

SCIENCE

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FRIDAY, NOVEMBER 15, 1901.

THE GEOLOGY OF ORE DEPOSITS.*

I.

I SHOULD hardly have ventured to talk on the subject of ore deposits to an audience which contains many men much more familiar with mines than I, if I had not approached the subject from a different point of view. The point of view from which the subject of ore deposits has been most frequently considered has been that of a study of ore deposits themselves. A geologist or mining engineer has studied this or that ore deposit, or a number of ore deposits in different districts, and has then generalized concerning the ore deposits of other districts, and perhaps of the world. I also have considered the subject of ore deposits to some extent from that point of view, but if I had done this only, I should not have ventured to give a general address upon the subject.

A number of years ago I began the study of the alterations of all rocks, by all processes and by all agents, in order, if possible, to ascertain how it is that the rocks change from one form to another. That rocks are metamorphosed has been known for many years. It has been realized that one mineral changes into another mineral;

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that one rock changes into another rock; that rocks may have different textures, structures and compositions from those they originally had. The chief immediate agent producing these changes is underground water. Everywhere underground water permeates the rocks. Everywhere it is the medium of exchange by means of which the mineral particles are changed from one form to another.

In order, therefore, to understand this matter of the alterations of rocks, it became necessary to consider the flowage of the underground water; to attempt to ascertain, if possible, how it moves through the rocks, in what directions, to what depth it penetrates, whence it comes, whither it goes. After a certain number of principles and conclusions had been reached upon the alterations of all rocks, by all processes—and especially by the work of underground water with the help of heat derived from the igneous rocks, from dynamic action, and the increment due to depth—it seemed to me that many of the principles of ore deposition followed as corollaries from these general principles. Therefore, it is from this general point of view that the question is discussed tonight; not from that of a particular ore deposit or particular district.

For many years ore deposits have been classified into those which are produced (1) by the direct action of igneous agencies, (2) by the process of sedimentation and (3) by the action of underground water. There is no difference of opinion as to the existence of all these three classes; but there is a difference of opinion as to their relative importance. Some hold that deposits of igneous origin are of very great importance. By this I mean ore deposits which have been directly formed by some of the strange processes of vulcanism. Also it is certain that large quantities of ore, and especially the placer gold deposits, are largely

the result of the process of sedimentation. But I hold that the greater number of ore deposits, those which contribute most to the wealth of Colorado, to the entire Cordilleran region, to the Lake Superior region, to the Mississippi Valley, to the Appalachian region, are those deposited by underground water; that is, they are the direct result of the work of the permeating solutions, which go for at least a considerable depth below the surface of the earth; and are taking material into solution all the time, depositing material from solution all the time. During the journey these underground waters take up from igneous, aqueous and metamorphic rocks the sparsely disseminated metallic material which is of consequence to man. This material is deposited in the openings of the rocks and within the more easily replaced rocks in sufficient abundance to form ore deposits. With the exception of iron, the quantity of metal which is contained in an ore is ordinarily small; in the case of gold, usually an exceedingly small fraction of one per cent.; in the case of silver, usually less than one per cent.; in the cases of copper, lead and zinc, from one per cent. to a rather high percentage, but in the great majority of instances less than 20 per cent. It therefore appears that the majority of so-called ores consist mainly of deposited materials other than the metals which are extracted from them. This predominant material is known as gangue, and plainly was deposited simultaneously with the ores, in the openings of the rocks, or else replacing rock material.

In a given instance to attempt to answer the question as to the source of the gold or the silver or any other metal, without at the same time considering the minerals with which it is associated, is futile. If we can answer the question as to where the gangue minerals came from, and how they got into the positions they now occupy, the question is in large measure answered as to

how the metal got there, and how it was deposited.

I shall not attempt to give all the evidence that the metallic ores and gangue are deposited by underground waters; but I wish to call attention to certain structures of veins which seem to favor this view. [At this point a number of lantern slides were used, illustrating the following statements.]

A massive rock may be produced by direct igneous agencies; sediments are arranged in strata and beds. But material showing a comb structure—or, as Posepny calls it, crustification—and the filling about particles of rock, is usually produced by underground water. No agent other than water can penetrate between the grains throughout a sandstone formation, or a conglomerate formation such as that of the Calumet and Heckla, or between the fragments of a great tuff formation such as that of the San Juan district of Colorado, and deposit material so as to transform them to hard rocks by cementing the particles. Many cracks and crevices, great and small, form in the rocks by the deformation to which they are subjected. Igneous material can intrude the rocks in a most intricate fashion and occupy these openings; yet in the great majority of instances the extremely intimate introduction of material is accounted for by transportation and deposition of material by underground waters. Those in this audience familiar with Colorado ore deposits know that many of the valuable minerals are in veins, many of them narrow, or between very small fragments within the rocks. Not only do the ores occur in the larger openings, but they frequently occur for some distance from the veins in the extremely minute, often subcapillary, openings of the wall rocks, or even replacing the individual particles of the wall rocks. But farther from the veins, if the metals are

present at all, they are only in exceedingly minute quantities. In the larger openings and adjacent to these openings the values are chiefly found. These facts are beautifully illustrated at Cripple Creek. No known agent except underground water is capable of penetrating the very small, and especially the subcapillary, openings, and depositing material.

My primary assumption is, therefore, that the great majority of ores are deposited by underground waters at the places where they are now found. Nearly all that follows is confined to this class of ores. Ores directly produced by igneous processes, and those formed by processes of sedimentation, are only indirectly considered this evening.

The second fundamental principle which I shall try to develop is that the waters derived the ores from the outer part of the crust of the earth—the part which I have called the zone of fracture. Even as late as 1893, at the World's Fair Congress, at Chicago, it was argued by Posepny that the ores came from the barysphere, or heavy-sphere, from well down within the earth; although even Posepny conceded that the agent which transported and deposited the metals at the places where they are now found was underground water. Posepny's theory of the derivation of the ores from deep within the earth is a very attractive one; because, if it be true, the deeper a mine, the richer an ore deposit is likely to become. Indeed, it is the belief of 90 per cent. or more of prospectors that if they only could get deep enough, deposits of surpassing richness and magnitude would be developed. But it seems to me that the hypothesis that the ores are derived by the underground waters from deep within the earth has no foundation in fact. It is alike opposed to the principles of physics and to observations in the field.

It must be remembered that gravity is a gigantic force ever at work pulling toward

the center of the earth. And it must be remembered that all rocks are limited in strength. The strongest rock tested has a crushing strength of something more than 40,000 pounds per square inch. A column of such a rock 10 or 12 miles high would be crushed by its own weight. It is easily calculable that if we suppose the outer part of the crust of the earth to be composed only of the strongest rocks, and we imagine openings to exist in these rocks, then at a certain depth these cracks must be closed by the pressure. And this deduction has been experimentally proved. Professor Adams, of Montreal, has shown that rocks subjected to pressures in all directions greater than their crushing strength may be mashed, and no perceptible openings produced. Therefore, openings of great size cannot be assumed to exist below a very limited depth in the crust of the earth. This conclusion is fully verified by observation. By examining the rocks in the cores of mountain ranges where there has been deep denudation, we may see what has happened to them when well below the surface. In the Front Range of Colorado, and at various places in the world, where the rocks have been deformed at considerable depth below the surface of the earth (ignoring recent fractures which have been produced since the rocks came near or to the surface), the process has taken place without the formation of openings larger than those discernible only with the microscope. Therefore, from the point of view of pure physics, from the point of view of experiment, and from the point of view of observation alike, we reach the conclusion that no large or continuous cracks or crevices exist except for a very limited depth below the surface of the earth.

In order to deposit the metals and gangue of an ore deposit, a vigorous circulation is required. The vigorous circulation of underground water is necessarily confined

to that part of the crust of the earth where there are continuous cracks and crevices of considerable size. As the openings decrease in size, the resistance due to friction increases rapidly; and where the openings are subcapillary, it is enormous, being in fact sufficient to practically check circulation. In Colorado a common gangue material is quartz. Springs have been analyzed, and it has been found that the water issuing from such springs bears perhaps one part in one hundred thousand, or one part in a million, of silica. It is probably rather uncommon for a solution to deposit as much as one part by weight in one hundred thousand of the gangue and ore material. If this be so and the gangue be quartz, in order to fill an opening with ore and gangue, at least 260,000 times as much water must have passed through it.

It therefore follows that if the majority of ore deposits are placed where they are by underground waters—and from this there seems no escape—the processes of their gathering and deposition must be mainly confined to the outer few miles of the crust of the earth. This is called the zone of fracture. *Therefore my second fundamental conclusion is that the ore deposits are derived from the zone of fracture.*

But is there an adequate source of supply of metallic material in the outer part of the crust of the earth? In answer to this question, it may be said that calculation clearly shows the relatively small quantities of ore which exist could have been derived from the zone of fracture, even if the rocks contain an exceedingly small fraction of one per cent. of metal. To illustrate, Mr. Buell has calculated for Professor Chamberlin, for the Wisconsin lead and zinc district, that if the richest portion of the district be taken, and it be assumed that the supply extended only one-half as far beyond the deposits as the radius of the productive area, and the depth of vertical distribution be confined

to 100 feet, one fourteen-hundredth of one per cent. of the metals in the rocks could supply all the lead and zinc which has been or is likely to be taken from the district. It is therefore not necessary to suppose that there is more than a minute quantity of metallic material in the zone of fracture, to furnish a supply adequate many times over to account for all the deposits which have been mined or are likely to be mined.

So far as the specific work of underground water is concerned, we have already seen that the metals for the ores are derived from the zone of fracture. But it does not follow that important supplies of metals to be later yielded to the water may not come from deeper within the earth. As a result of various causes, which cannot be discussed this evening, the igneous rocks rise from an unknown depth below the surface of the earth into the zone of fracture or even quite to the surface. Such igneous rocks bear materials out of which many important ore deposits are largely or wholly derived. Indeed, if we go far enough back in the history of the earth, all rocks were probably derived from the igneous rocks. So, directly or indirectly, the ultimate source from which ores are derived by underground water is igneous rocks, either ancient or modern. On this point there are no differences of opinion.

But there are differences of opinion as to the manner in which the ores are derived from the igneous rocks. Some geologists hold that the direct processes of igneous action produce many ores. They say that during the process of crystallization of the igneous rocks the ores are segregated by magmaticorpneumatolitic processes. There are cases in which this is probably true, as, for instance, the unimportant titaniferous iron ores of the Adirondacks and the Lake Superior region. Certain ores, as the tin

ores, possibly have this origin. But it is yet unproved that the great mass of ores, which are known as the oxidized ores, the carbonate ores, the sulphide ores, and the tellurid ores, have been thus derived. We know of these classes of ores that a large part have been taken from the rocks and brought to their present positions by underground water. Why, then, assume some other process of segregation for which there is no adequate evidence, when we have a wholly adequate agent in underground water? In the great majority of cases the ores are taken from the igneous, sedimentary and metamorphic rocks by the underground waters; are carried to their present positions by the underground waters, and deposited by the underground waters at the places where they are now exploited.

The next question which naturally arises is the source of the underground water. It is believed that the water is predominantly of meteoric origin; in other words, is the water which falls from the atmosphere upon the valleys and hills and mountains of Colorado and other parts of the world. It is true that each igneous rock usually carries a small amount of water; and in the aggregate this amount may be very great. Indeed, it may be that all the water upon the surface of the earth and that in the openings of the zone of fracture was originally derived from the igneous rocks. But even if this be true, it does not follow that in a given district, at the particular epoch in which the ore deposits were formed, the water directly derived from the igneous rocks is adequate or even important in accounting for this deposition. As already explained, it is necessary to consider not only the ore but the gangue material with which it is related; and it has been seen that in order to deposit an ore and its accompanying gangue probably required tens of thousands or even hun-

dreds of thousands of times as much water. The vast quantity of water necessary cannot be derived from the igneous rocks present at a given time and place, although they may have contributed a portion of it. But it is held that the major portion of this vast quantity of water could only have been derived from the rainfall. *My third fundamental premise is, therefore, that the circulating underground water is mainly of meteoric origin.*

The question which now arises is the cause of the flowage of underground water. Why does it move? Until we know the force which drives it, we cannot know the manner in which it circulates. Geologists have frequently appealed to the great energy of the subterranean heat, due to depth or to igneous rocks, to drive this water. But this is not enough. How does this subterranean heat act in producing this circulation? A few miles west of Denver are the crystalline or core rocks of the Front Range. To the east of these there is a series of sedimentary beds, some of which are water-carriers, and which dip below impervious strata. The water rises to the surface at Denver. Why is this so? Simply because the water is at a higher level where it enters the formations than where it issues at the surface. The force which drives the water is gravitative stress. Gravitative stress is everywhere and all the time at work. The longer column is pulled downward with greater force than the shorter column. The difference in the height of the two columns is called head. Therefore, the water in the longer column moves downward, and that in the shorter upward. *We now reach my fourth fundamental premise: That gravitative stress is the chief cause of the circulation of underground water.*

The flowage of water in the Denver artesian basin does not require the force of the subterranean heat below. But there is a way in which the subterranean heat can

promote the circulation of underground water; and, indeed, does. This is by heating it. When the water is heated as a result of the contact with igneous rocks, or heated because it penetrates deep into the earth, it expands. If it expands unequally, as it is likely to do, one column may become lighter than the other, even if they are of the same height. If so, circulation would be set up. This is the principle of hot-water systems of heating buildings. The heat of the fire expands the water and forms two columns of unequal density. Under this condition of affairs gravity pulls the denser column harder, and a circulation takes place. Therefore, the heat of the igneous rocks acting upon the underground solutions, or the heat of the rocks due simply to depth, provided the circulation be of sufficient speed, may result in flowage. Thus there are two causes which result in the underground circulation, which may work separately or together—(1) head, and (2) variable temperature. But in either case continuous movement of the water in a definite direction, or its circulation, is due to gravitative stress.

Therefore, we have these four fundamental premises: (1) *The chief class of ore deposits is segregated by underground water;* (2) *the source from which the water derives the metals is the zone of fracture;* (3) *the circulating underground water is mainly of meteoric origin;* (4) *the force which drives the water in its circulation is gravitative stress.*

It is now necessary to consider in some detail the manner in which underground water moves. For a long time I have realized that if underground water had a difference in head it might penetrate to a great depth and rise again to the surface; but I did not realize that it was not necessary to assume exceptional openings for such a circulation. I assumed that where such a circulation took place exceptionally favorable channels were available;

but a recent paper by Professor Slichter* upon the motion of ground waters showed me that this was an entirely unnecessary assumption, and gave me the additional data needed upon this point. This chart (Fig. 1) is a horizontal diagram. A repre-

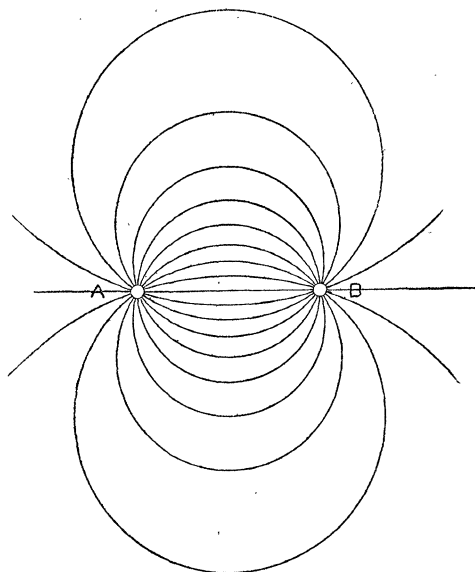


FIG. 1.

sents one well and *B* another well, separated by a homogeneous porous medium. Into the well *B*, I pour water. In the well *A* there is no water at the outset; and the water flows from the well *B* to the well *A* through the medium. What is the path of the water? Its flowage is represented by the curved lines. Some of the water goes in a nearly direct course. Another part takes a somewhat curved course. Still other parts of the water follow a very indirect course, represented by the longer curved lines. All the available cross section is utilized. If, for instance, this room were filled with water, and water were running in at one place in the front end of the room and were escaping at one place in

the rear end of the room in equal quantity, would the water simply follow the direct line between the two openings? You know perfectly well it would not. The entire available cross section of the room would be utilized, although the more direct course would be utilized to a greater extent than the more indirect course. This is intended to be illustrated on the chart (Fig. 1) by the lines representing the nearly direct courses being close together, and the lines representing the indirect courses being farther apart.

This chart (Fig. 1) then represents the horizontal circulation. If we pass to the vertical circulation the flowage is represented by this chart (Fig. 2). The water is being poured into the well *B* and passes to the well *A*. The water follows the course of the curved lines, so that with a difference in head equal to the difference in the level of the water in the two wells, a considerable part of the water being poured into *B* and passing through the homogeneous porous medium to *A* penetrates a considerable depth, from which it rises and enters the well *A*. Now what will be the limit in nature of the downward search of underground water? We have already given it. Manifestly the lowest limit of effective circulation at any place is the bottom of the zone of fracture at that place. The zone of flowage below is practically impervious. However, an impervious limiting stratum may exist at depths far less than the bottom of the zone of fracture. An impervious limiting stratum, perhaps a shale, may be found at a depth of 300 feet or less, or at any depth intermediate between this and the bottom of the zone of fracture for the strongest rocks. Where there are one or more pervious strata which are inclined, and above, below and between which are impervious formations, there may be two or more nearly independent circulations. To illustrate, at Denver, the

* 'Theoretical Investigation of the Motion of Ground Waters,' by C. S. Slichter, Nineteenth Ann. Rept. U. S. Geol. Surv., 1899, Pt. II., pp. 295-384.

porous strata of the Fox Hills, Laramie and Arapahoe formations have more or less independent circulations. If a limiting stratum be supposed to be half way down on the chart (Fig. 2) the lines of flow above

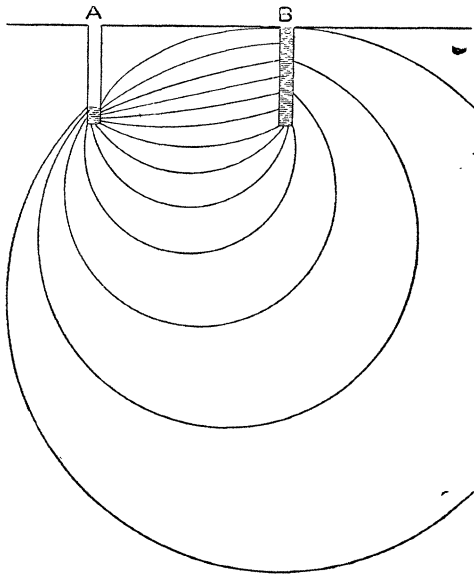


FIG. 2.

this stratum would not be as they are now, but would be flatter and would be limited by the impervious rock.

Under natural conditions, wherever there is an impervious rock there is a limit of some particular circulation in that direction. A limiting stratum may, therefore, be very near the surface, at the bottom of the zone of fracture or at any intermediate depth; and theoretically a moderate head is sufficient to do the work of driving the water to any of these depths. Indeed, there is no escape from the conclusion that at least some circulation does occur in the deeper parts of the zone of fracture with a very moderate head. Of course, in proportion as the head is great the circulation at depth is likely to be vigorous. But it may be objected that a deep circulation, while theoretically possible, must be exceedingly small in quantity, and consequently of

comparatively little account in the deposition of ores. But the consideration of the underground circulation in reference to the Denver artesian wells shows that this objection has little weight. Moreover, the deeply circulating water, if less in quantity than that near the surface, takes a longer journey and is longer in contact with the rocks through which it is searching for the metals. Not only so, but it is at a higher temperature than the water at higher levels; and this also is favorable to taking mineral material in solution. And, finally, because it has a higher temperature, it has less viscosity. While the variable viscosity of water is not so very important in reference to circulation in supercapillary tubes, in capillary tubes, which constitute a very large fraction of underground openings, and especially those at considerable depth, the viscosity is important—the flowage increasing directly as the viscosity decreases. The viscosity of water at 90° C. is only one-fifth as much as it is at 0° C.; and, therefore, with a given head of water in capillary tubes, if the temperature be considerably increased—and but a moderate depth is required to give considerable increase—the water moves several times as fast as it would at the surface under conditions similar in all respects save temperature. Therefore, because of these three factors, long journey, high temperature and low viscosity, we cannot exclude the deep circulation from consideration. This circulation is, indeed, believed to be very important in the deposition of ores.

We are now prepared to consider the actual journey of underground water. Where water falls upon porous ground it finds innumerable openings through which it enters and begins its underground journey. This circulating water, as far as practicable, under the law of the minimum expenditure of energy, follows the paths of easiest resistance. But these are the larger

openings, because resistance due to friction along the walls and within the current is very much less per unit circulation in large than in small openings. While, therefore, water enters the ground at innumerable small openings, as it goes down it more and more seeks the larger openings. Once found, it holds to them. The farther it continues its journey, the greater the proportion of the water which follows the larger openings. But if this be true, the water in its descending course is more likely to be widely dispersed and in the smaller openings; and in its upward course more likely to be concentrated and in the larger openings.

We can now follow the course of underground water in detail, but in doing this it is necessary to consider the elements of the problem separately. It is only by passing from a simple case to the very complex one of nature that we can understand the latter. Here is a chart (Fig. 3) which shows the

imaginable case. In this illustration we have represented the surface of the earth and the level of ground water. By the level of ground water is meant the depth at which the water saturates the rocks—that is, where the water remains at practically a permanent level. Above this level the paths of circulation are practically vertical; below this level the paths are curved. Of the water which enters the slope of a hill and issues in the adjacent valley, a portion flows along the slope of the hill, a portion in a less direct route, and a portion in a very circuitous route. Below the level of ground water all the openings in the rocks, great and small, are filled with water. In the case represented I have supposed that all the water enters at a single point, *A*; and that all of it issues at a single point, *B*. The curved lines represent the flowage of the water through a homogeneous porous medium.

In the next chart (Fig. 4) I have supposed water to enter at three points

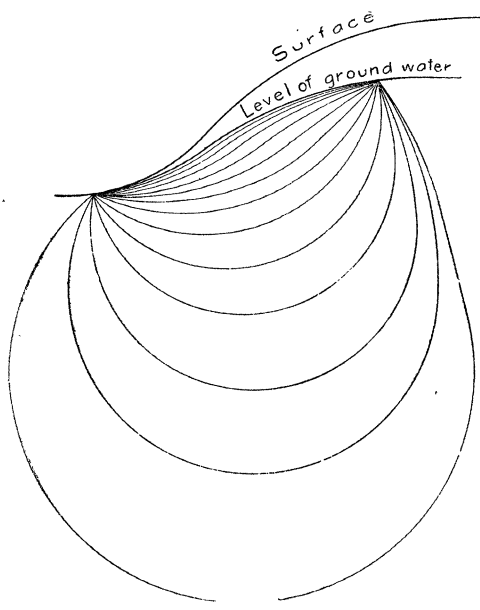


FIG. 3.

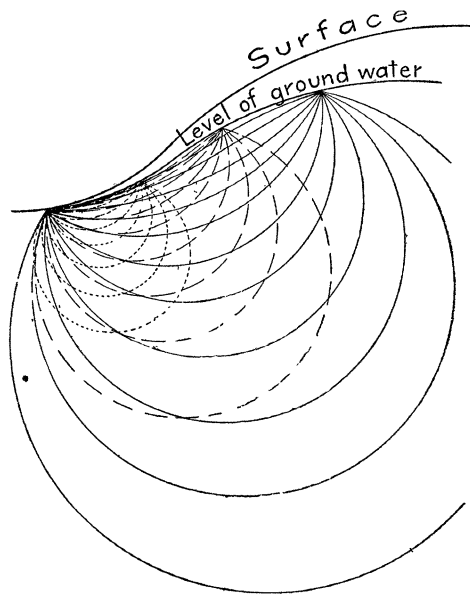


FIG. 4.

surface of a slope, the level of ground water and the flowage of water in the simplest

and issue at one; and I have supposed the flowage from each point of entrance

to occur just as if no water were entering anywhere else, and, therefore, the systems of flowage to be superimposed. Of course this is not a real case. Underground water does not diverge from a single point and converge at another point in independence of the water entering at other points. The water entering at innumerable points in vertical section and in horizontal section mutually interferes, and makes the course for any given particle of water rather simple. This I have tried to represent by another chart (Fig. 5). In this chart I

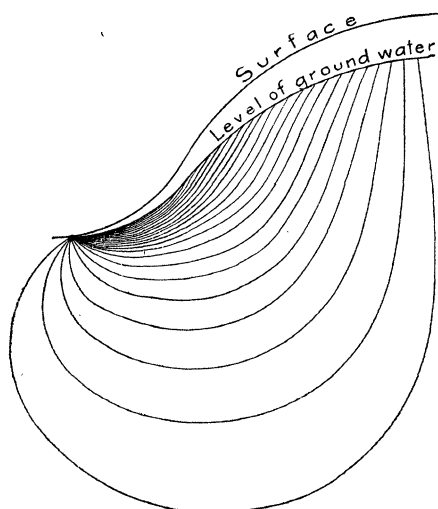


FIG. 5.

have supposed particles of water to enter at equal horizontal intervals, and issue at a single point. You note that the water near the crest begins its journey by almost vertical descent. In proportion as the entering water is near the valley the horizontal component becomes more important. The water near the valley follows a comparatively shallow course; but this water uses all the available space near the surface, and consequently the water entering at the higher ground necessarily follows a long, circuitous and deep course. The chart (Fig. 5), therefore, represents the flowage with many points of entrance and

a single point of exit, where there is interference of the circulating waters.

A portion of the water follows an approximately direct path; a portion of it less direct paths; and a portion of it a very roundabout path. That is, the underground water, following the lines of least resistance, takes not only the direct passages, but also the indirect passages. The lines in the more direct path are closer together, and the indirect path farther apart. These facts have been ascertained by experiment and by mathematical analysis. But everywhere gravitative stress is the driving force. The case represented by the diagram (Fig. 5) is an ideal one. Under the complex conditions of nature there is usually great departure from the simplicity represented; but in some districts this ideal simplicity must have been approached. For instance, except for the disturbance due to cutting dikes, the circulation in the past in the San Juan district of Colorado must have been very nearly like that represented in the diagram. Early in Tertiary time there was in that district a great volcanic plateau. Early in the erosion history of this plateau, the conditions must have been the same as at present in the Yellowstone Park and other volcanic plateaus of the West. At the stage when the San Juan plateau was still the dominating topographic feature, but cut by canyons, the conditions were practically identical with the conditions represented by the diagram. The water sank into the ground upon the hills and the plateau; it issued at the valleys, much of it having first penetrated far below the level at which it issued. The water carried on its search for metals through the volcanics, almost as shown in the diagram, except in so far as it was influenced by larger cracks or crevices, or by cutting dikes, or by impervious layers.

The principles illustrated by these diagrams show it is not necessary that

there shall be a difference of elevation of thousands of feet between where the water enters and where it issues, in order that the rocks shall be searched for depths of thousands of feet. A few hundred feet is sufficient. Therefore, the underground waters, falling on the slopes, passing through the areas where they may gather material, and issuing at various places in the valleys, have an opportunity to pick up the ores, provided the metals exist in the rocks traversed. By the water the metals are carried to the places where they now are.

Thus far it has been supposed that the ground is uniformly porous, like an evenly grained sandstone without joint or fracture of any kind, in which the water can go in all directions with equal ease. But absolute uniformity does not exist in nature. The openings in rocks are never of uniform size; they are never equally distributed.

It is now necessary to take up the final important point in the circulation of underground water. So far as it can, it passes from small openings to large openings. Where the openings are small the resistance per unit area is very large. Where the openings are exceedingly small, the resistance is very great. Where the openings are large, the resistance is slight; and the water, following the lines of least resistance, travels to the extent that space permits in the trunk channels. To illustrate, every engineer knows that if water be carried in pipes from the hills to the mines, one pipe will carry vastly more water in a given time with a given head than many smaller pipes of the same aggregate cross section. This is because of friction, which increases rapidly as the cross section decreases. And water does the same thing in natural as in artificial pipes. Therefore, the underground water more and more follows the larger courses. It falls everywhere on the slopes of the hills; it enters the ground everywhere. Therefore, in its earlier course it is

widely disseminated, and thus dispersed can most effectively pick up the valuable metals with which it comes into contact. But as the journey is continued, it collects more and more into the larger channels. But in the early part of the journey of ground water its vertical component is apt to be downward. But as it must sooner or later reach the surface, in the later part of its journey its vertical component is apt to be upward. However, it has just been seen that the early part of its course is apt to be in small openings, and the later part in larger openings. As it collects in the larger channels, it is more likely to be ascending. Therefore, upon the average—I say upon the average—descending water is mainly in the small openings, and ascending water mainly in the large channels.

It is now advisable to consider the circulation in definite vertical large, or trunk channels. Suppose half way down the slope there is a vertical opening of unusual size

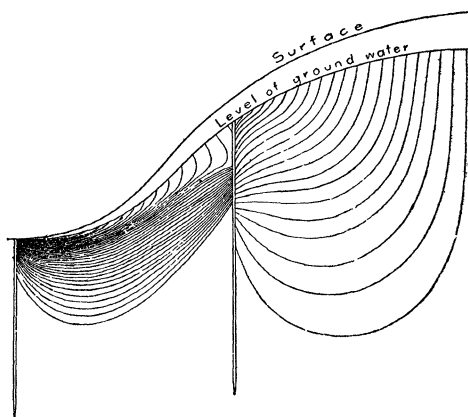


FIG. 6.

transverse to the plane of the chart (Fig. 6), and another similar opening below the valley. If you please, we will call them fissures. These fissures, because large openings, will be fully utilized by the underground water. We readily see that ground water will enter the higher fissure at many points and from various directions.

Ordinarily it will enter the upper part while it is still descending; it will enter the central part laterally; it will have begun its ascent before it enters the lower part. Therefore, a fissure upon the middle of a slope will be very likely to receive water from above, from the side and from below. But at a certain area of a fissure well up on the slope the water continuously received at the upper side of the fissure will escape laterally at the lower side. This water and that entering the ground below the upper fissure will make its way to the fissure below the valley. But here the level of ground water is at the surface. Consequently all the water entering this fissure will ascend quite to the surface, and issue as a spring. If there be a fissure at the crest we can see that the descending water will go a long way down; but the waters will nowhere be ascending. If there be a fissure on the slope, both descending and ascending waters will ordinarily be active; although it is of course recognized that in fissures thus located the conditions may be such that the waters will ascend or descend only. If there be a fissure below a valley where the level of ground water is at the surface the water will all be ascending; and there will be no descending water. At such places we have springs. Springs do not issue from the tops of mountains, but from slopes and valleys, most frequently the latter. Illustrating this are the Yellowstone Park springs of the Firehole River. The waters which feed the springs fall upon the crests and slopes of the mountains adjacent; on their way to the valley go deep below the surface, and at the Firehole ascend as hot springs and geysers. The water is driven by gravity due to a considerable head and the lower temperature of the descending column.

You are all doubtless aware that three theories are maintained as to the course of the waters which deposit ores. Some hold

that the waters doing the work are descending; others that they are laterally moving; others that they are ascending. The first is known as the descension, the second as the lateral-secretion, and the third as the ascension theory. If my argument be correct as to a limit to the zone of fracture, fissures, as well as all other openings, must gradually become smaller and smaller, and finally die out altogether. Water in a fissure may descend or may ascend for a considerable distance; but it is perfectly clear that, so far as fissures are concerned, except for the small amount entering the surface openings, the water must enter laterally. Consequently, if we apply the lateral-secretion theory broadly enough, we may say that all the waters which feed the fissures are lateral-secreting waters. But if we are descensionists, and consider only the upper part of a fissure on the slope—and that is what many very naturally have done, because this is the part of the fissure most easily observed—we may say that the waters which are doing the work are descending waters. Or, if we are in such a district as that of the Comstock lode, in which are found great volumes of ascending water, we may say that the waters which are depositing the ores are ascending. All may be correct. But in the past Sandberger held that lateral-secreting waters in the narrowest sense did all the work, and he refused to believe that ascending and descending waters were of importance; and Posepny held that ascending waters did nearly all the work, and gave small consideration to the lateral-secreting and descending waters; whereas you see with perfect clearness that each theory is incomplete. All are needed; they supplement one another.

The next point to consider is why the metals are precipitated in veins. The salts of the valuable metals may come from any of the places visited by the oc-

cupying waters. If one take a number of chemical solutions in the laboratory, and dump them together in a beaker, probably precipitation will occur. These conditions are precisely those of underground solutions in trunk channels. The water from one source meets the water from another source in the trunk channels. Analyses show that waters from different sources have different compositions. They bear different metals and precipitating agents. When they come together in the trunk channels, and mingle, precipitation is likely to take place. You, who are practical mining men, like your veins to intersect, or two veins to unite. The explanation of the frequent increased values at or adjacent to an intersection is simply that the different trunk channels bear solutions of different kinds, and when they mingle at or near the intersections, ore precipitation is likely to occur. One solution may bear its mite of silver or gold, and the other the precipitating agent, or both solutions may carry the metals, and when the two come together the ore be thrown down. However, this is not the only way in which precipitation may take place. In many instances the precipitation is due to the wall rock. The wall rock, or the solutions furnished by it, react upon the solutions coming from somewhere else, and precipitation occurs. These two causes for precipitation are not the ones which are ordinarily mentioned in treatises on ore deposits. The causes commonly assigned in text-books for precipitation are the diminishing temperature and pressure of the rising solutions. While these are real causes for precipitation, I believe them to be subordinate to the influence of the mingling of solutions from various sources in the trunk channels, to the influence of the wall rocks, and especially to the first.

C. R. VAN HISE.

(To be concluded.)

THE PHYSICAL SCIENCES AT THE BRITISH ASSOCIATION.

THE meeting last September at Glasgow, which was attended by nineteen hundred persons, was smaller than the last two meetings held in that city, and fell slightly below the average of the British Association gatherings. This was chiefly the result of the unexpectedly small number of local associate members enrolled, accounted for by the fact that an International Exhibition with several collateral congresses had satisfied whatever desire the inhabitants of the Scotch metropolis may have had to increase their knowledge of scientific matters. The foreigners numbered only twenty-one, but some who might have attended this meeting had already been in Glasgow early in the summer as delegates to the jubilee celebration of the University. Since the president of the Association this year is one of the most distinguished physicists in Great Britain, it was natural to expect a large gathering of workers in his branch of science, but here also certain well-known names were missed from the list of members, which may likewise be attributed to the above cause. The meetings of all the sections were very conveniently held in the splendid University buildings on Gilmore Hill, the Physical Section holding its sessions in the Natural Philosophy Class Room, rendered famous by Sir William Thomson, now Lord Kelvin. The only criticism that could be made of the local arrangements was the absence of notices at the doors of each section indicating what paper was being read, but the same complaint has frequently been heard at our American Association meetings.

Professor Rücker's presidential address, which has already appeared in *SCIENCE*, was a scholarly defense of the atomic theory of matter, but some disappointment was manifested that the objections of its opponents were not definitely stated. Lord Kelvin, who seconded the vote of thanks to the