depths ranging from 850 to 1,150 feet, which approximately represented the depth of the slate and granite contact. Below, tin became mixed with the copper, and both metals were contained in the ore for a further depth of from 200 to 250 feet, when the copper gradually disappeared and tin became the only important metal. At Klausen in Austrian Tyrol the veins are rich in silver, lead and zinc where they intersect slates and diorites, and rich in copper where they intersect mica schists and felsite; in the Salzberg Alps some of the veins contain gold where they intersect gneiss and silver where they intersect limestone.¹ In Montgomery and Chester counties, Pennsylvania, where the Triassic sandstone comes in contact with gneiss, copper often occurs in the former rock and lead in the latter.²

This influence of country rock on the nature of the ore in a fissure, however, is the rare exception and not the rule. The effect is much more frequently noticeable on the quantity of ore. Moreover an apparent but deceptive relation of the nature of the ore to country rock may sometimes be due to the fact that, in solutions rising in a fissure, as the pressure and heat diminish, certain ores may be deposited at a certain depth and others at another depth according to the conditions of pressure and temperature that permit the precipitation of each.³ If in this process a

¹ B. von Cotta, "A Treatise on Ore Deposits," Prime's translation, p. 48.

² H. D. Rogers and F. A. Genth, quoted by J. D. Whitney, "Metallic Wealth of the United States," pp. 328, 396-398.

³ A lowering of temperature due to local causes and not necessarily to an approach to the surface, may also have a similar effect in promoting deposition.

certain ore should happen to be deposited where the fissure intersects one rock and another ore where it intersects another rock, the impression might be given that the different rocks had caused the deposition of different ores, whereas the result had been brought about by other causes.

INFLUENCE OF SUPERFICIAL AND DEEP-SEATED ALTERATION.

Constant Changes in Ore Deposits.—An ore deposit is never in a state of complete chemical stability. Even before it is formed, the fissure or other position which it later occupies is the scene of constant changes as a result of the reactions of different solutions on each other. These reactions ultimately result in the deposition of ore, but no sooner is it formed than surface influences, and often deep-seated influences, begin to alter its chemical and physical condition.

Many ore deposits have been derived from hot solutions, often near hot igneous rocks, and after their formation there is a tendency to cool off, a process which may cause them to shrink and become cracked. Moreover, a fissure is a line of weakness and the movement that produced it may be repeated frequently along its course, even after an ore deposit has been formed in it. This is especially true where the fissure has been only partly filled with ore, the rest being more or less filled with selvage. The later fissuring may occur many times in the geological history of an ore deposit and often causes considerable crushing and brecciation in it. Transverse fissuring may also still further shatter the deposit.

These conditions tend to allow surface waters to percolate into the deposit from above, and sometimes subterranean waters to act from below. Moreover, orogenic movements may elevate the region and stimulate erosion, thus exposing new parts of the deposit to alteration; or similar movements may depress the region and subject the deposit to renewed attacks by deep-seated solutions; fresh movements along the fissure may cause renewed shattering, while climatic changes may alter the character of

the surface agencies and give renewed strength to their chemical activity.

Thus the influences to which a deposit is exposed are constantly changing, and no sooner does it show a tendency to chemical stability, than new conditions start fresh chemical activities; and we cannot say that the formation of an ore deposit is ever completed. From the time its formation begins to the time the miner carries away the ore, the deposit is being changed by natural agencies both from above and below. The result is often the formation of ore shoots in places where they did not exist before; or the modification of preëxisting ore shoots either by accretion or diminution of mineral contents. The processes involved in these changes are often similar to those already described in this paper, in other cases they are somewhat different.

Superficial Alteration.—In considering the superficial alteration of ore deposits, we discuss a subject analogous to the surface decay of rocks. The latter, however, involves but a limited number of rock-forming minerals, while the superficial decay of ore deposits involves a great variety of minerals, many of which, under surface influences, give rise to intricate chemical changes. These alterations are the result of the combined action of the atmosphere, surface waters, changes in temperature and the various organic and inorganic materials contained in the air and water. In nature we never deal with perfectly pure water, but different waters contain different ingredients derived from the air and from other materials with which they come in contact. Among the most important of these ingredients are oxygen and carbonic acid, together with numerous other acids, both organic and inorganic, either in a free state or combined with bases.

Surface waters thus charged with various chemical ingredients percolate down into ore deposits and cause great changes in their physical and chemical condition. The oxidation and hydration of certain ingredients, the formation of other new chemical combinations, the leaching of certain ingredients and their deposition below, or their removal altogether from the deposit, and many other effects, are produced. As a result, certain metalliferous

ingredients are sometimes leached from the upper parts of ore deposits and carried down into lower parts, where they are re-

FIG. 12. Longitudinal section through some of the principal mines of the Comstock Lode, Nevada, showing the distribution of ore shoots. Compiled by writer from data in the atlas accompanying Monograph III. of U. S. Geol. Survey, by George F. Becker. The black markings indicate ore. Scale: 1 inch = about 1730 feet.

precipitated by meeting other solutions, or by meeting rocks or minerals which cause deposition, such as calcareous and carbonaceous rocks, masses of sulphides, etc. Hence rich bodies of ore in the form of shoots often collect between the overlying altered part of a deposit and the underlying unaltered part. Such shoots, by their very mode of formation, often tend to have an oblong form, running in the direction of the vein rather than, as most other shoots, running downward in it. On their lower side they often extend out in long projections or tongues, tapering downward until they disappear. The miner's term "fingering out" well expresses this condition.

Ore shoots may be formed higher up in the altered parts of a deposit in cases where certain materials are more resistant to leaching than others, a condition resulting in the concentration *in situ* of the former by the removal of the latter. Thus in a deposit containing copper and gold, surface influences may leach the copper and deposit it below, forming a copper ore shoot, while the gold being less affected remains above, and may develop into a richer deposit than originally, by the removal of the copper and other soluble materials. In the same way the leaching of certain gangue minerals, like calcite or iron pyrites, may cause a concentration of certain metalliferous materials that offer more resistance to leaching.

The depth to which superficial alteration may go is influenced by the topography, the rapidity of erosion, the climate and many other causes, and ranges from a few inches to many hundred feet, perhaps in some cases to several thousand feet. Though most of the ore shoots due to this cause are more or less superficial, yet they are often of immense commercial importance in deposits of both precious and base metals. Many of the great ore shoots of the Comstock lode in Nevada, of the Butte City region of Montana, of the arid regions of Utah, Arizona and New Mexico, many of the iron deposits of Michigan, Wisconsin and Minnesota, and in fact many of the greatest ore bodies of the world owe their existence in part at least to this superficial alteration. As in other influences affecting ore shoots, however,

superficial alteration is not always favorable, and frequently it has an impoverishing effect, but when it enriches the deposit, the results are often wonderfully great.¹

The mines of Butte City, Mont., were originally started as silver mines, but at a depth of a few hundred feet, copper minerals appeared with the silver, and eventually were found in such enormous quantities as to form the basis of one of the greatest copper mining industries in the world. In this case the ore originally contained copper and silver, but the copper was leached from above, leaving the less soluble silver minerals, and was carried down into the lower parts of the deposits where it enriched the original ore. In a similar manner at the great Mount Morgan mine of Australia, the ore near the surface was rich in gold, but carried only insignificant quantities of copper. Lower down, however, copper became abundant, and the mine is now a producer of both metals. At the time of the visit of the writer to this mine in 1904, it had reached a depth of over 800 feet, and works were just being erected to treat the vast quantities of copper ore that had been found. In this case copper and other materials have been leached from the upper parts of the deposit and the gold left as a concentrated product, often of fabulous richness. Lower down, when the copper appeared, the

¹ This subject of the superficial alteration of ore-deposits is too large to be more than thus briefly mentioned in this general paper, but for its further discussion the reader is referred to:

"The Superficial Alteration of Ore Deposits," by R. A. F. Penrose, Jr., *The Journal of Geology*, Vol. II., 1894, pp. 288-317.

"The Secondary Enrichment of Ore Deposits," by S. F. Emmons, *Trans. Am. Inst. Mng. Eng.*, Vol. XXX., 1901, pp. 177-217.

"The Enrichment of Gold and Silver Veins," by W. H. Weed, *Am. Inst. Mng. Eng.*, Vol. XXX., 1901, pp. 424-448.

"The Iron Ore Deposits of the Lake Superior Region by C. R. Van Hise, 21st Ann. Rept. U. S. Geol. Survey, 1901, pt. 3, pp. 305-434.

"The Formation of Bonanzas in the Upper Portions of Gold Veins," T. A. Rickard, *Trans. Am. Inst. Mng. Eng.*, Vol. XXXI., 1901, pp. 198-220.

"Ore-Deposition and Vein Enrichment by Ascending Hot Waters," by W. H. Weed, *Am. Inst. Mng. Eng.*, Vol. XXXIII., 1903, pp. 747-754.

"Secondary Enrichment in Ore Deposits of Copper," J. F. Kemp, *ECONOMIC GEOLOGY*, Vol. I., 1905, pp. 11-25.

gold still remained, but not having been concentrated by the leaching of other materials, the ore was less rich in it.

The manganese deposits of the Batesville region of Arkansas are excellent examples of the concentration of ore as a residual product. Here the ore was once disseminated in limestone, and where surface waters have leached this rock, the less soluble manganese ore has collected in rich pocket in the residual clay left by the limestone.¹

Deep-seated Alteration.—While superficial influences are altering the upper parts of an ore deposit, deep-seated influences may also be active below. The repeated longitudinal fissuring of a deposit after its formation, as explained on page 124, may afford new channels for the circulation of new ore-bearing solutions from below, and these may profoundly affect the deposit. They may form new ore in new openings, or add to the ore already existing, or perhaps segregate ore formerly disseminated, in all of which cases ore shoots may result. Where large bodies of sulphide ores existed in the original deposit, these may be greatly increased by their precipitating action on the new ore-bearing solutions. The new solutions may sometimes carry different metalliferous materials from the older solutions that formed the original deposit, and may thus form new shoots of different ores. Where an ore body has been intersected transversely by later fissuring, results somewhat similar to those just described as following later longitudinal fissuring may result, but here the action is confined largely to the point of intersection, instead of being spread along the whole fissure as in longitudinal fissuring.

In all these processes, however, the result is not always an increase of value or volume of ore, and, as with most factors which influence ore shoots, there may be no effect at all, or there may be an actual diminution of ore. For instance, when the longitudinal movement along a fissure occurs at only more or less remote intervals, deposition of ore may be increased as just described, but when the movement is very frequent or almost con-

¹R. A. F. Penrose, Jr., "Manganese; Its Uses, Ores and Occurrence," Geological Survey of Arkansas, Vol. I., 1890, pp. 174-177.

tinuous, it is likely to retard deposition or even to prevent it, for deposition progresses best during intervals of repose after dynamic movements. This may be a cause of the fact observed in some mining regions, though by no means in all, that the ore deposits occur in the smaller fissures and not in those that have been the scenes of the greatest amount of movement.

An excellent case of enrichment from below as the result of repeated movements along ore-bearing fissures, is seen at Goldfield, Nev., where some of the deposits have been shattered by longitudinal fissuring many times and have received new supplies of ore at different periods.¹ Remarkable cases of enrichment after later fissuring, both longitudinal and transverse, are also seen at Butte City, Mont., and many other districts.

SUMMARY.

Ore shoots are bodies of mineral matter which are richer in certain valuable constituents than the enclosing materials. They may be of varying size, continuity, and shape, but their more or less circumscribed character is a distinguishing feature.

Ore shoots are the result of many different chemical and physical influences. These influences sometimes act singly, but generally two or more, often many, act together in producing a given shoot.

Segregation during the cooling of molten magmas in some cases influences the formation of ore shoots.

The occurrence of ore-bearing solutions in local vents influences the position of ore shoots by supplying materials for them in some places and not in others. Thus the channels of fumaroles and hot springs may become the receptacles for shoots.

Gaseous emanations may influence the position of ore shoots by causing precipitation where they occur or by forcing ore-bearing solutions along certain channels.

Structural conditions in a fissure may influence the deposition of ore shoots by offering advantageous openings for deposition.

¹F. L. Ransome, "The Mining Geology of Goldfield, Nevada," U. S. Geol. Survey, Professional paper No. 66, pp. 196-198.

by forcing the ore-bearing solutions into favorable positions for deposition and in other ways.

Cross fissures may influence the deposition of ore shoots by supplying an additional amount of ore-bearing solution, by shattering the wall rock at the point of intersection, by supplying solutions which cause precipitation from the solutions in the main fissure, by deflecting the solutions in the main fissure to advantageous positions for deposition and in other ways.

The nature of the wall rock of a fissure may influence the deposition of ore shoots to a very marked extent. Its influence is chiefly in affecting the quantity of the ore, but it may also affect the nature of the ore. Its influence is both physical in affording the places for deposition, and chemical, in causing precipitation of ore.

The superficial and deep seated alteration of an ore deposit after its formation may greatly influence the distribution of ore-shoots by the chemical and physical changes that they produce, forming shoots where they did not exist before, or modifying pre-existing shoots either by accretion or diminution of mineral contents.

CONCLUSION.

Many causes tending to produce ore shoots have been mentioned, and their action might have been discussed at greater length, but if one attempted to follow all the modifications and combinations of the processes described, too much detail would be involved for a general paper. Probably the most important and generally observed influences producing ore shoots are those of the wall rock, of intersecting fissures and of local emanations of ore-bearing solutions. These influences, however, rarely act singly; they generally combine with each other or with still different influences in producing ore shoots.

As has been frequently stated before in this paper, however, the influences that may produce ore shoots do not necessarily do so. An ore shoot is the exception and not the rule, and even when apparently the most favorable combination of influences

exists, there may be no ore shoots. Moreover, the causes that have produced a shoot in one region may have no such effect in another region, or in another ore deposit in the same region, or perhaps in another place in the same ore deposit.

In one place, the wide spots in a vein may be the most likely for shoots, in another, the wide spots may be barren and the narrow places rich. In one place, shoots may have a close connection with cross fissures, in another, such fissures may be entirely without influence; in one place, shoots may show a decided preference for certain rocks, in another, the same rocks may seem to discourage shoots. In some places, the action of surface influences causing a superficial enrichment has been a most important factor in developing ore shoots, in others, it has either had no influence, or may even have deteriorated the value of shoots that existed before its influence was felt; in some places later movements along a fissure that has already been filled with ore, have had a marked enriching effect, in others, such movements have had no effect.

More financially disastrous mistakes have probably been made in mining by supposing that because certain conditions hold good in one region, they must hold good in another, than from any other one cause. Every district is a law unto itself in the localization of its ore in shoots, and no district can be properly understood until it has been thoroughly studied *per se*. On the other hand, shoots are not one of those obscure and mysterious phenomena which baffle all efforts at explanation. They are simply the result of natural causes which have been, and are sometimes even yet, active. In almost any district where sufficient mining has been done to permit a thorough examination of the ore deposits, some sort of an idea of the probable cause of the ore shoots should be obtainable.

Though the occurrence of an ore shoot, even under conditions most favorable for its formation, is the exception and not the rule, yet it is worth while to study the causes that produced it, and to look for ore under similar conditions elsewhere. The search in many cases will be fruitless, but another "exception" exists

somewhere, and a knowledge of the conditions under which it may occur is helpful.

Just as the pearl in the oyster is an abnormal segregation resulting in a beautiful gem, so the ore shoot in the earth is an abnormal segregation resulting in precious minerals; just as there are thousands of oysters that contain no pearls to one that does, so there are thousands of apparently favorable receptacles for ore shoots that yet carry none; just as the pearl diver finds it remunerative to hunt for the oyster that may contain his prize, so the miner finds it remunerative to hunt for the spot that may contain his ore shoot; and though the paths of both are strewn with disappointed hopes, yet the possibility of realization leads them on.