resent the views of the majority of the faculty at any given time.

If in discussing the position of scientific men in this country I have given greater prominence to the conditions which tend to retard progress than to those which favor it, it is because I believe that the first step toward the removal of obstacles is to state clearly what those obstacles are. It is not improbable that some evils will disappear as soon as it is generally recognized that they are evils. We have seen that the public are more interested than they were in the welfare of scientific men, and the better they understand existing conditions, the better for us. If they now believe that organization and concentration are necessary in science, as in business, they should also understand that organization has its dangers as well as its advantages. While accepting the prevailing idea of the necessity of organization, we must, at the same time, insist that the future of science requires that a proper balance be maintained between general organization and individual independence. Furthermore, the organization needed in science does not consist in having scientific work placed under the control of purely business men but of scientific men who have a capacity for administration, and such men can be found. Purely financial matters must be entrusted to non-scientific business men, but science itself is something different from business in the ordinary sense. Even when placed in charge of scientific men, it is important to avoid carrying the organization of science so far as to repress individual effort and bring about a sort of bureaucracy which resents unfavorable criticism and requires all work to conform to a fixed narrow standard. Science should be a republic in which, with the approval of the majority of workers, the more capable become the rulers. Science should be well organized, but it should never become, in a purely business sense, a trust.

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THE PROBLEM OF THE METALLIFEROUS VEINS.[1]

The rush of the gold-seekers to California in 1849, and the quickly following one to Australia in 1851, were notable migrations in search of the yellow metal, but they were not the first in the history of our race. There is, indeed, no reason to suppose that, in the past, mining excitements were limited even to the historical period; on the contrary, the legends of the golden fleece, and of the golden apples of the Hesperides, probably describe in poetic garb two of the early expeditions, and long before either we can well imagine primitive man hurrying to new diggings in order to enlarge his scanty stock of metals. Among the influences which have led to the exploration and settlement of new lands, the desire to find and acquire gold and silver has been one of the most important, and as a means of introducing thousands of vigorous settlers, of their own volition, into uninhabited or uncivilized regions there is no agent which compares with it. In this connection it may be also remarked that there is no more interesting chapter in the history of civilization, than that which concerns itself with the use of the metals and with the development of methods for their extraction from their ores. Primitive man was naturally limited to those which he found in the native state. They are but few, viz., gold in wide but sparse distribution in gravels; copper in occasional masses along the outcrops of veins, in which far the greater part of the metal is combined with oxygen or sulphur, copper again, in porous rocks, as in the altogether exceptional case

[1] Presidential address before the New York Academy of Sciences, December 18, 1905.

of the Lake Superior mines; iron in an occasional meteorite, which, if its fall had been observed, was considered to be the image of a god, descended from the skies;[2] silver in occasional nuggets with the more common ones of gold; and possibly a rare bit of platinum. Besides these no other metal can have been known, because all the rest and all of those mentioned, when locked up in their ores, give in the physical properties of the latter but the slightest suggestion of their presence. Chance discoveries must have first revealed the possibilities of producing iron from its ore—really a very simple process when small quantities are involved; of making bronze from the ores of copper and tin; of making brass with the ores of copper and zinc; of reducing copper and lead from their natural compounds; and of freeing silver from its chief associate, lead. All of these processes were extensively practised under the Chinese, Phenicians, Greeks, Romans and other ancient peoples.

As the need of weapons in war, the advantages of metallic currency and the want of household utensils became felt, and as the minerals which yield the metals became recognized as such, the art of mining grew to be something more than the digging and washing of gravels; and in the long course of time developed into its present stage as one of the most difficult branches of engineering. Chemistry raised metallurgical processes from the art of obtaining *some of a metal* from its ore, to the art of obtaining *almost all* of it and of accounting for what escaped. It is, in fact, in this scientific accounting for everything, that modern processes chiefly differ from those of the ancients.

Of all the metals the most important which minister to the needs of daily life are the following, ranged as nearly as possible in the order of their usefulness: Iron, copper, lead, zinc, silver, gold, tin, aluminum, nickel, platinum, manganese, chromium, quicksilver, antimony, arsenic and cobalt. The others are of very minor importance, although often indispensable for certain restricted uses.

[2] As in the case of Diana of the Ephesians and the deity of the Carthaginians.

The manner of occurrence of these metals in the earth, and their amounts in ores which admit of practicable working are fundamental facts in all our industrial development, and some accurate knowledge of them ought to be a part of the intellectual equipment of every well-educated man. The matter may well appeal to Americans, since the United States have developed within a few years into the foremost producers of iron, copper, lead, coal, and until recent years of gold and silver; but with regard to gold, they have of late alternated in the leadership with the Transvaal and Australia, and in silver are now second to Mexico.

Despite the enormous product of foodstuffs, American mining developments are of the same order of magnitude; and the mineral resources of the country have proved to be one of the richest possessions of its people.

We may best gain a proper conception of the problem of the metalliferous veins, if we state at the outset the gross composition of the outer portion of the globe, so far as geologists have been able to express it by grouping analyses of rocks. We may then note among the elements mentioned, such of the metals as have just been cited and may remark the rarity of the others; we may next set forth the necessary percentages of each metal which make a deposit an ore, that is, make it rich enough for profitable working. By comparison we can grasp in a general way the amount of concentration which must be accomplished by the geological agents in order to collect from a naturally lean distribution in rocks enough of a given metal to produce a deposit of ore; and can then naturally pass to a brief discussion and description of those agents and their operations.

If the general composition of the crust of the earth is calculated as closely as possible on the basis of known chemical analyses, the following table results, which has been compiled by Dr. F. W. Clarke, of Washington, chief chemist of the U. S. Geological Survey.[3]

Oxygen	47.13
Silicon	27.89
Aluminum	8.13
Iron	4.71
Calcium	3.53
Magnesium	2.64
Potassium	2.35
Sodium	2.68
Titanium	.32
Hydrogen	.17
Carbon	.13
Phosphorus	.09
Manganese	.07
Sulphur	.06
Barium	.04
Chromium	.01
Nickel	.01
Strontium	.01
Lithium	.01
Chlorine	.01
Fluorine	.01
Total	100.00

Elements less than .01 per cent. are not considered abundant enough to affect the total, and equally exact data regarding them are not accessible. Among those given only the following appear which are metals of importance as such in every-day life: aluminum 8.13, iron 4.71, manganese .07, chromium .01 and nickel .01. They rank, respectively, in the table, third, fourth, thirteenth, sixteenth and seventeenth. Of the five, iron is the only one of marked prominence. No one of the remaining four is comparable in usefulness with at least five other metals which are not mentioned, viz., copper, lead, zinc, silver and gold.

An endeavor has been made by at least one investigator, Professor J. H. L. Vogt, of Christiania, to establish some quantitative expression for these other metals. His estimates are as follows:[4]

Copper percentage beyond the fourth or fifth place of decimals, that is, in the hundred thousandths or millionths of a per cent.

Lead and zinc, percentages in the fifth place of decimals or in the hundred thousandths of a per cent.

Silver, percentage, two decimal places beyond copper—or in the ten millionths to the hundred millionths of a per cent., or the ten thousandth to the hundred thousandth of an ounce to the ton.

Gold, percentage, one tenth as much as silver.

Tin, percentage in the fourth or fifth decimal place, that is, in the ten thousandths or hundred thousandths of a per cent.

These figures, inconceivably small as they are, convey some idea of the rarity of these metals as constituents on the average of the outer six or eight miles of the earth's crust. But they are locally more abundant in particular masses of eruptive rocks which are associated with ore deposits.

In the following tabulation I have endeavored to bring together a number of determinations which have been made in connection with investigations of American mining districts. In a general way they give a fair idea of the metallic contents of certain eruptive rocks from which were taken samples as little as possible open to the suspicion that they had been enriched by the same processes which had produced the neighboring ore-bodies.

In order to come within the possible limits of profitable and successful treat-

[3] Bulletin 148, p. 13.

[4] *Zeitschrift für prak. Geologie*, 1898, 324.

	Per Cent. in Eruptive Rocks.	From.
Copper,	.009	Missouri.[5]
Lead,	.0011	Colorado.[6]
Lead,	.008	Eureka, Nev.[7]
Lead,	.004	Missouri.[5]
Zinc,	.0048	Leadville, Colo.[8]
Zinc,	.009	Missouri.[5]
Silver,	.00007	Leadville, Colo.[9]
Silver,	.00016	Eureka, Nev.[7]
Silver,	.00016	Rosita, Colo.[10]
Gold,	.00002	Eureka, Nev.[7]
Gold,	.00004	Owyhee Co.,[11] Id.

ment the ores of the more important metals should have at least the above percentages, but that we may grasp the relations correctly, it must be appreciated that local conditions affect the limits. Thus in a remote situation and with high charges for transportation an ore may be outside profitable treatment, although it may contain several times the percentages of those more favorably situated. Iron ores in particular which are distant from centers of population, are valueless unless cheap transportation on a very large scale can be developed, while gold in an almost inaccessible region, like the Klondike, may yield a rich reward, even when in quantities which, if expressed in percentages, are almost inappreciable.

The nature of the ore is also a factor of prime importance. Some compounds yield the metals readily and cheaply, while others, which in the case of the precious metals are often called base ores, require complicated and it may be expensive metallurgical treatment. The association of metals is likewise of the highest importance. Copper or lead, for example, greatly facilitates the extraction of gold and silver, whereas zinc in large quantities is a hindrance. Conditions also change. An ore which may have been valueless in early days may prove a rich source of profit in later years and under improved conditions. For instance, from 1870 for over twenty-five years Bingham Canyon in Utah yielded lead-silver ores and minor deposits of gold. It was known that in some mines low-grade and base ores of copper and gold existed, but the fact was carefully concealed and in at least one instance the shaft into them was filled up, lest a general knowledge of the fact should unfavorably affect the value of the property. To-day, however, these ores are eagerly sought and their extraction and treatment in thousands of tons daily are paying good returns on very large capitalization. Another factor is the expense of extraction. If simple and inexpensive methods are possible, the area of profitable treatment is greatly widened. Thus gold may need little else than a stream of water or even a blast of air, whereas iron and copper require huge furnaces and vast supplies of coke and fluxes.

Iron ores are of little value in any part of the world unless they contain a minimum of 35 per cent. iron when they enter the furnace, but if they are distributed in amounts of 10–20 per cent., in extensive masses of loose or easily crushed rock in such condition that they can be cheaply concentrated up to rich percentages, they may be profitably treated and a product with 50 per cent. iron or higher be sent to the furnaces. Nevertheless, speaking for the civilized world at large, it holds true that as an iron ore enters the furnace, it can not have less than 35 per cent., and in

[5] Average of eight eruptives from Missouri, Anals. by J. D. Robertson. Report on Lead and Zinc, Mo. Geol. Surv., II., 479.

[6] Average of six different rocks, embracing eighteen assays; S. F. Emmons, Monograph XII., U. S. Geol. Surv., 591.

[7] One rock, a quartz porphyry, not certain the rock was not enriched. J. D. Curtis, U. S. Geol. Surv., Mono. VII., 136.

[8] Same reference as under 6. The zinc was determined in but two samples.

[9] Same reference as under 6, but p. 594.

[10] S. F. Emmons, XVII. Ann. Rep. U. S. Geol. Survey, Part II., p. 471.

[11] A. Simundi in Tenth Census, XIII., 54.

America with our rich and pure deposits on Lake Superior two thirds of our supply ranges from 60–65 per cent.

As regards copper, a minimum working percentage, amid favorable conditions and with enormous quantities, is usually about 3 per cent., but in the altogether exceptional deposits of the native metal in the Lake Superior region, copper-rock as low as three fourths of one per cent. has been profitably treated. This or any similar result could only be accomplished with exceptionally efficient management and with a copper rock such as is practically only known on Lake Superior. With the usual type of ore, not enriched by gold or silver, two per cent. is the extreme and in remote localities five to ten may sometimes be too poor.

In southeast Missouri, lead ores are profitably mined which have 5–10 per cent. lead, but they are concentrated to 65–70 per cent. before going to the furnace.

Zinc ores at the furnace ought not to yield less than 25–30 per cent., and when concentrated or selected they range up to 60 per cent.

The precious metals are expressed in troy ounces to the ton avoirdupois. A troy ounce in a ton is one three-hundredths of one per cent., and the amount is, therefore, very small when stated in percentages. If it be appreciated that in round numbers silver is now worth fifty to sixty cents an ounce and gold twenty dollars, some grasp may be had of values. Silver rarely occurs by itself. On the contrary, it is obtained in association with lead and copper, and the ores are, as a rule, treated primarily for these base metals, and then from the latter the precious metals are later separated. In the base ores there ought to be enough silver to yield a minimum of five dollars or ten ounces in the resulting ton of copper in order to afford enough to pay for separation. Now in a five per cent. ore of copper we have a concentration of twenty tons of ore to yield one ton of pig, or, more correctly stated, so as to allow for losses, twenty-one tons to one. We must, therefore, have at least ten ounces of silver in the twenty-one tons, which implies a minimum of about one half ounce per ton. Smelters will only pay a miner for the silver if he has over one half ounce per ton in a copper ore. In a pig of lead, usually called base bullion, it is necessary for profitable extraction to have fifteen ounces of silver. For smelting a lead ore we must possess at least ten per cent. lead and may have seventy. It is, therefore, obvious that from two to twenty ounces silver must be present in the ton of lead ore. The common ranges are ten to fifty ounces or one thirtieth to one sixth of one per cent.

Gold is so cheaply extracted that it may be profitably obtained under favorable circumstances down to one tenth of an ounce in the ton, but the run of ores is from one fourth ounce or five dollars to one ounce or twenty dollars. Ores of course sometimes reach a number of ounces. In copper or lead ores even a twentieth of an ounce may be an object and in favorably situated gravels, to which the hydraulic method may be applied, even as little as seven to ten cents in the cubic yard may be recovered or some such value as one two-hundredths to one three-hundredths of an ounce per ton.

The tin ores as smelted contain about 70 per cent., but they are all concentrated either by washing gravels in which the percentage is one or less or else by mining, crushing and dressing ore in which it ranges from 1.5 to 3 per cent. The tin-bearing gravels represent a concentration from much leaner dissemination in the parent veins and granite. Aluminum ores yield as sold about 30 per cent. of the metal. This is an enrichment as compared with the rocks, though not so striking a one as in the case of other metals. But the great change necessary in aluminum is in the method of combination. It is so tightly locked up in silicates in the rocks as to preclude direct extraction by any known method.

Nickel needs to be present in amounts of several per cent., say two to five, and occurs either alone or with copper. Cobalt is always with it in small amounts. Platinum occurs in exceedingly small percentages. It is almost all obtained from gravels in Russia, and the gravels yielded in 1899, according to C. W. Purington, about forty cents to the yard, platinum being quoted in that year at $15 to $18 per ounce. There was, therefore, in the gravels about one fortieth ounce in the yard, or one sixtieth in a ton or about 5.5 hundred-thousandths of a per cent. Platinum in some rocks has been found in amounts of one twentieth to one half ounce, or from 16 hundred-thousandths to 16 ten-thousandths of one per cent., but they are rare and peculiar types.

In order to be salable manganese ores of themselves must yield about 50 per cent., but if iron is also present they may be as low as 40. Chromium has but one ore, and it must contain about 40 per cent. Of antimony, arsenic and cobalt it is hardly possible to speak, since, except perhaps in the case of the first, they are unimportant by-products in the metallurgy of other ores.

In summary it may be stated that in the ores the metals must be present in amounts shown in accompanying table.

	Percentages in Ores.	Ounces to Ton.	Percentage in the Earth's Crust.
Iron,	35–65		4.71
Copper,	2–10		.0000*X*
Lead,	7–50		.0000*X*
Zinc,	25–60		.0000*X*
Silver,	1/12–1/150	2–25	.000000*X*
Gold,	1/300–1/6,000	1/20–1	.0000000*X*
Tin,	1–3		.000*X*–.0000*X*
Aluminum,	30		8.13
Nickel,	2–5		.01
Manganese,	50		.07
Chromium,	40		.01

We now have before us some fundamental conceptions from which as a point of departure we may set out upon the real discussion of the subject. We understand the gross composition of the outer earth; we have some idea of the quantitative distribution of the metals in the rocks, especially in the richer instances; finally we have seen the extent to which they must be concentrated in order that they may be objects of mining. The next step is to establish first the agent or solvent which can effect the collection of the sparsely distributed metals, and second the places where the precipitation of them takes place. We may then inquire more particularly into the source of the agent and the methods of its operation. In order to do this in the time at command I must remorselessly focus attention on the large and essential features, resolutely avoiding every side issue or minor point, however inviting.

The one solvent which is sufficiently abundant is water, and practically all observers are agreed that for the vast majority of ore deposits it has been the vehicle of concentration. Of course it need not operate alone. On the contrary, easily dissolved and ever-present materials like alkalies may, and undoubtedly do, increase its efficiency. It does not operate necessarily as cold water. On the contrary, we all know that the earth grows hotter as we go down, so that descending waters could not go far without feeling this influence. Volcanoes, too, indicate to us that there are localities where heat is developed in enormous amounts and not far below the surface. There is, therefore, no lack of heat and we only need to be familiar with the western country to know that there is no lack of hot springs when we take a comprehensive view. As solvents, hot waters are so incomparably superior to cold waters that they appeal to us strongly. We may, therefore, take it as well established that water is the vehicle. The chemical compounds which constitute the ores naturally differ widely in solubility and no sweeping statements can be made regarding them. Iron, for example, yields very soluble salts and is widely, one might almost say universally distributed in ordinary waters. Its ores are compounds of the metal with oxygen, and in this respect it differs from nearly all others, which are mostly combined with sulphur. Although almost all of them have oxidized compounds, the latter are on the whole very subordinate contributors to our furnaces.

Iron is everywhere present in the rocks and when exposed to the natural reagents it is one of their most vulnerable elements. It, therefore, presents few difficulties in the way of solution and concentration by waters which circulate on or near the surface and which perform their reactions under our eyes.

The compounds of copper, lead, zinc, silver, nickel, cobalt, quicksilver, antimony and arsenic with sulphur present more difficult problems and ones into whose chemistry it is impossible to enter here in any thorough way, but in general it may be said that the solutions were probably hot, that they were in some cases alkaline, in others acid, and that the pressure under which they took up the metals in the depths has been an important factor in the process. The loss of heat and pressure as they rose toward the surface no doubt aided in an important way in the result.

The first condition for the production of an ore-deposit is a waterway. It may be a small crack, or a large fracture, or a porous stratum, but in some such form it must exist. Naturally porous rock affords the simplest case, and provides an easily understood place of precipitation. For example, in the decade of the seventies rather large mines at Silver Reef, in southern Utah, were based upon an open-textured sandstone into which and along certain lines silver-bearing solutions had entered. Wherever they met a fossil leaf or an old stick of wood which had been buried in the rock the dissolved silver was precipitated as sulphide or chloride. Sometimes for no apparent reason the solutions impregnated the rock with ore, but the ore seems to follow along certain lines of fracturing. Again at Silver Cliff near Rosita in central Colorado, the silver solutions had evidently at one time soaked through a bed of porous volcanic ash, and had impregnated it with ore, which, while it lasted, was quarried out like so much rock. In the copper district of Keweenaw Point on Lake Superior, the copper bearing solutions have penetrated in some places an old gravel bed and impregnated it with copper; in other places they have passed along certain courses in vesicular lava flows, and have yielded up to the cavities, scales and shots of native copper.

It has happened at times that the ore-bearing solutions, rising through some crevice, have met a stratum charged with lime, and having spread sideways have apparently been robbed of their metals because the lime precipitated the valuable minerals. In the Black Hills of South Dakota, there are sandstones with beds of calcareous mud rocks in them. Solutions bringing gold have come up through insignificant-looking crevices called 'verticals' and have impregnated these mud-rocks with long shoots of valuable gold ores. In prospecting in a promising locality the miner, knowing the systematic arrangement of the verticals, and having found the lime shales, drifts along in them, following a crevice in the hope of breaking into ore. The very extended and productive shoots of lead-silver ores at Leadville, Colo., which have been vigorously and continuously mined since 1877, are found in limestone and usually just underneath sheets of a relatively impervious eruptive rock. They run for long distances and suggest uprising solutions which followed along beneath the eruptive, perhaps checked by it, so that they have replaced the limestone with ore. The limestone must have been a vigorous precipitant of the metallic minerals.

The fracture itself up through which the waters rise may be of considerable size and thus furnish a resting place for the ore and gangue, as the associated barren mineral is called. A deposit then results which affords a typical fissure vein. The commonest filling is quartz, but at times a large variety of minerals may be present and sometimes in beautifully symmetrical arrangement. In the latter case the uprising waters have first coated each wall with a layer. They have then changed in composition and have deposited a later and different one, and so on until the crack has become filled. Often cavities are left at the center or sides and are lined with beautiful and shining crystals, which flash and sparkle in the rays of a lamp, like so many gems. There are quartz veins in California which are mined for gold and which seem to have filled clean-cut crevices, wall to wall, for several feet across. More often there is evidence of decided chemical action upon the walls, which may be impregnated with the ore and gangue for some distance away from the fissure. As the source of supply is left, however, the impregnation becomes less and less rich, and finally fades out into barren wall-rock. The enrichment of the walls varies also from point to point, since where the rock is tight the solutions can not spread laterally, but where it is open the impregnation may be extensive. The miner has, therefore, to allow for swells and pinches in his ore.

Of even greater significance than the lateral enrichment is the peculiar arrangement of the valuable ore in a vein that may itself be continuous for long distances although in most places too barren for mining. Cases are, indeed, known in which profitable vein matter may be taken out continuously for perhaps a mile along the strike, but they are relatively rare. The usual experience reveals the ore running diagonally down in the vein filling, and more often than not following the polished grooves in the walls which are called slickensides, and which indicate the direction taken by one wall when it moved on the other during the formation of the fracture. The rich places may terminate in depth as well, and again may be repeated, but they must be anticipated, and for them allowance must be made in any mining operation.

Ores, therefore, gather along subterranean waterways. They may fill clean-cut fissures, wall to wall; they may impregnate porous wall rocks on either side, they may even entirely replace soluble rocks like limestones.

We may now raise the question as to the source of the water which accomplishes these results and the further question as to the cause of its circulations.

The nature of the underground waters which are instrumental in filling the veins, presents one of the most interesting, if not the most interesting, phase of the problem and one upon which attention has been especially concentrated in later years. The crucial point of the discussion relates to the relative importance of the two kinds of ground-waters, the magmatic, or those from the molten igneous rocks, and the meteoric or those derived from the rains. The magmatic waters are not phenomena of the daily life and observation of the great majority of civilized peoples, and for this reason they have not received the attention that otherwise would have fallen to their share. Relatively few geologists have the opportunity to view volcanoes in active eruption, and have but disproportionate conceptions of the clouds and clouds of watery vapor which they emit. The enormous volume has, however, been brought home to us in recent years, with great force, by the outbreak of Mont Pelée, and we of this academy, thanks to the efforts of our fellow-member, Dr. E. O. Hovey, of the American Museum of Natural History, have had them placed very vividly before us. It is on the whole not surprising that to the meteoric waters most observers in the past have turned for the chief, if not the only, agent. I will, therefore, first present as fully as the time admits, and as fairly as I may, this older view which still has perhaps the largest number of adherents.

Except in the arid districts, rain falls more or less copiously upon the surface of the earth. The largest portion of it runs off in the rivers; the smallest portion evaporates while on the surface, and the intermediate part sinks into the ground, urged on by gravity, and joins the ground-waters. Where crevices of considerable cross-section exist, they conduct the water below in relatively large quantity. Shattered or porous rock will do the same and we know that open-textured sandstones dipping down from their outcrops and flattening in depth lead water to artesian reservoirs in vast quantity. As passages and crevices grow smaller, the friction on the walls increases and the water moves with greater and greater difficulty. When the passage grows very small, movement practically ceases. The flow of water through pipes is a very old matter of investigation, and all engineers who deal with problems of water supply for cities or with the circulation of water for any of its countless applications in daily life must be familiar with its laws. Friction is such an important factor that only by the larger natural crevices can the meteoric waters move downward in any important quantity or with appreciable velocity. They do sink, of course, and come to comparative rest at greater or less distance from the surface and yield the supplies of underground water upon which we draw.

The section of the rocks which stands between the surface and the groundwater is the arena of active change and is that part of the earth's crust in which the meteoric waters exercise their greatest effect. Rocks within this zone are in constant process of decay and disintegration. Oxidation, involving the production of sulphuric acid from the natural metallic sulphides, is actively in progress. Carbonic acid enters also with the meteoric waters. The rocks are open in texture and favorably situated for maximum change. From this zone we can well imagine that all the finely divided metallic particles which are widely and sparsely distributed in the rocks go into solution and tend to migrate downward into the quiet and relatively motionless ground-water. If the acid solutions escape the precipitating action of some alkaline reagent such as limestone they may even reach the ground-waters, and their dissolved burdens may be contributed to this reservoir, but the greater portion seems to be deposited at the level of the ground-water itself or at moderate distances below it. Impressed by these phenomena which present a true cause of solution, and influenced by their familiar and every-day character, we may build up on the basis of them a general conception of the source of the metallic minerals dissolved in those aqueous solutions which are recognized by all to be the agents for the filling of the veins.

Let us now focus attention on the ground-water. This saturates the rocks, fills the crevices and forces the miner who sinks his shaft, to pump, much against his natural inclination. The vast majority of mines are of no great depth, and the natural conclusion of our earlier observers, based on this experience, has been that the ground-waters extend downward, saturating the strata of the earth to the limit of possible cavities, distances which vary from 1,000 to more than 30,000 feet. To this must be added another familiar phenomenon. The interior temperature of the earth increases at a fairly definite ratio of about one degree Fahrenheit for each 60–100 feet of descent. In round numbers, if we start with a place of the climatic conditions of New York—that is, with a mean annual temperature of about 51°, we should on descending 10,000 feet below the surface find a temperature of about 212°, and if we go still deeper, it would be still greater. Of course, under the burden of the overlying column of water, the actual boiling points for the several depths would be greater, and it is a question whether the increase of temperature would overcome the increase of pressure and the consequent rise of the boiling point so as to convert this water into steam, cause great increase in its elasticity, decrease in its specific gravity and thereby promote circulations. At all events, the rise in temperature would cause expansion of the liquid, would disturb equilibrium and to this degree would promote circulations.

There is one other possible motive power. The meteoric waters enter the rocky strata of the globe at elevated points, sink downward, meet the ground-water at altitudes above the neighboring valleys and establish thereby what we call head. In consequence they often yield springs. If we imagine the head to be effective to considerable depths we have again the deep-seated waters under pressure, which after their long and devious journey through the rocks may cause them to rise eleswhere as springs. The head may in small degree be aided by the expansion of the uprising heated column, whose specific gravity is thereby lowered as compared with the descending colder column.

May we now draw all these facts and supposed or assumed phenomena into one whole?

The descending meteoric waters become charged with dissolved earthy and metallic minerals in their downward, their deep-seated lateral and perhaps also at the beginning of their heated uprising journey. They are urged on by the head of the longer and colder descending column and by the interior heat. They gather together from many smaller channels into larger issuing trunk channels. They rise from regions of heat and pressure which favor solution, into colder regions of precipitation and crystallization. They deposit in these upper zones their burden of dissolved metallic and earthy minerals and yield thus the veins from which the miner draws his ore.

This conception is based on phenomena of which the greater part are the results of every-day experience. It is attractive, reasonable and is on the whole the one which has been most trusted in the past. Doubtless it has the widest circle of adherents to-day. It is, however, open to certain grave objections which are gaining slow but certain support.

The conception of the extent of the ground-water in depth, for example, is flatly opposed to our experience in those hitherto few but yearly increasing deep mines which go below 1,500 or 2,000 feet. Wherever deep shafts are located in regions other than those of expiring but not dead volcanic action, they have passed *through* the ground-water, and if this is carefully impounded in the upper levels of the mines and not allowed to follow the workings downward, it is found that there is not only less and less water, but that the deep levels are often dry and dusty. Along this line of investigation, Mr. John W. Finch, recently the State Geologist of Colorado, has reached the conclusion, after wide experience with deep mines, that the ground-waters are limited, in the usual experience, to about 1,000 feet from the surface and that only the upper layer of this is in motion and available for springs.

Artesian wells do extend in many cases to depths much greater than this and bring supplies of water to the surface, but their very existence implies waters impounded and in a state of rest.

To this objection that the ground-waters are shallow it has been replied that when the veins were being formed the rocks were open-textured and admitted of circulation, but subsequently the cavities and waterways became plugged by the deposition of minerals by a process technically called cementation, and the supply being cut off, they now appear dry. There must, however, in order to make 'the head' effective have once been a continuous column of water which introduced the materials for cementation. It is at least difficult to understand how a process, which could only progress by the introduction of material in very dilute solution, should by the agency of crystallization drive out the only means of its production. Some residue of water must necessarily remain locked up in the partially cemented rock. This residue we, of course, do not find where rocks are dry and drifts are dusty. In many cases also where deep cross-cuts have penetrated the fresh wall-rock of mines, cementation if present has been so slight as to escape detection.

If we once admit that this conclusion is well based, it removes the very foundation from beneath the conception of the meteoric waters and tumbles the whole structure in a heap of ruins.

While I would not wish to positively make so sweeping a statement as this about a question involving so many uncertainties, there is nevertheless a growing conviction among a not inconsiderable group of geologists that the rocky crust of the earth is much tighter and less open to the passage of descending waters than has been generally believed; and that the phenomena of springs which have so much influenced conclusions in the past, affect only a comparatively shallow overlying section. Such phenomena of cementation as we see are probably in large part due to the action of water stored up by the sediments when originally deposited and carried down by them with burial. Under pressure a relatively small amount of water may be an important vehicle for recrystallization.

It has been assumed in the above presentation of the case of the meteoric waters that they are able to leach out of the deep-seated wall rocks the finely disseminated particles of the metallic minerals, but the conviction has been growing in my own mind that we have been inclined to overrate the probability of this action in our discussions. In the first place our knowledge of the presence of the metals in the rocks themselves is based upon the assay of samples almost always gathered from exposures in mining districts. The rock has been sought in as fresh and unaltered a condition as possible and endeavors have been made to guard against the possible introduction of the metallic contents by those same waters which have filled the neighboring veins. But if we admit or assume that the assay values are original in the rock; and, in case the latter is igneous, if we believe that the metallic minerals have crystallized out with the other bases from the molten magma, we are yet confronted with the fact that their very presence and detection in the rock show that they have escaped leaching even though they occur in a district where underground circulations have been especially active. From the results which we have in hand, it is quite as justifiable to argue that the metals in the rocks are proof against the leaching action of underground circulations as that they fall victims to it. These considerations tend to restrict the activities of the meteoric waters to the vadose region as Posepny calls it, *i. e.,* that belt of the rocks which stands between the permanent water-level and the surface. Within it is an active area of solution, as we have all recognized for many years, but, as previously stated, experience shows that the metals which go into solution in it strongly tend to reprecipitate at or not far below the water-level itself.

It is of interest, however, to seek some quantitative expression of the problem and the assays given above furnish the necessary data.

I have taken the values of the several metals which have been found by the assays of what were in most cases believed to be normal wall rocks, selecting those of igneous nature because experience shows them to be the richest. The percentages have been turned into pounds of the metal per ton of rock; this latter value has then been recast into pounds of the most probable natural compound or mineral in each case. I have next calculated the volume of a cube corresponding to the last weight, and by extracting its cube root have found the length of the edge of such cube. If now we assume a rock of a specific gravity of 2.70, which is a fair average value, and allow it 11 to 12 cubic feet to the ton, or say 20,000 cubic inches, the edge of the cube-ton will be 27.14 inches. The ratio of the edge of the cube of metallic mineral to the edge of the cube-ton of enclosing rock, will give us an idea of the chance that a crack large enough to form a solution-water-way will have of intersecting that amount of contained metallic mineral. Of course in endeavoring to establish this quantitative conception I realize that the metallic mineral is not in one cube, and that through a cube-ton of rock more than one crack passes, but I assume that the fineness of division of the metallic mineral practically keeps pace with the lessening width and close spacing of the crevices. It is also realized that the shape of the minerals is not cubical. I am convinced from microscopic study of rocks and the small size of the metallic particles that their subdivision certainly keeps pace with any conceivable solution-cracks, and that no great error is involved in the first assumption made. The sides of a cube represent three planes which intersect at right angles and which are mathematically equivalent to any series of planes intersecting at oblique angles. Hence if we consider as cubes the subdivisions formed in our rock mass by any series of intersecting cracks, there are three sets of planes, any one of which might intersect the cube of ore. We must, therefore, multiply the ratio of probability that any single set will intersect it by three in order to have the correct expression. The chance, therefore, that a crack, of the width of the cubic edge of the enclosed mineral, will strike that cube is given by the ratios in the last column, which ratios I assume hold good with increasing fineness of subdivision both of metallic minerals and of cracks.

From the table it is evident that the chances vary from a maximum in the case of copper of one in six through various intermediate values to a minimum for gold of one in over one hundred. This is equivalent to saying that with cracks

	Per Cent. by Analysis.	Pounds Per Ton.	Pounds Chalcopyrite.	Volume Cu. In.	Edge of Cube.	Ratio of Edge to Edge of Cube-ton Rock.	Ratio of Probability.
Copper.	.009	.18	.52	3.42	1.5	1/18	1/6
			Galena.				
Lead.	.0011	.022	.025	.092	.45	1/60	1/20
	.008	.16	.186	.700	.89	1/31	1/10
	.004	.08	.092	.340	.70	1/39	1/13
			Zincblende.				
Zinc.	.0048	.096	.128	.90	.97	1/35	1/12
	.009	.180	.240	1.60	1.17	1/21	1/7
			Argentite.				
Silver.	.00007	.0014	.0016	.006	.18	1/148	1/49
	.00016	.0032	.0037	.014	.24	1/113	1/38
			Gold.				
Gold.	.00002	.0004	.0004	.00065	.086	1/313	1/104
	.00004	.0008	.0008	.00130	.109	1/249	1/83

whose width bears the same relation to the width of the rock mass as is borne by the diameter of the particle of ore, the chance of crossing a particle varies from one in six to one in one hundred. Or we may say that with cracks of this spacing from one sixth to one one-hundredth of the contained metallic mineral might be leached out.[12] When, therefore, as is often the case in monographs upon the geology of a mining district, inferences are drawn as to the possibility of deriving the ore of a vein by the leaching of wall-rocks whose metallic contents have been proved by assay, the total available contents ought to be divided by a number from six to one hundred if the above reasoning is correct. This diminution will tend to modify in an important manner our belief in the probability of such processes as have been hitherto advocated. We may justly raise the following questions. How closely set, as a matter of fact, are the cracks which are large enough to furnish solution waterways in the above rocks, and can we reach any definite conception regarding their distribution? Some quantitative idea of the relations may be obtained from the tests of the recorded absorptive capacity of the igneous rocks which are employed as building stone. G. P. Merrill in his valuable work on 'Stones for Building and Decoration,' pp. 459, has given these values for 33 granites and 4 diabases and gabbros. They vary for the granites from a maximum of one twentieth to a minimum of one seven-hundred-and-fourth. I have averaged them all and have obtained one two-hundred-and-thirty-seventh as the result. That is, if we take a cubic inch of granite and thoroughly dry it, it will absorb water up to one two hundred and thirty-seventh of its weight. The volume of this water indicates the open spaces or voids in the stone. The average of the specific gravities of the 33 granites is 2.647. If, by the aid of this value we turn our weight of water into volume we find that its volume is one ninetieth that of the rock. For the four diabases and gabbros, similarly treated, the ratio of absorption is one three-hundred-and-tenth; the specific gravity is 2.776 and the ratio of volume one one-hundred-and-tenth. We can express all this more intelligibly by saying that, if we assume a cube of granite and if we combine all its cavities into one crack passing through it, parallel to one of its sides, the width of the crack will be to the edge of the cube, as 1 to 90. In the diabases and gabbros, similarly treated, the ratio will be 1 to 110. These values are very nearly the same as the average of the ratios of the edges of the cubes of rock and ore given in the table above, it being 1 to 104. We may conclude, therefore, that in so far as we can check the previous conclusion by experimental data, it is not far from the truth.

[12] With regard to the flow of waters through crevices and the relation of the flow to varying diameters or widths a very lucid statement will be found in President C. R. Van Hise's valuable paper in the *Transactions of the American Institute of Mining Engineers*, XXX., 41, and in his Monograph on Metamorphism.

It may be stated that the porphyritic igneous rocks which have furnished nearly all the samples for the above analyses, are as a rule extremely dense, and that their absorptive capacity is more nearly that of the compact granites than the open textured ones. It is highly improbable that underground water circulates through these rocks to any appreciable degree except along cracks which have been produced in the mechanical way, either by contraction in cooling and crystallizing, or by faulting and earth movements. The cracks from faulting are very limited in extent and in the greater number of our mining districts affect but narrow belts, small fractions of the total. Of the cracks from cooling and crystallizing those of us who have seen rock faces in cross-cuts and drifts underground, where excavations have been driven away from the veins proper, can form some idea, if we eliminate the shattering due to blasting. My own impression is that in rocks a thousand feet or so below the surface they are rather widely spaced, and that, when checked in a general way by the ratios just given, they are decidedly unfavorable materials from which the slowly moving meteoric ground-waters (if such exist) may extract such limited and finely distributed contents of the metals.

I have also endeavored to check the conclusions by the recorded experience in cyaniding gold ores in which fine crushing is so important, and I can not resist the conviction that we have been inclined to believe the leaching of compact and subterranean masses of rock a much easier and more probable process than the attainable data warrant.

As soon, however, as we deal with the open-textured fragmental sediments and volcanic tuffs and breccias the permeability is so enhanced as to make their leaching a comparatively simple matter. Yet so far as the available data go, they are poor in the metals or else are open to the suspicion of secondary impregnation. They certainly have been seldom, if ever, selected by students of mining regions as the probable source of the metals in the veins.

Should the above objections to the efficiency of the meteoric waters seem to be well established, or at least to have weight, it follows that the arena where they are most, if not chiefly, effective is the vadose region, between the surface and the level of the ground-water. Undoubtedly from this section they take the metals into solution and carry them down. But it is equally true that they lose a large part of this burden, especially in the case of copper, lead and zinc, at or near the level of the ground-water and are particularly efficient in the secondary enrichment of already formed but comparatively lean ore-bodies.

Let us now turn to the magmatic waters. That the floods of lava which reach the surface are heavily charged with them, there is no doubt. So heavily charged are they, that Professor Edouard Suess, of Vienna, and our fellow member, Professor Robert T. Hill, of New York, have seen reason for the conclusion that even the oceanic waters have in the earlier stages of the earth's history been derived from volcanoes rather than, in accordance with the old belief, volcanoes derive their steam from downward percolating sea-water. From vents like Mont Pelée which in periods of explosive outbreaks yield no molten lava, the vapors rise in such volume that cubic miles become our standards of measurement.

There is no reason to believe that many of the igneous rocks which do not reach the surface are any less rich and when they rise so near to the upper world that their emission may attain the surface, we must assign to the emitted waters a very important part in the underground economy.

This general question has attracted more attention in Europe in recent years as regards hot springs than in America. So many health resorts and watering-places are located upon them that they are very important foundations of local institutions and profitable enterprises. Professor Suess, whom I have earlier cited, delivered an address a few years ago at an anniversary celebration in Carlsbad, Bohemia, in which he maintained that in the Carlsbad district the natural catchment basin was insufficient to supply the waters and that both the unvarying composition and amount through wet seasons and dry were opposed to a meteoric source. Water, therefore, from subterranean igneous rocks, well-known to exist in the locality, was believed to be the source of the springs. The same general line of investigation has led Dr. Rudolf Delkeskamp, of Giessen, and other observers to similar conclusions for additional springs, so that magmatic waters have assumed a prominence in this respect which leaves little doubt as to their actual development and importance.

All familiar with western and southwestern mining regions know as a matter of experience, that the metalliferous veins are almost always associated with intrusive rocks, and that in very many cases the period of ore formation can be shown to have followed hard upon the entrance of the eruptive. The conclusion has, therefore, been natural and inevitable that the magmatic waters have been, if not the sole vehicle of introduction, yet the preponderating one.

With regard to their emission from the cooling and crystallizing mass of molten material we are not, perhaps, entirely clear or well established in our thought. So long as the mass is at high temperatures the water is potentially present as dissociated hydrogen and oxygen. We are not well informed as to just what is the chemical behavior of these gases with regard to the elements of the metallic minerals. Hydrochloric acid gas is certainly a widely distributed associate. If, as seems probable, these gases can serve alone or with other elements as vehicles for the removal of the constituents of the ores and the gangue, the possibilities of ubiquitous egress are best while the igneous rock is entirely or largely molten. In part even the phenomena of crystallization of the rock-forming minerals themselves may be occasioned by the loss of the dissolved gases. Through molten and still fluid rock the gases might bubble outward if the pressure were insufficient to restrain them and would, were their chemical powers sufficient, have opportunity to take up even sparsely distributed metals.

On the other hand, if their emission as seems more probable, is in largest part a function of the stage of solidification and takes place gradually while the mass is congealing, or soon thereafter, then they must depart along crevices and openings whose ratio to the entire mass would be similar to those given above. They might have, and probably do have, an enhanced ability to dissolve out in a searching and thorough manner the finely distributed metallic particles as compared with relatively cold meteoric waters which might later permeate the rock; but as regards the problem of leaching, the general relations of crevices to mass are much the same for both, and it holds also true that the discovery of the metals by assay of igneous rocks proves that all the original contents have not been taken, by either process.

We may, however, consider an igneous mass of rock as the source of the water even if not of the ores and gangue, and then we have a well-established reservoir for this solvent in a highly heated condition and at the necessary depths within the earth. Both from its parent mass and from the overlying rocks traversed by it, it may take the metals and gangue.

In the upward and especially in the closing journey, meteoric waters may mingle with the magmatic, and as temperatures and pressures fall, the precipitation of dissolved burdens takes place and our ore-bodies are believed to result. Gradually the source of water and its store of energy become exhausted; circulations die out and the period of vein-formation, comparatively brief, geologically speaking, closes. Secondary enrichment through the agency of the meteoric waters alone remains to influence the character of the deposit of ore. In brief, and so far as the process of formation of our veins in the western mining districts is concerned, this is the conception which has been gaining adherents year by year and which, on the whole, most fully accords with our observed geologic relations. It accords with them, I may add, in several other important particulars upon which I have not time to dwell.

In closing I may state, that speculative and uncertain as our solution of the problem of the metalliferous veins may seem, it yet is involved in a most important way, with the practical opening of the veins and with our anticipations for the future production of the metals. Every intelligent manager, superintendent or engineer must plan the development work of his mine with some conception of the way in which his ore-body originated, and even if he alternates or lets his mind play lightly from waters meteoric to waters magmatic, over this problem he must ponder. On its scientific side and to an active and reflective mind it is no drawback that the problem is yet in some respects elusive and that its solution is not yet a matter of mathematical demonstration. In science the solved problems lose their interest; it is the undecided ones that attract and call for all the resources which the investigator can bring to bear upon them. Among those problems which are of great practical importance, which enter in a far-reaching way into our national life and which irresistibly rivet the attention of the observer, there is none with which the problem of the metalliferous veins suffers by comparison.

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SCIENTIFIC BOOKS.

The Tower of Pelée: New studies of the great volcano of Martinique. By ANGELO HEILPRIN, F.R.G.S. Pp. 62 + 23 plates. Philadelphia, J. B. Lippincott Company. 1904.

In the past three years a good deal of literature has appeared concerning the West Indian eruptions of 1902. A part of this is a simple record of observed facts. Perhaps a greater portion is devoted to speculative inquiries into the cause and nature of the eruptions and attendant phenomena, especially those of Pelée, whose remarkable characteristics have excited the curiosity and interest of students in more than one branch of science. The solution of many of the problems is rendered extremely difficult through the lack of sufficient data upon which to support hypotheses, and geologists often are compelled to admit that certain of the problems must remain unsolved. It has been impossible, in many cases, to obtain much-needed information in the field in regard to many obscure matters on account of the continued activity of Pelée, and this must be taken into consideration when an unusual diversity of opinion appears in the views of different observers.

In the present work, which was published nearly at the same time as Lacroix's report, Professor Heilprin presents his views in regard to the origin and nature of the tower of Pelée. The book contains five short chapters, in the first of which the author describes his experiences and the impressions he received on the occasion of his fourth ascent of Pelée,