Frank Holman Probert

Mit herzlichem Glück auf, Ihr
Ergebenster
F. Pošepný

THE

GENESIS OF ORE-DEPOSITS.

A TREATISE

BY PROFESSOR FRANZ POŠEPNÝ,

OF VIENNA.

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TO

MADAME CLOTILDE POŠEPNÁ,

WIFE, COMRADE AND COLLEAGUE

OF THE DISTINGUISHED AND LAMENTED

AUTHOR OF THIS TREATISE,

THE PRESENT VOLUME IS INSCRIBED

IN WITNESS OF GRATITUDE FOR HER CO-OPERATION,

AND SYMPATHY WITH HER BEREAVEMENT.

PREFACE.

The name of Franz Posepny appears in the first volume of the *Transactions* of the Institute as one of its foreign members. At the Boston Meeting of February, 1888, he was elected an honorary member, in recognition of his numerous and valuable contributions to the literature of economic geology, and particularly to the science of ore-deposits, which has borne in Germany, at least, since the days of the brilliant Cotta, the name of *Erzlagerstättenlehre.* The views of Cotta and his associates, sometimes called for convenience "the Freiberg school,". dominated for a generation the current theories and classifications of mining engineers. This is particularly true of the United States, where the excellent translation of Cotta's text-book by Prof. Frederick Prime, one of his pupils, and one of the original members of the Institute, was for many years the controlling, and indeed the only easily available authority on this subject in the English language.

As a personal friend, diligent student and hearty admirer of Bernhard Cotta, and no less as professional critic of his views, I feel myself bound to say that his theories, as stated more than thirty years ago, are still, to a surprising degree, valid and comprehensive. There is scarcely a single modern modification of them, for which he did not, with intuitive prescience, leave a place. On the other hand, it is a fair criticism of the whole "Freiberg school," that it gave too much prominence and attributed too much typical importance to fissure-veins of the class represented in the *Erzgebirge.* Such writers as Groddeck and Grimm have undoubtedly aided to modify this disproportionate emphasis. But it has not ceased to influence the conceptions entertained by miners and even by legislators, as the United States mining law (evidently based on the "true fissure-vein" as a general type) abundantly demonstrates.

Posepny had contributed to the subject numerous monographs, throwing much-needed light upon it from the detailed study of special mining districts. He had been for many years devoted to this particular branch of geology, and had occupied for ten years a chair as professor in the Przibram Mining Academy, dealing exclusively with the theory of ore-deposits. When I urged him to contribute, for the International Meeting of the Institute in 1893, a paper on that subject, I did not venture to expect so generous a response as I received, in the free dedication to the Institute of a treatise comprising a summary of the views and observations of the distinguished author, and covering the whole field of his specialty. Besides its wealth of details, this treatise presents a most interesting and suggestive attempt at a genetic classification—a feature confessedly absent from most earlier systems.

The translation of Prof. Posepny's work was to me a labor both instructive and delightful; and I take pleasure in acknowledging here that my task was greatly lightened in that regard by the marvellous accuracy and beauty of the German manuscript, the whole of which came to me in the exquisite handwriting of Madame Posepny. Her husband was for some months unable to write, by reason of an injury to his hand. Probably he regarded this accident as a misfortune; but I trust he will not be offended if I say that his American translator had reason to take, with gratitude, a different view of it.

My translation of the paper itself has received the author's approval; but the translation of his later communication, which appears in this volume in the course of the discussion, goes to press without final revision on his part. I can only infer, from his omission to return with corrections the copy sent him several months ago, that he has not found serious errors in it.

The presentation of this paper at the Chicago Meeting of 1893 was the signal for a lively and interesting discussion on the part of American geologists. That discussion has by no means come to an end; and it is likely that the impulse thus given to a renewed study of this important subject will continue to operate for a long time to come. It was, however, necessary to stop somewhere, in preparing the present volume for the convenient use of readers; and the line has been drawn at the end of Vol. XXIV. of the *Transactions* of the Institute, so as to include, with a complete analytical index, for ready reference, both the original paper and all the discussions of it contained in Vols. XXIII. and XXIV.

R. W. Raymond.

Postscript.—Since the above paragraphs were put in type, the tidings of the death of Prof. Posepny on March 27, 1895, after long and severe suffering, have furnished a sorrowful explanation of my failure to receive any recent communication from him. A biographical notice of him will be published among the papers of the Florida Meeting of the Institute (the first session of which was held on the day of his death) and in volume xxv. of the *Transactions*. In the absence of time and space for other tribute here, I have inscribed this book to his wife, and prefixed to it a portrait of himself, for which I am indebted to the publishers of the New York *Engineering and Mining Journal*.—R. W. R.

THE GENESIS OF ORE-DEPOSITS.

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INTRODUCTION.

ALL serious investigators of this problem have recognized its complex character, and the difficulty of solving it definitively in the present state of our knowledge. Single and simple occurrences are at present clearly understood; but the more complicated phenomena give rise to discordant and often totally contradictory views, showing that we are still far from the truth upon this subject. The study of it has been the labor of my life; yet I must confess that the little I have here and there accomplished bears no proportion to the great range of the inquiry. I collect, nevertheless, in this paper, some of the personal views to which I have been led, chiefly in order that they may be submitted for consideration and discussion to my American colleagues.

Looking upon a single, somewhat complicated ore-deposit, we must confess that a superficial, tourist's examination of it could not give satisfactory results. Yet the literature of this subject refers us to such materials chiefly. Even treatises based upon the profound studies of years do not exhaust the subject; for they are affected by the existing stage of development of the auxiliary sciences, by the existing degree of exploration and exposure of the deposits described, and by the personal views of their authors.

Mining, indeed, constantly furnishes fresh evidences in new openings, but it destroys the old at the same time; and if these are not preserved for science before it is too late, they are lost forever. The whole mining industry is in its nature transitory; but the nation, which intrusts to the miner, upon certain conditions, the extraction of its mineral wealth, has a right to demand that the knowledge thus gained at the cost of a part of the national resources shall not be lost to science.

PART I.

GENERAL FACTS AND THEORIES.

1. Systems of Classification Employed Hitherto.

Studies of individual deposits naturally involve speculations concerning their genesis, and many such monographs contain valuable data, which, for the more thoroughly examined mining districts, are so well established and so comprehensive as to invite a systematic arrangement and a genetic explanation. At first, only the form of the ore-deposit was considered in such classifications; afterwards the barren surrounding medium was included. From this standpoint, unfortunately still taken by some purely empirical experts, the earth's crust is primarily divided into ore-bearing and barren rocks.

It was especially the *true veins*, at one time the principal objects of mining, which gave rise to speculations and discussions, having now only a historic interest.* A. Werner was the first to frame a scientific theory. He distinguished between ore-deposits contemporaneous in origin with the enclosing rocks and those of subsequent

* The period 1556 to 1791, that is, from G. Agricola to A. Werner, is an illustration. See also *Die Besonderen Lagerstätten der Mineralien*, by J. Waldauf von Waldenstein, Vienna, 1824, p. 164, etc.; *Die Lehre von den Erzlagerstätten*, by B. von Cotta, 2d ed., Freiberg, 1859, p. 85, and the English translation by F. Prime; and J. A. Phillip's *Treatise on Ore-Deposits*, London, 1884, p. 74, etc.

formation, and proved once for all that veins are fissures filled with ore, thus furnishing the most important characteristic for the recognition of primary and secondary formations. As to the manner in which fissures have been filled, Werner's theory, based upon a comparatively limited field of observation, has, like many of his neptunistic views, failed to maintain itself; and this question remains still without a final answer.

Curiously enough, many systematizers reproached Werner for having introduced into his system a genetic principle, which they sought to eliminate, confining themselves to the form of deposit as a guide. Thus Waldenstein (*op. cit.*, p. 5) distinguished (*a*) tabular deposits (beds and veins); (*b*) stock-deposits, flat-lying or steeply inclined; and (*c*) scattered masses, such as nests and pockets.

Even Cotta, otherwise an earnest advocate of geological principles, classified ore-deposits according to their form and kind as beds, veins and masses, adding a new and somewhat indefinite group of "impregnations." J. Grimm* also followed in the main the old principles of classification; included in his system the eruptive ore-breccias which he had personally examined and the tabular segregations of ore, and pronounced not only ore-beds (*Erzlager*), but also certain bed-masses (*Lagerstöcke*) to be sedimentary formations. Dr. A. von Groddeck† followed genetic principles already acquiring predominance. He distinguished: (*a*) original deposits, and (*b*) deposits of débris. The former he subdivided into (1) those formed contemporaneously with the country-rock, and stratified (ore-beds, segregated beds, etc.) or massive; (2) those formed later (cavity-fillings, veins, cave-deposits, metamorphic deposits). He pronounced ore-beds (*Erzlager*) to be sedimentary, and included in his system the cave-deposits and metamorphic deposits without describing their occurrence in detail. He declared that his system, like all others, had only the purpose of arranging the material of observation conveniently for comprehensive study, and that the manifold products of nature could not be forced into a system of classification.

Groddeck's description of the series of forms of deposits is highly original. He presents a number of types, mainly characterized by the varying material of the deposits and its manifold combinations and transitions. Evidently there was before him the ideal of combining in a systematic representation the different standpoints from which the subject was to be viewed. At least, if I correctly under-

* *Die Lagerstätten der nutzbaren Mineralien,* Prague, 1869.

† *Die Lehre von den Lagerstätten der Erze. Ein Zweig der Geologie,* Leipzig, 1879.

stood his personal, oral communication of his views, he hoped to represent one standpoint by abscissæ and the other by ordinates, so that the intersection would determine the type of the deposit. This is true enough; but it presupposes an exhaustive knowledge from both standpoints, which we unfortunately do not possess. My way of looking at the subject was, as appears from his expressions in a later publication, incomprehensible to him.* It seemed to him a sort of heresy to doubt the contemporaneous deposition of the ore of the Mannsfeld copper-schists with the rock, although I assured him that this doubt need only continue until the chemical and physical possibility of such a deposition should be shown.

Groddeck's system comprises, it is true, the metamorphic deposits, but without special definition or illustrative examples. In answer to a criticism of A. Stelzner's† on this point, he replies that he has included in this class those deposits also which have been formed through alteration of the rock-material by the process which Stelzner had proposed to call metasomasis, but that the ore-bearing masses thus originated cannot be regarded as separate deposits, because they are only incidental phenomena of the filling of cavities. In other words, he grants but subordinate rank to one of the clearest and most important genetic aids to classification, furnished by the occurrence of rocks transformed into ore. After conceding that deposits of débris should probably be included among stratified deposits, he restricts his system to four chief classes: 1. Stratified or sedimentary deposits; 2. Massive or eruptive deposits; 3. Cavity-fillings; 4. Metamorphic and metasomatic deposits. This brings him essentially nearer to my view, which groups the first two classes together, as contemporaneous with the country-rock in origin, with the reservation, however, that the contemporaneity indicated by the stratigraphy should be verified by other evidence.

While the work of J. Grimm comprises all useful deposits, that of Groddeck is confined to ore-deposits, although it would be practicable to classify salt, coal and other beds under his system.

In England and America the subject has been variously viewed, considerations of practice being predominant, and stratification being regarded as the specially decisive factor. This conception appears

* "Bemerkungen zur Classifikation der Erzlagerstätten," *Oesterr. Zeitschr.*, 1885; *Rev. Univ. des Mines*, 1886, xix.; *Gornoj Jour.*, 1886, iii., p. 430. "Unverständlich ist es mir, dass Pošepný, der sich so grosse Verdienste um die Kenntnisse der Erzlagerstätten erworben hat, das Vorkommen sedimentärer Erze ganz ignorirt," etc.

† Cited in *Das neue Jahrb. f. Mineralogie*, ii., 1880, p. 50.

first, so far as I know, in the writings of J. D. Whitney,* who divides mineral deposits primarily into (1) superficial, (2) stratified and (3) unstratified. The stratified deposits are divided into (*a*) those in which the valuable mineral constitutes the mass of a bed, (*b*) those in which it is disseminated through sedimentary beds, and (*c*) those originally deposited from aqueous solution, but since metamorphosed. The unstratified deposits are again divided as irregular [subdivided into (*a*) masses of eruptive origin (*b*) disseminated in eruptive rocks; (*c*) stock-work deposits; (*d*) contact-deposits; (*e*) fahlbands] and regular [subdivided as (*f*) segregated veins; (*g*) gash-veins; (*h*) true or fissure-veins].

We find here an explanation of the term "gash-veins," unfamiliar in Europe. Whitney says (*op. cit.* p. 225):

"Segregated veins, which are peculiar to the altered crystalline, stratified or metamorphic rocks, are usually parallel with the stratification and not to be depended on in depth. Gash-veins may cross the formation at any angle, but are peculiar to the unaltered sedimentary rocks. True veins are aggregations of mineral matter, accompanied by metalliferous ores, within a crevice or fissure, which had its origin in some deep-seated cause, and which may be presumed to extend for an indefinite distance downwards."

Somewhat different is the classification of R. Pumpelly,† who distinguishes: I. *Surface-deposits* [(1) residuary, (2) stream-, (3) lake- and bog-deposits]. II. *Forms due to the texture of the enclosing rock or to its mineral constitution, or to both* [(1) disseminated concentrations, further subdivided as (*a*) impregnations and (*b*) fahlbands; (2) aggregated concentrations, comprising (*a*) lenticular, (*b*) irregular masses or "stocks," (*c*) reticulated veins or "stockworks," (*d*) contact-deposits]. III. *Forms due chiefly to pre-existing cavities or open fissures* [(1) cave-deposits; (2) gash-veins; (3) fissure-veins].

Dr. R. W. Raymond,‡ who followed, in the main, the classification of Lottner,§ distinguished: I. *Superficial Deposits* [(1) Deposits of débris (placers); (2) surface-formations in place (bog-ore, etc.)] II. *Inclosed deposits* [(1) sheet-formed or tabular, divided into (*a*)

* *Report of a Geological Survey of the Mississippi Lead Region*, Albany, 1868, p. 224, and *The Metallic Wealth of the United States*, Philadelphia, 1854, p. 34.

† Not possessing the original work, I quote from the monograph of S. F. Emmons, *Geology and Mining Industry of Leadville*, Washington, 1886, p. 373.

‡ *Report of the Commissioner of Mining Statistics*, Washington, 1871, and the reprint, *Mines and Mining of the Rocky Mountains*, New York, 1871, p. 373.

§ *Bergbaukunde*, Berlin, 1878.

lodes or veins, and (*b*) beds and seams; (2) mass-deposits, divided into (*a*) masses, and (*b*) impregnations, etc.; and (3) other irregular deposits, such as (*a*) pockets distributed in large deposits, (*b*) isolated segregations, gash-veins, etc.].

Prof. J. S. Newberry* adheres mainly to the classification of J. D. Whitney, with some new matter of his own, the value of which has been justly estimated by Raymond.†

An analogous line of thought is followed by J. A. Phillips.‡ He declares that a careful study of the origin, structure, and composition of ore-deposits, appears to justify their division into the following groups: 1. *Superficial* [(*a*) formed by the mechanical action of waters, (*b*) resulting from chemical action]; 2. *Stratified* [(*a*) constituting the bulk of metalliferous beds formed by precipitation from aqueous solutions, (*b*) beds originally deposited from solution, but subsequently altered by metamorphism, (*c*) ores disseminated through sedimentary beds in which they have been chemically deposited]; (3) *Unstratified* [(*a*) true veins, (*b*) segregated veins, (*c*) gash veins, (*d*) impregnation, (*e*) stock-works, (*f*) fahlbands, (*g*) contact-deposits, (*h*) chambers or pockets].

In France, comparatively little has been done in framing such systems, higher importance being attached to the synthesis of the minerals, the explanation by experiment of geological processes, and the attempt to confirm by the study of mineral-deposits in other countries the theories thus supported. Observations have been made in many cases, not to furnish material for new conclusions, but to prove the truth of existing theories, as, for instance, Elie de Beaumont's theory of "pentagonal symmetry" in the relation between mineral veins and the courses of mountain ranges, etc.

In recent times, the chemical standpoint has become dominant with the French school, and in the treatise of De Launay,§ which has just appeared, the attempt is, in fact, made to base a system of ore-deposits upon a purely chemical view of the subject. He distinguishes: 1, *Gîtes d'inclusions* (ores as primitive constituents of eruptive rocks); 2, *Gîtes filoniens* (containing ores deposited, no

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* "The Origin and Classification of Ore-Deposits," *School of Mines Quarterly*, New York, March, 1880; also, *Eng. and Min. Journal*, New York, vol. xxix., 1880, pp. 421 and 437.

† *Eng. and Min. Jour.*, vol. xxx., 1880, p. 1.

‡ "A Treatise on Ore-Deposits, London, 1884, p. 3.

§ "Formations des Gîtes Metallifères," *Encyclopédie Scientifique, des Aide-memoires publiée sous la direction de M. Léauté*, Paris, 1893.

matter how, in pre-existing cavities in the rocks); and, 3, *Gîtes sédimentaires* (where metallic substances have been laid down, either as sediments or as precipitates, in marine- or fresh-water basins). In another place I will say something of this view, which, in some respects, corresponds with my own.

It is evident from the foregoing mere enumeration of the names of groups and classes of the several systems that, as a general rule, every new observation, considered important by the observer, has been added to the established traditional conception, which, however, was primarily based upon distinctions of form and kind, to which genetic principles, if recognized at all, were secondary. I may refer, in illustration, to the class of "pipe-veins," and the exhaustive paper of Dr. Raymond* demolishing it. I myself once thought a new group to be warranted by conclusive observations, namely, *typhonic* deposits,† in which the ores occur cementing together the fragments of a brecciated mass. But I soon became convinced by the observation of other occurrences, equally difficult to fit into the existing system, that the whole system must be transformed before it could assimilate, without destruction to itself, the new facts observed in the course of time.

But a stable and complete system could only be framed, when all the controlling facts—in other words, all the ore-deposits—were accurately known. This is not likely ever to be the case. New observations are constantly made in mining, which, moreover, often obliterates the old ones, so that they cannot be verified and compared.

It is, however, absolutely necessary, in a field so complicated as that of ore-deposits, to have some general understanding, some sort of system, comprising what is known. And evidently, in framing a system, the characters of form, being the most obvious and the most familiar to the miner, would be naturally emphasized, while genetic characters were left in the background. But this ought not to check genetic investigation, or the advancing recognition of real relations. A genetic system must, indeed, involve hypotheses, and may not, for a while, be practically useful; but in time it will, like every other cultivated branch of geology, assume more permanent forms.

At the Przibram Mining Academy there was established, in 1879,

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* *Trans. A. I. M. E.*, vi., 1887, p. 393.

† "Ueber typhonische Gesteinsmassen," *Verh. d. k. k. geol. Anstalt*, 1871, p. 94.

a new chair of "The Geology of Mineral Deposits," which I occupied for about ten years. As the title indicates, it was not merely intended for instruction in the usual "science of mineral deposits," and not as a geological course, appended to the technical course in mining, as might be inferred from a title like "*Montangeologie*," or "Mining Geology." The leading subject in view was the genesis of the useful mineral deposits. In the present paper I purpose to give a brief statement of the substance of my lectures, which, apart from a few extracts, have never been published.

2. Standpoint and View of the Present Paper.

The principal genetic distinction is doubtless between deposits contemporaneous with the country-rock, and those subsequently formed in it.

The earth's crust consists of rock-elements, chiefly individualized as mineral species. Two or three dozen of them—the rock-forming minerals—constitute by far the larger part of the solid earth as known to us. The remainder, much greater in number and variety, ornament our mineral cabinets, but form an insignificant portion of the rocks. The greater part of this group is made up of the legion of minerals occurring in ore-deposits; and most of these have undoubtedly had a secondary origin in the rocks—for instance, all the cavity-fillings, which of course could only be deposited after the rocks were formed. The secondary origin of some minerals which do not occur in cavity-fillings is less evident. But they occur sometimes in company with those which clearly have this character; so that we may consider these numerous minerals, occurring in comparatively small quantities, as secondary.

We have two main groups of mineral aggregates: that of the *rocks*, and that which we will call comprehensively *the mineral deposits.* The minerals of the first group belong to it as native and original; those of the second are foreigners to the rocks in which they occur. The two groups may therefore be designated (from ἴδιος, one's own, and ξένος, strange) as *Idiogenous* and *Xenogenous* respectively.

It is not necessary here to consider the various origins of rocks, since we take as our starting-point the rocks already formed. The clearly sedimentary rocks consist of the débris of older formations—idiogenous as well as xenogenous; and we must distinguish in them, besides mechanical sediments, chemical precipitates and organic products.

The sediment of a basin is the detritus carried into it from the land and deposited in the form of a flat wide cone. Successive conical envelopes should therefore strictly be the form of such sedimentary beds, though frequently they present apparently level parallel strata. The deposition of a precipitate, on the other hand, takes place throughout the liquid in the basin, and its form more completely represents the ideal *stratum*. In both sediments and precipitates, we find sometimes, besides organic remains, finely divided organic substances, forming the bituminous portions of the rocks. But the great masses of vegetable matter forming the coal-beds were, according to the most widely held opinion, deposited in swampy bottoms, and are therefore neither sediments nor precipitates. Several coal-beds, one above another, indicate a slow sinking of the basin, and its periodical filling-up with detritus from the rivers to such an extent that vegetation could again take root.

A coal-basin with several beds becomes on this view the measure of the sinking which is doubtless the cause of every large basin, but which only becomes strikingly evident when the basin contains coal-seams.

The foregoing points are mentioned because they indicate original discordances in stratification among the sedimentary layers themselves, and between these and the precipitates and organic formations.

If we find in the midst of these formations ores lying exactly between two strata, this relation is not conclusive proof of their sedimentary or precipitative origin. This must be proved in every given case; for in the present state of our knowledge we cannot understand how the metallic sulphides so characteristic of ore-deposits could be formed in that way.

As to the eruptive rocks, we do not know what they once were, as we study them only from the moment of cooling. But we observe at once that iron—a metal widely distributed in ore-deposits and in nature generally, occurs primitive in these rocks, in the form of magnetite, a mineral of striking metallic appearance.

This idiogenite of the eruptive rocks can be detected without chemical aid; but with such aid we find traces of other metals besides iron; and this leads us to surmise that the eruptives have brought a whole series of heavy metals up from the "barysphere" into our "lithosphere," and that it looks as if the metals of our ore-deposits originally belonged to the barysphere. This surmise De Launay regards as already proved. He derives, as it were, *a priori*, all the heavy metals of our ore-deposits from the eruptive rocks, and erects upon this hypothesis an entire system.

3. The Xenogenites in General.

With relation to the xenogenites or mineral deposits, the first question concerns the space which every secondary mineral or mineral-aggregate requires to establish its existence. It must either have found this space waiting for it, or it must have made room by driving out an original mineral.

Although we shall chiefly consider cavities formed in rocks after the formation of the rocks themselves, we must not forget that some may have been primitive in the rocks. We know that in substances of the greatest apparent density small cavities or pores must exist, since we can, for instance, by adequate pressure, force quicksilver through them. Moreover, we encounter in the eruptive rocks larger cavities, suited to receive considerable mineral-aggregates—the so-called blow-holes. These phenomena must certainly be considered, although the cavities of secondary origin will first be the subject of attention.

With regard to the filling, I observe, first, that the mineral deposits upon the walls of cavities, from liquids circulating within them, usually have a characteristic structure, for which I propose the name "crustification," as a companion to "stratification." (Single crusts were formerly called mineral shells or scales; and Groddeck introduced the word "crust," which is comprehensible in most languages.)

Most frequently mineral crusts occur concentrically in regular succession, and fill the whole cavity (except the central druse), thus forming a symmetrical crustification. They cover, however, not only the cavity-walls, but the surface of every foreign body in the cavity, thus forming crusted kernels which greatly complicate the phenomenon. We shall see, however, that a geode-cavity serves much better than a fissure-cavity to explain the relations of crustification, and that the crusted kernels will give us no trouble in that regard.

Sometimes mineral crusts have undergone a secondary alteration (carbonates are replaced with silica, etc.). The crustification is thus made less distinct, or is even obliterated. As a general rule, however, *crustification is a characteristic feature of cavity-filling.*

The cavities are formed either by mechanical or by chemical forces; and these two classes must be sharply distinguished, in view of the important rôle of each. The former may be the effect of exterior and foreign forces, or of such as are interior, residing in the rock itself. Formerly I called such spaces (with reference mainly to the accompanying fault-phenomena) "Spaces of Dislocation;" but I believe the term "Spaces of Discission" (from *scindere*, to tear apart) would be more suitable. The latter class I formerly called "Spaces of Corrosion" (with reference to the effect of the leaching and attacking liquids); but I would now substitute the more self-explanatory name "Spaces of Dissolution."

Spaces of dissolution naturally occur in soluble rocks, especially limestone, and show, with wonderful clearness, the irregular course often followed by underground waters. At and near the surface, we often find the cavity-formations at the contact of soluble with insoluble rocks; and we may infer that this relation affects also the subterranean circulation. Solution seldom extends to the whole mass of the soluble rock. Usually it affects a part only, in which it forms more or less irregular chains of cavities, sometimes so large that pieces of roof fall in, and thus spaces of discission are locally produced. A cavity filled with secondary mineral, however irregular its form may be, and even though it cuts across the stratification, usually shows a predominant course, which we are thus led to recognize as the channel of circulation of the liquid to which we owe the mineral deposit.

As I shall show later, we must assume that the liquid which formed the space of dissolution also performed the filling; in fact, that both processes were almost contemporaneous. Nevertheless, they must not be confounded with the metamorphic processes where the idiogenite is expelled, atom by atom, by the xenogenite; for the deposits in spaces of dissolution show always a distinct crustification, and hence every single crust, at least, must have found free space waiting for it.

Concerning the origin of spaces of discission, so much has been written that it cannot even be stated in abstract here. Two groups of these are distinguished. Those of the first group do not extend beyond one rock, and the force which produced them probably has its seat in that rock. In the eruptives, they are usually deemed fissures of contraction; in limes and dolomites, J. D. Whitney called them gash-veins.

The cavities of the second group extend out of one rock into another. The force which produced them resided outside of the formation. Considerable movements of one wall along the other are often evident, whence the common name, "fissures of dislocation."

In a paper upon this subject*, about twenty years ago, I attempted to show that every fissure, in whatever material, must properly be a fissure of dislocation; that the tendency to dislocation (namely, an unequal tension in the rock), precedes the formation of fissures; and that whenever the condition of the rock permits, a dislocation of the fissure-walls can be always traced, even in fissures of contraction.

As to the filling of spaces of discission, it must not be supposed that they represent throughout their entire length open spaces of uniform width. The original fissure was sometimes closed, wholly or partially, by the detritus originating in the friction of the walls, or by the movement or "swelling" of the country-rock, or by other causes. Only the places remaining open would permit an active circulation of solutions and a regular deposition from them. At points obstructed there would be no circulation, or a very sluggish one. When high pressure was present, and the rock contained interstices, the liquid doubtless penetrated from the fissure into the rock, impregnating it with mineral; or a soluble rock was attacked, and spaces of dissolution were formed, to be filled in like manner as the fissure itself.

This explains the fact that, on the same vein-plane, rich deposits alternate with poor or barren spots, and that the miner, seeking a bonanza, persistently follows the barren traces of the vein, according to a well-known, fundamental law of prospecting.

From the genetic standpoint, the richer portions are interesting as sometimes occupying more or less regular belts in the vein-plane, called "channels," "shoots," "chimneys," etc. These names evidently designate the main channels through which the mineral solutions passed; and the occurrence of such forms in most kinds of deposits tends to prove that, notwithstanding other differences, they were all formed in a similar way.

The *primitive* rock-cavities (pores and blow-holes) may also be filled with secondary minerals. In the former, there results a finely disseminated mineral substance, constituting such a deposit as Cotta denominated *impregnation*. Blow-holes are very often filled with minerals of the quartz family (opal, chalcedony, etc.), and we are often able to infer from the structure of such geodes the process by which they were filled.

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* "Geol. Betrachtungen über die Gangspalten," *Jahrb. d. k. k. Bergakademien*, xxii., Vienna, 1874.

Where the mineral solutions found no cavity already prepared, they must have conquered the necessary place by expelling a corresponding part of the original material. When one mineral individual was replaced by another, as in cases of pseudomorphs, the nature of the process can often be inferred from a comparison of the composition of the two; and the laws thus discovered may frequently be applied to the problems of the origin of mineral aggregates. Many phenomena, however, even in the formation of pseudomorphs, are hard to explain,—the fact, for instance, that in some minerals the change commences within the mass and progresses outward, etc.

Where the original material was expelled, there must have been first an access for the liquids which began and executed this effect. Such may be furnished by original minute rock-cavities, or by secondary cavities.

The original substance of the greater part of the pseudomorphs known to us was composed of soluble minerals, such as carbonates, sulphates, and chlorides, which also occur as the elements of rocks. Hence it may be inferred that metamorphous or metasomatic deposits will be especially frequent in soluble rocks like limestone, dolomite, etc., and that we may also expect such deposits to occur frequently in company with those which fill spaces of dissolution.

Pseudomorphs show us one substance in the crystal-form of another. This indication is lacking for the recognition of metasomatic deposits; yet sometimes the original rock was characterized by peculiar structure, such as lamination or jointing—as, for instance, the cellular structure of the *Rauchwacke* (*Cargneule*), which is reproduced in the cellular calamine which has replaced it. Moreover, the original rock may have contained fossils, which have been replaced, with the rest, by the new mineral, retaining their form; for instance, the bivalves and mollusks of the Bleiberg limestone in Carinthia and at Wiesloch in Baden, reproduced in galena and calamine; the brachiopods of the Silurian iron-ores of central Bohemia, etc.

Most important for the study of the process are transitional forms between the earlier and the later material; for instance, coatings of the latter upon kernels of the former, such as limonite upon siderite or ankerite; and likewise important is the occurrence of regular pseudomorphs, replacing one element in a heterogeneous rock, like those of cassiterite after feldspar in the granite of Cornwall.

After the expulsion, atom by atom, of the original material, the resulting deposit must be massive, showing no crustification.

Frequently, however, there are only negative indications of the metamorphosis. It can be seen merely that the deposit is not an original rock; that it has not been deposited in pre-existing primitive or secondary cavities; and hence, that it must have been formed by replacement.

In general, two kinds of metamorphous deposits may be distinguished. In the first, the new material has replaced the more soluble ingredients of a heterogeneous rock, and the result resembles the description of an impregnation, in which the new material occupies the original interstices of the rock. In the second, a part or the whole of a homogeneous rock has suffered metamorphosis, and the deposit will bear a certain resemblance to filled cavities of dissolution.

As I have shown above, and will illustrate further on with some examples, we may thus establish certain types of deposits entirely without reference to form. Some of these may coincide with groups in earlier systems, but others appear together in one and the same group. This seems at first not to favor the practical usefulness of the above principles, but, as I have said, we do not yet know enough to frame a final system. That must be the aim of future studies, and it is obvious that our purely genetical factors will be more helpful than the arbitrary characters based upon the exterior form of deposits. We distinguish, then, *Idiogenites,* or deposits contemporaneous in origin with the rock, from *Xenogenites*, the deposits of later origin, including not merely those of ores, but mineral deposits in general; and to these we may add, in harmony with some older systems, the deposits of débris as a third class, *Hysterogenites,* or latest formations.

The *Xenogenites* we divide into such as penetrated pre-existing cavities (filling primitive cavities, spaces of discission, or spaces of dissolution), and the metamorphic or metasomatic deposits, which made room for themselves by the expulsion of an earlier material.

The form of all these deposits is not fixed, but depends upon various geological relations of the country-rock. The mention, under former systems, of regular forms of deposit, contemplated rather the ideal of the system itself. In reality, the ore-bodies in "veins" and "beds" are irregular, and form masses for which the most various names exist in all countries.

We must now speak more particularly concerning the method of formation of the different deposits. Probably no one doubts at the present day that they are predominantly the result of humid processes of solution and deposition. But such generalities are not enough. The processes alleged must be put upon the basis of actual causes, still operative, and capable of being proposed and discussed in explanation of geological phenomena. It is, therefore, necessary to introduce, at this point, the theoretical chapter which follows.

4. The Subterranean Water-Circulation.

In treating of the genesis of mineral deposits, this department cannot well be so lightly handled as it is in most text-books of general geology. Prof. A. Daubrée, in an authoritative discussion of the subject,* ascribes the mineral deposits, among other effects, directly to the liquids circulating underground. It is my desire, with the aid of personal observations incidental to my continuous study of such deposits, to present a somewhat closer view than that of Prof. Daubrée.

Surface phenomena exhibit clearly a constant circulation of liquids, and corresponding phenomena, so far as they are observable underground, indicate the persistence of this condition, so that we must infer a subterranean circulation connected with that of the surface. We have then to consider, first, the surface-phenomena, so far as they concern our purpose, and, second, the underground phenomena.

As to the former, we know that it is chiefly the solar energy which initiates the circulation by lifting above the land the water of the sea, and thereby imparting to it the potential energy which is variously exhibited in its return to the sea. The mechanical effects of flowing water† in erosion, transportation, and sedimentation need not occupy us here. As to the chemical effects, we know that the mineral constituents of the rocks, dissolved through this circulation, chiefly find their way in the rivers to the sea. In regions without drainage to the ocean, the dissolved minerals are concentrated by evaporation, which may lead to precipitation. I would remark, however, that in my opinion small proportions of salts are me-

* *Les eaux souterraines a l'époque actuelle*, etc., vols. i. and ii, Paris, 1887; and *Les eaux souterraines aux époques anciennes*, etc., Paris, 1887.

† *Die Wasserfälle des Niagara und ihre geologische Bedeutung*, by F. Pošepný, Vienna, 1879.

chanically taken up in the evaporation of sea-water,* as careful analyses of rain-water have proved, and that this fact leads to the explanation of the salt and salt lakes in regions without drainage, etc.

A. *The Vadose Underground Circulation.*

In connection with the underground phenomena, the *ground-water* has for us a special interest. As is well-known, a portion of the atmospheric precipitate sinks, through open fissures or through the pores of permeable masses, into the rocks, and fills them up to a certain level. When in a given terrain, by wells or other openings, the ground-water (that is, the water-level, *Grundwasserspiegel, nappe d'eau*) has been reached at several points, it is found that these points are in a gently inclined plane, dipping towards the deepest point of the surface of the region, or towards a point where an impermeable rock outcrops. The ground-water is not stagnant, but moves, though with relative slowness, according to the difference in height and the size of the insterstitial spaces, down the plane mentioned, and finds its way, in the first instance, directly into the nearest surface-stream, or, in the second instance, forms a spring, which takes indirectly a similar course. Thus stated, free from all complications, the phenomenon exhibits clearly the law of circulation. The atmospheric moisture evidently descends; and even the movement of the upper layer of the ground-water is only apparently lateral, but really downwards, and is determined (for equal sectional areas of the rock-insterstices) by the difference in height between the water-level and the surface-outlet.

For that part of the subterranean circulation, bounded by the water-level, and called the vadose or shallow underground circulation, the law of a descending movement holds good in all cases, even in those complicated ones which show ascending currents in parts. The total difference in altitude between the water-level and the surface-outlet is always the controlling factor.

When these two controlling levels are artificially changed, as often happens in mining, the law still operates. In sinking a shaft through permeable ground, it is of course necessary to lift continuously the ground-water. The water-level thus acquires an inclination towards the shaft, which may thus receive not only the flow of the immediate vicinity but even also that of neighboring valley-systems. A

* "Zur Genesis der Salzablagerungen, besonders Jener im Amerikanischen Westen," *Sitz. Ber. der k. k. Acad. d. W. im Wien*, 1877.

shaft imparts to the previously plane water-level a depression, giving it the form of an inverted conoid with parabolic generatrix. An adit produces a prismatic depression in the water-level; and so on for other excavations. On the other hand, a bore-hole, from which the water is not removed, does not affect the water-level.

Atmospheric waters falling upon impermeable rocks at the surface cannot penetrate them, but must join the existing surface-circulation. The rocks are usually covered with more or less detritus, in the interstices of which the ground-water can move; and the water-level is in most cases at the boundary between the permeable surface-formation and the impermeable rock below.

These relations are complicated by the occurrence of fissures (which the ground-water of course fills), and by the communication of such fissures in depth with permeable formations, which come to the surface somewhere at a lower level, though at great distance. In such cases, as is well known, a siphon-action is set up, and the ground-water of one region may find an outlet far away, even beyond a mountain range.

Peculiar conditions are created by the occurrence of relatively soluble rocks, such as rock-salt, gypsum, limestone and dolomite, in which, by the penetration of meteoric waters and the circulation of the ground-water, connected cavities are formed, constituting complete channels for the vadose circulation.

It is often possible to observe directly, not only the formation but also the filling of these cavities, and thus to obtain valuable material for the explanation of the origin of xenogenites outside the vadose circulation, and not observable in the stages of formation.

It is for our purpose a most valuable fact, that the phenomena of leaching indicate the path of the circulating liquids through soluble rocks, so that we can study the process in its several stages. The water flowing at the bottom of a cave in limestone is unquestionably ground-water; and it follows that the whole complex group of cavities has been eaten out by it. If in another limestone cave we see no flowing water, the current must have found some lower outlet; and the cave represents for us an ancient ground-water channel.

The many and various phenomena of the Karst region are well known: the *Dolins, Ponors* and *Katravons*—points where a surface-stream sinks into the earth; vertical openings, at the bottom of which flow subterranean streams; and caves out of which streams issue—illustrating the whole series of the entrance, the course and the exit of subterranean waters.

In 1864, I had opportunity to observe, at Máros Ujvár, in Transylvania, a very instructive illustration of this kind, which is shown in Fig. 1. Here the rock-salt comes to the surface with steep zigzag stratification, and is covered only with detritus, to the depth of a few meters.* Mining is carried on in great parallelopiped-shaped chambers, by means first of levels run horizontally from a shaft, and winzes sunk vertically from these. The workings were at that time 125 meters or 400 feet deep. A great difficulty in the extraction was the entrance of saturated brine from that side of the mine where the Máros river flowed by. Until the mine had been protected by an adit of semi-circular course in the impermeable rock, surrounding the salt-body, the water annually raised and delivered without utilization into the river contained 84,000 tons of salt, or more than twice the weight of the rock-salt mined.

Various investigations have proved that the water of the river passes through the overlying detritus to the salt-body, which it penetrates at the boundary of the impermeable rock of the hanging-wall, finding its way through separate channels to appear as saturated brine, at the deepest point of the mine-workings. These channels had most frequently a cylindrical shape, smooth walls, and sometimes so great a diameter that a man could crawl in. There were always several to be seen, of which, of course, only the lowest in position brought the brine.

The explanation is simple. The water from the river, reaching the salt-body through the detritus cover, acted at the border of the salt, where the principal depressions in the surface were located, and the saturated brine thus formed filled all insterstices in the adjoining salt-body. By the leaching of such solutions into each deeper level opened in the mine, a line of maximum activity of circulation was gradually formed, which was followed also by solutions not yet saturated, with additional leaching and the final creation of open channels as the result.

An example on a large scale of such a channel in rock-salt, created, however, without the aid of mining operations, was recently described by H. Winklehner,† who found among other striking phenomena of lixiviation in the rock-salt of the islands of the Persian Gulf, a horizontal natural channel or adit, on the island of Larak,

* "Studien aus dem Salinargebiete Siebenbürgens," by F. Pošepný, *Jahrb. der k. k. geol. Reichsanst.*, 1867, xviii., p. 506–516.

† "Salzvorkommen in Süd-Persien," *Oesterr. Z. für Berg-und Hüttenwesen*, 1892, xl, p. 581.

which he was able to follow for about 1½ kilom. (1 mile). It expanded in places to caverns 12 m. (39 feet) high, without ever extending outside of the salt.

In precisely the same way were formed the channels in other less soluble rocks, such as limestone, when, the level of the entrance being above that of the exit of the ground-water, a line of maximum activity of circulation was established between the two points. This line, and the cavities developed along it, would not, indeed, always have the regular parabolic course, but would be dependent upon various influences of the stratification, the presence of rocks of unequal solubility, or even an intermixture of impermeable rocks. A mass of the latter, occurring on the line connecting the two points named, might cause the channel to bend up and down, or even in places to assume an upward inclination.

Figs. 2 and 3 illustrate these conditions. S is the soluble, I the impermeable rock; *a*, the entrance-point and *z* the outlet-point of the ground-water; *a b c z*, the line along which approximately a channel might be made, if the impermeable rock were not present. In its presence, the dissolving current must take another road, *a d z*, following more or less the contact between S and I, and in Fig. 2, descending to a depth proportioned to the relation between the original rock-interstices and the hydrostatic head, while in Fig. 3 it first surmounts the dam formed by the impermeable rock, and then plunges towards the outlet *z*. We see that in this way various channels may originate at the contact of permeable and impermeable rocks, as indeed we find them often in nature.

But when to these factors fissures are added, the conditions are essentially changed, for the circulation follows in preference the open fissures, and, if they pass through soluble rocks, enlarges them by solution.

Sometimes the position and the level of the outlet are altered—as, for instance, in the progressive erosion of valleys; and it may then easily happen that the new channel, representing the new conditions, will take a totally different direction, crossing the line of the old one.

Siphon-action is to be observed in soluble, much more frequently than in permeable rocks, as the frequency of intermittent springs in limestone indicates. Such springs presuppose the existence of a siphon-like channel, through which the ground-water cannot flow to escape from the lower leg until the water-level has risen to the top of the bend of the siphon.

We have seen that the ground-water may traverse deep fissures leading to soluble or permeable rocks, and may follow such rocks for considerable distances. When the ground-water, warmed in depth, has an opportunity to reach the surface, such as is given in Fig. 6 by the difference, H, in level, a thermal spring is the result—a so-called *acrotherm*, if its water is not highly charged with minerals, and not unlike the ground-water of the place.

Artesian wells present an analogous case, also explained hitherto by the principle of hydrostatic pressure (see Fig. 7). The outcrop of the permeable layer has been assumed to be necessarily higher than the mouth of the well, in order to account for the rising of the water above the latter level. The cause has been conceived as the operation of communicating pipes, the drill hole being one leg, and the permeable layer the other, and it has been overlooked, that the latter is no open pipe, but a congeries of rock-interstices, in which the water has to overcome a great resistance, and that, perhaps, in level regions no hydrostatic head at all can be demonstrated. Certainly the powerful factor of the higher temperature, and in some cases the gaseous contents, of the ascending water, were omitted from the calculation.

It would be a matter of surprise to me, if the purely hydrostatic and strictly mathematical views heretofore current on this subject had not led to disappointment. I introduce Fig. 7, the conventional diagram of an artesian well, for the purpose of stimulating further thought on the matter.

The Filling of the Open Spaces Formed by the Vadose Circulation.—This is very important genetically, since it is a matter subject to current and direct observation, and capable of furnishing many conclusions applicable to inaccessible subterranean occurrences.

We can observe spaces on the bottom of which, frequently, the ground-water which excavated them is still flowing, and which are therefore filled for the most part with air. Liquids carrying various minerals drip into these spaces and leave a part of their contents on the walls; the cause of deposition being, on the one hand, the evaporation of a part of the liquid, or, on the other hand, such changes as the loss of carbonic acid, precipitating as carbonate the soluble bicarbonate of lime; the oxidation of soluble ferrous to insoluble ferric oxide; the reduction of ferrous sulphate by organic matter to sulphide, etc. The form and structure of these precipitates vary at different parts of the walls. On the roof occur the *stalactites*, and on the floor (if it be not covered with water) the corresponding *stalagmites*. The wall-deposits have characteristic forms likewise; so that we can recognize by the appearance of any piece of the deposited mineral the place where it was formed. But from water covering the bottom of the cavity only horizontal deposits can originate. Sometimes the cavity is contracted, so that its whole cross-section is occupied by the liquid. If it is accessible to observation, we can then see that the deposits from the circulating liquid cover the walls uniformly.

This can be much more clearly observed in artificial conduits, where precipitation occurs. We find, for instance, in the pipes which convey concentrated brine, the walls uniformly covered with a deposit, mostly of gypsum. But if air or gas is admitted into the pipes, the deposit occurs only at the bottom. We may thence infer that so long as the circulating liquid fills the whole cavity the attraction of the walls for the precipitated particles is controlling; but that when gas enters, gravity becomes predominant and draws these particles to the bottom.

In opal and chalcedony geodes we can often see both forms of precipitate: the crust uniformly covering the walls, and the horizontal deposit. Fig. 4 represents a geode of iron-opal, from Dreiwasser, in Hungary, in which, besides the crustification and horizontal deposit, stalactitic and stalagmitic forms also appear. A thin crust of translucent hyalite covers all parts of the wall, including the floor. The cylindrical stalactites are also of hyalite. Some of them extend to the bottom, and are perhaps joined to stalagmites rising from the crust there. The remaining space is half filled with a milk-white, opaque, opaline substance, in which occurs a thin layer of translucent hyalite. On the same specimen several other less regular cavities are visible. All of them were lined with the hyalite crust, and some have also the opaline layers. These layers are parallel in all the cavities; and it cannot be doubted that they were horizontally deposited. The stalagmites stand at right angles to them, and were unquestionably vertical when formed. The geode certainly occupied, therefore, at the place of formation, the position shown in Fig. 4.

I must resist the temptation to describe the manifold forms of deposit in limestone caves. Fig. 5, an ideal diagram, showing a wall-accretion, and stalactites and stalagmites, separate and grown together, is given, not to illustrate the variety of the phenomena, but to indicate their analogy with those of the little geode in the iron-opal of Fig. 4. It is easy to conceive, that, under some circumstances, particularly in old cavities, lying above the water-level and not subject to further enlargement, the formation of stalactites, etc., might ultimately fill the whole space.

The floor of caves often shows deposits colored with ferric oxide, the explanation of which is obvious. Sometimes we find in the upper caves traces of sediments also; and, in one instance I found in an outlet-cave pebbles of very hard rocks, which certainly came from the surface.* The chemical reaction of the formation and filling of these caves are so simple as to need no discussion here.

Much more various observations, however, can be made in the *artificial caves,* formed by mine-workings. Here we have conditions analogous to those of the natural caves, but much greater variety, since the most widely different substances come into play. The mine-workings are situated at an artificially depressed water-level, and will show, in general, processes analogous to those observed in limestone caves, particularly the formation of stalactites. From calcareous rocks, from mineral deposits, and from the mine-masonry, crusts, stalactites and sinter are formed, analogous to those which occur in cavities at the natural water-level. Processes of oxidation will here also play the leading part, although reduction may also be effected through the more abundant organic matter in the mine-waters. Thus stalactites of pyrites, evidently reduced from ferrous sulphate by organic matter, are often found in metal-mines. A respectably large number of observations already illustrates the processes which are going on under our eyes in mines, and from which we can draw conclusions as to the destruction and creation of many minerals by circulating under-ground solutions. But we must not forget that these proofs apply only to the conditions of the shallow or vadose circulation, and that, for the explanation of the formation of the more ancient deposits, we must look to the rock-regions below the water-level.

In order to give at least one American example, I refer to the observation of Raymond, who found in an old Spanish mine, in the Cerillos range of New Mexico, an iron pick-axe, the eye of which was filled with beautifully crystallized galena, evidently a reduction of lead sulphate by the decaying wood of the handle of the pick.†

It may be said, in general, that the results of the processes of

* "Geol. mont. Studie der Erzlagerstätten von Rézbánya in S. O. Ungarn," von F. Pošepný, *Ung. geol. Gesellsch.*, 1874, p. 48.

† *Trans. A. I. M. E.*, 1883, xi., p. 120.

oxidation, chlorination, and reduction, observed in those regions of ore-deposit which lie above water-level, have come to pass under conditions analogous to those just described; so that we are able to adduce extended series of proofs, not only as to formations now going on, but also as to similar formations long since finished.

B. *The Deep Underground Circulation.*

Thus far, we have considered only such processes as take place in the region above water-level, and are still, in some cases, open to our observation. As we descend to a deeper region, there is less hope of encountering formative processes still active. When we penetrate by mining into the depths, we artificially depress the water-level, and create conditions unlike those which attended the formation of the deposits.

But, if we compare the deposits formed below water-level, under proportionally greater pressure and at higher temperature, with those of the upper region, it appears beyond doubt that the former also must have been produced by deposition from fluid solutions.

When we compare the low solubility of certain ingredients of the deposits with the spaces in which they occur, often in large quantity, it is impossible to assume that they could have been precipitated from solutions existing in these spaces only. We must concede that immense volumes of solutions must have flowed through the spaces —in other words, that the deposits were precipitated from liquids circulating in these channels.

The formation of these cavities has been already discussed, and referred to mechanical and chemical causes. It remains to consider the manner of their filling. We have seen that the uppermost layer of the ground-water has an apparently lateral, but really descending movement; and it is very natural to imagine that this top layer slides, as it were, upon a lower mass, which is apparently stagnant. According to this conception, the deep region would be comparable to a vessel filled with various permeable, impermeable, and soluble materials, over which water is continually passed, so that, from the moment when all the interstices have been once filled, only the uppermost water-layer has any movement.

But, with increase of depth, the pressure of the water-column increases, as does the temperature. The warm water certainly tends to rise, if not prevented by interstitial friction, as is, no doubt, generally the case. But where the warmed water finds a half-opened channel communicating with the upper region, it will experience much less friction on the walls, and must evidently ascend. It might thus be conceived that the ground-water descends by capillarity through the rock-interstices over large areas, in order to mount again through open channels at a few points.

This subject was viewed by A. Daubrée in a much wider significance, and extended to cover the origin of volcanic phenomena.* He propounded the inquiry, whether the enormous quantities of steam which are daily liberated from the deeper region are continually replaced from the surface, and if so, how? He pointed out that this water-supply could not take place through open fissures, in which the liquid water descended at one time and the steam ascended at another, but he showed that the descent could be effected through the porosity and capillarity of the rocks. Jamin's experiments have taught us the influence of capillarity upon the conditions of the equilibrium established by means of a porous body introduced between two opposing columns. Daubrée constructed an apparatus in which the temperature in one part of the capillary passage was so high that the liquid must assume the form of steam, and thus escape the operation of the laws governing its infiltration. This apparatus comprised a sandstone slab, with water above and a chamber below, the latter provided with a manometer for measuring the pressure of the steam collected in it. The whole was exposed to a temperature of about 160° C. (320° F.), and steam collected in the chamber of 68 cm. mercury-column, indicating about 13 pounds over the atmospheric pressure in the manometer, or a total pressure of about 1.9 atmosphere. This steam could only come from the water above the sandstone through which, in spite of the pressure, a capillary filtration took place.

"The difference in pressure on the two sides of the stone not only did not drive the liquid back, but permitted it to filter quickly from the colder side (100° C. = 212° F.) to the hotter (160° C. = 320° F.), and favored the rapid evaporation and the drying of the hot stone surface" (*op. cit.*, p. 184).

"According to these experiments, therefore, water may be found by capillarity, operating in the same direction as gravity, against a strong interior counter-pressure, to descend from the shallower and cooler regions to deeper and hotter ones, where, by reason of acquired temperature and tension, it is capable of producing great mechanical and chemical effects" (*op. cit.*, p. 186).

Daubrée's experiment confirms our view that the portion of the ground-water lying below water-level is not stagnant, but descends by capillarity, and since it cannot be simply consumed in depth, re-

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* *Synthetische Studien zur Experimentalgeologie*, by A. Daubrée; German translation, by Dr. A. Gurlt, Brunswick, 1880, p. 180.

ceives there through a higher temperature a tendency to return towards the surface, which tendency is most easily satisfied through open channels. Stated summarily:* The ground-water descends in the deep regions also through the capillaries of the rocks; at a certain depth it probably moves laterally towards open conduits, and, reaching these, it ascends through them to the surface.

The solvent power of the water increases with temperature and pressure, and also with the duration of its underground journeying. Hence, while it is descending, it can dissolve or precipitate only the more soluble substances. But the ascending current in the open conduits is undoubtedly loaded more heavily and with less soluble substances, which, as the conditions of their solubility (temperature and pressure) gradually disappear in the ascent, must be deposited in the channels themselves.

The open channels, in which the solutions ascend, are not the deductions of theoretical speculation. They really exist, as we can prove by induction from appropriate observations.

The Ascending Waters Encountered in Mines.—A number of such phenomena are adduced by H. Müller.† For instance, in the Gottes Geschick mine, near Schwarzenbach, in the Erzgebirge, at the depth of 110 m. (360 feet) an acid spring containing CO_2 and H_2S emerges from a nickel- and cobaltiferous-silver ore-vein (*op. cit.*, p. 286). At the Wolkenstein Bad, an acid spring comes from the druses of an ore-vein containing a crust of barytes and amethyst. In the Alte Hoffnung Erbstollen mine, near Mitweida, bad air and exhalations of carbonic acid led, in 1835, to an analysis of the ground-water, which proved to be weakly acid. In the Churprinz mine at Freiberg a warm (25° C. = 77° F.) acid spring was struck on the Ludwig Spat vein at the depth of about 160 m. (525 feet). Besides these, Müller names a number of mineral springs occurring in Bohemia and Saxony at the outcrops of mineral veins never opened by mining. In spite of the great reserve which he exhibits, he summarizes his view as follows (*op. cit.*, p. 307):

"Mineral veins and mineral springs are certainly adapted to complement each other in genetic theory. On the one hand, the ore-veins, as extended, indefinitely deep fissures, gradually filled, indicate a very profound origin for the mineral

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* *Ueber die Bewegungsrichtung der unterirdisch circulirenden Flüssigkeiten*, von F. Pošepný. *Extrait du compte rendu de la 3me. session du Congrès géologique international.* Berlin, 1885, p. 71.

† "Ueber die Beziehungen zwischen Mineralquellen und Erzgängen." Cotta's *Gangstudien*, vol. iii., 1860, p. 261.

springs, and suggest variations caused by time and circumstances in the amount and mutual reactions of their contents, solid or volatile; and, on the other hand, the present relations of mineral springs explain the mode of ingress and deposit of the constituents filling the veins."

Soon after this publication (I think in 1864), a thermal spring of 23° C. (73° F.) was struck at the depth of 533 m. (1774 feet) in the Einigkeit shaft, at Joachimsthal, and in the same mine at two other points similar mineral springs, rising with strong pressure, were exposed. They prevented further increase in depth of that part of the mine, and were plugged as far as practicable. The analyses made in 1882 showed that they were acid springs containing considerable silica (33 grammes per ton.) In one of them arsenic was also proved to the extent of 22 grammes per ton.*

The mineral waters of the Joachismthal mines are said to come in contact, near the place where they were encountered, with basalt-like rocks (called *Wacken*), which traverse the ore-veins, and are, therefore, of later origin. In general, most of the ore-deposits of the Erzgebirge appear to have a decidedly recent origin, but even from this standpoint the mineral springs found in mining are to be regarded as nothing else than the continuation of those ascending liquids which have filled the ore-veins. Mining depresses the water-level, so that mineral waters circulating in the neighborhood are forced to those points in the mine where there is only atmospheric pressure.

This "neighborhood" may, indeed, extend to a comparatively long distance. For instance, the thermal spring at Carlsbad, which is the nearest to Joachimsthal, is 17 kilom. (10.5 miles) away and 380 m. (1246 feet) above sea-level, while the spring in the Einigkeit shaft at Joachimsthal was struck at 206 m. (675 feet above sea-level, that is, 174 m. (571 feet) lower than Carlsbad. The irruption of the thermal waters of Teplitz in Bohemia into the lignite-mine of Dux, 7 kilom. (4 miles) away, which took place first in 1879, and has occurred recently since, shows plainly that subterranean communications may thus be established for long distances by mining.†

* Since the metric ton of 1000 kilo., or the weight of m.³ (1 cubic meter) of water, is a rational unit of weight, I refer all tenors to it, and state them in grammes or milligrammes to avoid decimals. Thus 22 grammes per ton represents 0.022 per thousand, or 0.0022 per cent.

† "Einige, die Wassereinbrüche in die Duxer Kohlenbergbaue betreffende, geologische Betrachtungen," von F. Pošepný. *Oesterr. Zeitsch. f. Berg-u. Hüttenw.*, 1888, xxxvi., pp. 39–54.

Additional data for the study of these relations are furnished by the miners on the Comstock lode, where, with the advancing depth of operations, ascending thermal waters were unexpectedly encountered, the abundance and high temperature of which presented extraordinary obstacles to mining. The great richness of the deposit was the reason that the hope of going deeper was not abandoned, as in Joachimsthal, where the only effort was to dam out the waters from existing workings; but that, on the contrary, the struggle was accepted against the waters themselves and the enormous heat which they caused in the mines.

As is well known, the upper workings on the Comstock, before any ascending waters had been encountered, were not specially hot, though warmer (21° to 24° C, or 70° to 75° F.) than other mine-workings in similar positions. Dr. F. Baron v. Richthofen noticed no abnormal mine-temperature, although he ascribed the Comstock to earlier solfataric action.*

At a later period, upon the cutting through of clay-partings in the rock, the hot water repeatedly broke into the workings with great force, as, for instance, in the North Ophir mine, when, according to Clarence King, † the workmen had scarcely time to escape. The water is said to have had a temperature of 40° C. (104° F.), and filled the workings immediately to a height of 30 m. (100 feet). In another case the water broke into the 2200-foot level of the Savage mine, and filled the large spaces both of that mine and of the Hale and Norcross up to the 1750-foot level, or to a height of 137 m. (450 feet). Gas was continually but not violently evolved and although Prof. J. A. Church ‡ reports it to have been under a pressure of 200 pounds per square inch, he believes that this was not a gaseous, but a hydrostatic pressure.

The water which in 1880 flooded the Gold Hill mines came from a bore-hole in the Yellow Jacket shaft, at a depth of 939 m. (3080 feet); had, according to George F. Becker,§ a temperature of 77° C. (170° F.); and was heavily charged with hydrogen sulphide. In the upper levels of the mine, Becker says there is evidence of the presence of carbonic acid, and on the 2700-foot level where the tem-

* *The Comstock Lode, Its Character and Probable Mode of Continuance in Depth,* San Francisco, 1866, p. 54.

† *U. S. Geol. Expl. of the 40th Parallel,* vol. iii. *Mining Industry,* Washington, 1870, p. 87.

‡ *The Comstock Lode, Its Formation and History,* New York, 1879, p. 207.

§ "Geology of the Comstock Lode," etc., *U. S. Geol. Survey,* Washington, 1882, pp. 230, 386.

perature was 66° C. (150° F.) a deposit of sinter was found, consisting mainly of carbonates. Church (p. 206) remarks, that it was at first believed that the repeated irruptions of water came from chains of cavities existing in the rock, but that at the time of his visit the conviction was that they came through shattered and decomposed seams, parallel with the lode, and sometimes of great thickness.

Systematic and long-continued temperature-observations in several Comstock mines enabled Becker to represent comprehensively for different lines the increase of temperature with depth; and it thus appeared that this increase was greatest in the vicinity of the lode, diminishing with the distance from the lode; that the vehicle of heat was the water; and hence that it was through the lode itself that communication with the hot depths took place, and the phenomenon denominated "solfataric action" by Richthofen was caused.

The chemical constitution of these intruding waters will be considered further on, after certain phenomena occurring nearer to the surface have received attention.

Related Phenomena Near the Surface.—A sort of transition to the corresponding phenomena on the surface itself is illustrated by the mines at Sulphur Bank, Cal., which have furnished some of the most important data contributed by America to the study of the genesis of ore-deposits.

This is a once rich, but now (apparently) practically exhausted quicksilver-mine, in the working of which not only thermal waters but gaseous emanations were encountered as obstacles. At the time of my visit in 1876, an open-cut exploitation was in progress, the terraces of which had extended in some places about 5 m. (16 feet) below the natural surface. Sulphur, as well as quicksilver, was won; but it subsequently appeared that the sulphur-deposit was confined to the uppermost zone, while the quicksilver (or cinnabar) extended in considerable proportions to deeper regions.

At that time I found sulphur and cinnabar in a decomposed basalt, partly as the filling of irregular fissures, traversing the rock in all directions, partly as impregnations in the rock itself, which had often been reduced to a porous mass. The process of decomposition proceeded unquestionably from the fissures, which, moreover, gave forth hot mineral waters and gases. The odor alone was sufficient proof that the gases contained H_2S, to the oxidation of which into SH_2O_4 the acid reaction of the rock and its moisture was to be ascribed. The miners (mostly Chinese) chiefly followed in extraction the fissures (partly because it was the easiest way to make rapid progress; partly because the richest ores were there concentrated); and, as a result, large round blocks, often several meters in diameter, were left standing. These had a distinct shaly structure, but were so loosely held together that a kick would reduce them to ruins. In the interior of the larger, light-gray blocks, was often found a nucleus of solid, dark, undecomposed rock. (Some of these *nuclei* I have added to the collection of the Przibram Mining Academy.)

The cracks were filled chiefly with an opaline mass, in which a white, opaque ingredient was variously kneaded, as it were, with a gray to black one, translucent at the edges. The specimens taken fell into irregular pieces, bounded by fissures, evidently the result of loss of volume or loss of moisture by the opaline mass.

The cinnabar formed either distinct mineral crusts in the crevices or impregnations of the porous neighboring rock. This was true of the sulphur also; only, the latter appeared, as a rule, in crystalline aggregates upon the cinnabar crusts—an indication of its later origin. Occasionally the cinnabar was deposited in beautiful crystals on the fissure-walls, but these were generally so loosely attached that it was difficult to secure a specimen.

The pyrites, mostly disseminated in the rock, tended so strongly to decomposition, evidently by reason of its saturation with sulphuric acid, that specimens containing it soon fell to pieces.

These observations suffice to show that in this case hot mineral waters ascend through fissures containing ore-crusts and opaline deposits; and when it is considered that the deposit of amorphous, hydrated silica is unquestionably the work of the mineral water which decomposed the rock, and also, that the cinnabar occurs in the interior of the opaline mass, the two phenomena cannot well be separated, and it must be assumed that a metallic sulphide has here been deposited from an ascending spring. Fig. 10 represents the exposure as sketched in my note-book.

Later developments exhibit these relations still more clearly. Le Conte and Becker* found a shaft 50 m. (164 feet) from the basalt,

* "The Phenomena of Metalliferous Vein-Formation, Now in Progress at Sulphur Bank," by J. Le Conte and W. B. Rising, *Am. Jour. of Sci.*, xxv., p. 424.

"On Mineral Veins, Now in Progress at Steamboat Springs, Compared with the same at Sulphur Bank," by J. Le Conte, *Am. Jour. of Sci.* xxv. p. 424.

"Geology of the Quicksilver-Deposits of the Pacific Slope," by G. F. Becker, *Monograph U. S. Geol. Surv.*, Washington, 1888, p. 251.

about 92 m. (310 feet) deep in sandstone, from which drifts had been run northward at different levels under the outcrops of the deposit. It is to be regretted that their reports are not accompanied with precise descriptions of the mine-workings. In the third level (64 m. = 210 feet below the surface) the drift was 70 m. (232 feet) long, "cutting through the ore-body and reaching only barren rock on the other side. The fourth level has been pushed 31 m. (136 feet), and has reached the ore-body." From these data it is hardly possible to form an idea of the position of the ore-body traversed.

The data given concerning the interior structure of the deposits are, however, important. Sandstones and slates are here broken up by fissures in such a way as often to form a breccia. Whether the fragments belong together, and whether they present the relation which I have denominated typhonic, is not stated; but it may be inferred from the sketch of an ore-specimen from this place that the fragments do not belong together, and that their condition has been brought about by more extreme dislocations. The subject is highly important for us; and I have attempted in Fig. 11, although the original is not before me, to represent it according to Le Conte's sketch, so as to place it side by side with other phenomena, thoroughly familiar to me.

The fragments of slate and sandstone have somewhat rounded edges, and leave varied interspaces, which are filled, partly with a still soft or already indurated paste, containing finely disseminated metallic sulphides, partly with cinnabar, for the most part in coherent crusts. A part of the space is usually empty, exhibiting what I call a central druse. Sometimes, it is said, the rock-fragments are cemented together with massive cinnabar, and kernels of rock crusted with cinnabar occur frequently.

Hot mineral water and gases carrying H_2S force their way through the interstices of the deposit, as was the case observed in the upper zones. The silica deposits are found in all stages of consolidation, from a gelatinous mass to chalcedony and (Le Conte, *op. cit.*, p. 29) alternate with layers (crusts) of metallic sulphides (cinnabar and pyrites). Becker examined the whole neighborhood, and extended his studies to similar ore-deposits of the region. He does not consider the basalt of Sulphur Bank, as do G. Rolland,* and Le Conte, to be a lava-stream, but takes it to be an eruptive rock, originating on the spot, which has overflowed a fresh-water formation of recent

* "Les Gisements de Mercure de Californie," *Annales des Mines*, 1878, p. 26.

age. The bottom proper is a Cretaceous sandstone. The ore-bearing character extends from the basalt(about 16m. = 52 feet thick) through the fresh-water layers in to the Cretaceous sandstone. Concerning its relations in the middle layer we have no data, which is unfortunate, since the effects of the acid waters upon this calcareous material must have been considerable, and it is not unlikely that the deposit had in this region a totally different character. Fresh-water formations adjoining the deposit have preserved to a remarkable degree plant-roots etc., transformed into lime carbonate; and it would be very instructive to study their forms as metamorphosed by the mineral water.

Concerning the chemical constitution of the warm (80° C. = 176° F.) water, I shall speak further. According to Becker's analysis (*op. cit.*, p. 259), it is extraordinarily rich in chlorides, borax and sodium carbonate. The gas liberated from it often proved to be ammoniacal, and consisted in 1000 parts of 893 parts CO_2, 2 parts H_2S, 79 parts CH_4 (marsh-gas) and 25 parts nitrogen.

As to the presence of other metals besides mercury, it is worthy of mention that Dr. Melville found small amounts of gold and copper in the marcasite accompanying the cinnabar, and that G. Becker found in the efflorescence from the mine-workings, besides the substances detected in the mineral water, traces of cobalt and nickel.

As will be seen, this deposit furnishes genetic data, concerning not only the ores of quicksilver, but also those of other metals. An ascending mineral spring here passes from the deep into the shallow region, and suffers, besides the reduction of pressure and temperature, the oxidation of its H_2S, from which result a strong acid and the deposition of sulphur nearest the surface.

In depth no sulphur is found, but sulphides of quicksilver and iron, upon or within deposits of silica, both being in distinct alternating mineral crusts. It cannot be doubted that cinnabar and pyrites, on the one hand, and silica, on the other, have been precipitated from the solution which still ascends in these channels. At most, it may be doubted whether this precipitation is still going on. Le Conte adduces in support of the probable continuance of the process the occurrence of silica sometimes gelatinous and soft, as if recently precipitated. Becker and Melville tried to obtain direct evidence of the presence of quicksilver dissolved in the ascending mineral water of to-day, but their careful investigations failed to find it. Although the water contains ingredients in which quicksilver is soluble, there is no quicksilver dissolved, and it must have been already precipitated by some agent—as they suggest, ammonia.

There are among geologists unbelieving Thomases enough, who will believe in the presence of quicksilver in the mineral solution only when it has been actually precipitated for them; but there are those, on the other hand, who are convinced by the evidence thus far gathered that the sulphide deposits of this locality proceeded from the ascending thermal spring, whether the process of precipitation is still going on or not.

Equally weighty data are furnished by Steamboat Springs in Nevada, to which Laur and J. A. Phillips first called attention, and which Le Conte and Becker investigated thoroughly.* In a valley surrounded with eruptive rocks, but underlain chiefly by Archæan rocks, thermal springs may be seen at several points emerging from north-and-south fissures. The action of these springs has covered the ground with a sinter-deposit, predominately of lime carbonates, about 15 m. (49 feet) thick. In this sinter may be traced many fissures, here and there still open, but mostly closed by the deposit of silica on their walls. According to a sketch given by Le Conte, these very clearly crustified deposits extend somewhat above the general level of the surface, forming single mounds or chains of mounds.

From some of them hot vapors and gases still issue, chiefly CO_2 containing H_2S. In others, such emanations have been so greatly diminished that only by listening can the liberation of vapor in depth be perceived. Some of the fissures are completely filled, and give forth neither mineral water, steam nor gas.

In the group, about 200 m. (656 feet) wide and 1 kilom. (0.6 mile) long, which lies nearest to the railway-track, these phenomena are most strikingly exhibited. Besides the principal substances mentioned below in the table, Becker found in this mineral water also small amounts of metallic compounds, as, for instance, HgS, a trace of Na_2S, 1.0 gramme per ton of Na_2SbS_3, and 8.7 grammes per ton of Na_2AsS_3.

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* M. Laur, "Sur le gisement et l'exploitation de l'or en Californie," *Annales des Mines*, 1863, iii., p. 423.

J. A. Phillips, *Phil. Mag.*, 1871, xlii., p. 401. Also, *A Treatise on Ore-Deposits*, London, 1884, p. 70.

J. Le Conte, "On Mineral Veins now in Progress at Steamboat Springs Compared with the Same at Sulphur Bank," *Am. Jour. Sci.*, xxv., p. 424.

G. F. Becker, "Geology of the Quicksilver-Deposits of the Pacific Slope," *Monograph U. S. Geol. Survey*, Washington, 1888, p. 331.

About 1½ kilom. (1 mile) to the west is a group of similar fissures, yielding some steam and CO_2, but no mineral water. In the mineral crusts of these, however, several metallic sulphides occur. In 1863, Laur declared that he had seen in them distinct traces of gold. In 1878, one of these fissures was opened by an adit, about 15 m. (49 feet) under the surface, and produced a vein-matter carrying cinnabar, which was mined for a while as quicksilver-ore. The temperature of this mine was not so high as to cause serious trouble to the workmen.

G. F. Becker carefully analyzed the filling of several fissures, and found, besides hydrated ferric oxide, considerable quantities of Sb, As, Pb, Cu, Hg sulphides and gold and silver, as well as traces of Zn, Mn, Co and Ni. Since from 1 to 3.5 kilog. (2.2 to 7.7 lbs.) of the vein-stuff were employed for each analysis, the results are specially trustworthy, and I give the records of three analyses here, expressing them in grammes per ton (1 ton = 1,000,000 grammes):

	I.	II.	III.
Sulphides of antimony and arsenic,	......	23,000.0	150.0
Ferric oxide,	......	2,500.0	......
Sulphide of mercury,	1.4	2.5	1.0
Lead,	88.0	21.0	......
Copper,	0 3	12.0	......
Gold,	0 9	1.0	......
Silver,	0.3	0.3	......

(Considering the gold and silver to be alloyed in the above proportions, we should have bullion 0.750 and 0.769 fine, which is the general grade of the so-called "free gold" of Transylvania.)

The careful study of the phenomena, particularly by G. F. Becker, leaves no doubt that in this case ascending mineral waters have deposited, besides the various forms of silica (from opal to crystalline quartz), different metallic sulphides, and that the fissure-fillings exhibit a very clear instance of crustification. It is, indeed, not proved that the process is now going on. But that is not the main point. We may be content to have the proof that it has taken place.

Mineral Springs at the Surface.—When we isolate a spring characterized by high temperature, a large quantity of gas or of matter in solution, we notice at once that its level is higher than that of the ground-water. The more thorough the isolation or walling-in, the more striking is this phenomenon, so clearly unlike that of the vadose or shallow circulation.

Isolation is usually performed by digging as deep as possible, so as to get at the spring below the loose surface-material in an impermeable rock, and then by building a well-pit, to give it freer ascent. But since the circulation of the ground-water in the loose surface is very lively, the necessary depression of the water-level in such an excavation involves the lifting of large quantities of water. Moreover, the escape of gas from the mineral spring often hinders the operation; so that there is, as a rule, little opportunity for thorough investigations. Cases in which accurate observations have been properly recorded for preservation are very rare.

The first good fissure encountered in the bed-rock is deemed to be the channel of the mineral spring, and the well is built over it. Complete isolation from the ground-water is probably seldom practicable. Nevertheless, the mineral spring, being under higher pressure than the ground-water, will tend to exclude it from the well. The imperfection of the isolation is shown, however, when we try for any reason to pump out the well. To lower the water-level, say 1 m. (3.28 feet), we have to raise many times the amount of water which the spring itself would normally furnish (even taking into account the decreased pressure, which affects the flow in the proportion of the square root of the head). The excess, generally surprisingly great, comes from the ground-water which finds its way into the well.

If we allow the mineral water to ascend again quietly in the well, the level rises at first rapidly, then slowly, and finally remains (in the absence of change in the height of the ground-water and in the barometric pressure) stationary at a certain height above the ground-water level. This difference of height represents the ascensional force of the mineral spring.

If the spring makes a deposit at its mouth (mostly of lime carbonate, hydrated ferric oxide, and silica) it may thus build a conduit, extending above the ground-water level and the surface to the height represented by its ascensional force. Thus, we find conical mounds from the top of which mineral springs flow. This phenomenon is shown in the highest degree by geysers, *i.e.*, thermal springs in which paroxysmal developments of steam and gas occur, often forcing the water to notable heights. Some of the magnificent geysers of the Yellowstone National Park have built chimney-like conduits of considerable size. Their structure has much similarity to that of stalactites; indeed, we may recognize generally, in the various deposits of ascending mineral springs (in other words, in the products of the deep circulation), many analogies with the vadose circulation. This circumstance indicates a relation between the phenomena of the two regions which is often entirely ignored or even denied.

While, for instance, the geysers have a temperature above boiling-point, some mineral springs rise but little above the mean local temperature of the surface or of the ground-water. This may be especially observed in the acid springs; yet, these are also ascending springs, and must have been formed in the deep region.

Within the vadose region we have, sometimes, ascending waters, which are, however, mostly to be explained by hydrostatic pressure. But, within the deep region, hydrostatic pressure can play no part; and here it is the higher temperature and the presence of gas which cause the ascension of mineral springs. The extreme instances of this kind, such as geysers, steaming springs, mud-volcanoes, petroleum springs, etc., nobody will undertake to explain by hydrostatic pressure, and more moderate results of the same factors can scarcely, with consistency, be so explained.

It is a striking circumstance that ascending springs occur chiefly in the neighborhood of the later eruptive rocks, such as trachyte, basalt, etc. This is emphatically the case throughout the zone which crosses Europe from west to east, in France, Germany, Bohemia, Hungary, and Transylvania. Here the warm springs and the acid springs occur thickly, while north and south of this zone they are only sporadic. Their connection in the zone with the eruptive rocks is evident, and they are often considered as the last echoes of the processes of eruption. The sporadic springs, in places where eruptive rocks play no part, must have come through deep fissures of dislocation. For example, the line of the fault along which the Alps sank below the Tertiary basin of Vienna is marked by a complete series of thermal springs.

This circumstance has another and far-reaching significance. For ore-deposits are similarly distributed. They are most numerous and most closely grouped in the neighborhood of eruptive rocks, especially extended zones of eruptive rocks, as in the American West, and in Hungary and Transylvania, while among other rocks they are fewer and more scattered.

Chemical Constitution of Mineral Waters.—Ascending mineral springs have widely varying composition; some, like the "aerotherms," representing strictly only warmed ground-water, while others are strongly mineralized, and carry some substances almost to saturation. The material bearing on this subject is too voluminous and heterogeneous to be fully cited and discussed here. I must be content with the exhibit of a few analyses, specially interesting for the present purpose.

The following is a list of the localities, etc., represented in the table below:

Waters Encountered in Mines.

No.	Locality.	Temperature. °C.	°F.	Authority.
1	Gottesgeschick mine, Schwarzenberg,	11.	38.1	R. Richter.
2	Einigkeits shaft, Joachimsthal,	28.7	47.9	J. Seifert.
3	The "Sprudel," in Colliery at Brüx, Bohemia,			J. Gintl.
4	Comstock, Savage, 600 feet level,	28. ?	47.6 ?	S. W. Johnson.
5	Comstock, Gould and Curry, 1700 feet level,	48. ?	58.6 ?	S. W. Johnson.
6	Comstock, Gould and Curry, 1800 feet level,	50. ?	59.8 ?	S. W. Johnson.
7	Comstock, Hale and Norcross,	70. ?	70.9 ?	S. W. Johnson.
8	Comstock, Ophir,	40. ?	52.2 ?	Attwood.

Water in Ore-bearing Fissures.

No.	Locality.	Temperature. °C.	°F.	Authority.
9	Sulphur Bank, Herman shaft,	70. ?	70.9 ?	G. F. Becker.
10	Sulphur Bank, Parrot, shaft,	70.	70.9	G. F. Becker.
11	Steamboat Springs,	75.	73.7	G. F. Becker.

Some Bohemian Thermal Springs.

No.	Locality.	Temperature. °C.	°F.
12	Sprudel, Carlsbad,	64.	67.6
13	Kreuzbrunn, Marienbad,	12.	38.7
14	Wiesenquelle, Franzensbad,	13.	39.2
15	Urquelle, Teplitz,	50.	59.8

Weak and Strong Mineral Springs.

No.	Locality.	Authority.
16	Ottoquelle, Giesshübel,	Dr. Novak Kratschmann.
17	Josephsquelle, Bilin (1875),	Dr. Ruppert.
18	Puits de l' Enclos des Celestins, Vichy,	Bunsen.
19	Rippoldsau, Josephsquelle (1875),	Bunsen.
20	Rippoldsau, Wenzelquelle (1875),	Bunsen.
21	Rippoldsau, Leopoldquelle (1875),	Bunsen.
22	Kissingen, Pandurquelle (1856),	Liebig.
23	Kissingen, Rákoczyquelle (1856),	Liebig.
24	Yellowstone, Cleopatra, Mammoth Hot Springs (1888),	F. H. Gooch.
25	Yellowstone, Grand Geyser,	T. E. Whitefield.

It is well known that analysts in combining their results do not follow the same rule. One supposes a certain acid to be united with

Analyses of Some Ascending Waters.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
One Thousand Kilogrammes of Mineral Water contain, in Grammes:																									
Alkal. carb....	1150	352	2297	145	110	449	460	70	1954	325	333	2356	167	1167	415	1312	3374	5437	.....	.....	.....	.....	.....	.....	378
Earthy "	510	55	729	51	.....	.....	.....	48	54	57	17	127	146	381	100	565	586	981	1257	1170	1653	1110	1087	625	9
Alkal. sulph..	82	12	37	.....	.....	.....	.....	57	.....	689	172	535	500	3339	23	34	954	314	1273	1105	917	.....	.....	145	39
Earthy "	.....	.....	6	535	246	286	386	222	23	.....	.....	.....	.....	.....	56	.....	.....	.....	299	240	37	978	892	559	0
Chlorides......	62	6	58	2	1	20	23	10	1150	1115	1612	1031	170	1213	63	30	381	534	85	69	44	6441	5998	304	619
Silica...........	.....	51	72	31	38	69	60	38	37	42	391*	73	8	61	48	59	43	65	57	97	86	13	4	52	303
Other subst....	.....	.....	6	.....	.....	.....	.....	5	1883†	2412†	325†	.....	120	34	13	5	1	84	5	17	20	15	9	46	42
Total.....	1804	476	3205	764	395	824	929	450	5101	4640	2850	6126	1111	6195	718	2005	5339	7415	2976	2698	2757	8557	7990	1731	1390
One Thousand Grammes of Solid Residuum contain, in Grammes:																									
Alkal. carb....	632	739	717	118	278	545	495	156	383	70	117	384	150	188	577	655	631	735	.....	.....	.....	.....	.....	.....	273
Earthy "	288	115	127	67	.....	.....	.....	107	10	12	6	28	135	61	139	283	108	132	422	436	601	130	136	362	6
Alkal. sulph..	46	24	11	.....	.....	.....	.....	125	.....	148	60	409	450	539	32	17	183	42	427	412	332	.....	.....	84	28
Earthy "	.....	.....	2	699	623	347	415	492	5	.....	.....	.....	.....	.....	77	.....	.....	.....	100	88	13	114	111	323	.....
Chlorides......	34	12	17	2	2	24	25	23	225	242	569	166	153	195	87	15	70	72	28	22	16	754	751	175	445
Silica...........	.....	107	22	40	96	83	64	83	7	9	137	12	8	10	61	30	8	8	18	36	31	1	1	30	218
Other subs....	.....	23	14	74	1	1	1	14	370†	519†	111†	1	104	7	27	.....	.....	11	5	6	7	1	1	26	30
Total.....	.....	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

* Sodium quadrisilicate, $Na_2 Si_4 O_9$. † Mostly sodium biborate, $Na_2 B_4 O_7$

an alkali; another gives the same acid to an earthy base, etc. What interests us in the comparison afforded by the table is the substances occurring in large proportions, the carbonates and sulphates of the alkalies and alkaline earths; the chlorides, the silica, and the quantity of organic matter (if it were determined by a uniform procedure).

I deem it most convenient to take 1 ton of 1000 kilogrammes (representing, for waters not too rich in mineral, the weight of 1 cubic meter), and to express the weights of the salts in grammes, to avoid decimals. In order to show the relations of the salts, one to another, it is well also to represent them on the basis of 1000 parts of the solid matter.

For the Comstock waters, the rationally-stated analysis of S. W. Johnson, from the 600 foot level of the Savage mine (C. King, *op. cit.*, p. 87), served me as a guide, according to which I have recalculated the figures (Church, *op. cit.*, p. 204), for other mines and levels.

These analyses show the irruptive waters on the Comstock to be poor in dissolved substances. According to the determination of solid residuum by E. S. Bristol (C. King, *l. c.*, p. 88), this would not be the case. He finds the mine-water of the 500 feet level to contain in the Savage north drift 2660 grammes, and in the Yellow Jacket west drift as much as 3271 grammes of solid material in one ton (1000 kilos.). But it is a question whether these figures do not refer to ordinary mine-waters, as the term west drift seems to indicate.

The predominance of sulphates over carbonates is nothing unusual; but the decided predominance of lime, sulphate or gypsum in the Comstock waters is unique. This relation would still remain if we should reckon a part of the sulphuric acid as combined with the alkalies. The two most trustworthy analyses of Attwood and Johnson give 222 and 535 grammes of gypsum per ton of water, and 492 and 700 grammes per ton of dry residuum. Apart from their gypsum, the Comstock irruptive waters may be classed among the weak or acrothermal springs, like those of Teplitz in Bohemia.

The Sulphur Bank and Steamboat Springs waters are distinguished from all others in the table by a considerable proportion of sodium biborate, and resemble unmistakably certain Suffioni and Lagoni waters of Middle Italy. Their degree of impregnation and their large proportion of chlorides bring them near the waters of Carlsbad and Franzensbad, Bohemia. The proportion of sodium chloride is not surprising in the American West, in the neighborhood of undrained and therefore salt regions, but it is surprising in Bohemia, a country notoriously free from salt, in which no rock is known to contain these highly soluble substances. We must assume that they exist in the deeper region, in forms not yet decomposed, such as sodalite ($3Na_2Al_2Si_2O_8 + 2NaCl$) which must be chemically decomposed before its NaCl can be dissolved. The presence of quantities of salt smaller than those here under consideration can be attributed (as I at one time attempted to show*) to atmospheric precipitation. A. Bobierre† found by careful and continuous analysis of the rain-water falling in Nancy throughout the year 1863, 14 grammes of salt per ton or cubic meter; and G. Zoppe‡ has argued that the sometimes considerable contents of sodium chloride in the springs of the Iglesiente district, in the island of Sardinia, can only be explained by the transportation of salt from the sea by wind. (A stormy cloud-burst, March 7, 1886, showed as much as 387 grammes per ton or cubic meter). The salt of the atmospheric precipitation is concentrated by evaporation. In Bohemia, for instance, only one-fourth of the rainfall escapes into the Elbe; in more southern regions the whole evaporates. The descending ground-water is still further concentrated; so that in this way the salt normally found in the ascending waters may be accounted for.

But while the water of Steamboat Springs is rich in sodium chloride, the Comstock mine-water is poor, notwithstanding the comparatively near neighborhood of the two places. Both adjoin eruptive rocks, especially basaltic outflows; but the Steamboat Springs break out of crystalline rocks. May not the ascending waters have derived their abundant sodium chloride from minerals, like sodalite, which contain it chemically bound?

Hydrogen sulphide plays an important part in the ascending waters. Its presence seems to be the cause of a greater abundance of dissolved substances. It is attributed to the decomposition of sulphates through the organic matter, traces of which are found in most of the ascending waters. By re-oxidation, it produces the sulphuric acid which transforms carbonates into sulphates. It is remarkable that in many mineral springs H_2S appears periodically in surprising excess, and often disappears again, almost without leaving

* "Zur Genesis der Salzablagerungen, besonders jener im nordam. Westen," *k. k. Akad d. Wissensch.*, Wein, 1877.

† *Compt. rend.*, lviii., p. 755. *Bullet. Soc. Chim.*, liv., p. 467.

‡ "Descrizione geologico-mineraria dell' Iglesiente," *Memorie descritt. della Carta geol. d'Italia*, iv, Roma, 1888, p. 119.

a trace. It is probable that an alternation of the processes of oxidation and reduction would produce this phenomenon.

The most important geological factor in ascending waters is undoubtedly carbonic acid; for it is chiefly this compound which in the deep region, under high temperature and pressure, develops a greater solvent power for most of the elements of the rocks. The alkalies, earths and silica of our mineral springs have certainly been dissolved from the rocks by carbonic acid, and the carbonates thus formed usually predominate over the associated sulphates. The analyses do not give us the conditions in which they exist, because the statements of results depend largely upon the individual views of the analysts.

The general exhibit sketched above shows that in the Comstock waters the sulphates exceed the carbonates, and that the chemists have been led to connect the sulphuric acid preferably with the earths. They have simply found an excess of sulphuric over carbonic acid, as is the case also in the strong thermal springs of Bohemia. The relation between the two analyses of Sulphur Bank water is remarkable; one showing the sulphates, and the other carbonates, to be predominant. Apparently one sample was taken from water which had been for a considerable period in contact with the atmosphere, so that the liberated H_2S gas, oxidizing to H_2SO_4, expelled the CO_2 from a part of the carbonates. The three irruptive thermal waters, Nos. 1, 2 and 3 in the table are acid, and also contain a notable quantity of free CO_2 in solution—which, indeed, determines their acid character. I have added for comparison Nos. 16 and 17, two favorite Bohemian acid springs. No. 18 is the famous Vichy spring in France; No. 16 is a weak water, esteemed for table-use; and No. 17 is the celebrated stronger water of Bilin. A few years ago, the quantity of the latter spring had seriously fallen off; and there is reason to surmise that a part of its water had found a way into the collieries of Brüx, where similar acid springs appear at several points. Fortunately for Bilin, an increased supply was obtained there by means of an adit and bore-hole. It is known that distilled water at normal barometric pressure and ordinary indoor temperature may contain in absorption an equal volume of carbonic acid, and that mineral water under the same conditions has a somewhat higher absorption-coefficient. The free CO_2, not held in bicarbonates, is mostly given by analysts in terms of weight. These, by the employment of the well-known volume of one gramme of CO_2, could be easily transferred into terms of volume, a more practical form for all cases, which is unfortunately not yet generally used.

Since in the deep regions the absorption-capacity of water for CO_2 is diminished by increased temperature, but, on the other hand, increased in much greater proportion by increase of pressure, a portion of the gas absorbed in depth is liberated in the higher region and contributes energy to the ascending current.

Thus far the substances present in mineral waters in the largest proportions have been chiefly considered. We must now study also those which occur in minute proportions, since these concern most nearly the question with which we are dealing.

Minute Metallic Admixtures in Mineral Waters.—Ordinary analyses show the presence of some metals, especially iron and manganese, which occur as easily oxidizable protoxides, giving rise to the precipitation of hydrated peroxides. Lime carbonate, in solution as bicarbonate, is simultaneously precipitated by evaporation and the loss of CO_2; and silica is likewise thrown down under certain conditions. Such precipitates are called, according to their predominant ingredients, ocher, sinter, tufa, travertine, etc.

Minute metallic admixtures are found:

1. Dissolved in the mineral water itself.

2. In the ochers or sinters deposited at the mouths of springs, where they are concentrated in observable quantity, having been, without doubt, originally held in solution by the springs.

3. Moreover, there are found, in some places, at the mouths of springs, substances which were not originally in the solution, but have been subsequently dissolved and ultimately precipitated by the action of the mineral water upon various foreign bodies attacked by it.

The proportions of metallic ingredients found in ordinary spring-analyses were at first generally regarded with doubt, unless a chemist of the rank of Berzelius vouched for them. Fresenius and others admitted that such ingredients might be taken up from metallic conduits. But at last they were proved to exist in springs, excluding this hypothesis. Of course, "traces" are worthy of less confidence than ponderable quantities. According to Dr. Loschner,* Göttl found in the Giesshübl waters "traces" of copper, and even of gold. Of the fifty-nine chemical elements recognized in 1847, twenty-four were known to Elie de Beaumont† as occurring in mineral springs. Of these only six (Ur, Mn, Fe, Bi, Sb, As) were metals.

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* *Badeschrift über Giesshübl,* 3 Aufl. Prag, 1855.

† *Bulletin de la Soc. Geol. de France,* 2 Ser., iv., p. 1249, etc.

G. Bischof* doubled this list, and the knowledge of the subject has been greatly increased since by Liebig, Will, Fresenius, Rammelsberg, Wackenroder, Thenard and Chevalier. It is chiefly from the deposits of springs that we learn of the minute metallic substances once dissolved in them. The oxides of Cu, Sn, Co, Zn, Sb, Ni, etc., were precipitated together with the oxide of iron. Ochers are especially rich in arsenic. Tin is often found in the thermal deposits of Wiesbaden, Soden, Homburg, Rippoldsau, Alexisbad, Driburg, Bruckenau, Kissingen, etc.

Lead occurs in the springs of Rippoldsau (according to Will, 1.6 to 3.7 milligrammes per ton), Kissingen (10 to 13 mg. per ton) Alexisbad, Ems, Homburg, Carlsbad (in the Schlossbrunn, according to Göttl), Pyrmont, etc.† Copper has long been known to exist in acid mine-waters (*e. g.*, the cement-waters of Schmöllnitz, Herrengrund in Hungary, etc.), and is found also in ascending waters at Carlsbad (authority, Göttl), Aachen (Liebig), Bagnères de Luchon (Filhol), Bourbonne (Tomsier), Luxueil (Braconnot, Henry), Wiesbaden (Fresenius), Brückenau (Keller), Rippoldsau (Will), and in many other chalybeate waters.‡ Arsenic is, of course, often found in mineral waters. I will mention only the Magdalena spring of Mont-Doré (45 to 55 grammes per ton, says Thenard), St. Hectaire (6 to 8 per ton), Royat (35 g. per ton), and Bourbole (815 g. per ton). G. Bischof § gives as follows the maxima found in mineral springs up to 1854:

	Milligrammes per Ton.	
	Of Water.	Of Ocher.
Arsenious acid,	1.5	38.460
Antimony oxide,	0.1	......
Zinc oxide (sulphate),	13.3	......
Lead oxide,	0.1	1.900
Copper oxide,	6.4	1.000
Tin oxide,	0.1	.50

I add, as illustration, the contents of the mineral waters of two important localities, as calculated from the contents of the ocher. The chief constituents of these waters are given in the table on page 38. The first three springs are at Rippoldsau.

* *Lehrb. d. Chem. Geologie*, Aufl., i., p. 2078.

† Dr. B. M. Lersch, *Hydrochemie*, i, Berlin, 1864, p. 432.

‡ *Ibid.*, p. 438.

§ Dr. H. Ludwig's *Die natürlichen Wässer*. Erlangen, 1862, p. 96. Compare J. Roth's *Allgemeine Chem. Geologie*, Berlin, 1879, p. 564, etc.

LOCALITY:	Rippoldsau (acc. to WILL.)			Kissingen (acc. to KELLER.)	
Springs:	Josef.	Wenzel.	Leopold.	Pandur.	Rákoczy.
Constituents.	Milligrammes per ton.				
Protoxide of tin	25	17	38	134	166
Antimony oxide	16	10	24	107	134
Copper oxide	104	69	156	128	150
Arsenious acid	600	400	900	1120	800

In discussing Steamboat Springs I have already mentioned the metals found by G. F. Becker, among which are Hg, Au, and Ag.

I would only, in addition, call attention to the variations in the deposit of one and the same spring, for which purpose I select the Puits de l' Enclos des Celestines, at Vichy,* of which an analysis is given in the table on page 38. This contains in 1000 parts:

	Residuum obtained by evaporating the mineral water.	Ochreous deposit.	Calcareous deposit.
Alkaline carbonates,	735	......	......
Earthy carbonates,	129	169	980
Ferrous carbonates,	3	......	......
Manganous carbonates,	......	......	4
Iron oxide,	......	474	10
Alkaline sulphates,	42	......	......
Chlorides,	72	......	......
Silica,	8	10	......
Arsenic acid,	0.4	70	......
Other constituents,	10.6	277	6
	1000.0	1000	1000

Alterations Produced by Mineral Springs.—Daubrée, in the chapters devoted to this subject, distinguishes the action of mineral waters upon the rock they traverse, and their action upon artificial substances which have found their way into the mineral water.†

a. Under the first head he cites alunite, kaoline, and serpentine as the result of mineral springs in general. I would call attention, however, to the circumstance, not yet sufficiently appreciated, that the rocks in the neighborhood of a mineral spring often have a very different appearance from those at a distance. In the case of springs carrying sulphuretted hydrogen, this is self-explanatory.

* Dr. H. Ludwig's *Die natürlichen Wässer*, Erlangen, 1862, p. 199.

† *Les eaux souterraines a l' époque actuelle,* ii., p. 67, and *Les eaux souterraines aux époques anciennes*, p. 178.

Sulphur Bank represents the phenomenon in a striking way as regards basalt. Granite is often decomposed in the neighborhood of springs,—as in the Carlsbad region, where some acid springs, like that of Giesshübl, emerging on the contact between granite and the overlying Tertiary rocks, have transformed the granite into kaoline. I have observed similar decomposition at the springs of Johannisbad, in Bohemia, and at many other places. It is to be regretted that these phenomena have been seldom studied, as yet, from a chemical standpoint.

Daubrée has pointed out the effect of mineral water upon various rocks and artificial building-materials in the masonry shafts of the springs at Plombières and Bourbonne-les-Bains;* for instance, the zeolites (chabazite, harmotome, christianite, mesotype, apophyllite) formed in the Roman bêton; the hydrous silicates (plombierite, chalcedony, hyalite) in the Roman bricks at Plombières; recent formations of calcite and aragonite, and also the funnel-shaped cavities eaten out of the dressed limestone of the masonry. The latter are specially interesting as having been excavated from below upwards,—that is, in the direction of the ascending spring. Fig. 9 illustrates this action upon such a building stone.

An analogous, and, for our purpose, still more important observation, was made in 1845, at Burtscheid, near Aachen, by J. Nöggerath. A terrace was constructed at that time in the neighborhood of the hot spring, as the site for a house. Blasting in the Devonian limestone exposed several vertical channels of nearly circular section and 20 to 90 centimeters (8 to 35 inches) diameter, some of which contained thermal water and emitted steam. They had been partly choked by rock-débris, but one of them showed a depth of about 4 metres (13 feet). Immediately around these tubes the elsewhere solid limestone had been altered for a distance of 15 centimeters (6 inches) to a gray, earthy mass, almost plastic when damp, and separable in thin scales. In places, this earthy mass had fallen away, and on the sides of the enlargements of the tube thus formed, crusts of white lime-sinter had been deposited.† Nöggerath does not doubt in the least that the mineral water emerged 5 to 6 metres (16 to 20 feet) above the present exit, and eroded the channel for itself. He believes even that the channels of all the mineral

* *Experimental Geology*, p. 82.

† J. Nöggerath, "Ueber die sogenannten natürlichen Schächte oder geologischen Orgeln in verschiedenen Kalksteinbildungen." Karsten's *Archiv. für Min., Geogn., u. Bergbau*, 1845, p. 513.

springs of Burtscheid and Aachen, which came from the limestone, have a similar shape.

He calls attention to the fact, observed by him and his friend G. Bischof, that the slabs of black marble covering the curbing of the Kaiserquelle, near Aachen, and the Schwerdbad, at Burtscheid, had been transformed by the constant action of the steam upon their inner surfaces into a doughy mass, which could be easily scratched away with the finger-nail.

Besides this evident action of thermal springs upon limestone, we may conclude from the foregoing that such waters, tending to an upward movement, may actually eat their way through limestone to the surface, or to rocks offering communication with the surface. This circumstance was not known to me when I published my monograph on the Rézbánya deposits,* in which I attributed to ground-water the erosion of the channels in the limestone which are filled with ore, instead of allowing them to have been formed by the ascending mineral waters.

The treatise of Nöggerath above cited contains also observations upon the analogy between the thermal-water channels of Burtscheid, the so-called "geological organ-pipes" (*les orgues géologiques*) in the chalk-deposits of Maestrich, and the "natural shafts" (*puits naturels*) in the Eocene limestone of the vicinity of Paris. The latter, however, have shown neither mineral water nor any traces of its former presence, and are of little interest for us. Recent investigations of both the phenomena referred to are unfortunately not now at hand.

b. Regarding the effects of mineral waters upon artificial products immersed in them, we are indebted to Daubrée for the preservation of numerous important observations in the masonry pits of the springs of Plombières and Bourbonne-les-Bains.†

The springs of Plombières occur in the neighborhood of ore-bearing quartz veins, and furnish at 68° C. a water rich in carbonic acid but poor in solid constituents, the residuum after evaporation being 400 grammes per ton (0.04 per cent.). Those of Bourbonne-les-Bains, on the other hand, have a temperature of 58° C., and are rich in mineral matter, the residuum being 7000 to 8000 grammes per ton (0.7 to 0.8 per cent), chiefly sodium chloride (5.800 grammes).

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* *Geol.-mont. Studie der Erzlagerstätten von Rézbánga in S. O. Ungarn.*, Budapest, 1874, p. 179.

† "Formation contemporaine de diverses espèces minerals cristallisés dans la source thermale de Bourbonne-les-Bains." *Annales des Mines*, 6 series, 1875, viii., p. 439. Also, the German edition of Daubrée's *Études synthétiques*, 1880, p, 57.

They flow from the variegated marls of the upper Trias, underlying the Muschelkalk, in the vicinity of large fault-fissures. Carbonic acid appears to be present in traces only, and the same is true of hydrogen sulphide, which is detected by its odor, and has given rise also to small deposits of sulphur.

In 1874, with the aid of powerful pumps, the abundant current of the spring was successfully overcome, and the foundation of the old Roman curbing was made accessible. The mineral water rises from horizontal clay beds through a funnel filled with sand, which scarcely represents the original channel. At the bottom of the masonry lining a clayey slime was encountered, in which, besides thousands of hazelnuts, acorns and fruit-seeds, many Gothic and Roman coins were found, with numerous other objects, such as bronze statuettes, needles, rings of electrum, pieces of leaden framing, etc. The gold coins weighed in all 25 grammes, the silver coins 625 grammes, but of the bronze coins there were 20,800 grammes, and many had disappeared entirely, leaving only their impress, and forming shapeless masses of the products of their decomposition, mixed with grains of sand. Of the minerals formed from the bronze, the greater part came from the copper (red copper-ore, copper-glance, chalcopyrite, peacock-ore, tetrahedrite, atacamite,) and only one from the tin—on a coin which still showed bronze in its interior, but was covered with a white layer of tin oxide. The action upon lead had produced coatings of galena and phosgenite, scales of lead oxide, and cerussite. Iron had not been altered to ordinary rust; the product of its oxidation contained silica. Moreover, pyrite, instead of the earthy black sulphide often occurring on the surface, had been formed from the iron, and was found covering pebbles and grains of quartz, angular fragments of sandstone, and also some evidently artificial products, such as flint knives—thus indicating indubitably its recent origin.

Strange to say, in spite of the quantity of chlorides in the water, and the great affinity of silver for sulphur, the silver coins had not been very seriously attacked, and their designs were still quite distinct, when they had not been coated with sulphides from the neighboring bronze coins. They must have been protected from chemical action by something not now determinable.

Moreover, iron and silica (or a hydrated silicate) had penetrated the wood found in the springs.

"At Bourbonne, as at Plombières, the intrusive formations are less than 8 meters (28 feet) below the surface; and yet they are very different from what we are accustomed to see in our laboratories. A temperature was sufficient for them which is low in comparison with that which obtains at greater depths. What forces would we not see at work, if we were permitted to follow downward the channels which have been the pathway of hot springs!"—Daubrée, *op. cit.*, p. 91.

Structural Features of the Deposits of Mineral Springs.—The original conditions at the point of outflow of mineral springs have seldom been preserved intact. Even when their channels have been successfully prolonged through the ground-water to the surface, erosion, on the one hand, has partially removed them (since they often emerge in valley-bottoms), or human agency on the other hand, has variously disturbed them by diverting, choking, or walling them, or by the erection of buildings with foundations. For our purpose it is important to be able to show that, in all channels extending to the surface and still uninjured, a regular filling with symmetrically arranged mineral crusts may be observed.

Such a regular filling of the fissure-channel of a spring I have seen at the tufa mounds of the Bad of Arczó near Parajd in Transylvania.* The filling of a fissure 25 centimeters (10 inches) consists of variegated crusts of aragonite, as thin as paper, the fibers of which are perpendicular to the walls of the channel. The latest crusts are darker, and give a bituminous odor when dissolved in hydrochloric acid; the oldest are usually milky white, and leave after similar treatment a residuum of gelatinous silica. The water tastes very unpleasantly salt and bitter. The gas which hisses from the depths of the fissure is doubtless mainly carbonic acid, perhaps with an admixture of hydro-carbon.

Since the drawing of the mouths of Steamboat Springs given by Le Conte (*op. cit.*, p. 423) may not be entirely comprehensible, I introduce in Fig. 8 an ideal section of one of the spring-mounds of Arczó.

It is only the channel which is filled with solid, almost transparent crusts; the deposits on the side of the mound are a fine-grained, white lime mass, and in the less immediate vicinity of the springs there are in many places horizontal layers of a lime tufa, containing plant-remains.

Pigeon and Voisin describe an analogous but much larger phenomenon in Vichy, at the *rocher des Celestins*, where an almost ver-

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* F. Pošepný. "Studien aus dem Salinargebiete Siebenbürgens," *Jahrb. d. k. k. geol. Reichsanstalt*, Vienna, 1867, xvii., p. 477.

tical aragonite filling, 2 meters (6.5 feet) wide and 200 meters (650 feet) long, with fibers perpendicular to the planes of the crusts, may be observed (Daubrée, *op. cit*, p. 159).

The waters flowing away from mineral springs likewise make solid deposits, which often form horizontal layers, covering considerable areas. These are the so-called travertines—formations analogous to the Carlsbad *Sprudel-* or *Erbsenstein*, etc. But we are concerned at this point with the deposits in the spring-channel itself and in its immediate vicinity, including not merely the crusts upon the walls proper, but also those surrounding large or small fragments of rock within the channel. Many such deposits are characterized by the pisolite formation, which we may observe also in ore-deposits (concretionary iron-ores, etc.). These pisolites are evidently incrusted kernels, the crusts being proportionately much thicker than the kernels. The Carlsbad *Sprudelstein* shows, indeed, the same structure on a small scale as many ore-deposits exhibit on a large scale. The pisolites, like those of Tivoli and Hamman Meskoutine, consist of lime carbonate, pure or slightly intermixed with iron oxide and silica. At the last-named locality pyrite occurs between the layers of carbonate, so that the formation must be pronounced to be crusts of lime carbonate and pyrite upon a foreign nucleus, which was elevated and incrusted so long as the ascending column of the spring had energy enough to move it.

A few words may be well added here concerning the Carlsbad *Sprudelschale* and *Erbsenstein*. As is well known, the *Sprudel* represents an action like that of geysers, ejecting thermal water and steam to a considerable height. The precipitate at the present time is a porous, somewhat ferruginous aragonite or travertine mass. The ground from which the *Sprudel* breaks forth is composed of horizontal layers of a much denser aragonite mass, which can be polished, and furnishes material for artistic lapidary-work. A part of the town of Carlsbad stands on this so-called *Sprudelschale*, from which new thermal springs sometimes break out, and the structural history of which may have been like that of the rising succession of basins at the Mammoth Hot Springs of Gardiner river, in the Yellowstone National Park.

Certain layers of this *Sprudel*-deposit are exclusively aggregates of pisolites of pea-size, whence the name *Erbsenstein* (pea-stone). Evidently these have been formed, like those of the Hamman Meskoutine spring, immediately at the outflow of the mineral water. The precipitate from the solution (at the moment supersaturated) was deposited around individual rock-grains, which had found their way into the spring, to be for awhile kept in motion by its current. Successive crusts were thus deposited, until the pisolite became too large to follow the movement of the spring and sank to the bottom, where its accessible surfaces received still further precipitate-crusts. It might easily occur, that single cavities might remain, into which the precipitate could not penetrate. These would represent, according to our terminology, the central druse. Fig. 12 illustrates this process, while Fig. 13 shows a single pisolite, including pyrite-crusts, from Hamman Meskoutine.

I have had opportunity to see a completely analogous result produced by falling drops at Offenbánya, where, at certain points in an adit abandoned for some thirty years, water rich in lime carbonate trickled from the roof, forming upon the floor a deposit several centimeters thick. At the spot where the drops fell directly upon the floor, a small basin-like depression was formed, in which lay, like eggs in a birds' nest, various bodies like pisolites, consisting of a sand-grain at the center, surrounded by concentric crusts of carbonate. Some of these formations lying in the middle of the nest were quite loose, so that they were turned over by the force of the falling drops, which explained the tolerably uniform incrustation upon them. Others situated near the edge were already fixed, could not move any longer, and showed at points a deposit of sinter* (Figs. 14 and 15). Similar formations, known as "birds' nest," are described by Schmidt in the old mine-workings of Riegelsdorf and Bieber.† Such formations appear to be by no means rare in metal-mines. I found, for instance, in Offenbánya at the face of a level which had been abandoned for some years, that small chips of rock had been covered by the falling drops with two separate thin crusts: first, a white lustrous smithsonite, and thereupon a black, easily-detached crust of a maganiferous substance.‡ (Fig. 16). The pisolitic bodies formed by falling drops are not easily confounded with those formed by a flowing spring, and when such are found in the interior of an ore-filling, they cannot well be ascribed to drippings.

Pisolitic forms appear in many ore-deposits. Thus the calamine-deposit of Santander in Spain betrays an oölitic structure, and I have observed in the gold mines of Verespatak, pisolitic forms, the

* F. Pošepný, "Ueber concentrisch-schalige Mineralbildungen," *k. Akad. d. Wissensch*, Vienna, 1868.

† *Beiträge zu der Lehre von den Gängen*, p. 42.

‡ See my paper on crustified mineral formations, cited above.

kernel being an aggregation of gold, and the surrounding thin crusts, carbonates of lime, manganese and iron. To this subject I shall recur.

From what has been said concerning the structural relations of mineral-spring deposits, it appears that at the mouths of such springs phenomena are shown, such as crustifications of wall-deposits, pisolitic forms, etc., which we meet frequently in ore-deposits also—an additional reason for declaring the latter to have been formed by mineral springs.

5. Origin of Ore-Deposits in the Deep Region.

We have seen that the mineral springs which ascend to the surface are dilute metallic solutions, and that at their outflow (the only point where we can directly observe their activity) they form deposits, containing metals, among other things, and exhibiting a structure which occurs in ore-deposits likewise. We have followed to a not inconsiderable depth one ore-deposit which occurs upon an ascending spring, and have found that, apart from changes conditioned by the vicinity of the surface, it continues its character. Finally, we have encountered mineral springs in many places where mining has followed ore-deposits in depth. Joining these several links of observation, we cannot avoid the conclusion that the ore-deposits found in the deep region are the products of mineral springs, the more so since many of them have a structure and form which can only be explained as the result of precipitation from liquids circulating in channels. The deposits from these liquids contain substances which are foreign to the surface and to the shallow region, and hence could not have been brought into circulation by the descending groundwater, but must have come from a deep region, where higher temperature and pressure (the two factors increasing the solubility of all substances) exist.

Comparing the average density of the earth (which is, according to the very recent and careful investigations of R. von Sterneck,* 5.6) with the average density, 2.5, of the rocks forming the earth's crust, we must admit that in the central mass substances much denser than 5.6 have been accumulated, that is to say, the deep region is the peculiar home of the heavy metals.

If we imagine ourselves standing in the deep region in front of

* I would call attention to the labors of v. Sterneck, pursued upon this point for a decade, and described in the *Mittheilungen des k. k. Militär. Geograph. Institutes*, in Vienna.

the profile of an ore-lode, like the Adalbert at Przibram, for instance, 1110 m. (3600 feet) below the surface and 564 m. (1850 feet) below sea-level, we perceive a fissure-space of discission, filled with symmetric mineral crusts, chiefly argentiferous lead sulphide. Remembering that this filling has been stoped continuously to the surface, we can find no other satisfactory explanation than the hypothesis that it was brought up from still greater depths, and, in view of the comparative insolubility and the large quantity of the metallic sulphide here accumulated, it must have been deposited from perpetually renewed, and, therefore, from *ascending*, mineral solutions. Whoever has had opportunity to study an ore-lode in the deep regions can conceive no other explanation. The miners themselves have always held this opinion; in other words, they have all been *ascensionists*. In the case of ore-deposits occupying tubular channels in soluble rocks, the origin of these spaces is not at once clear; and it has thus happened that one or another observer, misunderstanding the analogy of the substance and the conditions of filling, has suggested a different hypothesis, as, for instance, S. F. Emmons, whose conclusions as to the Leadville deposits I shall take the liberty of controverting in a later part of the present paper. I do not deny that there are ore-deposits permitting such a different explanation, but they occur in the shallow region only, and not in the deep region.

In the two groups of ore-deposits already discussed, and formed in pre-existing spaces, a distinct crustification leaves no doubt as to the manner of filling. Where crustification is obscure or absent, it is indeed not possible at once to offer this convincing proof of the manner of deposition. Recourse must then be had to the analogy of the substances and their paragenesis. If these correspond with the contents of spaces filled with crusted deposits, a similar origin must be inferred; that is to say, even in cases in which mineral solutions, ascending from the deep region, found no open, continuous channels, but were forced to create the necessary space by the removal of a previously-existing material, the conditions of the deep circulation still controlled. From these considerations it follows that all the deposits of the deep region are referable to one general ruling process, clearly shown to be the action of ascending mineral solutions; that is, they were all formed by ascension.

This conception is diametrically opposed to the view recently suggested by Dr. F. Sandberger, that ore-deposits are formed by so-called lateral secretion. This view was at first asserted to be universally applicable. Afterwards, the author characterized it as holding good for the majority of ore-veins only, and restricted it by the following definition:

"The theory of lateral secretion was conceived in this sense only, that the material for the filling of veins is derived from the country-rock through gradual leaching by seepage-water (Sickerwasser), which brings the dissolved substance from both sides to the vein-fissure, where it is then converted by chemical decompositions into insoluble gangue-minerals and ores, and so deposited."*

It will be seen that he started from the wholly erroneous assumption that the ore-veins of the deep region stood open (like the fissures in a rock upon the surface), so that seepage-water from both sides could deposit material in them. That is, he conceived of a fissure containing air only, and forgot entirely that such open fissures are found exclusively above the ground-water level, below which every newly-formed fissure must be immediately filled with water. The term *sickern* corresponds with the English "seep," "trickle," or "drop," and can only be understood as describing the downward movement of a small quantity of liquid. It is thus impossible to suppose that Sandberger's meaning has been misunderstood; and we are forced to conclude that he boldly extended his conclusions to cover a region with the physical conditions of which he was unacquainted.

A lateral secretion in this sense is, as I have elsewhere shown,† possible above the ground-water level only. It is indeed conceivable that even in the deep region isolated spaces may exist, from which accumulated gases find no way to the surface, and in which formations may occur, similar to those in cavities above water-level; but such instances (as at Wiesloch, in Baden, and Raibl, in Carinthia) are demonstrably exceptions to the general rule above stated.

What interests us most is, that in order to establish his theory, Sandberger was forced to discredit the fact of actual deposition in the channels of mineral springs. The proof of this fact at Sulphur Bank and Steamboat Springs was highly inconvenient. Since, as he had said, "waters which flow with such rapidity as that of ascending mineral springs containing carbonic acid are shown by experience to produce no deposits in their channels, but to do this

* F. Sandberger, *Untersuchungen über Erzgänge*, 2tes Heft, Wiesbaden, 1885, p. 159.

† "Ueber die Bewegungsrichtung der unterirdisch circulirenden Flüssigkeiten." —*Comptes rend. de la session du Congrès géol. internat.*, Berlin, 1885.

only in the immediate vicinity of their outflow" (*op. cit.*, p. 5), he was not convinced by the conditions shown at Steamboat Springs, where the deposits are near the outflow. With regard to Sulphur Bank, he was not acquainted with the works of Le Conte and G. F. Becker, showing that the ore-deposit is found in the channel itself. Although he did not doubt "that ore-deposits are here observed in process of formation" (*l. c.*, p. 13), he recalled the well-known solubility of mercury sulphide in alkaline sulphides; argued that "the leaching of pre-existing quicksilver-deposits by alkaline sulphides presents no difficulty" (*l. c.*, p. 15); and was inclined to believe that the cinnabar-deposits near the outflow were referable to older ones. Endeavoring thus to render harmless the two instances unfavorable to the lateral-secretion theory, he summed up his consideration of them at that time with the remark that "in California no proof is presented of the formation of ore-veins by ascending springs" (*op. cit.*, p. 16). After reading Le Conte's account he returned to the subject in the second part of his work,* asserting (p. 162) that in the numerous excavations connected with the walling-in of mineral springs, it has never been observed that hot springs have deposited "metals" in the immediate vicinity of their channels. He confesses again (p. 161) that here is "unquestionably an ore-deposit, formed by the precipitation of silica and cinnabar from a hot alkaline sulphur-spring, which has found and dissolved mercury sulphide somewhere below;" and admits that hot alkaline sulphur-waters may precipitate, besides quicksilver, also gold, tin, bismuth, arsenic, and antimony,—but not copper, silver, and lead-ores, which are often associated with the foregoing. These, he says, cannot have been deposited from hot alkaline sulphur-springs. "There is, therefore (p. 162), no reason in the conditions of Sulphur Bank for restoring the ascension theory to its former authority in the science of ore-veins."

It will be seen that his chief argument is, that according to his opinion, no metallic deposit has ever been found in the channel of a spring, for he seems not to consider as conclusive the deeper workings at Sulphur Bank. Such a sweeping assertion is easy; for it is not likely that in walling a mineral spring excavations will be carried deep enough to reveal the condition of its channel proper.

Sandberger's contention comprises two propositions: (1) Metals

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* *Untersuchungen über Erzgänge*, Wiesbaden. First part, 1882; second part, 1885.

have been found hitherto only in the ochreous deposits from mineral springs; and (2) in walling mineral springs, deposits formed in their channels have not yet been found. These two assertions are not controverted; but the conclusion, that because hitherto, in digging out mineral springs, we have found no metals in their channels, therefore they cannot be deposited in the channels, but only at the outflow, is illogical.

Excavations for the walling of mineral springs do not extend to the channels of the deep region. Heavy pumping is required to penetrate even a few meters below the ground-water level; whereas, to decide this question, a depth must be reached at which the ascending spring is not altered by the descending ground-water, the oxidation and chlorination due to surface agencies no longer appear, etc.

We know that temperature and pressure, the two great factors of solubility, are continually diminished as the surface is approached; and we can directly observe one result of this change in the liberation of the carbonic acid absorbed at greater depths. Why should not the substances rendered insoluble by the decrease of these factors be deposited in the channels? If no such deposition has occurred, then the precipitates must have been carried upward by the current, and should be separable by filtration from the water. G. F. Becker, in filtering the Steamboat Springs water before analysis, found (*l. c.*, p. 346) in the filtrate a precipitate of antimony and arsenic sulphides, with silica, which he ascribes to the fall of temperature and the action of low forms of plant-life.

But we find in various closed conduits of mineral water—*i.e.*, in artificial channels—that deposits are formed, not only at the mouth, but also in the channel itself. Why should natural channels form an exception?

I think it has been shown that Dr. Sandberger's chief objection to the formation of ore-deposits by ascending mineral springs is without foundation, and that the entire chain of phenomena corroborates our explanation. But the lateral-secretion theory of Sandberger suffers from several other fundamental defects, which I cannot avoid indicating in this place, because that theory was for a while accepted as a simple and welcome explanation of the genesis of ore-deposits, and began to hinder the progress of knowledge on that subject.

It found many disciples, especially among mineralogists, because it permitted the most extensive genetic generalizations, without requiring the observer to leave his mineral collection and laboratory, to descend into the mine, and to study the ore in the place of its origin. On the other hand, it must be confessed that the promulgation of this theory led to many investigations of rocks, which will be useful to science in other directions.

Sandberger, being convinced that he had detected foreign admixtures of the metals in silicates, felt himself warranted in explaining by his theory all ore-deposits in the silicate rocks; but he could not so well deal with those in limestone, which were cited by Stelzner as a chief argument against the universality of his conclusion.* With regard to Raibl, in Carinthia, it occurred to him to examine the marly slates (*Mergelschiefer*) overlying the limestone; and finding in these, besides traces of Li, Cr, and Cu, more considerable quantities of Pb and Zn, he concluded that the metals in the ore-channels of the limestone under these slates had been leached out of the latter (*op. cit.*, p. 34). This was already a descending, and not a lateral secretion.

In a paper upon the applicability to this case of the lateral-secretion theory,† however, I pointed out that also below the ore-bearing limestone of Raibl, at Kaltwasser, there are silicate rocks, which probably contain likewise minute quantities of metal, and that if Sandberger had successfully analyzed these, he would have been obliged to assume an ascent. In the same paper, I argued that the lateral-secretion theory does not account for the sulphur and the metallic sulphides; and I brought forward for discussion the veins of Przibram, assuming that in that district, where sedimentary rocks are traversed by heavy eruptive masses, Sandberger could consider the latter only as the original source of the metals in the veins. From average analyses for the latest year of production, I calculated that each square meter (10.75 square feet) of vein-surface stoped represented 190 kilogrammes (261 lbs.) of metallic sulphides, or in detail:

	Pb.	Zn.	Fe.	Cu.	Ag.	S.	Sb.	As.
Kilogrammes,	132	13	5	0.3	0.8	34.6	2.5	1.7

If these substances had been derived by lateral secretion from the country-rock (the eruptive mass being 30 meters thick by the main vein, or 100 meters for the whole group of veins) there must needs have been in each cubic meter (35 cubic feet) of the country-rock

* A. Stelzner, *Jahrb. f. Min.*, 1881, p. 209.

† *Oester. Z itsch. f. B. u. H.* 1882, xxx., p. 607.

1.9 to 6.3 kilogrammes (4 to 18 pounds) of metallic ingredients—a quantity not to be called minute. Or, reversing the calculation, and starting with the largest proportion of metal ever found in these eruptive rocks, it would have required more than one hundred times the thickness of such rocks actually present in the district to supply the contents of the veins. By these calculations and other arguments, I showed, as I thought, the special inapplicability of the theory to Przibram, but I expressed a willingness to examine some of the eruptive dikes for minute metallic admixtures, preferring only that such an examination should be checked by another person.

The management of the government mining department entrusted to the chemist, A. Patera, the investigation of individual samples of Przibram rock, but also called Dr. F. Sandberger to Przibram, where the first tests were executed with the aid of a Commission, of which I was a member.*

Unfortunately an ailment of the eyes forced me to inactivity, and I could do little on the Commission.

Dr. Sandberger submitted a statement (*op. cit.*, p. 305-327) or compilation, from which it appeared that he attached less importance to the analysis of the eruptive rocks than to that of the stratified rocks, composed of the detritus of the central Bohemian gneiss mass. According to this view, the metals of the Przibram veins came from the mica of the gneiss detritus. According to Dr. Sandberger, however, (*op. cit.*, p. 362–3,) the investigation disclosed that "an essential part of the lead and silver contents of the ore-veins is due to the eruptive rocks"—which involves a modification of the above theory.

Twenty-five rock-samples, selected by the Commission, were tested for metallic admixtures according to a method agreed upon (but not very strictly followed) by Dr. Sandberger, H. Freiherr von Foullon, A. Patera and C. Mann, with tolerably concordant results, although Patera in particular expressed some doubts as to the correctness of the method. This led Prof. A. Stelzner in Freiberg† to make a thorough test of the means employed, which showed that Sandberger's method cannot decisively determine whether the

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* Untersuchungen von Nebengesteinen der Przibramer Gänge mit Rücksicht auf die Lateralsecretionstheorie von Dr. F. V. Sandberger, ausgeführt 1884–7 und veröffentlicht im Auftrage Seiner excellenz des k. k. Ackerbauministers J. Grafen von Falkenhayn."—*B. u. H. Jahrb. d. k. k. Bergakad.*, etc. xxv., 1887, p. 299.

† A. Stelzner, "Die Lateralsecretionstheorie und ihre Bedeutung für das Przibramer Ganggebiet."—*Jahrbuch der k. k. Bergakad.*, 1889, p. l.

metals detected in the silicate were original constituents, or whether they are not secondary impregnations, left undissolved by the reagents employed.

It is thus rendered probable that minute metallic admixtures detected in the country-rock by Sandberger's method are really derived from the ore-deposit, *i.e.*, are not idiogenous but xenogenous. His assumptions in this field also are thus shown to be indefensible.

While I acknowledge fully the great importance of chemical data for the explanation of vein-phenomena, I cannot give here, without becoming too prolix, all the chemical views, often quite discordant, and must content myself with the description of a theory of ore-deposits based upon purely chemical grounds, which has just been made public by De Launay. The author starts chiefly from the views of Elie de Beaumont* concerning volcanic and metallic emanations, adding to these the results of the studies of Fouqué, Senarmont, Ebelmen, St. Claire Deville, Daubrée, etc. He begins with the primitive occurrence of magnetite in the eruptive rocks, which he extends to many other metals and minerals whose primitive presence in eruptives has not been demonstrated. Certain metallic substances were segregated in cooling from the molten mass; others have been dissolved from the eruptive rock in depth by "mineralizers," such as emanations of chlorine, fluorine, sulphur, etc., and have been deposited in the channels leading to the surface. De Launay is a very positive ascensionist; he also doubts the primitive deposition of ores in marine basins, and thus comes by the path of chemical speculation to results analogous to mine. Volcanic and ancient eruptive rocks; fumaroles and mofettes; geysers and thermal springs—these indicate the ways by which the metals have reached the earth's surface. But of such assumptions we must obtain assurance through observations in other directions. Views based upon purely chemical conclusions are not sufficiently convincing for us, because they are gained in the chemical laboratory under conditions different, especially as to pressure and temperature, from those which obtain in the deep region.

Manner of Filling of Open Spaces in General.

We know already that cavities, however originated, are always filled in analogous ways. We find in vein-spaces, in the spaces of

* Elie de Beaumont, *Bulletin de la Soc. géol. de France*, 2 ser., iv., p. 1249.

dissolution, and even in individual geodes of opal and chalcedony, always the same elements of structure, though in the most widely different materials.

Considering the matter closely, we find that many things are peculiar to the shallow region, as the nearest to atmospheric influences; but some things experienced in that region may be used to explain the phenomena of deposits in the deep region also.

Since we have seen that the precipitate in an approximately horizontal pipe, entirely filled with liquid, attaches itself to the whole interior surface, the same must be true for an underground channel, and all the more if it approaches a vertical position. Under such circumstances the deposit or mineral crust will cover uniformly the whole wall-surface.

Evidently the same laws govern here as in sedimentation. When the section of the passage through which the liquid flows under a given pressure is relatively small, the deposit will take place only when the passage is enlarged. This explains the sometimes unequal distribution of ore in one and the same mineral-water channel.

As in a saturated solution a precipitate may be obtained upon any solid body introduced, so in our mineral-water channels deposits will be made upon all solid bodies—splinters or masses of rock fallen into the fissure, loose pieces of older mineral crusts, and individual crystals floating in the liquid.

The size of the rock-fragments here considered is very variable. We might include, for instance, those which are inclosed between two regular vein-branches. But we will narrow our view to what can be seen from a single standpoint in the mine, and then we observe that horses of several square meters' surface are uniformly crusted, like small pieces of country-rock found in the vein-filling, the only difference being, perhaps, that the crusts are thicker and more numerous upon the larger masses. The fragments of rock, either angular or already more or less rounded, form, when incrusted, the so-called sphere-, cocarde-, or ring-ores. Crusted rock-kernels may often be observed coexisting with distinct wall-crusts. Sometimes the latter are less prominent than the former, and the ore-deposit then has the appearance of a breccia or a conglomerate, the several fragments of which are held together by the mineral crusts. If, on the plane of a given section, there appear no points of contact between the fragments, it must not be concluded that they originally hung free in the vein-space, or that they have been pressed apart at a later period by the force of crystallization of the mineral crusts, for the actual points of contact can be found in a parallel section; at least, I have always found them when I have sliced into plates a specimen on the surface of which they were not shown. I mention this circumstance because many extensive discussions have been based upon imperfect views of single sections, giving deceptive indications of structure.*

I would recommend the frequent preparation of sections and slides of such apparently complicated structures, and I am convinced that seeming contradictions and difficulties would be simply explained thereby. It is only a question of correct observation and representation, for which, it must be confessed, the use of coloring may be necessary. In this connection I must remark that illustrations, erroneous in this respect, have found their way even into text-books, as, for instance, the picture of cocarde-ore given by Cotta,† which is taken from a careful but uncolored drawing by Weissenbach,‡ of which I reproduce a part in Fig. 17. Fragments of mica-slate are crusted with layers of quartz and pyrite, and in the vugs there is sometimes also manganese or brown-spar. The radial appearance of the crusts in the drawing is evidently due to the position of the crystals perpendicular to the wall-surfaces, and is, as a rule, observable in all such cases. The same figure from Weissenbach has been used by A. Daubrée also§, as an instance of a *filon brècheform;* but the several crusted rock-fragments are separated by heavy lines, which make the representation not only incorrect but incomprehensible.

The phenomenon may be most generally illustrated by Fig. 18, which represents a section through a gold-specimen from the Katrontza ore-body at Verespatak, and of which I intend to publish in my monograph on the occurrence of gold in Transylvania a series of parallel sections in color. Four pebbles, three of quartz-porphyry and one of mica-slate, are regularly crusted with (1) a thin zone of hornstone, (2) a thin crust of pyrite, composed of several layers no thicker than paper, (3) hornstone, in which occurs (4) a zone, 5 mm. (0.2 in.) in average thickness, of fine aggregates of native gold, extending often into the next following crust (5) of quartz, containing

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* *E.g.*, *Trans. A. I. M. E.*, 1883, xi, 119.

† *Lehre von den Erzlagerstätten*, Part I., Freiberg, 1859, p. 33.

‡ G. G. A. von Weissenbach. *Abbildung merkwürdiger Gangverhältnisse.* Leipzig, 1836, Fig. 2.

§ A. Daubrée. *Les eaux souterraines aux époques anciennes.* Paris, 1887, Fig. 24, p. 64.

scattered clouds of hornstone. The series ends in this specimen (6) with open central druses. But other specimens from the same deposit show also minute crusts of manganese-spar, to which I shall recur.

Fig. 11, representing the occurrence of cinnabar in the deeper workings at Sulphur Bank, is an interpretation of the description and sketch given by Le Conte (*op. cit.*, p. 28). Fragments of sandstone and slate with somewhat rounded edges are regularly surrounded with crusts of cinnabar which fill the space between, up to the central druse. Sometimes crusts of hydrated silica and pyrite appear also. Fig. 10 is a picture of a rich portion of the surface-workings of 1874, which I sketched at that time in my note-book. The basaltic country-rock is thoroughly cut up by irregular seams, which have disintegrated it to a shaly mass. In the seams, especially where they come together, larger spaces have been formed, often filled with decomposed country-rock, often showing separate crusts of cinnabar and opal, with a central druse. The porous material of rock and filling is impregnated with native sulphur.

Fig. 19 shows the filling of a space of dissolution at Raibl. It is a diagram from the accurate picture in my monograph upon the deposit.* A nucleus of limestone is surrounded by innumerable fine crusts of wurtzite and more compact but less regular layers of galena.

Fragments of earlier mineral crusts, which have been in some way separated from their original position, are often found surrounded by mineral crusts of later origin. An example is shown in Fig. 20, representing boiler-scale from one of the Przibram pumping plants. Here fragments of dislocated scale, about 2 mm. (0.08 inch) in diameter, are enveloped in later, thin crusts, and thus united to a breccia. The mass consists chiefly of fibrous gypsum, the fibers of which stand perpendicular to the surfaces to which they are attached.

Figs. 21 and 22 present a very distinct example, in which earlier mineral crusts, together with adhering pieces of country-rock, are surrounded by recent crusts. These figures are taken from the valuable treatise of I. Ch. Schmidt,† and refer to Zellerfeld in the Harz,

* "Die Blei-und Galmei-Lagerstätten von Raibl in Kärnthen."—*Jahrb. d. k. k. geol. R. Anstalt*, xxiii., 1873, Bd. I., Fig. 13.

† I. Christian Lebrecht Schmidt.—*Beiträge zu der Lehre von den Gängen*, Siegen, 1827.

whence A. von Groddeck also has obtained very interesting illustrations of vein-filling.*

I have seen a more complicated example from the Katrontza ore-body at Verespatak, where very rough ancient crusts of black hornstone and parti-colored quartz have been cemented together by deposits of later quartz and manganese spar to a compact mass, with some central druses. Similar conditions will be seen to obtain in the so-called pipe-ores of Raibl, Figs. 25 to 28.

The variable relation between the diameter of the nucleus and the thickness of the surrounding crust naturally contributes greatly to the variety of the resulting appearances. In the pisolitic formation, for instance, the crust is many times thicker than the nucleus.

In some cases the kernels are individual crystals. I. Ch. L. Schmidt describes pisolitic forms from Warstein, in Westphalia, the kernel of which is a crystal of yellow eisenkiesel, about 5 mm. (0.2 inch) in diameter, showing prismatic and dihexahedric faces, and covered first with a thin, white coating, upon which are crusts of coarsely fibrous eisenkiesel. The edges of these are gradually rounded, until egg-shaped spheroids, about 12 mm. (0.5 in.) in diameter, are formed, touching each other at single points, and leaving interspaces, which are either filled entirely with granular eisenkiesel, or contain residual vugs lined with transparent, finely crystalline quartz.

Fig. 24 represents the geologically important occurrence of crusted kernels of native gold from the Mátyas Kiraly mine at Verespatak. Minute aggregates of native gold are systematically surrounded by distinct, beautifully pink to carmine, thin crusts of rhodonite or rhodochrosite. So long as the kernels were completely separated, or were kept suspended by the disturbance traversing the cavity, these crusts were deposited entirely around each. After they had become fixed, later deposits of the same sort covered them; then followed carbonates of lime and iron; and finally came the quartz, the beautiful water-clear crystal-tips of which project into the central druses.

The occurrence of gold in manganese spar is not rare at Verespatak; ornaments cut from this material are pretty widely sold. But I have found but once such a distinct envelopment of the gold by the rhodochrosite crusts. The figure represents a piece cut for a brooch, which is in my wife's possession. It is specially interesting, also, as showing that the gold was not derived from the secondary

* A. von Groddeck.—*Ueber die Erzgänge des Oberharzes.* (Inaugural dissertation) Berlin, 1867.

decomposition of auriferous sulphides or tellurides *in loco,* but was directly precipitated from the mineral solutions which subsequently deposited the surrounding crusts.

We have seen that within the domain of vadose or shallow circulation peculiar deposits, classed as stalactites, are very common, not only in the spaces eroded by the natural circulation of the ground-water, but also in spaces created through the artificial depression of the water-level by mining. In the latter case, since mining often follows ore-deposits into the deep region, a much larger variety of substances is exposed to alteration, so that stalactitic formations of all kinds of materials may be encountered. Chiefly, however, we find in this form the results of oxidation, and it is somewhat exceptional to meet with the products of reduction, effected by organic matter in the mine. The most frequent of these are stalactites of pyrite.

This circumstance led to the opinion that stalactites in an ore-deposit should be taken as characteristic of a vadose or shallow origin, through the descending movement of the solutions which formed the stalactites. This view has been most clearly advanced by Dr. A. Schmidt.* The earliest formations in the instructive Wiesloch deposits are the sulphides, marcasite, galena and wurtzite, to the decomposition of the latter of which, through the metasomatic replacement of the carbonate of lime by the carbonate of zinc, the zinc-ore deposits are due. These he held to be clearly vadose in origin; and since the sulphides also occur in stalactites, he concluded that they likewise must have been formed by infiltration from above. The fact that these latter formations now lie below water-level, whereas the formation of stalactites requires a space filled with air or gas, only forced him to endeavor to explain this contradiction by the hypothesis of suitable elevations and depressions either of the water-level or of the land itself.

But all this would have been unnecessary if he had borne in mind that ascending liquids under a certain pressure will penetrate into a cavity from all sides, and may enter through the roof if the bottom and walls are less permeable. He distinguishes in general two forms of development in the original ore-deposition, namely, the filling of the lower part of a cavity with nearly horizontal, undulating crusts of wurtzite, with a little galena, and the stalactites which hang from the roof, there being no discoverable trace of corresponding stalagmites below. This indicates that the cavity was not

* *Die Zinkerzlagerstätten von Wiesloch in Baden,* Heidelberg, 1881, p. 94.

wholly filled with gas, but only in its upper part, to which, consequently, the stalactitic forms are confined. As to the manner of the later decomposition of the wurtzite, which extends down to the present water-level, there can be no doubt (*op. cit.*, p. 101).

Similar conditions are found in Raibl, where I have carefully studied the stalactites locally called "pipe-ores."* I find these, it is true, not in their original position at the roof of the cavities, but in the midst of the filling, already broken off and surrounded by the latest mineral crust, in a dolomite spar. They seem to have occurred at many points in this deposit, but my observations were confined to two, one of which was on the 5th Johanni level, about 400 meters (1312 feet) above the deepest adit (the bottom of the valley), while the other was on the 7th deep level, about 60 meters (196 feet) below the said adit. The former of these two points was within the influence of the ground-water.

Under the conditions, decomposition of pyrite and zinc-blende had been specially great; that of galena less so. It was often possible to extract from the dolomite mass the stems of galena which were loose in it. The axis of such a stalactite-stem (frequently over 10 centimeters—4 inches—long) was often an open space through which one could blow air, whence the name "pipe-ore" given to this surprising occurrence. Specimens not decomposed or in early stages of alteration showed, besides galena, crusts of pyrite and zinc-blende, concentrically disposed around the axis.

Figs. 25, 26, 27 and 28 (taken from my former treatise) and representing sections of individual stalactites, are intended to cover the variety of forms in these occurrences. Fig. 25 shows a circular stalactite in which small quantities of galena may be seen in the pyrite surrounding the axial cavity. The outer crust consists of thin layers of wurtzite (*Schalenblende*). In Fig. 27 a galena mass of rhombic section, with regular striations of secretion, sits immediately on the side of the cavity. In Fig. 26 the annular mass of galena is surrounded by blende. In Fig. 28 a decomposed body of blende lies within the galena mass, which latter is deposited immediately in the granular dolomite. It will be seen that the crusts upon the stalactites present a varying order of succession, and that the stalactites have fallen from the roof at different stages of their growth.

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* F. Pošepný, "Die Blei-und Galmei-Erzlagerstätten von Raibl." *Jahrb. d. k. k. geol., R. A.*, xviii., 1873, p. 372; also "Ueber die Röhrenerze von Raibl," *Verhandl, d. k. k. g. R. A.*, 1873, p. 54.

That portion of the ore-deposit which surrounds the localities of these stalactites has an entirely normal structure, corresponding with that of other portions, and can only have been formed in the same way, namely, from ascending mineral solutions in the deep region. When, under such circumstances, a cavity contains stalactitic deposits instead of the ordinary wall-deposits, that particular part of the channel must have been filled with gas. The decomposition of the blende is due here, as in Wiesloch, to the subsequent action of the vadose circulation.

In the Mátyas Kiraly mine in Verespatak, from which I have already described the envelopment of gold-aggregates by various metallic carbonates and quartz, there has been found also a stalactitic form of analogous composition. This specimen is in my possession, but there are two others in the National Museum at Budapest which practically came from the same mine. One of the latter is shown in Figs. 29 and 30, and my own in Fig. 31, in twice the natural size. The latter showed, after being broken from the rock in which it occurred, a projecting thread of gold; and in polishing the surface several angular (and hence crystalline) gold-aggregates were found in the axis of the stalactite. The shaded portion indicates the pink manganese crusts, and the unshaded portion the colorless carbonates. The outermost crust, separated here and there from the others by a small druse, is quartz.

Wonderful occurrences of this kind must exist in the Vallé mines in Missouri; but we have only mere diagrams of them, which do not exhibit the true details and cannot be corrected with the aid of the accompanying text. The careful objective representation of a series of these tubular deposits would be a service to science. I shall recur to these relations, represented in Figs. 32 to 35, when I come to consider the Missouri deposits again.

The variety of the occurrences described above might be still further illustrated; but enough has been said to furnish from observation the elements for explaining the filling of all crustified deposits. When the elements actually found in such deposits are taken together with what we know of the conditions of underground circulation, no competent person can well believe in any other origin for these deposits than that of the circulation we have described. Whoever has followed the foregoing simple statement of the whole chain of phenomena will be led to distinguish sharply between the effects of the descending vadose and those of the ascending profound circulation, and to avoid the confusion of the two which sometimes characterizes the discussion of the subject.

But there remains a serious difficulty in determining the genesis of non-crustified deposits. Here the indications, by which the structure and gradual growth of the deposit may be traced, are at first lacking. But they will certainly be found by patient search; and this knowledge must be furnished by engineers who have opportunity to study the phenomena on the spot where they occur, namely, in the mine.

The non-crustified deposits consist, however, of the same minerals as the crustified, and cannot well have a different origin; only we are not yet in a position to offer for them similar proofs of the manner of their formation. Certainly they also are the products of ascending mineral solutions; but they were not deposited in pre-existing spaces, and consequently they show no crustification. In describing various instances of this class, I shall have occasion to adduce some data bearing upon their genetic relations.

But even the crustified deposits need to be further illustrated by examples, especially because they seldom occur in nature in pure, unmixed types. We ought not to consider ore-deposits without reference to the medium which contains them; hence we must take into consideration the country-rock, and seek to represent the analogies of nature by grouping them graphically, as it were, with relation to two axes, representing respectively the genetic class and the country-rock. We may thus distinguish the following general groups:

Fillings of spaces of discission (fissures, etc.).

Fillings of spaces of dissolution in soluble rocks.

Metamorphic deposits in soluble rocks; in simple sediments; in crystallines and eruptives.

Hysteromorphous deposits (secondary deposits, due to surface agencies).

PART II.

EXAMPLES OF CLASSES OF DEPOSITS.

I have attempted to show above that in the two regions of subterraneous circulation the formation of ore-deposits must have taken place according to different, almost diametrically opposed principles: in the vadose region through descension and lateral secretion, and in the profound region by ascension, as the product of upward currents. I have pointed out that the deepest rocks reached by mining can scarcely be the original sources of the metallic solutions, and that these sources must lie at still greater depths.

That is to say, I advocate the views of the old school, and stand opposed to the assumptions of the new one, lately become popular, which does not need to go to inaccessible depths for the source of the metals, but professes to find it conveniently by simple chemical tests, without the necessity of leaving the laboratory and searching out the natural deposits. The new doctrine has thus far failed to take into consideration the two different underground regions; and we may expect that in proportion as it comes to do so, its conclusions will acquire quite another meaning.

I think it has been shown that the deposits of the deep region are precipitates from ascending springs. It remains to inquire, what has become of the substances which were not precipitated in such channels, but reached the surface in solution? Evidently these have been taken up, partly by the surface circulation, partly by the vadose underground currents; and, in the latter case, the deposition of such substances in the vadose region is possible. But I do not believe that we are as yet in a position to form a correct conception of the process of such a deposition; and therefore I leave this question open. Possibly, many impregnations, for which we can trace no direct connection with ascending springs, yet which are certainly not idiogenous (*i.e.*, of contemporaneous origin with the rock-matrix), may have originated in this way. Possibly, the sulphides which occur confined to the neighborhood of organic remains have been reduced from sulphates. But this must be confirmed in each case by a direct study of the facts, and not propounded as a safe generalization for all cases.

All these conclusions are based upon the undoubtedly correct hypothesis that the individual minerals of the deposits are precipitates from aqueous solutions. The important part played by the direct products of the barysphere—the eruptive rocks—is not ignored. But there has been a tendency of late to consider the proof of any solvents as superfluous, and apparently to assume that certain minerals were segregated directly from the eruptive magma. With respect to ferriferous oxides, this view has some foundation; but the notion, apparently held in some quarters, that sulphides also were thus segregated from the magma, surpasses my comprehension. It is true that pyrite is sometimes seen upon the lavas of active volcanoes; but this occurs, so far as I know, only when fumaroles and solfataras emit gases and vapors which decompose the rock, and therefore the agency of a solvent is not lacking. I am therefore obliged to conclude that aqueous solvents are the chief factor in the genesis of ore-deposits; and I shall be guided by this principle in the following illustrations of the leading genetic groups.

1. Ore-Deposits in Spaces of Discission.

The spaces produced in rocks by mechanical forces are predominantly fissures; but simple forms are sometimes rendered irregular by pre-existing conditions, such as those of stratification. Splitting upon a bedding-plane, coupled with a simultaneous longitudinal movement (such as gave rise to the ore-stock-works which the Norwegian miners call "lineal") may produce very complicated spaces, which must, however, be classed as spaces of discission.

Every fissure is the consequence of a tendency to dislocation transmitted into the rock. Hence the principal effect of the process is the production of the dislocation, not that of the fissure.* Where yielding stratified rocks are exposed to such a force, they first bend in its direction, and the fracture takes place when the limit of elasticity is passed. In such cases it is evident that the movement precedes the fracture. Fig. 70, from Rodna, and Fig. 69, from Raibl, are examples. In the latter, the gently southward-dipping contact between limestone and slate is bent and faulted by a N. and S. fissure. At Kisbánya, in Transylvania (Fig. 99), the strata of gneiss and chloritic slate, striking N. and S., are so bent by the E. and W. Nagynyerges vein as to give the appearance of an ore-bed.

Although the fissures produced by dislocating forces appear to be straight, they exhibit (as may be observed where veins have been traced for long distances) various changes of direction and more or less gradual curves. This hinders or checks the movement of one convex portion upon another, and promotes the creation of open spaces. The dislocating force, however, continually crowds the projecting surfaces together, and thus a space already partly filled with mineral deposit may be closed, or an open space may be filled with the detritus of friction. But the space finally left open facilitates communication with the deep region, from which it is filled.

* F. Pošepný, "Geol. Betracht. über die Gangspalten," *Jahrb. d. k. k. Bergakademien*, Vienna, 1874.

According to this conception, the vein-sheet must not be regarded (as is too often done) as a uniform plate of ore. On the contrary, it consists of several portions of very unequal value. The most valuable, doubtless, is the cavity-filling which forms the *bonanza* proper. In another portion the mineral solutions have been forced to penetrate the country-rock, and impregnate it with ore. A third portion remained altogether impenetrable to the solutions, and represents barren ground. These three kinds of ground may evidently show, at least in the same district, a certain regularity of relation; and of course it is most important to determine for a given district some law of distribution of the rich ore-bodies. In certain instances some knowledge of this distribution has been, in fact, successfully acquired for a given vein, before it had been exhausted by mining. In many other cases we cannot establish the law, even afterwards, because the most necessary records were not made during the exploitation. On the whole, we must confess that our knowledge of the laws of bonanzas is nothing to be proud of. In this respect the work of Professor Moissenet may be consulted.*

Obviously, in all such investigations, the question of the origin of the fissure must be separated from that of its filling. The former can be answered only upon the broad basis of a knowledge of the stratigraphic relations of the whole vicinity, and with reference chiefly to the physical properties of the rocks, while in the latter their chemical properties come to the front.

As a rule, however, the country-rock of an ore-vein is more or less altered, not only by decomposition, but also by subsequent solidification, thus rendering much more difficult the comparison with conditions existing far from the vein. This alteration of the country-rock is universally ascribed to the mineral solutions which deposited the ore; and it is not improbable that a close study of it might enable us to draw conclusions as to the nature of these solutions. Unfortunately, petrography is still confined mainly to fresh, typical rocks, and the study of the decomposed country-rock of ore-veins has not been cultivated so much as could be wished.

All veins which exhibit friction-phenomena, such as crushed country-rock, slickensides, and striations, are structurally fault-fissures. Such a vein may be conceived, therefore, as the boundary-surface of a mass which has undergone movement. The vein-phenomena of the Hartz especially support this conception.

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* M. L. Moissenet, *Études sur les filons de Cornwall; Parties riches des filons; Structure de ces parties*, etc., Paris, 1874. Engl. tr. by J. H. Collins, London, 1877.

Some vein-fissures are confined to a given rock, and do not extend into the adjacent rock. These cannot be ascribed to structural dislocation, but must rather be considered as caused by changes of volume in the immediate formation. They are often called fissures of contraction. The most striking example which I have encountered is shown in Fig. 36, which is from the gold-district of Beresov, in the Ural mountains. Palæozoic slates are there traversed by a number of granite veins, 20 to 40 meters (66 to 131 feet) thick, and striking chiefly N. and S.; and each of these granite veins is again traversed by E. and W. gold-quartz veins, which at the borders of the granite either become barren or cease altogether. Near the Beresov is the Pysminsk district, in which the granite veins are replaced by diorite and serpentine; but strange to say, the gold-quartz veins occupy in these rocks the same position as in the peculiar Beresov granite, locally called beresite. Judging from Beresov alone, one might suspect the veins to have been filled from the granite; but the occurrence in Pysminsk suggests caution.

Finally, the veins of the well-known very deep mines of Przibram might be ascribed to the contraction of the eruptive dikes in which they occur (although they depart here and there into the stratified rocks); but we cannot dream of deriving their metallic filling from the dikes. The Commission, already mentioned, established to test the applicability of the lateral-secretion theory to Przibram conditions, found the material of the dikes to be the same in depth as in the upper zones. The largest amount of metallic contents attributed to the diorite dikes would account for a portion only of the thickness of ore in the veins. The greater part must certainly be regarded as of deep origin; and it is more convenient to treat the entire metallic contents of the veins as derived from greater depths.

Granting, then, that the vein-spaces at Beresov were formed by the contraction of the granite dikes, the vein-filling must be ascribed, like that of other deposits, to metallic solutions ascending from the deep region.

With regard to structure, the fillings of ore-veins very often exhibit distinct crustification, and sometimes even a symmetric succession of crusts from both walls to the central druse. But this phenomenon often retires into the background; crustification becomes indistinct or disappears, as is frequently the case in gold-quartz and other metamorphosed veins, in which its last traces appear in the crystal-tips of the central druse and the occasional indication of fibers perpendicular to the walls.

Sometimes one part of a vein shows distinctly a crustification which in other parts is discerned with difficulty, or is even wholly absent. Fig. 53 represents a specimen from the Drei Prinzen Spat vein in the eighth level of the Churprinz Friedrich August mine at Freiberg. It is interesting also by reason of the two dislocations which it exhibits. The oldest vein (*a*) of quartz, with irregularly disseminated galena and zinc-blende, is traversed and faulted by a second, very clearly crustified, vein, the filling of which consists of hundreds of very thin alternate crusts of (*b*) fluorite and quartz and (*c*) barite, symmetrically arranged on both sides, with a central druse (*d*) containing a gray earthy mass. A quartz seam (*e f*) then faults both veins. The manager of the mine assured me that the specimen occurred in the vertical position in which I sketched it. (In order to be certain at all times on this important point, it is advisable, before removing a specimen from its natural position, to mark it in color with a vertical arrow, head downward.)

Very often the crustification of a vein-formed ore-deposit is only to be traced in the appearance of the whole, since each of many irregular veinlets may represent separate mineral crusts. Accurate pictures of such occurrences are highly instructive, since the complications are often so great that the most detailed description can convey no correct notion. Figs. 45 to 52, by reason of their small scale, do not give all the details contained in the originals from which they are taken. Figs. 45, 46, and 47 are from Weisenbach's famous book,* and represent Freiberg occurrences. The rest are from Austrian publications.† Figs. 48, 49, and 50 refer to Przibram, Figs. 51 and 52 to Joachimsthal. We have in Fig. 47 a specimen, so to speak, of the transition from a vein to a bedded deposit. But this is not the type called by the Germans bed-vein (Lagergang), which is strictly a fissure-vein, the fissure of which coincides with the plane of stratification instead of crossing it. Sometimes it is a joint or cleavage-plane (often confounded with the bedding) which the bed-vein occupies—a case which, I believe, I have found at Mitterberg in Salzburg and at the Rammelsberg near Goslar.

In this category belong also the instances of a squeezing of strata

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* *Abbildung merkw. Gangverhältn. aus d. sächs. Erzgebirge*, Leipzig, 1836.

† *Auf Befehl s. Exc. Julius Grafen Falkenhayn herausgegebene Bilder v. d. Lagerst. d. Silber-u. Bleibergb. zu Przibram*, etc., Vienna, 1887. *Geol.-bergmänn. Karte mit Profilen u. Ortsbildern zu Joachimsthal*, etc., Vienna, 1891.

near the vein, so that hanging or foot-wall, or both, show for a certain distance a stratification parallel with the ore-deposit, and only beyond this zone does the normal stratification in a different plane appear. This case is best represented by Fig. 99, a sketch showing an E. and W. vein in a country of slate striking N. and S. The occurrences at Rodna (Fig. 70) and Raibl (Fig. 69) furnish also some illustrations, though here it is chiefly barren fissures which traverse and bend the stratification.

The text-books usually present only simple outline-sketches of such conditions; and accurate pictures are calculated to surprise those who have not been much in mines, by exhibiting the complications of the actual occurrences. (Of course, complete objective accuracy would require photographs of polished surfaces.) I will here refer only to one of the most complex pictures, shown in Fig. 47 and taken from Weissenbach's collection (*op. cit.*, Plate 22). The Gabe Gottes vein of the Bescheert Glück mine at Freiberg consists of separate masses of decomposed gneiss, bounded by barren fissures, and the stratification of which has been disarranged by their mutual pressure. The fissures have no filling, but the gneiss shows filling, nearly representing its stratification, *i.e.*, in planes almost perpendicular to the walls of the vein. According to my view, the vein being in this place split up into small fissures, a movement must have occurred, probably on the lowest of these fissures shown in the picture; but the result, instead of being an ordinary fault, was a pulling-apart of the hanging-wall strata, which created spaces perpendicular to the vein-plane, and approximately between the strata. These spaces were subsequently filled in the same way as was the simple main fissure itself in other parts of this vein. The case may furnish also an explanation for certain kinds of bed-veins.

The greater number of ore-veins, as of ore-deposits in general, occur in eruptive rocks—a circumstance which doubtless indicates that their metallic contents have been derived, directly or indirectly, through these or other media, from the barysphere. The most productive ore-veins are wholly in such rocks, but others occur in stratified rocks, traversed by eruptives. Comparatively few occur wholly in stratified rocks. In such cases large faults have unquestionably opened communication with the barysphere. To emphasize these relations, I will bring forward some illustrations from well-known ore-vein districts comprising such occurrences:

a. In stratified rocks, entirely unconnected with eruptives;

b. In the neighborhood of eruptive masses, and partially enclosed therein;

c. Wholly within large eruptive formations.

a. Ore-Veins in Stratified Rocks.

Genuine ore-veins entirely unconnected with eruptive rocks are not easily to be found—especially not in cases of important and well-studied districts. Clausthal, in the Hartz, still comes nearest to fulfilling these conditions. The Hartz range is a mass of folded palæozoic strata, which lifts itself, in lenticular form, above the North German plateau of mainly Mesozoic rocks. The strata comprising the Hartz generally strike at right-angles to the W. N. W. direction of the axis of the range, but most of the faults are approximately parallel to this axis, so that the terms "axial" and "cross" mean here the opposite of what they would mean in ranges the main axes of which coincide with the strike of the strata.

Clausthal.—The ore-veins of Clausthal are somewhat peculiar. There are zones of altered rocks, 20 to 80 meters (65 to 262 feet) wide and extending as far as about 15 km. (9 miles), in which the ore-bodies are somewhat irregularly distributed. These rock-zones are called vein-clay-slates (Gangthonschiefer), to distinguish them from the ordinary slates (Culmschiefer) of the district; and recent careful investigations have shown that their composition practically corresponds with that of the latter. They are therefore in fact country-rock, altered for the most part mechanically, and only to a slight extent chemically. They are foliated; but the foliation rather parallels the planes of movement, being somewhat steep, while the strata of the surrounding region have generally but a slight dip. These zones may therefore be best conceived as the result of the friction of the great masses which have here been rubbed together.

In recent times, chiefly by A. von Groddeck, it has been actually proved that these zones represent great faults, along which either the footwall mass was moved S. W. downward, or the hanging-wall was lifted N. E. The vertical movement, measured at certain points, would be about 400 meters (1312 feet); but it is probable that the movement of one mass upon the other did not follow the true dip, and that the horizontal component was much greater than the vertical. The faulted portions of a kersantite vein discovered by Groddeck show that each southern mass was moved further west, or each northern mass further east.

The network in these zones of dislocation is also peculiar. As indicated in Fig. 37, lenticular masses have been isolated, after undergoing severally a movement in the direction of the axis of the Hartz range; so that the whole zone of lenticular masses expresses the displacement which the solid crust has experienced. The structural significance of the zones is thus clearly disclosed, as a means of communication with a deep region from which the mineral solutions ascended, to deposit ores in the fissures of dislocation. As I have already remarked, an ore-vein is thus represented as the boundary of a displaced rock-mass, and so is brought into direct structural relation with the country-rock.

A glance at the geological map of the Hartz Mountains will show, however, that even this region is not free from eruptive rocks; for the stratified formations crossing the mountain axis are traversed by masses of granite, which have evidently played a part in the building-up of the range above the plateau. Moreover, according to the investigations of Dr. K. A. Lossen,* and others, contact-metamorphosis of the stratified rocks has proceeded from them. E. Kayser† fixes the elevation of the granite between the end of the Carboniferous and the beginning of the Permian, and since several of the faults extend into this rock, he thinks it cannot have been a factor in the fissure-formation. Lossen, on the other hand, is inclined to ascribe to the granite an active part in the formation of the ore-deposits, and (if I understand him correctly) to believe that these deposits were influenced by their position against the granite nucleus of the Hartz Mountains, which is said to lie steep on one side and more flat on the other, beneath the sedimentary strata.

Accurate geological surveys of the Hartz have noted a large number of fault-fissures, some of which connect the two great ore-deposits of Clausthal and Andreasberg. Those which are called *Ruscheln* resemble the dislocation-zones of Clausthal. They are fissures, up to 30 meters (108 feet) wide, approximately parallel with the mountain-axis, and filled with a clayey or fragmentary material, full of striations and slickensides and generally of dark color.

Andreasberg.—Roughly parallel with these *Ruscheln* run the silver-ore veins of Andreasberg, which carry ore only on one side

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* "Geol. u. petrogr. Beiträge zur Kenntniss des Harzes," *Jahrb. der k. preuss. geol. Landesanstalt ü. Bergak für* 1881, p. 47.

† "Ueber d. Spaltensystem am S. W. Abhang des Brockenmassivs," etc., *Ibid.*, p. 452.

of the *Ruscheln*, and lose their ore when they approach the latter. It was formerly imagined that the two main *Ruscheln* enclosed a lenticular mass of the country, to which the silver-ores were confined; and H. Credner* still expresses this view. But Kayser (*op. cit.*, p. 443) observes that the mines have disclosed a convergence of the *Ruscheln* to the west only, and that a similar convergence to the east has been purely assumed from analogy, whereas the surface-indications are rather those of a wider separation in that direction. (See Fig. 38.)

We have here a case in which the ores occupy, not, as in Clausthal, a previously prepared zone of dislocation, but a network of veins. H. Credner has pointed out that the mineral solutions were unable to penetrate the walls of the dislocation-zones, and conceived in this connection that these walls enclosed a lenticular body of rock. But the main question concerns the origin of the more recent network of fissures. We must assume that when the dislocation-zones were formed, the mineral solutions had no opportunity to enter them, because (as was the case in many great faults, *e.g.*, those of Przibram) no spaces of discission were formed. Afterwards, however, a second system of fissures originated, adjusting itself to the conditions created by the first, and producing rock-fragments, the relatively slight movement of which did not fill the interstitial spaces with the detritus of friction.

But outside of the angle between the *Ruscheln*, there are also veins, which, considering their direction, may be continuations of the silver-veins inside, although, being differently filled, they are not so regarded.

It was formerly attempted to connect two eruptive rocks with the formation of these ore-veins; the granite which appears to the north, beyond the fault-fissures; and the diabase which touches them at many points to the south. The latter, however, is now considered to be a stratified layer in the series of the country. Both rocks have been passive in the formation and the filling of the fissures, and we must look again to the deep region as the source of the ores.

b. Ore-Veins in the Neighborhood of Eruptive Masses.

The Erzgebirge.—It would be impossible here to pass in review the innumerable veins of the *Erzgebirge* in Saxony and Bohemia. Such a review will soon be furnished by the publication of a work

† "Geogn. Beschreib. d. Bergw. distrikts von. Andreasberg," *Zeitsch. d. deutsch geol. Gesell.*, xvii., p. 221.

on this subject by the eminent Saxon mining geologist, H. Müller (who has received the honorary title of "Gangmüller," to distinguish him from the many other Müllers of Germany). In this region, veins in the greatest variety occur in gneiss, with here and there an eruptive dike; but the latter can scarcely be considered as more than indications of a former communication with the barysphere.

Besides different porphyries and diorites, there is an occasional dike of basalt. At Joachimsthal, in Bohemia, we can recognize pre- and post-basaltic ore-deposition. We find here, as in many other districts, two vein-systems at right angles; one striking N.–S., and accompanied with porphyry dikes; the other striking E.–W., and accompanied with dikes of basalt and (according to recent views) phonolite. The E.–W. fissures are occupied partly by basaltic dikes, partly by ore-veins which were deposited, some before and some after the basalt, a satisfactory proof that the fissures were formed at the period of basaltic eruption. How far the basalt took part in the ore-deposition, however, has not yet been shown.

In the basaltic and "basalt-wacke" dikes of this district, at the considerable depth of some 300 meters (984 feet) below the surface, petrified tree-trunks were found, a fact which furnishes an analogy to the reported discoveries in the Bassick mine in Colorado.

Przibram.—An entirely different picture is presented by Przibram in central Bohemia, where we encounter not only a great structural fault, but also eruptive dikes, which are followed by most of the ore-veins.

In central Bohemia the general strike is NE.–SW. for all rocks except the diorite dikes, which strike N.—S., thus varying 45° from the prevailing direction. Above the granite lies first a formation of pre-Cambrian slates; upon this follows unconformably the Cambrian system, consisting below of conglomerates and sandstones, and above of fossiliferous slates. Sections across the strike show repetitions of the pre-Cambrian and Cambrian strata due to great faults, which likewise strike NE.–SW. (Fig. 40).

The one main fault which has been exposed by mining to the depth of 1110 meters (3600 feet) is properly a so-called *Wechsel*, by which the older stratum (in the hanging-wall of the fault) has been slid over the later stratum (in the foot-wall). Several other faults, similar in character, though not explored on an equal scale, occur in the district; and it may be imagined that before this shoving together of the Palæozoic strata of central Bohemia they must have occupied a much larger area than at present.

This main fault, called the "*Lettenkluft*," is constituted by a zone of clay and crushed rock, from 2 to 10 meters (6.5 to 33 feet) wide. At Przibram itself, the sandstones which contain the ore are succeeded in the hanging-wall side by pre-Cambrian slates. A little further SW., at Bohutin, granite appears on the hanging-wall of the *Lettenkluft*—evidently, as the cross-section indicates, the granite foundation, here outcropping a second time, of the whole palæozoic series.

Numerous N.–S. dikes occur, and in the ore-bearing zone they are so close together that some cross-sections show them to constitute almost one-third of the total rock-mass. The ore-veins are mostly in these diorite dikes. Only occasionally do they enter the stratified rocks, returning soon to the dikes they have left, or to others of the group. In dip also they mainly follow the dikes, so that we may here assert with confidence that the already existing dikes determined the formation of the ore-bearing vein-fissures.

As already narrated in Part I., this district was made a test of Sandberger's lateral-secretion theory. Careful and repeated analysis showed the presence of metals in the rocks, but could not decide the question whether these metals were primitive ingredients or secondary impregnations. Since such metallic traces occur in both the eruptive and the sedimentary rocks, but cannot possibly be in both cases primitive, it is probable that they are in both cases secondary. There is then in this case, notwithstanding the connection of the ore-veins with the dikes, no proof that they were formed by the leaching of the country-rock. If the vein-material (as is very likely), was derived from eruptive rocks, these were situated much deeper than the eruptive rock disclosed down to 1110 meters (3600 feet) below the surface, or 500 meters (1640 feet) below sea-level.

The Cambrian sandstone basin of Przibram is unsymmetrical; one side dips gently northwest, the other (next to the fault) slightly southeast. In the latter part, which is also more highly metamorphosed, lies the bonanza or rich ore-ground, which therefore starts *from the intersection of the great structural fault with the zone of eruptive rocks,* in other words, from the point relatively nearest to the barysphere.

In the steeply-dipping sandstone series, certain strata are petrographically characteristic; and when these are traced to the intersecting dikes, it becomes clear that the latter (and hence the ore-veins also), are fissure-faults. Thus Fig. 39, a section through the Franz Joseph shaft, shows dislocations of the strata (adinole-beds) as great as about 200 meters (656 feet).

It should be added, that the dikes present different kinds of eruptive rock, and that they are generally decomposed in the neighborhood of the ore-veins—a result naturally to be attributed to the action of the mineral springs; also, that stratified rocks show, near the granites, a contact-metamorphosis which has converted them into hornstone. This phenomenon recalls the Hartz, especially the St. Andreasberg district.

c. *Ore-Veins Wholly Within Large Eruptive Formations.*

Hungary.—If we turn to Hungary, we find many veins wholly included in eruptive rocks. One of the best known districts is that of Schemnitz, which presents in geological conditions the nearest analogue of the Washoe district and the Comstock lode in Nevada.

In both cases, various eruptives, principally Tertiary, such as diorite, andesite, trachyte and rhyolite, ranging to basalt, are spread over a Mesosoic (mainly Triassic) foundation. The N. and S. extension of these masses and of the ore-veins they contain is alike in both districts. The number of veins at Schemnitz is very large, and they exhibit a very great variety of filling. In some of them, so-called "ore-columns," *i.e.*, specially rich ore-channels (chimneys or shoots), have been recognized. Those in the Grüner vein, according to M. V. Lipold,* are short horizontally, but much prolonged in the direction of their pitch, obliquely on the dip of the vein. In other ore-veins, *e.g.*, in the Spitaler master-lode, which is about 40 meters (131 feet) wide, and has been traced for 8 km. (5 m.); also in the Bieber and other veins, the ore-bodies are said to have covered large areas of the vein-sheet. The ore richest in gold is reported to be the so-called *Zinnopel*, a crust consisting of jasper, with pyrite, chalcopyrite and galena, which surrounds fragments of an earlier quartz crust.

In the trachyte range of Vihorlat Gutin, which runs NW. and SE., approximately parallel with the Hungarian boundary, there is a series of gold and silver mining districts, containing occasional large veins with numerous small ones. Among the former are those of Nagybánya and Felsöbánya, where several domes of trachyte or of andesite, breaking through the late Tertiary "*Congerien*" strata, are in turn traversed by large veins, which split up near their outcrops, so as to exhibit in vertical cross-section a fan-shaped arrangement.

* "Der Bergbau von Schemnitz in Ungarn," *Jahrb. d. k. k. geol. R. Anstalt.*, 1867, p. 403.

Further east is the Kapnik mining district, containing a series of separate veins; then comes Rota, similar in character; and finally (over the line in Transylvania), the district of Oláhláposbánya, the veins of which are partly in the eruptive rock, partly in the old Tertiary strata which it traverses.

Throughout the range, silver-ores predominate, occasionally with a considerable gold-value. In the eastern portion, copper-ores appear.

The Dacian Gold-Field.—In southwestern Transylvania, in the Dacian gold-district, all the gold-mines are grouped in connection with four separate eruptive zones of recent origin. The main rock of the region is Cretaceous sandstone, with occasional exposures of Jurassic and Triassic strata, the latter of which include heavy outflows of melaphyre, and also masses of crystalline rocks. The recent eruptives, comprising porphyry, diorite, andesite, basalt, etc., occur in a triangle, the base of which is formed by the widest range, the Cietrasian, which strikes NW. and SE., and in which are the mines of Nagyag, Magura, Füzesd, Boiza and Ruda. In a second, approximately parallel range, are the mines of Faczebaja and Almás; in a third, those of Vulkoj and Verespatak and in a fourth, forming the apex of the triangle, those of Offenbánya.*

These mines, which are for the most part very ancient (pre-Roman), I shall treat fully in a monograph now in course of preparation. In the whole Dacian gold-district the predominant deposits are fissure-veins, sometimes represented by mere "knife-blade" seams, continuous for short distances only. In some places, as in the celebrated Verespatak district, other types of deposit are represented, the ores of which, however, also occur in spaces of discission, namely, in eruptive breccias, between the related fragments, in the form which I have elsewhere called typhonic masses; but these are ore-bearing only where they are in contact with the ore-veins. The same is true of the conglomerates into which these breccias sometimes pass, and in which the ore takes the place of the interstitial cement, as I have explained in a preceding chapter, and illustrated in Fig. 18. For further elucidation, I show in Fig. 41 a breccia, and in Fig. 42 a conglomerate. (It should be observed that the mutual relation of the fragments of a breccia can be recognized only when they have not suffered much movement after fracture). In both these speci-

* F. Pošepný, "Allgem. Bild d. Erzführung im Siebenb. Golddistrikte," *Jahrb. d. k. k. geol. R. Anstalt.*, xviii., p. 297.

mens, the rock is quartz-porphyry with quartz-crystals of pea-size. In Fig. 41 the interior of the fragments is considerably decomposed, whereas the exterior shows a thin layer, either of undecomposed rock, or of material subsequently impregnated with silica from the open interstices, and thus made capable of resistance. Sometimes the porphyry is found to be traversed by a complex network of fissures, filled (except as to some wider spaces of intersection), with a clastic mass, like sandstone. The interstices of the conglomerate, Fig. 42 (except the spaces containing crusts of manganese spar and quartz) are filled with a clastic cement, mostly silicified into hornstone.

This sort of ore-filling is comparable in some degree with ore-deposits in soluble rocks, when the filling has passed from the space of discission proper into the rock, after room has been made for it in the latter by dissolution. In the cases before us such room was made by the partial washing away of the (probably clayey) cement of the breccias and conglomerates.

Verespatak.—The gold-district of Verespatak is situated at the north end of the second eruptive range. The two porphyry masses of Kirnik and Boi form a center, around which sandstone and porphyry-tufa lie almost horizontally, and in part unconformably, upon folded Cretaceous sandstones below. The whole district is surrounded by a zone of trachytes, andesites, and their lavas, which once (as may be inferred from the fragments remaining on the porphyry and tufa) overspread the entire district, and have been removed by erosion, laying bare the two older eruptive masses of the porphyry.

A funnel-shaped depression seems to have been formed in the folded Cretaceous strata, from the middle of which ascended the porphyry-outflows, furnishing also the material for the porphyry-tufa, which fills this funnel-shaped basin.

The principal gold-bearing rock is the porphyry, yet the tufas and the Cretaceous rocks near the porphyry-outflow carry gold ; whereas, no gold or ore of any kind occurs in the trachytic and andesitic lavas which once covered the region.

Vulkoj.—At Vulkoj, however, at the southern end of the second eruptive range, almost the opposite is the case. Here the older and deeper quartzose rock carries little ore, while gold abounds in the overlying andesites. Several mines of the Dacian gold-district have encountered in depth the stratified rocks through which the eruptives came, and the result has generally been disastrous to the miner, the ore-veins having either ceased entirely or become pinched to barren fissures. In the first case it would appear that the vein-fissures had been formed by the contraction of the eruptive material. But, in general, it should be said that these phenomena are by no means clearly and reliably reported. The prejudices of the miners play too large a part in their reports. This much is certain, that any fissure, in passing from one rock to another, is likely to exhibit a certain irregularity in both direction and filling, and that a change of this kind should not be allowed to discourage at once all further exploration.

In some cases there has been found, below an eruptive rock containing ore-veins, a decomposed breccia of the same, which was quite barren. The great porphyry mass of Kirnik, at Verespatak, has been pierced through and through with ancient and modern workings, like the pores in a sponge. In recent years deep adits have been driven into it to reach fresh ground, but with unsatisfactory results. A short time ago the deepest of these adits encountered in the nucleus of the Kirnik mass not the ore-bearing porphyry, but decomposed clastic rock and porphyry-breccia, which may be supposed to be the filling of the crater-opening. The Vulkoj mass, which has been almost cut into two halves by very ancient open-workings along its crest, contained a series of N.–S. veins, the richest of which (the Jeruga) was cut in depth by adits from both sides. On the south side appears a slaty Cretaceous rock, underlying the porphyry, and extending (see Fig. 43) upon the Jeruga plane, with two offsets, to the deepest adit on the north side, where it strikes the decomposed breccias, in which the very rich ores mined above can no longer be found to continue.

As to the continuation of the veins in the slaty rock, the following facts are pertinent. West of the Vulkoj mass, in the sandstones and slates, there is another gold-field, that of Botesiu, the veins of which are analogous, both in strike and in ore-filling, to those of Vulkoj. Botesiu shows no eruptive rocks; nevertheless, a study of the whole region shows that the formation of its vein-fissures must have been connected with them, and it is even not impossible that they may once have extended as far as this, and may have been removed by subsequent erosion. It follows that we must assume the Vulkoj veins to extend below the andesite into the slate, though this has been doubted by some. Fig. 44 shows the situation in an E.–W. section.

In the region of Boitza the eruptive zone (predominantly of quartzose dacites or porphyries) crosses an exposure of Mesozoic limestones and melaphyrs, and the veins pass directly from the porphyry into the underlying melaphyr.

At Nagyag, Magura, and Füzesd, in following the gold-veins in depth, masses of Tertiary sandstones and conglomerates are formed, broken through and enveloped by the eruptive rocks.

At four places in the Dacian gold-district, namely, Offenbánya, Faczebaja, Fericiel, and Nagyag, telluric ores occur. In the neighborhood of Zalatna there is cinnabar, and at several points near Körösbánya there are copper-ores carrying a little gold. Gold is, however, mainly connected, as has been observed, with the four ranges of Tertiary eruptives, and appears chiefly in these rocks, though also in the stratified rocks which they traverse.

The occurrence of gold in this case is thus somehow related to the eruptions; but since I have never found it as a primitive or idiogenous constituent of these rocks, I do not believe that it was derived originally from them. There is, therefore, nothing left but to consider the eruptions as the agents of a communication with the deep region, from which at these points the mineral springs ascended. The Dacian gold-district will furnish, upon further exploration, important contributions to the inquiry into the original source of the gold. For instance, if the auriferous character of the veins of Vulkoj should be found to continue in the shaly sandstones underlying the andesite, my view would be confirmed.

The Comstock Lode.—The most thoroughly studied American vein-phenomena bearing on this question are doubtless those of the Comstock lode. It is not necessary to enter here upon a detailed description. I content myself with a reference to the three large treatises upon the district,* of which Becker especially discusses the genetic question. To appreciate this question, however, some simple illustrations are required; and these have been compressed into Figs. 58 to 63.

As already observed, the general geological conditions of the Comstock lode show a strong analogy to those of the Schemnitz district. Only occasional bodies of sedimentary rocks are found, while the principal mass of the whole elevated region consists of a great variety of eruptive rocks, principally of the more recent periods. The altitudes of the more important points above sea-level are about as follows:

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* Clarence King, *U. S. Geol. Explor. of the 40th Parallel*, iii., *Mining Industry*, Washington, 1870.

J. A. Church, *The Comstock Lode: Its Formation and History*, New York, 1879.

G. F. Becker, "Geology of the Comstock Lode," etc.—*U. S. Geol. Survey Monograph*, Washington, 1882.

	Meters.	Feet.
Mount Davidson (the highest point of the region), ...	2420	7941
Outcrop at the Gould and Curry mine (the datum-line for measurements of depth), ...	1950	6400
The Sutro Tunnel, at different points, 1840 to 1865 feet below datum-line, ...	1390 1382	4560 4535
The deepest point in the Belcher and Crown Point shaft, 3414 feet below datum, . . .	910	2986

These figures alone indicate the immense extent of the eruptive material.

The stratified rocks occur in a considerable continuous body at Gold Hill, in the southern part of the district, while in the northern part only a small body enclosed in eruptive rocks is found in the Sierra Nevada shaft.

The several eruptive rocks have been differently defined at different times, according to the changes in petrography and in the methods of investigation pursued. Becker distinguishes: 1. Basalt (B). 2. Later hornblende-andesite (LHA). 3. Augite-andesite (AA). 4. Earlier hornblende-andesite (EHA). 5. Later diabase or black dyke (LDb). 6. Earlier diabase (EDb). 7. Quartz-porphyries (QP). 8. Metamorphosed diorites (MDr). 9. Porphyritic diorites (PDr). 10. Granular diorites (GDr). 11. Metamorphic rocks (M). 12. Granites (G). This classification is based upon careful microscopic examination.*

The two principal veins (the Comstock and the Occidental) strike N. S., and the Comstock has been traced 5 or 7 km. (3 or 4 m.), according as its branches are omitted or included in the measurement. The position and the branching of the veins are shown in the sketch-map, Fig. 58, in which the two most important eruptive rocks, the diorite and the diabase, are emphasized by shading, the others being indicated by letters, as in the above list. The diorite forms the foot-wall from Gold Hill to Virginia City. South of Gold Hill metamorphic slates form the foot-wall, and even extend across in part to the hanging-wall side, as does the diorite to the north of Virginia City. Moreover, in one place a dike of diabase—the so-called "black dike,"—occurs immediately on the foot-wall.

* Messrs. Arnold Hague and J. P. Iddings (*Bull.* 17, *U. S. Geol. S.*, 1885, "On the Development of Crystallization in the Igneous Rocks of Washoe," etc.), have stated as their conclusion that GDr, EDb and AA are identical; PDr is EHA; MDr is LHA; and LDb is B; apparent differences being due to conditions of cooling. In *Bull.* No. 6, *Cal. Acad. of Sc.*, 1886, Mr. Becker, after a reinvestigation of the locality, denies this conclusion *in toto*, so far as the Comstock rocks are concerned.

The hanging-wall is principally diabase, at least in depth. In the upper region it is sometimes covered with other eruptives, most frequently with hornblende-andesite.

On the whole (with variations at some places), the Comstock presents wide, gently-dipping masses, predominantly of crushed and decomposed country-rock, and enclosing large flat "horses" of the same. The filling is, as a rule, saccharoidal granular quartz (sometimes more compact), in which the ores are very finely disseminated. At some points they have occurred concentrated, forming the bonanzas to which the colossal gold- and silver-production of the district is due. The ores are silver-ores (stephanite, polybasite, argentite), with sometimes galena and zinc-blende. The bullion produced from them contains about half its value, or 6 to 7 per cent. of its weight, in gold.

Some of these bonanzas were in the upper region and came to the surface. Others (like the richest one of all, in the Consolidated Virginia and California mine) were found in the deep region; and it is asserted that they were limited on all sides, without connection with other ore-bodies. This would make them unlike our ore-channels or chimneys, which usually do have interconnection. But I cannot conceive of their formation in any other way than upon the hypothesis that in such places more open spaces existed, through which larger quantities of dilute metallic solutions passed and made deposits.

The distribution of the bonanza-areas upon the vein-area is quite irregular; and it has not been possible hitherto to trace any connection between the bonanzas and the petrographic or structural conditions in their vicinity. In form they are equally without any law, as far as has yet been observed. The bonanzas of the Con. Va. and Cal. consisted of a main body and three lenticular masses higher up, which, taken together, have a flat pitch to the north. The bonanza between Belcher and Yellow Jacket, on the other hand, followed the true dip of the vein; while the bonanza in Justice—a mine on the NW.–SE. branch, which dips NE. much less steeply than the main lode—shows again a north pitch.

This NW.–SE. branch of the Comstock shows a filling different in some respects from that of the main lode, and may be considered as a cross-vein, running into the Comstock, or into the black dike which accompanies its footwall. (Becker's atlas, ix.)

In the Justice mine, namely, the filling is mostly calcite, with little quartz, instead of quartz with very subordinate calcite, as in the main lode. According to Becker (*l. c.*, p. 219) the calcitic filling is characteristic of the whole SE. branch. According to Church, (*op. cit.*, 173) compact crusts of calcite alternate in the Justice mine with their quartz crusts. This is the only clear report of crustification any where on the Comstock. (I believe, however, that I was able to observe upon a rich specimen from the Con. Va. bonanza, after polishing, a parallel structure in the mineral aggregate. I received this specimen in 1876 from Mr. Fair, one of the "bonanza kings," as a sort of compensation for the refusal to permit me to enter the then rich mine!)

A comparison of the many cross-sections of the Comstock published by King, Church and Becker, and representing, of course, various stages of knowledge of the vein, shows that no normal or average section can be given, because the condition at different points on the strike are so different, and at some places, *e. g.* the junctions of the branches, developments have not given satisfactorily complete exposures. The sections, Figs. 59 to 63, are given (on a scale too small to show much) merely to illustrate the distribution of the country-rocks. They are reduced from Becker's monograph. In the three northerly sections the footwall is granular diorite; in the two southern (Yellow Jacket and Belcher), and along the SE. branch, it is metamorphic slate. In the southern portion, the so-called black dike (according to Becker, later diabase) appears on the foot-wall, and follows the vein beyond the point where the SE. branch leaves it. The hanging-wall is diabase, except at the northern end, where diorite becomes the hanging-wall as well as the footwall. In the upper region, however, earlier diabase is covered by other eruptives. Diabase is the hanging-wall of the SE. branch also; but in the footwall of that branch, besides the metamorphous slates, granular diorite and quartz-porphyry appear.

So far as the sources of the eruptive rocks can be inferred, they were all (except that of the diorite) on the hanging-wall side of the vein, as were also the mineral springs which subsequently decomposed these rocks. But the ascending thermal waters encountered in these mines were within the vein itself; whence it may be concluded that the ore-bearing solutions came by that road from the deep region, and not, according to the lateral-secretion theory, from the side. In other words, the Comstock ores were not washed from those rocks which have been mined between 1950 and 910 meters (7,941 and 2,986 feet) above sea-level, but from material lying much deeper.

The investigations of G. F. Becker were made at a time when importance was still attached to Sandberger's theory, and the correctness of his method of inquiry was assumed. The matter takes a different aspect when we (quite justifiably) doubt whether the minute metallic admixtures detected by wet or dry analysis were originally in the rock, and acknowledge that they may possibly have entered it afterwards. This is evidently the case with the precious metals in the pyrite of the ore-bearing rock. That this pyrite is a secondary impregnation can be proved with the microscope, and is admitted by Becker also. In my opinion, any eruptive rock may give rise by metamorphosis to the type which we call in Hungary, greenstone, greenstone-trachyte, etc., and which F. von Richthofen named propylite, because of its frequent occurrence as the country-rock of ore-deposits. Whether the precious metals can be detected in this rock depends wholly upon its impregnation, or that of one of its constituent minerals, with pyrite. But it does not follow that this was the primitive condition. From this standpoint are to be regarded the metallic values reported by Becker, and here reduced, for the sake of better understanding, from cents per ton to grammes per 1000 kilograms. A pyrite washed from decomposed diabase, near the face of the north branch of the Sutro tunnel, contained 3 cents silver and 8 cents gold, *i.e.*, 0.72 grm. silver and 0.12 grm. gold, per metric ton. The pyrite from the slates in the Belcher mine carried even 18 c. (4.32 grm.) silver and 20 c. (0.30 grm.) gold. Fresh diabase is said to have contained 4 to 5 c. (0.6 to 0.7 grm.) gold; the diorite of Bullion ravine, only a trace; while the andesite yielded about as much as the diabase. Augite separated by Thoulet's method from the diabase was found to be eight times as rich as a corresponding quantity of the feldspar.

Comparative investigations are reported to have shown that the decomposed diabase contains only half as much silver as the fresh—a circumstance which was interpreted in favor of the lateral-secretion theory, on the assumption that the decomposed diabase had given up half its silver to the vein-filling.

Since the diorite in the upper portion of Bullion ravine shows only traces of silver, but at the mouth of the ravine, near the vein, contains a considerable amount, Becker considers this indicative rather of an impregnation of the rock proceeding from the vein.

Moreover, the andesites and quartz-porphyries also contain small amounts of silver; while the strongly calcareous metamorphic diorite carries 8 c. (1.92 grms.) per ton, which might be connected with the vein-filling in the Justice mine. Finally, the basalt contains nearly as much silver as the older diabase; but the basalt cannot be cited as a source, because it comprises the freshest rock in the district, and shows no trace of decomposition in its olivine (Becker, *l. c.*, pp. 223–225). These facts would be favorable to the notion of lateral secretion, if only it could be proved at the same time that the metalliferous character was primitive. But our knowledge does not go so far as that; and the Comstock, like the deep mines of Przibram, ceases, therefore, to be a proof of the lateral-secretion theory.

The Comstock differs in many respects from typical ore-veins. It is properly a quartz-vein, in which, at various points, important ore-concentrations have been formed, not showing (except in the Justice mine) any clear crustification, though this may have been present at some time, and may have been obliterated by metamorphosis of the vein-mass, *e.g.*, through the replacement of calcite by quartz. It is also, in the main, a contact-vein, between a diorite foot- and a diabase hanging-wall, with steep spurs running upward into the diabase and traversing also still more recent eruptives.* Some of these peculiarities are represented in other districts.

2. Ore-Deposits in Soluble Rocks.

In this group we shall find two genetic types represented: the fillings of spaces of dissolution, and the metasomatic deposits, the origin of which will be particularly considered, together with some related metamorphic deposits in soluble rocks, which have not yet been sufficiently studied to be classed apart.

The expression "soluble rock" is to be understood in its ordinary sense of solubility in the waters commonly represented on the earth's surface. Acid and caustic waters will attack, more or less, nearly all rocks, though not so as to dissolve them completely, as we see limestone dissolved. I include especially among the soluble rocks, rock-salt, gypsum, limestone, and dolomite. Of the following instances I shall describe most fully those which I have personally studied, giving only the essential outlines of other related occurrences.

Rodna.—The ore-deposit of Rodna, in NE. Transylvania, is interesting to me (apart from analogies which it offers with Leadville, Colo.), as the first in which I had the opportunity to study the origin of an ore-deposit by replacement.

It is situated on the line of two andesite ranges, having a com-

* This is denied by Hague and Iddings, *op. cit.* p. 41.—See foot-note on p. 83 of this paper.

mon strike,—the Hungarian Vihorlat Gutine, stretching NW., and the Transylvanian Hargitta range, running SE.,—and at the point where this line cuts through the mass of the Rodna Alps. The predominant rock is mica-slate, with numerous intercalations of limestone, and is traversed by many dikes and masses of andesite. Ore-deposits have been found at many points in the district. The most important, situated in the Benyes mountain, was carefully studied by me in 1862, after the ore-bodies in the mine had been worked out. J. Grimm had examined the mine in 1834, and had considered the deposits to be primitive beds at the contact between limestone and mica slate, and to have occupied that position before the andesite eruption, by which they had been much shattered.

The ores (pyrites, black zincblende, and argentiferous galena, slightly auriferous, with quartz and calcite) often occurred, it is true, on the gently-dipping contact-planes; but in certain E. and W. lines they stood steeply, much like veins. In these places the flat deposit, and with it the stratification, had suddenly turned upward and it was clear to me that the occurrence represented a peculiar form of fault, namely, a bending of the strata, followed by fracture in the direction of the dislocating force, when the limit of cohesion had been passed. Here and there, in these steep places, the stopes had been carried beyond the contact, and the resulting appearance was as if the steep deposit had been the primary one, and had supplied the ore to the contact. Occasionally eruptive breccias were observed along the steep deposits. At lower levels, in the downward continuation of the fissure of the steep deposit, eruptive rocks and thin breccias occurred; and these became predominant in the lowest part of the mine.

The structure of the ore-beds was mainly massive, and not crustified. In some places, however, druses had been developed, which showed the same paragenetic succession as the mass of the bed, and which contained pseudomorphs of pyrite and galena after calcite. The thickness of the ore-bed was extremely variable, the greater part of the contact-area being scarcely worth working, while at single points colossal masses of ore were found. These circumstances led me to consider the deposits, not as contemporaneous in origin with the rock, but as subsequently formed by the circulation of mineral waters along the contact-planes. In other respects I adopted at that time the explanation of J. Grimm.*

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* Some results of my studies at Rodna will be found in the *Verhandlungen d. k. k. g. R. Anstalt.*, 1865, pp. 71, 163, 183, and 1870, p. 19.

Mining was then active chiefly on the north slope of the Benyes divide; and the sedimentary rocks were cut off towards the south by andesite. I pointed out that on the south slope, beyond the andesite, there were various ancient mines, and recommended that they be explored in depth, by means of an adit. This led to the discovery of several deposits, which gave new life to the industry. After cutting through the andesite, the explorers found steep deposits at the contact of andesite and limestone, and, in the limestone, near its contact with the mica-slate, a flat deposit, which, being above the ground-water level, had been transformed into carbonate of lead.

The somewhat complicated conditions are shown in Fig. 70, as far as this can be done in a single section. The deposit at the contact of andesite and limestone indicates at once a genetic connection with the eruptive rock, and renders it probable that the ore-beds also are due to the after-effects of the eruption. Even on the north slope there were some reasons for this conclusion. For instance, at the ore-bodies locally called *Thonstrassen*, ores occurred in the midst of eruptive breccia, which could not be taken for fragments of the original bed. Baron Constantine von Beust * found traces of "ring-ores," indicating a formation in open cavities.

In seeking an explanation of all the facts, I was led to give up the view of J. Grimm, † which he, however, still maintained, citing Offenbánya as another instance in which a pre-existing deposit on the contact between limestone and mica-slate, had been shattered by an andesite-eruption. But in that instance, also, I had the opportunity to satisfy myself that the then accessible mine-workings showed no fragments of an earlier ore-deposit, but only ore-formations under the influence of the andesite.

Grimm had had in mind the deposits of Rodna and Offenbánya when he established, under the first division in his systematic classification, ‡ the second sub-division, "Occurrences of Ores as Fragments of Earlier Deposits, in Breccias," etc.

Offenbánya.—Offenbánya, in the Transylvania gold district, has various deposits analogous to those of Rodna, and also veins, with

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* "Bemerkungen über d. Erzvorkommen von Rodna," *Verh. d. k. k. geol. R. A.*, 1869, p. 367.

† J. Grimm, "Zur Kenntniss der Erzvorkommen von Rodna," *Verh. d. k. k. geol. R. A.*, 1869, p. 367; and F. Pošepný, "Die Natur der Erzlagerstätten von Rodna," *ibid.*, 1870, p. 19.

‡ *Die Lagerstätten der nutzbaren Mineralien*, Prague, 1869, p. 32.

telluride ores. We are here interested in its mass-deposits, at the contact of limestone and andesite, one of which is illustrated in Fig. 71.

Beneath the limestone widely extending through the district, mining has disclosed a mica-slate (the so-called underground slate); and at the contact of the two a flat, pyritous deposit. The whole stratified series is traversed by andesite; but near its contact with the limestone a steep, rich mass-deposit extends from the surface down to the mica-slate. This deposit is highly crustified, and was evidently formed in a pre-existing space.

The flat deposit shows no crustification, and may have been formed by metasomatic replacement of the lime at the contact between the impermeable and the soluble rock. The analogy with the conditions on the south slope of the Benyes mine, at Rodna, is evident, though I do not know whether at Rodna the flat deposit has been followed as yet to its junction with the steep one.*

Rézbánya.—Rézbánya in S. E. Hungary represents different conditions. Here, in an indistinctly stratified Mesozoic limestone, occur long spaces filled with ore, descending steeply and irregularly in shape like that of the cavity produced by pouring a stream of warm water upon a snow-bank. This extreme case is of great theoretical interest, although such ore-bodies having but one considerable dimension, and that in the most unfavorable direction for mining, mainly downward, are not attractive from a commercial standpoint. I visited Rézbánya first in 1868, and published some observations concerning it, which may have contributed to induce the Hungarian government to take up the subject later, and intrust to me a more thorough investigation. I will here mention only some things, interesting from the genetic standpoint, and refer for details to my published monograph upon the subject.†

In the Rézbánya region, lying above clay slates and Permian and Liassic sandstones, appear numerous isolated bodies of limestone, indicated by their fossils to be of various ages, from the Lias to the Neocomian, seldom distinctly stratified, and, when they are traversed by eruptive rocks, often showing a crystalline structure.

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* At the time of the visit of G. vom Rath, in 1878 (described by him in the *Zeitschr. d. d. geol. Gesellsch.*, xxx., 1878, p. 556), this ore-body, 28 meters (92 feet) thick, had been developed for a height of 85 meters (280 feet) and a length of 120 meters (394 feet) without reaching its termination.

† *Geologisch-montanistische Studie der Erzlagerstätten von Rezbánya*, Budapest, 1874.

The ore-filling is mostly confined to the neighborhood of the eruptives, and sometimes to the contact, where garnet-rock occurs as a well-known product of local metamorphosis. Since my examination, there may have been, in this region, many interesting and scientifically important developments, which are unfortunately unknown to me. On the basis of my old notes only, I shall confine myself to the description of a single district, cut off from commercial communication, that of Valle Sacca. The name is that of the valley, which heads in a high mountain range of Permian and Liassic sandstones, and after a short course ends in a wild limestone cañon, leading into the Galbina valley. The sides of Valle Sacca consist chiefly of limestone, which is traversed by a number of eruptive dikes and one larger mass of a syenitic character. Fig. 64 gives a somewhat generalized section of the NW. slope of the valley and district on the line of the so-called fourth adit. At the adit-mouth is cut the syenite mass, which extends also to the opposite slope; and the adjoining portion of the limestone has been metamorphosed to a crystalline mass, while the limestone further SW. is for the most part still compact. On the west side, the limestone adjoins sandstone along a N.–S. line, which doubtless represents a large fault. Approximately parallel to it run the greenstone dikes, which, though they seem to be mutually parallel, in reality intersect one another at very acute angles, thus constituting a highly elongated net-work. The dikes are not alike. Most of them may be considered aphanitic or dioritic; one, however, is quartz-porphyry, with dihexahedra of quartz, of pea-size.

The principal deposit is the so-called Reichenstein stock, which had been worked, during the period prior to my visit, to a depth of about 400 meters (1300 feet), from its outcrop, 340 meters above the deepest adit, to a level 60 meters below the adit. Fig. 65 shows the form of the ore-channel on the strike. The horizontal section of the body was most frequently circular or elliptical. In some places one dimension strongly predominated, so as to give the appearance of a fissure-filling. At the outcrop, according to the old maps, there was but one channel. Below, this divided into neighboring and mutually connected branches. Several of these might continue parallel and independent for considerable distances. The total sectional area of these channels averaged perhaps 20 to 30 square meters (215 to 322 square feet); but at some levels the deposit was only present in traces, whereas at others it had many times its average section. Fig. 66 shows, by the difference between the plumb-line and the arrow, the angle between the true dip and the pitch of the ore-body, oblique to it.

The ores were doubtless sulphides originally, but were afterwards oxidized in places. Rich silver-ores predominated, especially argentite, pieces of which weighing several pounds appear to have been no rarity. Besides this mineral there were hessite (telluride of silver), tetrahedrite, redruthite, galena, bismuthinite, and various pyrites. Taking these together with the oxidized ores, the deposit represented a whole mineral cabinet. The maximum silver-value was reported as 12 to 20 kilos per 1000 (1.2 to 2 per cent.), the gold being 3 grammes to each kilo of silver. The percentage of lead was about twenty times, and that of copper about ten times, as great as of silver. The metric ton (2206 pounds) would yield, at this rate, 24 to 40 per cent. of lead, 12 to 20 per cent. of copper, 12 to 20 kilos (386 to 643 ounces troy) of silver, and 36 to 60 grammes (1.15 to 1.83 ounces troy) of gold. The deposit was therefore a bonanza in the American sense. In fact, it yielded from $100 to $150 per ton.

Although I could not see this deposit in process of extraction, I was able to conclude positively, from specimens of the ore and from the analogy of similar deposits in the district, that it had been formed by the precipitation of successive crusts.

As regarded the origin of the cavity, I was at first influenced in my views by the numerous caves of the region. The mines repeatedly reached caves, into which the mine-water could be discharged without filling them, there being some subterranean outlet. But these caves, as I have explained in Part I., were formed by descending liquids of the vadose circulation; and to assume a similar origin for the cavities filled by the ore-bodies would be to assume that the latter cavities were formed in a manner directly opposite to that in which they were filled—which is highly improbable.

It was not until later, when I had become acquainted with the observations of J. Nöggerath (cited in Part I.) on the thermal springs of Burtscheid, that I recognized that ascending mineral springs are able to cut their own way to the surface, forming the channels which they ultimately fill with ore. The most difficult feature of all, namely, the nearly cylindrical form of the ore-bodies of Valle Sacca, was thus satisfactorily explained.

The channel of the Reichenstein body runs vertically for 400 meters (1312 feet) in limestone between greenstone dikes; or, in other words, in a zone of lime between two zones of impermeable rock. The dikes therefore control its direction. It follows downward nearly at the angle of their steepest dip, but with a pitch southward, giving it a "false dip."

The sections of the various workings show that the ore-body apparently ended at one side of the dike and recommenced at the other side, as if it had passed through. In that case, porous places in the dike-mass, at the intersection, will have determined the track of the channel. It is significant that the Reichenstein ore-channel passes in depth through the dikes to the SW., towards what is probably a great fault-fissure, and not in the direction of the present drainage. Nor could the former deep drainage from this channel have been to the NE., along the contact between the limestone and the underlying Liassic sandstone (which, in fact, appears at a lower level, where the Valle Sacca joins the Galbina valley), for the reason that all the barriers of the greenstone dikes, unquestionably extending from the limestone into the sandstone, would have opposed that flow. The stratigraphical conditions thus exclude the possibility that this channel was formed by vadose circulation, and render more probable the view that it owes its origin to the ascending waters of the deep circulation, which certainly effected the filling of it.

Raibl.—Raibl, in Carinthia, is the best representative of a group of deposits which were at a recent period taken to be genuine beds even by V. M. Lipold,* then the best authority on the mines of the Alps in general. Here and there, as, for instance, by A. Morlot,† observations were made which threw some doubt on this conception; but since they did not fit into the prevailing system, they remained disregarded. It was my fortune to establish the truth of the situation. Prof. von Groddeck kindly characterized my investigation ot it as "opening a new path," and adopted the filling of spaces of dissolution as a class in his system (*op. cit.*, pp. 10, 236, etc.).

Such deposits occur in Carinthia, in an E.–W. limestone alpine range, of which Raibl is the western end; and also somewhat further north, in the zone of Bleiberg near Villach, chiefly in a limestone, early denominated for this reason the ore-bearing limestone, and more recently determined as Triassic.

The ores occurred mostly in the vicinity of certain intercalated slates, which seemed always to occupy the same "Raibl horizon," and thus led to the conclusion that the ore-deposits (naturally believed to be of contemporaneous origin) likewise occupied a fixed

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* *Jahrb. d. k. k. g. R. Anst.*, 1862, *Verh.*, p. 292.

† *Ibid.*, 1850, i., p. 266.

horizon. But it soon appeared that the slate at Bleiberg belonged to a somewhat different horizon in the Trias; and I ventured to assert that the impermeability of the slates, as compared with the solubility of the limestone, had had something to do with the ore-deposition, which was a secondary formation in the rocks.

There are found at Raibl, some distance below the slates, in the limestone which conformably underlies them, what seem indeed at first glance to be beds of ore. They consist chiefly of a coarsely crystalline galena, with pyrites, and a zincblende (wurtzite) in very thin crusts, hence called *Schalenblende.* A closer study, however, of the extremely distinct crustification reveals that it does not represent the stratification, which, on the contrary, it crosses at all angles, being in fact the filling of irregular spaces, traversing the limestone in every direction.

Further light is furnished by the seams which here occur. As is generally the case in limestone, these are rarely wide fissures, but usually mere partings between two polished walls in close contact. Slickensides, etc., identify them at once as results of friction, caused by the forcible rubbing together of walls perhaps originally irregular. The plane of contact with the slates offers a means of determining the extent of the movement along some of these insignificant-looking seams; and it appears that dislocations as great as 40 to 60 meters (131 to 196 feet) have thus taken place. Since the slates possess some flexibility, they were sharply bent in the immediate neighborhood of the fault, a feature which, on account of its theoretical importance, I have illustrated in Fig. 69.

In the seams themselves (locally called *Blätter* or "leaves") there can be, of course, no deposit of ore; but such deposition occurs outside of the fissure, when soluble rocks like this limestone are traversed. Geode-spaces were thus leached out, and are found filled with distinct mineral crusts, as is shown in Fig. 72, representing the face of a level on the so-called *Johanniblatt.*

It cannot be doubted that the ore-supply came from the seams; and when we find such seams also in large and rich deposits of similar character, like those on the north slope of the Königsberg at Raibl, we must concede to them a similar significance as regards the ore-deposition.

To the more important of these seams, J. Waldauf von Waldenstein* and Dr. W. Fuchs† had already called attention. These are

* *Die besonderen Lagerstätten d. nutzb. Mineralien,* Vienna, 1824, Plate III., Fig. 4.

† *Beiträge zur Lehre von den Erzlagerstätten,* Vienna, 1846, Plate I., p. 23.

the Morgen, Abend, Johann and Josef. The first three meet at an angle of about 30°, and form the boundaries of ore-bodies, extending downwards along the seams with a horizontal length of 40 to 80 meters (131 to 262 feet) and a total thickness (including portions too poor to work) of 10 to 50 meters (33 to 164 feet). Many of the mine-managers believed that there was here a continuous ore-bed which had been faulted into separate bodies by the seams, and numerous exploring levels were undertaken to develop this assumed bed, but all in vain. Nothing was found, except a few more or less independent ore-shoots on one or both sides of the seams, similar to those which have been encountered in recent years at Leadville.

The foregoing observations will facilitate a comprehension of Figs. 67 and 68, the former showing a section (not strictly in one plane) of the ore-shoots in the government mine, and the latter a similar picture of the Struggl private mine. In the former, separate ore-bodies are observed to the distance of 500 meters (1640 feet) above the bottom of the valley, and in 1870 the continuous ore-shoots extended from 425 meters (1394 feet) above to 150 meters (492 feet) below that level, a total vertical height of 575 meters (1886 feet).

It will be seen that the several portions of the slopes descend more or less parallel with the stratification and the lime-slate contact, but with steps or offsets. The highest portion of the Abendblatt ore-shoot is about 300 meters (984 feet) in the foot-wall of the slate-contact; at greater depths there are portions 130, 150, 85 and finally 10 meters only (426, 492, 279 and 33 feet) from that plane.

It thus appears that the ore-shoots are approaching the contact in depth, and will probably follow it below. It is, therefore, not here the case that a particular layer in the limestone has favored the formation of spaces of dissolution. If that were true, the ore-body, notwithstanding the convergence of the seams southward, should maintain a more or less uniform distance from the contact, which it does not do, either in the section of Fig. 67 or in that of the Struggl mine, Fig. 68, where the opposite occurs, namely, the ore-shoots depart from the contact in depth. I must confess myself unable to explain these variations in the Raibl ore-shoots with the light afforded by the mine-workings down to 1870. But I am convinced that the explanation will be found by further thorough study. Meanwhile, I can only claim the credit of having placed the inquiry upon what I deem to be the true road, and express my regret that in the twenty years since the publication of my monograph on the Raibl deposits no further progress seems to have been made in the interpretation of the very numerous analogous ore-deposits.

The North of England.—I cannot omit to mention here the region, classic in this respect, of the North of England. Lead-mining is actively carried on in the carboniferous limestone of Northumberland, Durham, Cumberland and Westmoreland, where the limestone alternates with sandstone and slate and occasional intercalated eruptives or their tufas. This formation is traversed and faulted by a variety of seams and veins; and the veins are generally richer where they are in the limestone. The thinner and more extensively faulted of the limestone strata are entirely severed, so that they appear in different horizons on opposite sides of the faulting-fissure. Where they are thicker or less widely thrown by the fault, however, limestone appears on both sides of the latter. It is obvious that an accurate picture of these conditions would furnish valuable data concerning the ore-genesis.

The several descriptions of the mines do not specify whether the ore of such veins as become rich in the limestone occurs in the fissures proper or outside of them in spaces of dissolution in the limestone. The latter is clearly the case in the so-called "flats." In certain horizons, where the seams encounter the soluble lime-stratum, the ore-filling departs from the fissure into the geodes of the rock, forming frequently very rich ore-bodies of highly irregular form, but flat, by reason of their following the soluble stratum. The ore-filling continues to a very uncertain distance from the fracture-plane, and is generally accompanied with frequent cavities, the walls of which are covered with crusts of calcite, blende and galena. Empty caverns also occur.* We cannot but recognize immediately in this description the type as to character and position of the Raibl deposits, the druses of which are here represented by the incrusted cavities. The empty caverns have doubtless been formed by subsequent processes of dissolution.

These phenomena occur in the North of England on a very large scale. Veins are mentioned which have been traced for several miles, and the connected subterranean channels of dissolution must be also of considerable length. The existence of laterally extensive ore-channels, and hence of an underground circulation of mineral

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* See J. A. Phillips, *Ore-Deposits*, p. 180; also, D. C. Davies, *Metalliferous Minerals and Mining*, London, 1880, p. 216; and the works of W. Wallace, T. Sopwith, Westgarth Foster, C. E. De Rance, R. Hunt, etc.

waters not formerly suspected is thus revealed, and an entirely new light is thrown upon the so-called "ore-beds."

These observations are confirmed in another quarter by developments in Western North America, where very numerous ore-deposits are connected with limestone. It is impossible to bring forward here the whole of this material. I must limit myself to certain localities, which have been thoroughly studied and described in publications.

Leadville.—I will begin with Leadville, the recent blossom of the mountain-world of Colorado. I am, indeed, not personally acquainted with this locality, the importance of which was not recognized until after my visit to the United States; but my lively interest in it is testified by the article concerning it, which I laboriously compiled in 1879 from the incomplete data then available.* Later, when S. F. Emmons had finished his surveys, but before the publication of his epoch-making work,† I had opportunity to exchange views with him concerning the genetic condition, and to confess that I was unable to share his opinion as to the downward course of the mineralizing solutions—an opinion which was opposed to the then prevalent belief. The mine-workings have been greatly extended since that time, and Emmons's suggestion has been shown by several mining engineers,‡ on the basis of thorough studies underground, to be untenable; so that the Leadville deposits appear, as regards the origin of their metallic contents, to form no exception to the history of other similar deposits. I think Emmons himself must have acknowledged the force of these criticisms, which do not detract in the least from the merit of his accurate investigation of the district.

On the west slope of the Mosquito range appears a series of undulating Palæozoic strata, with heavy layers and intrusive masses of eruptive rocks, and traversed by numerous faults. This formation covers a large area, only a comparatively small portion of which, namely, the vicinity of Leadville, is ore-bearing,—a circumstance which of itself points to a local origin for the ore. As is well-

* "Leadville, die neue Bleistadt in Colorado."—*Oesterr. Zeitsch.*, 1879.

† "Geology and Mining Industry of Leadville."—*U. S. Geol. Survey,* Monogr. xii., Washington, 1886.

‡ F. T. Freeland, "The Sulphide-Deposits of South Iron Hill."—*Trans. A. I. M. E.*, 1885, xiv., 181; C. M. Rolker, "The Leadville Ore-Deposits."—*Ibid.*, p. 273; A. A. Blow, "The Geology and Ore-Deposits of Iron Hill."—*Ibid.*, 1889, xviii., 145.

known, the series of rocks has the following order downwards: white porphyry, blue limestone, gray porphyry, white limestone, lower quartzite,—which I will denote, for brevity, by their initial letters. The ore-deposits occur chiefly at the contact between the first two members of the series, below the WP. and above the BL. In the upper levels they are oxidized and chloridized (doubtless in this, as in other places, through the action of descending ground-water); in lower levels they appear in their original form as sulphides. That this was the condition in which they were originally precipitated, Emmons admits; only their position seems to him to exclude the hypothesis of ascending solutions. He says (*op. cit.*, p. 573).

"The principal water-channel at the time of deposition was evidently the upper contact of the blue limestone with an overlying porphyry; and from this surface they penetrated downwards into the mass of the limestone. It may be assumed, therefore, that the currents were descending under the influence of gravity, rather than ascendiug under the influence of heat."

But he omits to explain how he conceives it possible that mineral solutions descending by gravity, and hence certainly having been in contact with the surface-region, could deposit sulphides. Assuming such an explanation to be furnished by reduction through organic substances, the question arises whither such descending currents could go. Here the theory is in conflict with our conception of the underground circulations.

As A. A. Blow has shown, however, a leaching of the WP. cannot by any means have supplied the ore; for this rock is not at all decomposed, as in that case it must have been. On the other hand, there are found in the intrusive beds and dikes of the lower GP. various indications that this rock had more to do with the ore-deposition. Along these dikes lie the ore-shoots,—in other words, the channels in which ore was deposited.

It was at first tacitly assumed that the ore occupied the whole plane of the contact, although it was known that the richest bodies occupied particular zones in this plane. The importance of these ore-shoots was recognized later; and we may now consider the Leadville occurrence as presenting, not a single contact-deposit or ore-bed, but a complex group of ore-shoots, such as we have observed in other ore-deposits in limestone. These ore-shoots lie, in Leadville, at the contact between the soluble and the eruptive rock; while in Raibl they appear near the contact of two stratified rocks, one soluble and the other impermeable. The physical process forming these ore-shoots was doubtless the same in both cases. The mineral solutions, ascending under pressure, and seeking a path to the surface, followed, as some would say, the line of the least resistance; or, as I would prefer to express it, there was established in the soluble rock a line of maximum circulation, resulting in the dissolving-out of a channel.

Such dissolution, however, occurred not only on the contact between WP. and BL., but also at other contacts. Thus L. D. Ricketts (Rolker, *l. c.*, p. 284) gives a section of a mine on Carbonate Hill, showing a second, deeper ore-horizon between the GP. (dike porphyry) and the underlying limestone. According to Rolker, the BL. of Fryer Hill was relatively thin, and has been replaced with ore and accompanying minerals, all but small remnants of dolomitic sand. These are generally above the ore, *i.e.*, along the upper contact, whereas, according to Emmons's theory, they should be replaced with ore.

The sections given by F. T. Freeland (*l. c.*, Figs. 1 and 6) show two ore-horizons, the thicker of which is below the W. P., and the other below an intrusion of G. P.; and Mr. Blow's sections from Iron Hill reveal similar phenomena (see Fig. 73, a section through the McKean shaft). The ore-shoots are, of course, irregular in form; but a main general direction can be recognized, which is eastward in Fryer Hill, but northeastward in Carbonate and Iron Hill, representing the course of the channel through which the mineral solutions circulated.

In the data at hand concerning the structure of the deposits, nothing is said of a distinct crustification. It is to be remembered, of course, that mining operations hitherto have been largely confined to the upper and decomposed zone, whereas this phenomenon, if ever so fully developed, would show itself clearly only in the undecomposed zone. When we read, however, of great "horses" of country-rock, encountered in the midst of the ore, we must believe that the deposit is due not so much to a metasomatic replacement of the limestone as to the filling of spaces of dissolution; and hence it should exhibit the characteristic sign of such a filling, namely, crustification. It seems to me that this point has not received the attention it deserves; and I hope that observations in the undecomposed ore-zones will give more definite data as to structure. It is difficult to believe that metasomatic processes could produce such pronounced ore-shoots as those described at Leadville.

Impressed by Emmons's views, and long before the connection of the ore-deposition with the GP. of the dykes had been shown, I wondered, at one time, whether the ore might not have come somehow from the fault-fissures into the contact-channels. But Mr. Emmons pointed out to me that the faults contain only ore which has been dragged in from the pre-existing bodies, the formation of which was complete before the faulting took place.

Conditions analogous to those of Leadville are exhibited in most of the ore-deposits in limestone occurring in the American West. But, with few exceptions, we have only hasty descriptions of them, and sometimes nothing more than business "puffs."

Red Mountain.—A remarkable occurrence has been described in the Red Mountain district, Ouray County, Colorado.* In the midst of the deposits of the San Juan region, which are connected with eruptive rocks, appears a body of Mesozoic strata, carrying, at the contact of a quartzite with the underlying limestone, a deposit of the sulphides of iron, lead, copper, silver, and the products of their decomposition, rich in silver and somewhat auriferous (2110 to 3980 grammes of silver and 3 to 6 grammes of gold per metric ton, or 59 to 111 ounces of silver and 0.08 to 0.17 ounce of gold per ton of 2000 pounds). At certain points the ores extend far down into the limestone, and in the section shown in Fig. 74 the ore follows a fault-fissure through the whole thickness of the limestone into a second quartzite stratum below. The stratified formation is mostly covered with andesite, in which occur ore-bearing veins in fissure-form.

In the neighborhood, at Mineral Farm, another contact-deposit between limestone and quartzite is known, consisting of barite with argentiferous galena and tetrahedrite. Both the above deposits are but briefly described, and perhaps have not been extensively worked. Their conditions of position and the predominance of lead and silver-ores strangely remind one of Leadville.

In the adjacent Territories of New Mexico and Arizona, various copper-deposits occur in limestone, and at its contact with eruptive rocks; as, for instance (according to the outline-description of A. F. Wendt†), in the Clifton and Bisbee districts. The sections accompanying Mr. Wendt's paper remind me of some of the deposits described in my monograph, at Rézbánya, at Mědnorudjansk, and at Bogoslavsk in the Ural. Fig. 75 is an interesting section from

* G. E. Kedzie, "The Bedded Ore-Deposits of Red Mountain District," *Trans. A. I. M. E.*, 1886, xvi., 570.

† "The Copper-Ores of the Southwest," *Trans. A. I. M. E.*, 1886, xv., 25.

the Clifton district, in Arizona, showing two steep ore-shoots, parallel with the felsite dike, and a flat one, parallel with the bedding.

Utah.—With respect to Utah, the paper of O. J. Hollister* gives a general survey of the deposits of the Territory, and mentions a number which occur in limestone. Some of those in central Utah I have had the opportunity to see personally, during the period when mining was still confined chiefly to the decomposed upper levels. I refer to the Prince of Wales and the Reed and Benson, in Big Cottonwood; the Emma and the Flagstaff, in Little Cottonwood; the Old Telegraph, in West Mountain, and the Hidden Treasure, in Dry Cañon district.

Palæozoic strata are here traversed by frequent eruptive dikes, and by two intersecting systems of faults. The ore-deposits, of varying thickness, in the limestone have, as a rule, the form of "chimneys," either lying flat, with the bedding, or standing steeply along the dikes and faults. This gave rise in the beginning (when the nature of the deposits was not understood, and the conception of a typical "lode" generally prevailed) to a series of disappointments and mistakes in mining, of which the history of the Emma mine furnishes an interesting example. Apparently the irregularity and the complications of these deposits came to be better known afterwards The (sometimes very rich) ores consist chiefly of sulphides of lead and silver, and the products of their decomposition. In some cases (*e. g.*, Hidden Treasure) cuprite occurs, with native copper; and in the Camp Floyd district cinnabar also is found.

Nevada.—In Nevada, adjoining Utah on the west, deposits of this class are likewise abundantly represented. I will mention only the two districts which have been most thoroughly studied, namely, White Pine and Eureka.

With regard to the former, the work of Arnold Hague (1870)†, demonstrating the peculiar character of the White Pine deposits, led me to seek for European analogues.‡ I found that, apart from the condition of the ores, which at White Pine are found in the oxidized and chloridized zone, there was an analogy with all the European ore-deposits in limestone, but especially with the conditions at Raibl.

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* "Gold- and Silver-Mining in Utah," *Trans. A. I. M. E.*, 1887, xvi., 3.

† "Geology of the White Pine District," *U. S. Geol. Surv. of the 40th Parallel*, vol. iii, *Mining Industry*, p. 409.

‡ F. Pošepný, "Das Erzvorkommen vom White Pine District, u. dessen europäische Analogien," *Verh. d. k. k. g. R. A.* 1872, p. 186.

Devonian limestones and calcareous slates are overlain at White Pine by Carboniferous clay-slates, sandstones and limestones; and the ores occur only in Devonian limestone and at its contact with the calcareous slates on a N. and S. anticlinal. The ores and the associated minerals (quartz, calcite, gypsum, fluorspar, barite, rhodonite, rhodochrosite, with the chlorides, bromides, oxides, and carbonates of various metals, especially silver, lead and copper) fill the cavities in the limestone and surround its fragments.

The various mines represent different stages in one and the same process. In the Eberhardt, two fissures crossing the anticlinal bound the ore-body (like the *Morgenblatt* and the *Abendblatt* at Raibl.) This consists of a lime-breccia (Kalktyphon), the fragments of which fit together, and are cemented by ore-bearing quartz seams. The Hidden Treasure mine contained the ore in geodes, at the contact of the limestone and slate. In the Aurora, the ore was in bodies stretching N. and S. In Bromide, Chloride and Pogonip Flats, the ores occurred in geodes and masses included in lime-breccia, in a zone parallel with the bedding. It is Arnold Hague's opinion that the Eberhardt mine probably represents the source of the ore-solutions which impregnated the limestone, wherever cavities existed, up to the level of the overlying calcareous slates, which were impermeable to the solutions. The slate-cover having been removed by erosion, the ores thus accumulated below it were exposed immediately at the surface; and the surprisingly large product of the district was derived from open cuts and shallow workings.

The other leading analogue in Nevada is found in the Eureka district, and was made widely known and practically significant by the law-suit between the Eureka and Richmond companies,* which involved the definition of a deposit not contemplated in the United States mining law. Similar difficulties have arisen under the old European mining codes. Such deposits were known in some districts of Europe, but they were not so widely distributed as the fissure-veins, for the conditions of which the ancient codes were framed. Conflicts were therefore inevitable. I will mention only Bleiberg in Carinthia (which presents some degree of analogy with Eureka) where, besides the general mining code, special statutes became necessary, departing from the usual rules with regard to prospecting and the location and the acquisition of claims.

* R. W. Raymond, "The Eureka-Richmond Case," *Trans. A. I. M. E.*, 1877, vi., 371.

The geological conditions of the district have been described in an elaborate monograph by J. S. Curtis,* based on the developments existing in 1882. Further knowledge may have been gained since, but, so far as I know, nothing later has been published. I made a brief visit to Eureka in 1876; but as no comprehensive maps of the mine-workings were then available, I could only observe in a general way the analogy with European deposits examined by me.

According to Arnold Hague,† the series here occurring of Prospect Mt. quartzite, Prospect Mt. limestone, Secret Cañon shale, and Hamburg limestone, is Cambrian. The ore is confined to the limestone first named, and in particular to a portion thereof on the N. E. slope of Ruby Hill, enclosed between two fault-fissures. The features of the NW.—SE. ore-bearing zone are too variable to be indicated by a normal cross-section. Fig. 76 shows a generalized and Fig. 77 an actual section, as represented by Curtis.

The main fault-fissure separates, in the upper level, the massive limestone in its hanging- from the crushed, ore-bearing limestone in its foot-wall. In the lower levels it shows, in the foot-wall, quartzite with intercalated "Lower shale," and in the hanging-wall, further down, shale and quartzite. An ideal restoration, above the present saddle of Ruby Hill, of the foot-wall rocks which have been removed by erosion, would bring to light a relative displacement of 150 to 600 meters (492 to 1968 feet), the indications being that the foot-wall has been lifted. This would explain at once the crushing of the limestone in the foot-wall, and the creation of a second fault near the contact between the limestone and the underlying quartzite.

The ores occur chiefly in the well-known form of chimneys and in individual masses, mostly interconnected by traces of ore, at least at the depth where the two faults come together. In the mines to the SE., about 180 meters (590 feet) from the Eureka-Richmond boundary, the fissures come together at the depth of about 400 meters (1312 feet), the line of their intersection thus dipping gently NW.

The ores encountered in the upper zones, above water-level, were, with the exception of a few insignificant remains of sulphides (mostly argentiferous galena), oxidized ores, such as cerussite and anglesite, chlorides, etc., carrying a considerable amount of silver and

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* "Silver-Lead Deposits of Eureka," *U. S. Geol. Surv.*, Monogr. vii., Washington, 1884.

† "Abstract of Report on the Geology of the Eureka District," *Third Ann. Rep. of U. S. Geol. Surv.*, 1881–1882, Washington, 1883, p. 241.

a little gold. The present water-level follows approximately the line of intersection of the two faults, but the fact that oxidized ores have been found still deeper indicates that the water-level was once lower down.

It might consequently be expected that caves formed by the vadose circulation would also occur at considerable depths, especially as the whole wedge of limestone is traversed by ore-shoots, the oxidation of which would, of course, give occasion for cave-formations. The newly-formed caverns would often lie along the ore-channels, and especially in their upper portions. (See J. S. Curtis, *l. c.*, p. 100.)

Some of the irregularly distributed ore-bodies follow rather the quartzite-limestone contact; others rather the main fissures, with a NW. dip, like that of the limestone wedge. Of the two largest bodies, which have furnished the chief product of the district, the east ore-body exhibits a steep SE. pitch for nearly 400 meters (1312 feet), and the west ore-body, for nearly an equal distance, a flat NW. pitch.

In considering their structure, we must distinguish sharply between their original and their decomposed condition. The latter often hinders a clear recognition of the former. The strata-like deposits of cerussite and other products of decomposition mentioned by Curtis (*l. c.*, p. 98) are perhaps, like those in my sketch, Fig. 78, from the Old Telegraph mine, remains of the original crustification, and his statement (p. 104) that "when the ore is not oxidized there are no signs of a banded or concentric structure, and the phenomena observed point entirely to substitution of the sulphurets for country-rock," may thus be explained. In like manner his assertion, in the same place, that "the internal structure of the ore-masses in no way resembles those of Raibl," is so far correct that the original filling is at Raibl extraordinarily distinct, and at Eureka, on the contrary, perhaps, only obscurely traceable.

I personally saw in the Eureka mine some small ore-masses, which exhibited crustification, if not in a striking degree, yet sufficiently to be recognized by an impartial observer. Mr. Curtis himself (*l. c.*, p. 98) says that "rounded boulders of limestone as a nucleus" occasionally occur in the ore-mass, and that in a limestone-breccia "small masses of ore sometimes completely fill the spaces between the limestone walls,"—two phenomena which indicate crustification, and are explained by the hypothesis of a filling of pre-existent spaces.

A metasomatic removal of the limestone, such as has taken place in the secondary calamine-deposits of Raibl, cannot well be supposed for the original ore-deposition at Eureka, but may have attended the formation of the secondary, decomposed products.

I believe that later mining in deeper zones has developed more clearly the structure of the original Eureka deposits, and that specimens of the ore have shown, after polishing, traces, at least, of crustification.

In short, I consider the original Eureka ores to have been deposited in pre-existing spaces by ascending mineral solutions, while their decomposition and the formation of the caverns are the effects of descending surface-waters.

I agree with Mr. Curtis that the ore-solutions ascended from the deep region through the "main fissure" (which has, in the NW. the character of a *Blatt* at Raibl, and in the SE. part of the district is filled with rhyolite), and that they formed and filled the ore-channels in the soluble, fissured limestone.

Missouri and Wisconsin.—We have dealt thus far with ore-deposits in mountain districts, where tilting and folding, as well as the occurrence of eruptives, betray a disturbance of the original relations of stratification. But there are also deposits in limestone in plateau-regions, where the strata show no considerable disturbance. Under this head two great districts deserve attention; namely, the lead-regions of Missouri and Wisconsin.

Concerning the former, we may refer to a number of more or less detailed descriptions.*

We have in this case not a perfect plateau, since here and there domes of the underlying Archæan come to the surface, as especially in the continuation of the Ozark mountains; but the predominant character is nevertheless that of a structural plateau. The ore-deposits, chiefly confined to the Silurian limestone, are in part primary xenogenous and in part hysteromorphous (débris) deposits; the latter, as is well known, consist of the detritus from the weathering and erosion of the outcrops of the former. In the former, we find all the phenomena encountered in the deposits of mountain regions. One of these is peculiarly developed, namely, the gently inclined

* J. R. Gage, "Lead-Mines of S. E. Missouri," *Geol. Sur. of Mo.*, 1873–4, p. 603, and *Trans. A. I. M. E.*, iii., 116.

G. C. Broadhead, "The S. E. Mo. Lead-Districts," *Ibid.*, p. 100.

A. Schmidt and A. Leonhard, "The Lead-and Zinc-Region of S. W. Mo," *Geol. Surv. of Mo.*, 1873–4, p. 384.

A. Schmidt, "The Lead-Region of Central Missouri," *Ibid.*, p. 503.

cavities or ore-channels, shown in the Vallé and Bish mines of Jefferson and St. Francis counties, concerning which J. R. Gage has given some (unfortunately not very clear) notes and sketches.

In the Vallé mines, a shaft 49.9 meters (164 feet) deep, situated 33.5 meters (110 feet) above the valley-bottom, encountered at three different depths, respectively of 44.5, 46.3, and 49.9 meters (146, 151 and 164 feet) flat-lying ore-channnels, 1 to 2 meters, (3 to 6 feet) wide, which, winding in different directions, produce networks, connected at the intersecting points by chimneys from one level to the other. The cross-section of these channels in the horizontal limestone or dolomite contracts sometimes to a few square centimeters, or enlarges to several square meters, with a height of 3 to 4 meters (10 to 12 feet).

The original metallic filling was galena, pyrite and zincblende, but is already oxidized to cerussite, anglesite, smithsonite and calamine, which are accompanied with barite and a red clay. We are specially interested in the original structure of this filling; but this is not easily detected in the mere diagrams at hand.

Figs. 32 to 35 reproduce four of Mr. Gage's sections, the first three being Figs. 17, 18 and 19 of his paper in these *Transactions*, and the fourth, Fig. 72 of his article in the report of the Missouri survey. They indicate for both the metamorphosed and the original mineral crusts a prevailing horizontal position, so that we might conclude that the deposits took place in cavities, the upper portions of which were filled with gas only. A very peculiar formation is the red clay which in some instances covers the walls of the caverns and surrounds on all sides the central filling. The data at hand afford no clue to its origin.

Mr. Gage's description of Fig. 35 (*l. c.*, p. 618) is as follows:

"Fig. [72] represents the occurrence of these minerals. The solid limestone contains a fissure, entirely filled with minerals and gangue. The minerals are completely enveloped by the red clay. Above are two thin folds of silicate of zinc, separated from each other and from the limestone by the red clay. The folds of the zinc-ore are sometimes perfectly solid, being from one to six inches thick, and consisting of alternate layers of the same material in very compact folds; again, the mass of zinc-ore is from one to six inches in thickness, but, instead of being dense, consists of a thin crust, with a cavity, whose interior walls are lined with beautiful, brilliant crystals of the silicate and occasionally the carbonate of zinc. More rarely, crystals of galena are in the cavities, but, in this case, are invariably covered with a thin coating of the silicate; and not infrequently portions of the cavities are partially filled with red clay, highly impregnated with oxide of iron, and having the appearance of a highly-decomposed brown hematite. Occasionally, heavy spar (barytes) lies in a dense mass in close contact with the zinc-ore; but more frequently it is associated with the galena. Often, but not invariably, immediately below the folds of zinc-ore, occur irregular masses of the zinc-ore in the crystallized form, as pseudomorphs of galena," etc.

All the doubts which arise concerning the mode of this formation would probably be solved by a series of *objective* pictures of it; and it is to be hoped that an occurrence so interesting theoretically will be accurately recorded before it is too late.

The deposits occurring near the "islands" of granite and porphyry, have special interest. While the Silurian limestones of the surrounding country, farther from these islands, present chiefly only lead- and zinc-ores, other metals, such as copper, cobalt, and nickel, occur as the Archæan foundation-rocks are approached; and this circumstance is, to my mind, an indication that the source of the lead-deposits also is to be sought in depth.

Mine la Motte.—As an example, I may cite the district of Mine la Motte, to which I once made a brief visit. The rock here is usually the same, namely, a Cambrian dolomite, containing, however, sandy portions and a clayey stratum characterized by numerous fossils (*Lingula*). The ore occurs predominantly as an impregnation in the rock, more concentrated in a given zone. The so-called sandstone does not here, as in other instances, cut off the impregnation; it is, in fact, only a sandy limestone and dolomite, and its carbonates can be replaced by ore as well as those of adjoining strata.

I thought that I noticed in the open workings called the Jack and the Seed-tick diggings a very remarkable phenomenon; namely, the ore-impregnation in the almost horizontal stratified rock was conformable not to the bedding but to planes crossing it at a very acute angle (about 10°). A pretty long terrace was exposed; and the impregnation-planes cut pretty regularly through the sandy dolomite also. This appearance indicates plainly a later formation of the ore, independent of the deposition of the rock-strata; and one is almost involuntarily forced to believe that it was the former ground-water surface which formed the cavities to be impregnated. But it was, and is, inconceivable to me how these cavities could be filled with sulphides; and I can only urge that occurrences of this kind should be subjected to a more thorough study than it has been in my power to give to them.

Wisconsin.—In Wisconsin, and in parts of Iowa and Illinois, there is an extensive true plateau, the calcareous members of which contain many and various deposits of lead- and zinc-ores. An excellent monograph concerning them, by my esteemed friend, Prof. J.

D. Whitney,* is at hand. The author seeks to show that the mineral solutions depositing these ores came from above, not from below. He appeals to the circumstance that of the two stratified formations, the upper and the lower Magnesian limestone (underlain by an upper and a lower sandstone, respectively), the ores occur chiefly in the upper, and only seldom, and in small quantity, in the lower; while the two sandstones (the lower of which is assigned to the Potsdam) do not reveal any traces of ore, as they should do if the solutions had come from below. I confess that this conclusion is not obvious to me. There may have been a passage through these sandstones at a distant point, not yet exposed; and the mineral solutions may have found or created spaces in the soluble rock.

The argument that the ores must have come from above because it has not been possible to discover, in the Wisconsin region, fault-fissures and eruptive dikes, such as have brought up similar ores in the north of England and other places, seems to me likewise inconclusive. And as little can I accept the explanation of an occurrence near Dubuque, discovered by T. Lavins and described by Whitney (*op. cit.*, p. 291 and Fig. on p. 392), which I reproduce in Fig. 79. The fragments of galena, crusted with cerussite, which hang from the roof of a natural cavern, are taken as a proof that the solutions which deposited them must have come from above. But a continuation of this cavern is indicated in the bottom, filled with clay, mixed with scattered pieces of galena. In my opinion, this was doubtless originally the filling of a vertical fissure, which was enlarged by the ground-water, as indicated by the dotted line. The symmetrical crusts, as I suppose, of that filling were in part broken up, and fell into the clay accumulating in the space below; while the upper part of the filling remained attached to the rock of the roof.

3. Metamorphous Deposits.

Metamorphism has been most truly defined by A. de Lapparent as the sum of the chemical changes undergone by the sedimentary rocks after their deposition. General or regional metamorphism, affecting the rocks over wide areas, is distinguished from local or contact-metamorphism, caused in certain groups of strata by eruptive intrusions. In studying the occurrence of useful minerals, we occupy rather the local standpoint, and start with an assumed original

* *Report of a Geological Survey of the Upper Mississippi Lead-Region*, Albany, 1862.

condition of the rock, though its really original character may not always be demonstrable—understanding thereby, for our purpose, a so-called typical condition, usually shown at most places where the rock occurs.

We distinguish the replacement of some constituents of a compound rock, for which the term "impregnation" is more appropriate, from the replacement of the whole homogeneous mass by metasomasis. But since every rock undoubtedly contains small primitive cavities, it is difficult, and sometimes impossible, to decide whether a new, xenogenous substance has not been deposited in such pores; and a case of this kind would fall under our notion of impregnation. The new substance may indeed have found entrance through the pores, if the mineral solutions were under sufficient pressure to overcome the friction of their walls, at least in the line of least resistance; and these solutions, thus introduced, may attack and replace one or another element of the rock. The entrance of such solutions will be greatly facilitated by the fissuring of the rock, whether by internal or external forces. We find in connection with ore veins, and also with the thinnest mere seams, an impregnation of the country-rock, which Cotta has called subordinate or dependent (*unselbständige*) impregnation.

The particles of certain substances possess a peculiar mutual attraction. In the sandstone of Fontainebleau occur aggregates of calcite crystals, which have come together in spite of the separating medium of sandstone; and in a similar way, as we have seen, another substance of strong crystallizing power, namely, galenite, forms, in the pipe-ores and script-ores of Raibl, crystalline masses, in spite of the intervening diaphragm of a foreign medium.

In like manner are formed the so-called concretions, the calcareous and marly masses (*Lösskindlein*) in the Loess, and the *Marleker* of the ancient Scandinavian beaches. For the formation of the former, occasion was given by decaying plant-roots; for that of the latter, by various animal remains, mussels, fishes, etc. In Norway, they have preserved a complete fauna of the Glacial and post-Glacial epochs.

Similarly, we find in some spherosiderite concretions of the Saarbrücken coal-basin the remains of fishes. A discernible nucleus is not always found in such concretions; sometimes no cause for this peculiar formation can be discovered. The concretions occurring in stratified rocks are usually lenticular, comprising portions of several similar strata. Even spherical forms, resembling pisolites, occur.

If we imagine, for instance, spherosiderite concretions formed closely side by side in one stratum, we shall have a regular bed of clay-ironstone. Leaving out of view the agency of fissures, or contacts with intruded rocks, impregnations following certain strata may be formed, constituting a second kind of ore-beds. A third kind may result from the more or less complete replacement of the original rock, especially when the latter is a soluble precipitate, like gypsum or limestone. In thick limestone formations the ore-beds occur at the contact with insoluble rocks, as at Rodna.

In all these cases the deposits have the form of a bed, but the ores rarely cover the whole contact-surface, occupying, on the contrary, only certain zones of it. In other words, in these as in other deposits, ore-shoots occur.

Much more complicated relations result when the mineral solutions ascend along structural fissures and rock-contacts; and in order to a comprehensive description of this suite of phenomena, it will be well to consider first the simpler conditions obtaining in soluble rocks, and afterwards the more complex occurrence of such deposits in crystalline and eruptive rocks. We will, therefore, review the metamorphous deposits as they occur in (*a*) distinctly stratified rocks; (*b*) soluble precipitates; and (*c*) crystalline schists and eruptive rocks.

a. Metamorphous Ore-Deposits in Distinctly Stratified Rocks.

We find in unquestionable sediments not only metallic oxides and salts, but also sulphides, in the form of ore-beds which, by reason of this stratigraphical relation, have been held to be of contemporaneous origin, that is, idiogenous. As a consequence, it has been necessary to assume that they were precipitated in a sea-basin, in which, before and after their precipitation, only barren sediments were deposited. These metals must, therefore, have been dissolved in the water of the basin, and that in very large quantity, as indicated by the frequently great thickness of the ore-beds. But for such an assumption we have no present analogy.

The Deposition of Ores from Sea-Water.—In this particular, however, we have to do rather with suggestions than with demonstrations of fact. So far as sea-water is concerned, traces of metals have been found in the water itself, in the ashes of marine plants, and in the solid constituents of marine animals, for instance, corals, by Malagutti, Bibra, and Forchhammer.* Traces of silver, iron,

* G. Bischof, *Chem. u. Phys. Geologie*, vol. i., Bonn, 1843, pp. 445-447.

and manganese were detected in the water, and lead, zinc, cobalt, and nickel in the marine organisms; and since there are in sea-water small amounts of hydrogen sulphide, Bischof considers the deposition of metallic sulphides from the sea to have been possible. He observes (*op. cit.*, p. 432) that the occurrence of metallic sulphides in sedimentary rocks, such as that of copper and silver sulphides in *Kupferschiefer*, or that of lead sulphide in *Buntsandstein*, may be thus explained; and even indulges (p. 836) in the following teleological conclusion:

"Since it cannot be doubted that the rivers flowing into the ocean bring with them metallic salts, though in very dilute solution, it seems a wise arrangement that in the hydrogen sulphide of sea-water a precipitant is presented to throw down the smallest minima, and thus to prevent the gradual accumulation of substances *so injurious to animal life.*"

Of the various metals dissolved in sea-water, iron is least injurious to animal life. Indeed, animal life assists, in the so-called lake-ores, the segregation of this metal. Moreover, the precipitation of ferrous and ferric oxides from concentrated solutions is probable, so that a precipitation of iron-ores directly from sea-water seems to be established as a possible origin for some iron-ore beds.

But the conveyance of metallic salts by rivers to the ocean and the formation of hydrogen sulphide in sea-water are unquestionably continuous; and the precipitation of metallic sulphides must, therefore, have taken place uniformly in all sediments and precipitates of the ocean; whereas, we find the ore-beds in fact only in certain strata. If these are to be thus explained, we must assume that the ocean was at certain periods much more strongly impregnated with metallic salts —a scarcely tenable hypothesis as applied to the mighty deep,—or we must suppose with Carnall, as H. Hoefer has recently done,* a subsequent re-deposition of the primitive metallic salts, contained in minute quantities in the sea-deposits—in other words, their solution and re-precipitation at certain horizons. Hoefer cites the lead- and zinc-deposits of Upper Silesia and other districts, which occur in marine Triassic limestones. He assumes the maintenance of uniform horizons by these deposits to be demonstrated, but points out that some of these horizons were already ore-bearing when first formed.

In short, a number of investigators have adopted the hypothesis of an original ore-deposition from the ocean, without giving any

* "Die Entstehung der Blei-, Zink- u. Eisenlagerst. in Oberschlesien."—*Oesterr Zeitsch. f. Berg. u. H-wesen,* 1893, xli., p. 82.

other reason than the observed relations of stratification. Yet, in a considerable experience with ore-deposits in marine limestones, I have never been able to find genuine ore-beds among them, but always only ores of subsequent introduction; so that I feel warranted in believing that such ore-beds proper do not exist.

As to the primitive ore contained in marine sediments and precipitates, innumerable chemical analyses, especially of limestone, have failed to show the metallic traces which, according to the above hypothesis, should be present. For this reason, as I have already observed, even Sandberger did not venture to derive the metals from the limestone, preferring, for instance, at Raibl, to look to the overlying slates.

The maintenance of certain ore-bearing horizons was set up by A. von Groddeck, to render more plausible the notion of a direct deposition from the ocean; but I do not believe it possible to prove such an identity of horizon for different ore-deposits. Similar ores and stratigraphical conditions are not confined to the Trias. On the Rhine, in England and in America they occur at much lower horizons in the Palæozoic rocks. Even in Carinthia the ore-bearing limestones of the richest deposits do not occupy the same horizon. That of the Raibl slate is very different from that of the Bleiberg slate (carrying *Ammonites aon*), and the deposits in these localities are by no means beds, but, as I have shown, channels in the limestone, filled with ore.

Ore-Deposition in Fresh Water.—The demonstration of direct ore-deposition in fresh-water strata encounters the same difficulties, though it may be supported by the same chemical speculations. Here the hypothesis is favored by the analogy of the lakes of regions without drainage to the sea, in which the salts brought in by rivers are necessarily concentrated by evaporation. But since organic life is restricted in these salt lakes to a few animal species, the analogy can have but a limited application. Moreover, it would be necessary to suppose cataclysmic changes, like the interposition of a period of no drainage in the midst of an epoch of fresh-water sedimentation.

Without the assumption of such cataclysms, I do not believe that the Mannsfeld *Kupferschiefer*, in which the organic (fish) remains can be traced continuously from foot- to hanging-wall, could be explained in this way. It deserves mention, that some of the earlier geologists, like Freiesleben, accepted the sometimes contorted attitudes of the *Palæoniscus* in the *Kupferschiefer* as a proof of contemporaneous ore-depositions, and alleged that these fishes had been thrown into violent contortions by the copper-solution, in which condition they died and were buried in the sediment. The *naivete* of this diagnosis (which, nevertheless, some modern writers have not hesitated to repeat), is evident. Contorted fish-remains occur in other formations outside of the *Kupferschiefer*, and clearly show the advanced state of decomposition in which the bodies reached the sediments.

The Kupferschiefer of Mannsfeld.—The Mannsfeld *Kupferschiefer*, as is well known, is a thin bed of bituminous slate, lying between the Permian sandstone below, and the marine member of the same formation, the *Zechstein*, above, and containing sulphides of copper, silver, lead, zinc, antimony, mercury, nickel and cobalt. The copper amounts to 20 to 30 kilograms (44 to 66 pounds), and the silver to 125 to 150 grammes (4 to 5 ounces, Troy), per metric ton of 2204 pounds. In polished sections, the ore can be seen in thin leaves lying between laminæ of slate, and often accompanied by gypsum. But the same ores occur in scattered bunches in the sandstone below, and small bodies of redruthite are found in the limestone above.* This circumstance alone, that ore occurs also in the marine limestone, above the fresh-water *Kupferschiefer*, is unfavorable to the contemporaneous origin of ore and rock.

Kupferschiefer in Thuringia and Bohemia.—The same bituminous slate occurs in the Thuringian forest on the south slope of the Hartz, and in other points a considerable distance away. It must therefore have been deposited in a large basin. But it is a question, whether it anywhere carries ore and deserves the name of *Kupferschiefer*.

In NE. Bohemia, the same Permian slate, with almost the same fossils, is widely distributed, but without the marine member which covers it in Germany. The Permian of Bohemia carries copper-ores in many places; and in one locality, namely, at Hermannseifen, these ores occur in the bituminous slate, which might properly here be called *Kupferschiefer*. I had opportunity in 1858 to examine the mines. The richness in metal was not unsatisfactory; but there was much complaint of the numerous faults which seriously enhanced the difficulty of mining.

Precisely the same difficulty exists at Mannsfeld and in the Thuringian forest, as Cotta (*op. cit*, § 50), reports in part as follows:

"The fault-fissures themselves, are, however, rarely ore-bearing, yet often seem

* See Groddeck's *Erzlagerstätten*, § 58, and Cotta's manual, § 50.

nevertheless to have influenced the ore-bearing character of the strata traversed by them. This influence is shown in the increase or diminution of the proportions of ore, not only in the immediate neighborhood, but sometimes also for a considerable distance, even as far as the next master-fault. It is shown also in the transfer of the metallic contents from one stratum to another."

This and other observations concerning the influence of the faults upon the ore-distribution bear decidedly against the contemporaneity of the ore-deposits, and in favor of a later introduction of ore through the fault-fissures.

But this conclusion becomes much clearer upon a consideration of the remaining occurrences. Thus, according to Cotta (*op. cit.*, § 39), the *Kupferschiefer* at the edge of the Thuringian forest is not so rich in ore as on the southern border of the Hartz. More important than the copper-slate itself are the fault-fissures which traverse the whole group of strata, but only carry ore in certain zones in which they intersect certain strata—the *Kupferschiefer* among them. "Strange to say," observes Cotta, "near Camsdorf it is almost exclusively where the *Kupferschiefer* has suffered such disturbances that it is rich enough to repay mining." In speaking of Riegelsdorf he says, "The cobalt-ores have in some cases made their way from the veins into the country-rock."

Westphalia.—At Stadtberg (*op. cit.*, p. 76), in Westphalia, there are even several copper-bearing strata, and these are cut by copper-bearing veins. At Bieber, veins traverse the whole group of strata into the underlying mica-slate, and "the irregularly distributed ore occurs, strange to say, chiefly interleaved in the mica-slate, and not, as in the Hartz and the Thuringian forest, in the horizon of the *Kupferschiefer;* while, on the other hand, the impregnations from the veins have penetrated chiefly the bituminous marly slate."

In consideration of the expressions partly quoted *verbatim* above, it is difficult to see how there can be any doubt of the secondary nature of the ore-deposits in the *Kupferschiefer* throughout. Yet Groddeck* has reproved me for coming to this conclusion. He says himself† expressly (evidently having in mind the typical Mannsfeld occurrence):

"The ores were laid down contemporaneously with the slime-deposit, the bituminous marly slate as the ore-matrix." . . . . "It is entirely impossible that the ores could have entered the bed somehow from the fissures, at a later period, after the covering of the marly slate with more recent rocks. If we assume that the ore-

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* "Bemerk. zur Classification d. Lagerstätten," *B. u. H. Ztg.*, 1885.

† *Erzlagerstättenlehre*, § 142.

solutions were introduced through the fissure faulting the bed, it remains inconceivable why the filling of metallic sulphides, through a field of many square miles, should be uniformly and exclusively confined to the stratum of marly slate, about ½ meter (19.5 inches) thick, and should not also occur more or less near the fissures in the strata above and below, there being in these no lack of carbonates and bituminous constituents, available as precipitants of the solutions—the *Stinkschiefer*, for instance, lying not far above the *Kvpferschiefer*, being rich in such substances."

Groddeck here overlooked the principle, elsewhere urged by him, that a single link in a whole chain of phenomena should not be exclusively considered. He contemplated only the special development at Mannsfeld; assumed, moreover, similar developments for many square miles, which show in fact many variations, and did not take into account the circumstance that when the *Kupferschiefer* is not cut by fault-fissures, it is also not valuable for mining. Finally, he was unacquainted with the theoretically important occurrence of the *Kupferschiefer* in Bohemia. The contemporaneous origin of the ore and rock at Mannsfeld was with him, so to speak, a dogma, as may be perceived in some of his expressions (*op. cit.*, p. 302):

"The local ore-bearing character of the foot- and hanging-walls of the *Kupferschiefer*-bed is no proof to the contrary, for it is always confined to the immediate neighborhood of the bed." (?)

"Into the sea, rich in fishes and plants, from which the marly slate was deposited, flowed abundant metallic solutions, which killed the organisms and were themselves reduced by the products of decay." (?)

The first of these propositions becomes logical if it is simply reversed in sense; and the bold hypothesis of the second indicates a doubt which the author is seeking in this way to set at rest. His statement (p. 302):

"It is not to be doubted that metallic sulphides may be formed at the earth's surface, under ordinary pressure and temperature, beneath a water-covering which excludes the air,"

is quite correct; but when he adds:

"And there is therefore nothing to prevent the belief that sulphuretted ores could be precipitated at the same time with the deposition of sedimentary rocks,"

it is necessary to add, "*provided* the metallic salts were present in the sea-basin."

This is, indeed, the center of gravity of the whole question; and, as I have shown, the proposition presents an improbability.

Various other peculiarities of individual ore-occurrences are cited in favor of the theory of contemporaneous origin; but all of them, when impartially weighed, are equally consistent with a different genetic explanation, and fail to be as significant as the Mannsfeld type for the theory in question.

The Copper-Sandstones of Bohemia.—In Bohemia and on the west slope of the Urals, the copper ores of the Permian strata occupy by no means a continuous horizon, but occur as impregnations in different beds, beside, above, or below one another. There are here, as in the German *Kupferschiefer* mines, fault-fissures which may have served as ore-conduits; and in these regions the notion of a primary sedimentary origin of the ores has not been so often suggested. At some places in Bohemia, as, for instance, at Starkenbach, melaphyres appear above the ore-beds.

In almost all these, as in many of the German deposits, the copper sulphides, especially redruthite, occur in the neighborhood of plant-remains; and oxidized copper-ores predominate, as a rule, in the ore-beds in sandstone.

Not only Permian, but also Triassic and still more recent sandstones, exhibit analogous deposits, containing lead, silver, and antimony, as well as copper. At Boleo, in Lower California, such an ore-deposit is known in Tertiary strata. The range of illustrations, therefore, is an extensive one. I can mention but a few.

St. Avold.—Concerning the copper-ores in the Triassic sandstone of St. Avold and Wallerfangen, Groddeck gives (p. 90) a brief description, based on an article by C. Simon.* The sporadic ores are most abundant in the vicinity of fault-fissures; but only single strata are rich, while other porous layers near by are barren of ore. The ores extend in zones, independent of the course of the fissures, which they often even cross at right-angles. These two features are said to prove the contemporaneous origin of the ore and rock, "since the enrichment of a zone where it is cut by the fissures can be simply explained by the leaching-out of ores in higher strata, and their re-deposition in or near the fissure." I must confess that this explanation is not satisfactory to me. Figs. 80 and 81 illustrate the situation.

At Bleiberg, in St. Avold, concretions of galena, of pea-size, occur in the sandstone; and below the same layer considerable masses of solid galena are encountered.

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* *Berg u. H. Ztg.*, 1866, p. 412.

*The Lead-Deposit of Mechernich, near Commern.**—This deposit has a special interest in this connection, since it consists of sandstone of considerable thickness, somewhat porous, and impregnated with small concretions of galena (*Knoten*), which have often been considered as contemporaneous in deposition with the rock. The district, situated on the north edge of the Eifel Mountains, embraces a zone about 7 kilometers (4¼ m.) long, through Call, Keldenick, Mechernich, and Strempt. Already in the Roman period, at the Tanz Mountain, near Keldenick, mining was done upon galena veins in the Devonian limestone, which is overlain by the sandstone and conglomerate of the variegated sandstone formation. The conglomerate covering the sandstone has the name of *Wackendeckel*, and sometimes carries ore, the cement between its pebbles being traversed by galena and oxidized products, especially cerussite, which were formerly mined.

It is at present the sandstone, impregnated with galena concretions (*Knoten*) to the extent of 5 to 30 kg. (0 5 to 3 per cent.) of lead, and 1 to 6 grammes (0.03 to 0.18 oz. Troy) silver per metric ton of 2204 pounds, which is the principal basis of an extensive mining industry.

The thickness of this *Knotensandstein*, the number of its intercalated conglomerate layers, and the richness in ore of each stratum vary greatly, as do also the number, direction and manner of throw of the fault-fissures by which it is traversed. Fig. 82, representing the stratigraphy SW. of the boundary of the mining grant at Meinerzhagen, shows the irregularity of the displacements. Within the grant, the several *Knoten*-layers are united into a single bed, about 22 meters (72 feet) thick, separated by a conglomerate layer from the Devonian rocks below, and overlain by another conglomerate, the so-called *Wackendeckel*, above which is the barren red sandstone. In general terms, there lies here upon an impermeable floor a pervious group composed of sandstones and conglomerates, overlain by argillaceous red sandstone and loam.

The *Knoten*, never larger than peas, exhibit, when prepared in thin sections and mounted in Canada balsam, crystalline aggregates of galena, in which the crystal-faces are turned outwards, away from the center; that is, they are by no means composed of spherical masses, as they seem to the naked eye to be, when examined as

* Baur, "Das Vorkommen von Bleierzen am Bleiberge bei Commern," *Eschweiler Pumpe*, 1859.

F. W. Huperts, *Der Bergbau u. Hüttenbetrieb des Mechernicher Bergw. akt. Vereins*, Köln, 1883.

Ellsworth Daggett, "The Lead and Silver Works of the Mechernich Mining Company," *E. and M. J.*, xxiii.

they come from the crumbly rock. Their distribution in the sandstone generally follows the bedding; but in the neighborhood of the cross-faults I observed an accumulation of *Knoten* in zones parallel to these steep fissures. Moreover, I found occasionally in the fissures themselves threads of galena and pyrite; and hence I do not doubt that the ore-deposition here was secondary, and proceeded from the fissures. To gain a clear view of this question, it is necessary to include the ore-occurrence in the conglomerates, where, as already observed, it impregnates the material cementing the pebbles, and also, the nearest ore-occurrence in the Devonian limestone, where it appears in fissure-veins.

In my opinion, the loose, pervious sandstone, enclosed between less permeable strata, and cut by many fault-fissures, was impregnated by ascending springs, which employed it as a path in their circulation; but it cannot be determined what constituted the centers around which the galena concretions are formed. May it have been minute particles of feldspar, such as are still occasionally visible; or was it organic substances, which have now entirely disappeared?

Freihung.—Perhaps additional hints may be furnished by the mines of Freihung in the Bavarian Upper Palatinate, which Cotta considers analogous to those of Mechernich. Here galena and cerussite impregnate the *Keuper* sandstone, the steep dip of which they share. At the Nuremberg Exposition of 1882, maps, ore- and rock-specimens from the mines of the Bavarian Lead-Mining Co. were exhibited. Fig. 83 is a section through the Vesuvius mine. I was struck with numerous specimens of tree-stems changed to galena; and, coming subsequently into possession of such a specimen, I had a polished section prepared from it. The pieces of these stems exhibited are about 20 centimeters (8 inches) long, and elliptical in sections, say 5 to 7 by 10 to 15 centimeters (2 to 3 by 4 to 6 inches.) The fiber and the annual rings could be recognized on the surfaces of fracture, but were extremely plain in the polished section. Indeed, they were indicated by the cleavage of the specimens. I have thin slivers, 2 to 4 mm. (0.08 to 0.16 inches) in diameter and several centimeters long, representing the fibers of the original wood. The former bark is replaced by a zone of first pyrite, and then quartz grains cemented with pyrite. I do not know that the determination of the species of the wood has been attempted, but I think it should be approximately practicable. Fig. 84 is a diagram of the section of such a stem altered to galena.

Certainly we have here another instance showing that the organic substance attracted metallic solutions and reduced them to sulphides, and this, under conditions similar to those of Mechernich. The latter occurrence may, therefore, be most simply explained by the hypothesis of an organic substance, distributed through the rock, which reduced the circulating mineral solutions and occasioned the formation of the concretions (*Knoten*).

Silver Reef.—Accustomed as we are to find silver associated with lead-ores, we are surprised by the occurrence, in the Silver Reef district of Utah, in probably Triassic sandstones, of silver accompanied by copper. So far as can be gathered from the various descriptions at hand,* there occur here two beds (the outcrops of which are called "reefs"), which carry silver, either exclusively or with a little copper—the former usually as a chloride, but sometimes native; and the latter in the ordinary oxidized ores. It may be reasonably inferred that the deposit has been thus far exposed in its upper, chloridized, and oxidized zones; and that in depth it would be found to contain sulphide-ores. Whether such depth has been reached by the miners I do not know.

The beds consist of red and gray argillaceous sandstones and arenaceous clay-slates, between the laminæ and in the cross-joints of which the ores occur, being the more concentrated, the more highly fissured the condition of the rock. Although traces of silver are found throughout the bed, the pay-ore is confined to separate chimneys or channels, which descend on the true dip, or pitch obliquely to it. The richest bodies are said (Rolker, *l. c.*, p. 25) to be most frequently found above a certain thin, very clayey, sandstone stratum. Very often, but not always, the silver-ore is accompanied by carbonized vegetation, such as trunks and stems of trees, and reed-like plant-remains, which are covered and impregnated with horn-silver. The copper- and silver- ores, while occurring to a certain degree in association, seem to exclude one another, and are seldom found in actual mixture.

The same sandstone which here carries ore is said to be represented in the plateau cut by the Colorado river; but there the strata

* "The Silver Reef District, Southern Utah," (by R. P. Rothwell or Thomas Couch ?), *Eng. and M. Jour.*, xxix., pp. 25, 45, 59, 79, 351.

C. M. Rolker, "The Silver-Sandstone District of Utah," *Trans. A. I. M. E.*, ix, 21.

J. S. Newberry, "Report of the Stormont Silver Mining Co.," *E. and M. J.*, xxx., p. 269.

are horizontal and undisturbed, whereas in the ore-district they dip rather steeply, are much disturbed, and are in many places covered with eruptive rocks, including basalt. This neighborhood to eruptives renders it probable that here, as in so many other places in Western America, the ores have been introduced by the mineral springs which usually follow eruptive activity. Rothwell, Couch, and Rolker are of this opinion; whereas, Newberry is inclined to suppose a contemporaneous origin of ores and rock. The principal arguments for his view are, the alleged great area of silver-bearing Triassic strata in that region; and the circumstance that the richest bedded and lenticular ore-bodies are enclosed in almost impermeable slate-clays, which would not have permitted a subsequent entrance of the mineral solutions. Neither of these statements disproves the secondary origin of the ores. They could have been deposited in any given way on a large scale, as well as a small one; and that the almost impermeable slate-clays did not prevent the entrance of solutions is proved by the subsequent alteration of the original filling to chlorides and oxides.*

Moreover, the deposits are not regular strata but chimneys and channels in parts of strata, and this character, which they possess in common with so many other deposits, should be decisive in favor of their secondary origin—a conclusion which, in my opinion, is always reached when observations are not confined to single localities, but extended over whole series of analogous phenomena.

Copper-Deposits of New Mexico and Arizona.—Traces of similar ore-distribution in sandstones seem to be not infrequent in the American West. Thus F. M. F. Cazin† says of the copper-ores of the probably Triassic sandstones of the Nacimiento mountains in N. W. New Mexico, which J. S. Newberry had described in 1860:

> "The ore occurs nearly exclusively as the petrefaction of the leaves, stems, limbs and trunks of palms. Frequently the ore is coated with a film of jet or coal. It is always easily separated from the rock. The ore is predominantly erubesite, copper-glance and melaconite, and it appears to be distributed all over the massive stratum, but is more densely collected on seams and cleavages, in some instances forming a single layer of petrified parts of palm-wood."

This occurrence, which is analogous to those in Bohemia and in

* Compare F. M. F. Cazin, "The Origin of Copper- and Silver-Ores in Triassic Sandrock," *E. and M. J.*, xxx., p. 381.

† "New Mexico *vs.* Lake Superior as a Copper-Producer."—*E. and M. J.*, xxx, pp. 87, 108.

the province of Perm, was declared to possess great economic importance. Its later developments are not known to me.

W. P. Blake* has described an analogous occurrence in the sandstones and conglomerates overlying the granites in Copper Basin, Yavapai county, Arizona, where the copper-ores are found unconnected with any organic substances. In the underlying granite, however, there are fissures filled with copper-ores. He thinks it probable that copper sulphides circulating in the highly permeable sandstone were precipitated as carbonate by carbonate of soda, while the resulting sulphate of soda escaped in solution, to be concentrated by evaporation, forming deposits of thenardite, which is common in Arizona.

Lower California.—At Boleo, opposite Guaymas, on the peninsula of Lower California, E. Fuchs† has described a remarkable deposit of copper-ores in Tertiary sandstones, conglomerates and tufas, which must be mentioned under this head. The east slope of the (mostly eruptive) mountain range extending through the peninsula is a plateau, gently descending towards the Gulf of California, and cut by precipitous cañons. It is formed of strata containing characteristic Miocene fossils. Tufas decidedly predominate, and the series contains three or four copper-bearing beds, covering a large area, and out-cropping at many places in the cañons. These lie immediately upon conglomerates of pebbles of eruptive rock (different and characteristic for each horizon) and are overlain by clayey tufas. The whole is traversed by several fissures, of which the largest and most important is a fault-fissure, occurring at the western border of the district and striking about parallel with the sea-shore.

In the ore-beds above the ground-water level, disseminated oxidized ores prevail, such as black oxide of copper, and the protoxide, with atacamite ($CuCl + 3\ CuO + 3H_2O$), azurite, malachite and chrysocolla, with crednerite ($2\ Mn_2O_3$, $3\ CuO$). In the second ore-bed (counting downwards) there are peculiar globular concretions, like oölites, of copper oxide and carbonate, sometimes several centimeters in diameter, which are locally called *boleos*, whence the name of the district. Though greatly interested in this type of ore, I have never succeeded in getting specimens, and am unable to form

* "The Copper-Deposits of Copper Basin, Arizona, and their Origin."—*Trans A. I. M. E.*, xvii., 479.

† "Note sur les Gisements de Cuivre du Boleo."—*Assoc. Française pour l'Avancement des Sciences*, 1885.

from the hasty description of Fuchs a clear conception as to its genesis.

The third bed lies in part below the ground-water level, and contains, in addition to the foregoing minerals, the copper sulphides chalcosine (Cu_2S) and covelline (CuS).

The ore-beds are composed of tufa (the slime, according to Fuchs, of volcanic eruptions), in which ores in disseminated spots and veinlets ("*sous forme de mouche ou de veinules*"), as well as globular concretions, are irregularly distributed, with a visible tendency to concentrate towards the bottom of the bed, where they form a compact ore-layer, 15 to 25 centimeters (6 to 10 inches) thick.

With regard to genetic questions, we must bear in mind that the fossils found in these strata indicate an open though not very deep sea; it is, therefore, impossible to assume that iron-, manganese- and copper-ores were dissolved in it, and were precipitated from it at the same time with the rock. A periodical metallic precipitation, three or four times repeated, in an open marine basin, is out of the question; and we are forced in this case, even more strongly than elsewhere, to assume a secondary origin for the ores. The data necessary for its explanation are still wanting, but can undoubtedly be secured by the further advance of mining work. E. Fuchs contented himself with pointing out the after-effects of eruptive processes, and did not enter upon the genetic question. Certainly the conglomerates underlying the ore-bed must have played an important part, representing, very likely, the channels through which the mineral solutions ascended, to be reduced, probably by the presence of organic matter, in the tufas above.

b. Metasomatic Deposits in Soluble Rocks.

A metasomatic replacement of the original rock-material was clearly proved long ago for some instances—*e.g.*, calamine-deposits—while in other cases, where proof has not been obtained, analogies in the observed circumstances speak for such an origin. Parts of such deposits, it is true, may be fillings of spaces of dissolution, rendered unrecognizable, as such, by the absence of clearly-defined crustification in the ore-precipitates. We must accustom ourselves to the fact that for many deposits, not yet closely enough studied, it is impossible to determine positively the mode of genesis, and we must often choose provisionally, of the two modes just named, the one which appears to represent better the given data.

Calamine-Deposits.—The calamine-deposits of Raibl in Carinthia, Wiesloch in Baden, Vieille Montagne, with its vicinity, in Belgium and Germany, and other places, furnish, in the fossils of the limestone which have been transformed into calamine, the clearest proofs of a metasomatic replacement of the carbonate of lime by carbonates and silicates of zinc. Moreover, the structure and form of the ore-deposits is characteristic of this origin, these being mostly bodies of irregular outline, with portions projecting far into the country-rock. Often the progress of the replacement can be traced. Thus, at Raibl (Fig. 85), in places where the process has started from seams, the gradual advance from the seam into the rock may be observed; the outermost portions being relatively the most recent, and lying against a peculiarly uneven, rough surface of limestone.

Sometimes features of the original rock-structure are repeated in calamine, as, for instance, the cellular structure of the so-called *Rauchwacke* (the *cargneule* of the Swiss geologists), which consists of a skeleton of thin, smooth lime-partitions, from among which the limestone has been in part dissolved away, or left only in separate decomposed splinters. This is evidently the result of a very complex metamorphosis, which Groddeck has observed also in the quicksilver-deposit of Avala in Servia. The cell-walls, which represent the fillings of cracks in a shattered limestone, have been subsequently changed to calamine, and covered with botryoidal clusters of that mineral (Fig. 86).

Calamine is frequently formed by atmospheric agencies above the ground-water level, and is a frequent accompaniment of lead- and zinc-deposits in limestone.

Space does not permit the description here of the manifold deposits in Belgium, Rhenish Prussia, Westphalia, Upper Silesia, Sardinia, Algiers, etc., which are, moreover, not known to me by personal observation. The text-books of Cotta, Groddeck and Phillips give some account of them, and refer to sources of more detailed information.

Laurium.—It is only in recent periods that the features of the extensive mining region of Laurium in Greece,* worked two thousand years ago, have been described. Although various kinds of deposits are represented, most of them belong under the present head.

In the Camaresa district, a series of nearly horizontal, non-

* A. Cordella, *La Grèce sous le Rapport Géologique et Minéralogique*, Paris, 1878; and *Le Laurium*, Marseilles, 1869. A. Huot, *Rapport sur les Mines du Sumium*, 1880, and *Mémoires de la Société des Ing. Civ.*, 1876–78.

fossiliferous limestones and crystalline schists is cut by a number of eruptive dikes, and suddenly assumes on the NE. a steep dip, probably indicating a considerable dislocation. The whole group is traversed by a number of ore-veins, which, in the schists, are often rich enough to pay for mining. But the main mass of the ores lies on the contact between limestone and schist, and extends into the former in separate bodies or shoots. At the so-called second and third contacts, the bodies have a prevailing funnel-shape and a vertical position. Fig. 87, an illustration from Huot, shows the apexes of the funnels to point on one contact upward, and on the other downward—but, in either case, into the limestone, according as it overlies or underlies the schist. The first form may be explained by the pressure of the ascending solutions. The second, as shown in this figure, is perhaps somewhat ideally sketched; at least the sections of this third contact given by Cordella show ore-bodies following the contact-plane itself.

According to Fig. 88 (also from Huot) the ore-bodies are funnel-shaped in N. to S. section, but from E. to W. have a flat westward pitch, which is hard to explain unless it represents some kinds of cleavage parallel to the dislocation already mentioned. Below the second contact, which carries chiefly lead, there are (at the Jean Baptiste shaft, for instance, according to Cordella) great masses of calamine, the secondary origin of which from zincblende is doubtful, since it would involve the assumption that the ground-water zone had extended to this depth. As to the present subterranean water-level, I find in the descriptions at hand only the statement that the region generally is very dry, and that the ancients, who mined to the depth of 120 meters (394 feet) had no water to hoist. With regard to the structure of the galena-deposits, I may say that I saw in the exhibit of the *Cie Française des Mines de Laurium*, at the Paris Exposition of 1867, masses of galena, blende and pyrite showing distinct stratification, but did not learn from which deposit they came.

Which of the various eruptive rocks of the district (eurite, porphyry, diabase, serpentine, trachyte) gave occasion for the ascending springs which brought up the ore, cannot as yet be determined.

The minerals accompanying the products of decomposition in such deposits, particularly of calamine, are naturally often limonite and other ores of iron. In many countries these play an independent part, being often formed by the metasomasis of limestone, as proved by the irregular masses of the deposits and the contained fossils transformed into ore.

Alsace.—An instance is furnished by the so-called *Bohneisenerze* of Alsace and adjacent regions which have been described and correctly explained by Daubrée.*

At Liebfrauenberg, irregular, lean beds of this character, composed principally of limonite, but scarcely workable with profit, lie on both sides of an anticlinal of Vosges sandstone, and are covered with alluvium. In one place, however, near Goersdorf, an undecomposed body of pyrite and mispickel occurs instead of limonite.

Cumberland.—In Cumberland, limonite-deposits occur on the contacts of the Carboniferous Mountain limestone, both with the overlying millstone grit and with the underlying Silurian schists. They are connected with fault-fissures, on both sides of which they appear, as is shown in Fig. 89, taken from a paper by Mr. J. D. Kendall.†

Carniola.—The Alps offer some remarkable examples of *Bohneisenerze.* These occur, according to A. von Morlot,‡ in the region of Wochein in Carniola (known for its iron-ores and bauxite) in the dolomite and limestone mountains only, and either in the form of beds under the dolomite detritus, or in clay, in the caverns of the dolomite. Fig. 90 is a section showing the latter form. In this case the flatter-lying cavern was partly filled with lime-detritus and clay up to its connection with a higher vertical cavern, while the latter was filled with *Bohnerze* enclosed in loam, and had been mined, according to Morlot, to the considerable depth of 250 meters (820 feet). Here and there a nucleus of pyrite is found in the iron-ore. The beds and mass-deposits of bauxite associated with limonite sometimes show also the "bean-structure."

c. *Deposits in Crystalline Schists and Eruptive Rocks.*

Without entering here upon a discussion of the subject of regional metamorphosis, I may remark that, as a general rule, the older a rock is, the more changes it will be found to have undergone; yet that these changes do not advance in all places uniformly. Many Cretaceous and Tertiary formations of the Alps present a highly metamorphosed, and therefore ancient, appearance; while many Silurian formations—as, for instance, that which surrounds St. Petersburg—

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* *Les Eaux Souterraines aux Époques Anciennes*, p 79.

† *Trans. N. of E. Inst. of M. E.*, 1878, vol. xxviii., pl. xxviii.

‡ "Geol. Verhältn. von Ober-Krain," *Jahrb. d. k. k. Geol. R. A.*, i., 1850, p. 407.

have been so little altered that the fossil shells which they contain still have the mother-of-pearl luster. Some regions, in a word, have been more strongly attacked than others, through causes which we will not here pause to consider; and when we follow the stratified groups downward, we come upon the various crystalline schists often traversed by eruptives, and showing no longer any trace of the clastic sediments, which have been wholly transformed to crystalline masses. We cannot hope to find petrified organisms in these masses; but the occurrence of disorganized organic material in the form of anthracite and graphite proves that at the time the rocks were formed, organic life must have been represented in the sediments.

Many indications, available in the distinctly sedimentary rocks as guides in the determination of the relative age of their ore-deposits, are here wanting. The bedding becomes more and more obscure, and is sometimes no longer distinguishable from the cleavage. Many of the ore-deposits in these rocks have also become in whole or part crystalline, adjusting themselves to the prevailing stratification or cleavage, so that most of them present a bed-like structure and form. Whoever believes in the possibility of a contemporaneous formation of the ores with the rocks will not trouble himself here with genetic speculations, but will see in these deposits simply "ore-beds," according to the old classifications.

Taberg, Sweden.—The circumstance that magnetite is a constituent of many eruptive rocks has inclined many geologists to regard masses of magnetite in the neighborhood of such rocks as immediately belonging to them. This theory originated in connection with the Taberg deposit, in Smaland, Sweden, and was propagated by F. L. Haussmann,* W. Hissinger,† and A. Daubrée;‡ and Taberg has been regarded ever since as an example of the primitive existence of magnetite-deposits, those of Kackanar, Visokaya Gora, and Blagodat being classed with it.

The question arises, where the line is to be drawn between an eruptive rock containing magnetite and a magnetite deposit. An eruptive rock, like that of Samokov, in the Pils mountains in Bulgaria, from the weathered detritus of which magnetite is obtained by ore-dressing, is not properly an ore-deposit; but, on the other hand, that of Taberg, where the ore is not only finely disseminated

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* *Reise durch Skandinavien*, Göttingen, 1811–18, i., p. 165.

† *Versuch einer mineralog. Geographie von Schweden* (Woehler's translation), 1826, p. 205.

‡ *Scandinaviens Erzlagerstätten* (edited by G. Leonhard), Stuttgart, 1846, p. 25.

in large amount, but also occurs in separate, solid veins, may fairly be so called. According to A. Sjögren,* the rock consists of olivine, magnetite, and a little plagioklase, with mica and apatite as accessories. In other words, it is an already metamorphosed rock. Considering that at several places in Scandinavia magnetite occurs in the crystalline schists also, it seems unlikely that the magnetite of Taberg belongs to the primitive rock. This is confirmed by the observation of Th. Kjerulf, that all the ore-deposits of Norway follow the courses of eruptive rocks. Taberg will scarcely prove to be an exception, and may, therefore, be regarded as a secondary or xenogenous ore-deposit.

Before proceeding further I must mention the action of the mineral solutions upon the country-rock of some veins, which might be also classed as impregnation. In this respect tin-deposits are most interesting, because they carry ore, not only in the space of discission, *i.e.*, the vein-fissure, but to a large extent in the neighboring country-rock also. If the veins occur in granite, this is changed for a certain width into greisen, *i.e.*, it is robbed of its feldspar, which is even, in some cases, replaced by cassiterite and associated minerals. Thus are formed the beautiful pseudomorphs of cassiterite after feldspar, which adorn many mineral collections. (See Fig. 91.)

Figs. 91–93 are taken from C. Le Neve Foster.† Fig. 91 represents the alteration of the granitic country-rock to greisen on both sides of a fissure, which is here filled with symmetrical quartz-crusts, to the central druse or comb. Often such fissures occur close together; and since each has its own zone of greisen, the result is a *Stockwerk*, constituting a metamorphosis of the granite, and formed by these fissures.

Cornwall.—In the slate or *killas* of the Cornish miners, there is often a disturbance of the bedding in the neighborhood of the fissure (Fig. 92), such as is observed in connection with fault-fissures elsewhere; but in this case the *capel*, or adjacent portion of the slate, is altered chemically also, being impregnated with quartz and traversed by streaks of ore. The fissure itself is filled with quartz, cassiterite, chlorite, pyrite, and fragments of the *capel*. When several fissures come together, the result is somewhat complicated, but can be reduced to the simple case just described.

* *Neues Jahrb. f. Mineralogie*, 1876, p. 434.

† "Remarks on Some Tin-Lodes in the St. Agnes District," *Trans. Roy. Geol. Soc. of Cornwall*, 1877, ix., Pl. III.

Still more interesting is the tin-deposit of East Wheal Lovell, described by the same authority.* At the side of a narrow quartz vein the ores occur in the granite, from which they are not separated by any definite boundary, so that the ore-body is an almost vertical shoot, confined to the neighborhood of the fissure, yet lying in the country-rock. It is clear that a mineral water of high solvent power, must have ascended under great pressure, in order to bring about such effects in a rock ordinarily regarded as insoluble. Fig. 93 shows the situation of one of these ore-shoots in granite, at the East Wheal Lovell mine.

The ore-deposits in metamorphous and eruptive rocks occur especially in the great crystalline northern areas, in Scandinavia, Canada, and the northeastern United States.

Scandinavia.—In Scandinavia, the science of ore-deposits, like that of petrography, has had a comparatively independent development. Although these countries have been often visited by foreign observers, few analogies with European deposits have been noted—chiefly, no doubt, because of the peculiar character of the occurrences examined, but also partly because of the differing standpoints and views of native observers. In recent times a difference of interpretation has developed itself between the Norwegian and the Swedish geologists; and the former, since Kjerulf, have approached more nearly the Continental view.

As already remarked, Kjerulf traces all the ore-deposits of Norway to the filling of spaces of discission, and particularly of a peculiar space, produced by the sliding of the rock along a bedding-plane, and locally called a *Lineal.*

With respect to the ore-filling, he points out that the occurrence of the ore-deposits must always be studied on the large scale, and that this method shows the ore-deposits to occupy certain lines, characterized by the presence of eruptive rocks.† The ores appear chiefly in the crystalline schists, but also in traces along the contact, and sometimes in the eruptive rocks themselves. In the first case, the different sulphides, mostly accompanied with quartz, lie parallel with the bedding or cleavage of the rock, and thus look like beds; but their secondary origin is indicated by the slickensides, the branching of the deposits and other signs. Sometimes it is made evident

* C. Le Neve Foster, "Remarks upon the Tin-Deposits of East Wheal Lovell," *Trans. Roy. Geol. Soc. of Cornwall*, 1876, lx., Pl. II.

† *Die Geologie des südl. u. mittl. Norwegen* (authorized German edition, by Dr. A. Gurlt), Bonn, 1880, pp. 81, 284, 293.

by the course of the ore-masses, cutting across the bedding or cleavage. In the museum at Christiania there are many large specimens of the ore, some of which, having been polished, show this structure plainly. Pictures of some of them have also been published by Kjerulf.*

In this connection, the primitive ore-bearing character of the *Fahlbänder* (so often cited by geologists as primary ore-beds, which enrich the veins by which they are crossed) is entirely denied (*l. c.*, p. 323). It has been proved that the ores of the Modum fahlbands are connected with the malakolite and the augite-rock which intrudes in "lineal" form between the steep strata of quartz-schists. Figs. 94 and 95 are intended to show the appearance of these deposits, formerly deemed to be beds. The former represents a specimen from the Kongens mine at Roras, and the latter a part of the specimen illustrated by Kjerulf, from the Mug mine at Trondhjem. In the former, the subsequent entrance of the ore is at once recognized. The latter appears as if the crystallization of the minerals had taken place after the ore-impregnation.

Of course, the political boundary does not divide the nature of the ore-deposits of the Scandinavian kingdoms. Those of Sweden are often the continuations of the Norwegian. The crystalline rocks are here peculiarly developed, and have also been peculiarly named by the Swedish petrographers. In the Swedish granulite, for instance, one would scarcely recognize its Continental namesake. These rocks are not in general so coarsely crystalline that their constituent minerals can be distinguished with the naked eye. The so-called eurites are still finely crystalline, and the *hälleflinta* is almost amorphous, consisting only of the ground-mass of the massive rocks. The beds and mass-deposits of the crystalline rocks are often, like many of the Norwegian deposits, associated with talcose and chloritic slates. Sometimes limestone is also present, as at Falun, Tunaberg, etc., where the ores lie on the limestone contacts. The ores of some of the deposits suffer in depth a remarkable change. Thus the mass of copper pyrites at Falun has diminished in depth; but, on the other hand, gold-bearing quartz-veins appear in the midst of the pyritic body, and have yielded in recent years considerable amounts of gold.

Ammeberg.—I will cite as an example one of the most interesting

* "Pragstufer med Braeciestruktur fra Muggruben og Stovarts," *Magazin for Naturvidens, Kobern*, xxvii., B., p. 335.

deposits, namely, the zinc-blende mine of Åmmeberg,* belonging to the Vieille Montagne Company, which I have personally examined.

In a winding line, chiefly E.–W., and about 3½ kilom. (2 m.) in length, occur steeply-dipping beds of zinc-blende in granulite, or gneiss resembling granulite. At certain points they show very beautiful, close folds. At first glance they seem to be genuine intercalated beds of the same age as the rock. The ores, however, do not continue along the whole line, but form separate lenses, up to 15 meters (49 feet) thick, which show a distinct stratification, consisting in layers of fine-grained to amorphous material resembling *hälleflinta,* alternating with the coarser granulite. Fig. 96 is a polished specimen, which exhibits clearly the secondary ore-invasion. The original bedding is here indicated by a series of light and dark dense *hälleflinta* layers; and these are broken through by masses of coarsely crystalline rock and of ore. The entrance of the ore into the coarsely crystalline layers seems to have been attended by an enlargement of their volume, which resulted in their breaking through the dense layers.

The same explanation is required for some parts of the bed, in which, between the plane surfaces of two fine-grained, barren strata, ore occurs in highly folded and contorted layers. This folding is due by no means to an exterior mechanical energy, but to interior chemical forces

Some of the blende layers carry a considerable admixture of galena, as, for instance, the two ore-layers shown in Fig. 97, separated by a fine-grained, yellow to brown, barren stratum of eurite. The whole mass is traversed by fine fissures perpendicular to the bedding, which are filled with leaf-silver, looking like tin-foil. A replacement with ore of the original rock-constituents is here beyond question.

It is supposed that the blende has taken the place of the mica of the granulite. But the whole country-rock also is metamorphous. At the open cut of the Godegärd II. mine-working I found in the midst of the schists what I took to be limestone, but I subsequently lost on my journey the specimens intended for more careful examination. But petrographers have probably long since determined this point.

This Åmmeberg, deposit then, although so distinctly bedded, is by no means of primitive origin; and still less can such an origin be supposed for the others, which occur as lenses of the greatest variety

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* A Sjögren, " Undersökning of den omgrifande Bergarten on Åmmebergs Grufvor." *Geol. Föreningens i Stockholm Förhandl.*, 1880, V.

of filling, enclosed in the crystalline schists. If mica may be replaced with zinc-blende, magnetite, etc., such a change will, of course, be confined to certain portions of the rock, immediately within range of its cause; and these portions, as distinguished from the rest of the country-rock, are to be considered mineral deposits.

Some of the ore-deposits of the Alps have a certain similarity to those of Scandinavia, for instance, Prettau, in the Ahrn valley, in Tyrol; Brennthal, near Mühlbach, in Salzburg; and Schneeberg, near Sterzing, in Tyrol.

Prettau in Tyrol.—There is here a very ancient copper-mining industry, which was overwhelmed in 1878 by a great disaster, and will not soon recover; namely, the settlement at the smelting-works was buried by an avalanche so deep in débris that it has been necessary to sink shafts nearly 20 meters (65 feet) deep and mine out the stock of manufactured copper and other objects of value.

The crystalline schists, which here strike E. and W., and dip steeply S., contain impregnations of copper and iron pyrites, very short horizontally, but considerably prolonged on the dip. The deposit has been opened to a vertical depth of 500 meters (1640 feet), representing 600 meters (1968 feet), so that the horizontal projection, or distance between the top and bottom is only 350 meters (1148 feet). Figs. 56 and 57 are a vertical section and plan. Figs. 54 and 55 are sketches from the roof and side of the Ottilie gallery, where the chlorite-slate and pyrites present highly complicated forms, somewhat like the structure I have observed in the Transylvania rock-salt. It may be explained, in my opinion, either by an interior increase of volume or by a distortion of the chlorite-slate in the steep westward-pitching line indicated by the ore-deposit. It is extremely difficult to form a correct conception of this deposit. I was able to study some of the lower levels only.

It is remarkable that the pyrites-mine of Brennthal, near Mühlbach, shows an entirely similar structure and form of ore-bodies, and almost the same westward pitch upon the E.–W. plane of the stratification. It looks as if dynamic movements connected with the mountain had played a leading part in thus determining the same pitch for the ore-bodies of deposits on opposite sides of the Central Alps.

Where the ore-body begins to grow poor, and the pyrites appear disseminated in grains and crystals through the chlorite, the secondary character of the impregnation is clearly recognizable. The space for the massive ore-body was probably prepared by mechanical forces. That a metamorphosis was the cause is not likely, because the original minerals of the stratified group could scarcely have assumed such abnormal form and dimensions.

The older rocks occupy in America large areas; and there also many ore-deposits occur and are worked which, although somewhat unlike those of Scandinavia, belong to a similar type. I do not intend to describe here the numerous and well-known ore-deposits of the Eastern and Northern States; but I cannot avoid brief mention of some peculiar types.

Lake Superior.—The copper-district of Lake Superior offers a number of very interesting occurrences, some of which, though developed by extensive mining, and often described at considerable length, have not yet been satisfactorily explained. It is remarkable that copper and silver occur here almost exclusively native; but it is very generally admitted that this is not the usual primitive form of copper. Sulphides seem to occur but seldom, and they receive, as a rule, no attention. I saw once, at Lac-la-Belle, an old working upon pyrite, chalcosite and galena, which was said to have carried some native copper in its upper levels. But Foster and Whitney do not mention it.*

The native copper of this district occurs notoriously in both veins and beds, in a stratified group lying between the Huronian and the Cambrian, and traversed by numerous flows of eruptive rocks.† We are here concerned with the beds. The ore in the Calumet and Hecla mine is a conglomerate of porphyry pebbles; another, in the Copper Falls mine, is a dark lava-flow, the so-called "ash-bed." The latter is impregnated with copper on both sides of the Owl Creek vein, which traverses it (Fig. 98); while in the Calumet and Hecla conglomerate, copper sometimes constitutes the cementing material.

In both masses the spaces now filled with copper were unquestionably once filled with other substances; and the present conditions are the result of whole series of complicated replacements.

R. Pumpelly, who originally believed in a contemporaneous ori-

* *Report on the Geology and Topography of a Portion of the Lake Superior Sand-District*, i., Washington, 1850, p. 139.

† M. E. Wadsworth, "Notes on the Geology of the Inland Copper-Dist. of L. Superior," *Bull. of Mus. of Comp. Zool.*, Harvard College, Cambridge, vii., 1880.

R. Pumpelly, "The Paragenesis and Derivation of Copper and its Associates on Lake Superior," *Am. Jour. Sci.*, 1872, iii.

R. Duer Irving, "The Copper-bearing Rock of L. Superior," *U. S. Geol. Sur.*, 3d *Ann. Rep.*, Washington, 1883.

gin of the copper and the enclosing rock, became subsequently convinced that the copper had replaced especially epidote and chlorite, and that certain phases of metasomatic processes were here represented. The eruptive rocks have usually been strongly attacked—for instance, the pebbles of the conglomerate, the rocks on Isle Royale, etc. Some portions, on the other hand, *e.g.*, the Ash-bed, have been little attacked. The former instance (which the latter, it is true, contradicts) was used, long before Sandberger, as proof of a sort of lateral-secretion theory; and now and then, where the copper-bearing rock was overlain by an eruptive flow, the theory of descending solutions was also brought into play.

Some of the attempted explanations assume, in my opinion correctly, as the cause of the first ore-depositions, the action of hot springs—in which connection it is only to be emphasized that these thermal effects occurred long after the intrusion of the eruptive flows between the sedimentary strata, so that the ores were brought, not by or in the eruptives themselves, but by the later springs, from great depths and perhaps from considerable distances. This explanation, applicable to all the deposits, suits also the exceptional case cited by R. D. Irving, namely, the Nonesuch copper-bed in the sandstone of Porcupine Mountain, far from an eruptive outflow.

As to the condition in which the ores were first deposited, and the manner in which they became reduced and associated with zeolites, additional data must be sought for the formation of an opinion.

Sudbury, Canada.—Quite recently, A. B. von Foullon has published his observations in the Sudbury region, Canada,* expressing certain theoretical conclusions of great interest, which, however, flatly contradicted my view. They concern the pyritic deposits which occur in Huronian rocks, but at the borders of eruptive outflows of diorite, etc., and were described by T. G. Bonney† and afterward by R. Bell.‡ The ores are associated with masses of diorite, intercalated conformably in the stratified rocks. The ore-bodies have the form of "stockworks," and consist of an irregular mixture of rock and metallic sulphides (?). In the ore, which contains gold, platinum, tin, lead, silver, zinc and iron, occur also feldspar, quartz and apatite. This account, taken from Bell's description, indicates a strong analogy with the Scandinavian deposits.

* "Ueber einige Nickelerzvorkommen," *Jahrb. d. k. k. R. A.*, xliii., 1892, p. 276.

† "Notes on a Part of the Huronian Series in the Neighborhood of Sudbury," *Quart. Jour., B.*, xliv., 1888.

‡ "The Nickel- and Copper-Deposits of Sudbury District," *Bull. Geol. Soc. of Am.*, ii., Rochester, 1891.

Foullon, who made in this field a series of highly valuable observations, supported by careful chemical analyses, expresses himself finally concerning the genesis of these deposits, as follows:

"The irregular mixture of pyrites and silicates, presenting copper pyrites and magnetic pyrites enclosed in the rock in the most varied quantities and in all conceivable forms; and, furthermore, the circumstance that sometimes the ore occurs disseminated in the diorite, and sometimes the diorite is enclosed in the ore, now the rock, and again the pyrites, being the ground-mass, prove unmistakably their contemporaneous origin. At certain periods of the diorite eruption, the magma was rich in accessory constituents which rendered possible the formation of the metallic sulphides; and these were segregated during solidification."

R. Bell has expressed himself still more plainly.

"The ores are not of humid, but of molten origin, as is proved by their occurrence in the diorite, with which they ascended. The masses of molten diorite must have remained long liquid, so that the metallic sulphides could separate, become concentrated at certain points, and continue with the fragments of diorite. Large quantities of the molten diorite, and the heavy metals, must have retired again."

These surprising statements assume a chemical impossibility, namely, the presence of metallic sulphides in the magma of the molten eruptive rock, after the fashion conceived by H. C. von Leonhard,* on the strength of metallurgical analogies.

Shaft-furnaces, operated for a separation of the ingredients of the charge, produce slag, metallic sulphides (matte) and reguline metal. But the above hypothesis involves rather a common fusion of all, and a separation *in cooling* of slag (diorite) and matte (metallic sulphides). These authors should certainly not omit to explain further the principles upon which their explanation is based, taking into consideration at the same time the inner structure and other relations of the deposits in question, such as their conformity with the stratified rocks of the region; the occurrence of ore-channels, quite similar to those encountered in deposits formed by aqueous circulation, etc.

These pyritic deposits contain almost all the heavy metals, including platinum and gold, and it is remarkable that the latter here occurs in quartz, exactly as it does generally, throughout the world.

The untenable character of the explanations above quoted must be evident, and this brief mention of them will be sufficient. Yet it appears that there are other inquirers into the genesis of ore-deposits who purpose to take a similar standpoint.†

* *Hüttenerzeugnisse und andere auf künstlichem Wege gebildete Mineralien als Stützpunkte geologischer Hypothesen*, Stuttgart, 1858.

† For instance, J. H. L. Vogt, of Christiania, "Bildung von Erzlagerstätten

4. Hysteromorphous Deposits.

Under this title are included the deposits formed by the chemical and mechanical influences of the surface-region, from the original deposits of which the conditions of origin have been considered above. These formations have been considered and named from various standpoints. Thus the name "deposits of débris" emphasizes the idea of a mechanical crushing or disintegration; the German term *Seife*, like the Spanish and American "placer," is based upon the manner in which such deposits are often mined for their metallic contents, and so on. The expression "secondary deposits" satisfies, it is true, the definition given above, but is rendered ambiguous by its frequent use in other meanings connected with the genesis of ores. I feel warranted, therefore, in proposing for this group the more distinctly significant name "hysteromorphous" (later-formed).

The influences of the present surface upon deposits found in the deep region are so characteristic as to permit us to draw conclusions concerning the processes of earlier periods, when the surface occupied a very different position. Unquestionably, effects similar to those of to-day were produced then also, and we must include in our consideration of the subject the hysteromorphism of former geological periods.

a. Chemical Effects.

The chemical effects proceeding from the present surface have been already discussed in many respects. They involve not only phenomena on the surface itself, but extend beneath it to the groundwater level, and even below that level, so far as the vadose circulation is traceable.

On the surface it is especially the oxidizing effect of the atmosphere, its contained carbonic acid, and the solvent and chloridizing action of atmospheric precipitation, simultaneously aided by the mechanical effects of wind and moving water, which bring about what Justus Roth* has called "simple weathering," to distinguish it from more complicated forms of decomposition. In considering not merely rocks, but outcrops of complex ore-deposits, we encounter what Roth calls "complicated weathering."

Decomposition underground, through the action of the same

durch Differentiationsprozesse im basischen Eruptionsmagma."—*Zeitsch. f. prakt. Geol.*, 1893, i., p. 4.

* *Allgem. u. Chem. Geologie*, vol. i., Berlin, 1879, pp. 69–159.

atmospheric constituents of the surface-water, extends, as is well-known, to the ground-water level, where it may manifest itself in a striking way by reason of the frequent occurrence at that level of the alternation of dryness with moisture, which is a factor greatly promoting decomposition.

A similar condition is presented, as was pointed out in Part I., by the workings of mines, where the water-level has been artificially lowered, and a zone of depth previously untouched by the vadose circulation is brought within the domain of that agency. Deep and old metal-mines especially exhibit in a striking way the effects of the vadose circulation, and, in addition, a phenomenon but seldom found in places under the influence of the natural water-level, namely, the effect of the mine-waters upon various surface relations and products.

Limonite-Deposit near Rio Tinto, Spain.—One of these rare instances is cited by J. A. Phillips* in his group, "Deposits resulting from chemical action." Namely, in the vicinity of the great iron and copper pyrites-deposits of Rio Tinto, in Spain, there occurs a deposit of hydrated ferric oxide, shown by the fossils it contains (which correspond with species still living in the region) to be of recent origin, and undoubtedly produced by the weathering and decomposition of the neighboring pyritic deposit. It was deposited in a swamp-like basin with peaty matter, and subsequent erosion has left of it two remnants only, at Mesa de los Pinos and Cerro de las Vacas respectively. Evidently, in this case, the detritus of the pyritic deposit has not been mechanically swept away and collected elsewhere, but a chemical action has taken place, removing material in solution, exactly as in the formation of bog iron-ores. The formation here is certainly earlier than the Roman period, for Roman tombstones have been found, made of this recent iron-ore.

Mine-waters contain the solutions of all substances directly or indirectly dissolved by the vadose circulation, and some of these, encountering suitable precipitants, may be thrown down. Thus, ferrous oxide becomes by oxidation hydrated ferric oxide; many metallic sulphates are reduced by organic matter to sulphides; copper-salts may even be thus reduced to metal, etc. These new precipitates will mark the track of the mine-waters.

Finally, while the solutions formed by surface-waters, like those of the mine-waters, mostly find their way to the points where the

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* *A Treatise on Ore-Deposits*, London, 1884, p. 15.

water-level reaches the surface (drainage-points), yet as a part of the ground-water penetrates to greater depths, such solutions may very likely produce, in the deep region itself, impregnations, which must, however, differ in character from those produced by the deep circulation proper.

The primitive deposit from which such solutions have come will show remaining in it principally substances not easily soluble, together with such as, like precious stones, resist all atmospheric influences. Meteoric waters, carrying oxygen, some carbonic acid, and small quantities of chlorides, will first oxidize whatever is oxidizable, especially the metallic sulphides. On this subject S. H. Emmens* has published a clear statement, with some practical deductions. He distinguishes in the order of liability to decomposition the following degrees: (1) marcasite, (2) pyrite, (3) pyrrhotite, (4) chalcopyrite, (5) bornite, (6) folgerite, (7) millerite, (8) chalcosite, (9) galena, and (10) zinc-blende. The acid ferric sulphate formed from the first members of this series immediately attacks the latter members. The carbonic acid contained in the circulating waters has a high solvent power, and, among other things, dissolves the carbonate of lime as a bicarbonate, which reacts upon the basic sulphates, producing gypsum and free carbonic acid, and ultimately transforming lead sulphate into carbonate (cerussite). Copper oxide and, under some circumstances, native copper, may be formed from copper sulphate, and so on.

For the chlorine of the chlorides, lead and silver have the strongest affinity, and these metals will consequently be often found in the upper zone as chlorides.

The decomposition above water-level of gold- and silver-bearing deposits facilitates the extraction of these metals. Metallic gold can be extracted by simple processes of mechanical concentration and amalgamation from oxidized material, while gold in undecomposed sulphides, etc., must be roasted, smelted, or chlorinated with more or less cost and difficulty. Silver likewise occurs, as a rule, in this upper decomposed zone in the form of easily amalgamated combinations (free-milling ores), while the refractory ores of deeper zones are much harder to treat.

It is doubtless for these reasons that mining enterprises often come into very critical conditions when they reach water level, and many mines even cease to be profitable. An important part, no doubt, is

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* "The Chemistry of Gossan," *E. and M. J.*, 1892, liv., p. 582.

played by other causes, such as the necessity of hoisting increased quantities of water, the cost of the required machinery, etc.

It is remarkable that in western North America the ground-water level lies deeper than is generally the case in Europe. I suppose the reason to be, that the present area of the Interior Basin of North America, which has no surface-drainage to the ocean, was formerly cut by deep valleys of erosion, which made a deeper escape of the ground-water possible. This suggestion is confirmed by the level valleys of Utah and Nevada, several miles wide and filled with very recent sediments, between comparatively narrow mountain ranges, which seem to be, so to speak, the tops only of the former ranges.

In Europe, the upper zones of the ore-deposits were worked out long ago, at a time when the science of chemistry was in its infancy. But we know from the remnants in these workings that chlorides, lead and silver carbonates, and various sulphates, such as anglesite, occurred in them, though they were not recognized. In Transylvania the decomposed products of the outcrop-zone were called *Bräunen* ("browns"), with evident reference to the brown hydrated ferric oxide. The well-known maxim of the German miners concerning the "iron hat" is very ancient; and the same may be said of the Cornish proverb, "Gossan rides a high horse." Limonite is certainly a characteristic indication of the outcrop of an ore-deposit; and no doubt its reddish-brown color has chiefly suggested the South American miners' names, *pacos* and *colorados*.

In a few instances the "iron hat" has been actually mined as an iron-ore. As a rule, it is the decomposed, porous and honey-combed vein-material of the upper zone, and is colored only with limonite. The part of the ore-deposit above water-level has a characteristic appearance. Quartz and other refractory gangue-minerals are surrounded and impregnated by earthy limonite masses. As a rule the original texture of the deposit has become obscure; and sometimes fragments of the mineral crusts, broken off and crushed through changes of volume, are found chaotically thrown together. Occasionally, however, the original structure may still be traced in the decomposition-products of the several crusts, unaltered nuclei of the ore being discoverable in them. Some substances (especially calamine formed from zincblende) display the stalactitic forms characteristic of the vadose region. Original druses as well as recently formed cavities are filled with new material; and in this way a secondary crustification may occur.

I must not forget to mention that there are some observations according to which gold has been precipitated chemically in hysteromorphous deposits. Oscar Lieber,* F. A. Genth and A. R. C. Selwyn expressed the opinion that detrital gold generally, or a portion of it, has been deposited from solutions. Laur, J. A. Phillips, Wilkinson, Newberry, Daintree,** Skey, Egleston,† etc., have accepted this view as more or less generally applicable. E. Cohen‡ has undertaken to examine it critically, and is inclined by his own experience in South Africa "to adopt the conclusion reached by Devereux for the Black Hills of Dakota, and to assume that by far the largest part of the detrital gold has been liberated by the mechanical destruction of older deposits and has been mechanically laid down; while, on the other hand, a precipitation from solutions undoubtedly takes place, but plays a very subordinate part only."

My own opinion on the subject is expressed in the above quotation.§ No doubt here and there, in the detrital deposits, traces of chemical activity are discoverable; but they are not sufficient to weaken the evident proofs of the mechanical origin of detrital gold.

b. Mechanical Effects.

The mechanical effects of moving air and water, of frost and ice, are grouped under the head of erosion, and are treated at length, so far as rocks in general are concerned, in the geological text-books. We are here concerned especially with effects of this kind produced upon those portions of ore-deposits which are exposed at the surface. We notice at once that mechanical, unlike chemical effects, are confined to the surface or a very small distance below it. In general, we must assume that the chemical changes took place first, but that the progress of erosion brings both to our view at the same time.

Verchoviky, or Surface-Deposits in Situ.—Not only water and ice (glaciers), but also wind, takes part in erosion. For instance, if an ore-deposit, by reason of its greater resistance, crops out above the level of the country, the wind will continually tend to blow away the finer and lighter portions of the detrites formed by chemical

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* In Cotta's *Gangstudien*, and in *Geol. Rep. of S. Carolina*, 1860.

** See A. G. Lock's *Gold, its Occurrence and Extraction*, p. 746–800.

† "The Formation of Gold Nuggets and Placer-Deposits," *Trans. A. I. M. E.*, ix., 1881, p. 633.

‡ "Ueber die Entstehung des Seifengoldes," *Mitth. d. Naturw. Vereins f. Neypommern u. Rügen*, xix., 1887.

§ See my article, "Zur Genesis der Metallseifen," *Oesterr. Zeitsch. f. B. u. H. wesen*, 1887, xxxv., p. 325.

processes of weathering; so that, in the course of time, there must remain of the original outcrop only the heavier portions, so far as these are not carried away by water. In fact, I have observed in the Urals that the gold-diggings of the valley, undoubtedly formed by water, extended up the slopes to points where this could not have been their origin. The gold-bearing weathering-detritus is then called *Nagornyje rozsypy* and *Verchoviky.*

A similar feature was observed by W. C. Kerr* in the auriferous deposits of North Carolina; and I have seen it in the old gold-workings of Bergreichenstein and Nesvacil, in Bohemia,† where flat mountain ridges are covered with old pits and dumps. It is impossible to consider them as diluvial terraces, for the alluvium passes over, so to say, into the solid gneissic rock, which is traversed by many quartz veins. The gold occurs concentrated in the deepest portion of the weather-detritus, that is to say on the contact with bed-rock, and has penetrated all the open, loosely-filled fissures in the latter.

Cotta‡ speaks also of deposits of débris in place, which occur on high plateaus and mountain slopes, and consist of products of weathering which are not rounded pebbles or sand and slime, accumulated by water-currents. A. G. Lock§ speaks of surface-deposits being "a result of the disintegration of the rocks *in situ,*" and says:

> "The gold it contains is quite angular, hackly, or crystalline, and is derived fromauriferous quartz reefs or leaders, existing in the immediate vicinity."

Similar conditions obtain very significantly in the Kackar district, to be hereinafter more fully described.

Theory of the Sinking of Heavier Constituents.—But the great agent in the transportation and re-deposition of the metallic portions of original deposits has unquestionably been flowing water; and this is an equal factor in the removal of the rock-detritus of erosion, which it is constantly striving to carry to the ocean. River-sediments are notoriously unstable. What is deposited this year is carried further down stream in the years next following, and so on until it comes to comparative rest in the sea. The

* "Some Peculiarities in the Occurrence of Gold in North Carolina," *Trans. A. I. M. E.*, x., 475.

† "Zur Genesis der Metallseifen," *Oesterr. Z. f. B. u. H. wesen*, 1887, xxxv., p. 325.

‡ *Erzlagerstätten*, i., Freiberg, 1859, p. 100.

§ *Gold, its Occurrence*, etc., London, 1882, p. 828.

original deposits, furnishing the material thus transported over great distances and areas by water, are well called by the Russians *Korennyje mestorozdenyje*, or root-like deposits,—that is, as it were, the roots of the scattered hysteromorphous deposits.

The attempt has been made to explain the concentration, especially of heavy metals, like gold and platinum, in certain paying layers of the detritus, by a sort of natural concentration process. The circumstance that the richest gold-deposits most frequently lie in the lowest stratum of the detritus, immediately on the bed-rock, yet that several such horizons occur one over the other, is difficult to explain in this way; for Cotta's assumed separate periods of formation (*op. cit.* i. p. 102) are scarcely satisfactory, involving as they do either periodic transportation or periodic deposition, neither of which is probable.

I believe that I have found in the Ural gold-placers a much more probable explanation, based on the principle that the specifically heavier elements of a loose mass are able, with the aid of water, to work their way down through the lighter portions. At the Przibram concentrating-works, it is found that if the pulp is left standing for a considerable period, the galena will accumulate at the bottom. In gold- and platinum-concentrating establishments, it may be often observed that these heavy metals find their way into the floor and woodwork of the mill, from out of which they are from time to time recovered by working up these materials. Why should this happen in artificial operations only, and not also under natural conditions, where the descent of the heavier portions is essentially aided by the percolation of atmospheric waters through the loose covering-material?

This view is supported by the features of all gold-placers, especially those of the detritus of weathering in place, where the agency of running water cannot be adduced, and the accumulations of gold at the contact of the loose and the solid material must be explained by its sinking through the former.

Stream-Detritus.—The detrital deposits produced by running water are generally characterized by the predominance of permeable material, such as sand, gravel, etc. Under this covering mass lies the solid, impermeable " bed-rock " or " rim-rock " of the Americans, the *plotik* or *posva* of the Russians; and in all the gold-fields of the world, the richest pay-deposits are found, as a rule, at the border between the cover and the bed-rock. If the latter is decomposed, fissured, or otherwise loosened, the fine gold will sink into it, making it sometimes rich enough to be mined and concentrated; and this occurs without regard to the petrographic character of the rock. Thus in the Ural, palæozoic schists, limestone and eruptive rocks indifferently are charged with gold. This circumstance indicates also the error of the assumption that these bed-rocks originally carried gold.

But layers of impermeable material sometimes occur in the cover, as, for instance, lava-beds in Australia and California, or, in general, solid conglomerates and clays. In such cases there is often a concentration of gold on the more solid layer, called in America the "false bottom," and in the Ural *loznyj plotik*—that is, a material erroneously taken for the bed-rock. There are often in the detrital cover two or more such gold-bearing layers, which are easily explained on the theory above suggested. The hypothesis of a natural concentration in running water is embarrassed by the fact that the material of gold-placers shows no arrangement according to size, but consists, as a rule, of elements of all sizes.

The movement of the elements of a loose mass has been already pointed out by W. C. Kerr,* who admits the possibility, according to A. G. Lock, of the sinking of the heavier particles, though this is only in a passing remark, and without indication of its far-reaching importance. He says:

"The superior weight of the precious atoms would cause them to sink through the moist surrounding matters, till a hard layer was met with. The occurrence of this process would constantly add to the deposits, the gold always gravitating to the bottom, quickly or slowly, according to circumstances."

It seems to me that this idea must have impressed itself upon other impartial observers also; and I can only wonder that it has not been more frequently expressed.

R. Helmhacker has recently communicated some observations in the Altai region of Siberia, such as the sinking of heavy metallic objects in the loose wash, which confirm the above views. Among other things, he identified grains of metallic lead formed in the gold-placers, as shot, scattered in hunting, which had sunk into the earth.

As is well known, auriferous detritus occurs not only in present but also in ancient river-beds, long since dry; and since, in the latter, the remains of diluvial animals, such as the mammoth, etc., have been found, a distinction has been made between alluvial and

* "The Gold-Gravels of North Carolina," *Trans. A. I. M. E.*, 1880, viii., p. 462. *Gold, its occurrence, etc.*, London, 1882, p. 916.

diluvial gold-deposits. But discoveries of yet older organic remains have shown that such gold-deposits were formed in still more ancient periods. The old river-beds of California cross the present streams, and the auriferous detritus of the former is covered with thick lava-beds—a feature which may be observed in Australia also. During the deposition of the gold, therefore, conditions very different from those of the present day must have obtained.

In another respect, also, the relation between ancient and modern river-beds is sometimes peculiar. The late channels have been rendered by erosion deeper than the older ones. But on the eastern slope of the Ural this is almost totally reversed. The diluvial gold-deposits characterized by the remains of the mammoth often lie below the water-level of the present streams, so that the latter must be diverted in order to mine the ancient beds. This condition apparently extends throughout the whole Siberian plain, and may be taken as evidence that the erosive energy of its rivers has decreased since the Diluvial period, their fall having been reduced, either by the accumulation of the erosion-detritus or by changes in the relative altitude of the Ural range.

The eastern slope of the Ural is characterized by numerous lakes and swamps along the tributary streams, and a number of these contain auriferous detritus, which has been mined for gold.

Marine Detritus.—In some regions, the auriferous detritus, after being repeatedly deposited and again swept away, to be re-deposited further down the valleys, has at last reached the sea. The coast of Oregon, in western North America, and Vladivostock, in southeastern Siberia, are examples. Here the ebb and flow of the tide operate very nearly on the principles of artificial ore-dressing; and one would think that a concentration of the heavier particles might be thus effected. But it does not appear that such effects have been recognized hitherto.

Kackar District, in the Ural.—At the beginning of this section, in the discussion of features of auriferous erosion-detritus, some characteristics of the Ural placers were described. A few additional particulars concerning them may be of interest. The gold-bearing stratum occurs at no definite depth. As a rule, the whole of the barren or poor cover is stripped off and thrown aside, before the auriferous layer, thus laid bare, is systematically attacked. Open cuts (*Razregy*) in the surface, of greater or less depth, are thus created, and are usually left to be filled up by the rivers. In the district of Kackar, already mentioned, in the Southern Ural, original gold-deposits ("root-deposits") of gold have been repeatedly found in the bottom of these cuts. They were well-defined quartz-veins, carrying in the upper zone free gold, but at greater depth sulphides and arsenides rich in gold. In the case I have in mind, the original open cut extended for a considerable distance along the strike of the vein; but the bed-rock (which was at the same time the country-rock of the vein) was much decomposed, so that the difference between detritus and bed-rock was not strikingly evident; and the placer-working passed only by gradual stages into vein-mining.

Hysteromorphous gold-deposits may thus be said, in a general way, to occur in the following positions:

1. In the simple detritus of weathering, immediately upon the original deposit (root-deposit).
2. Mixed with the sand and gravel of present streams.
3. At certain points, in the river-bottom, into the crevices and fissures of which the gold has sunk.
4. Mixed with the impermeable material of older water-courses, through which the gold could not sink.
5. On the false bottoms or bed-rocks.
6. On the true bed-rock.
7. In the decomposed bed-rock itself.

In considering the chemical changes of the outcrops of deposits (including, of course, those which give rise to hysteromorphous derivatives) we have seen that sulphides suffer total decomposition, and that of their constituents only the unoxidizable metals, such as gold and platinum, remain unaffected. Silver-ores and native silver, being attacked by the chlorides of the vadose circulation, are consequently not found in hysteromophous deposits. But gold occurring in nature is for the most part alloyed with silver. The gold from the veins of Budweis, in Bohemia, contains by weight about two parts of silver, and that of Transylvania contains by weight more than three of silver, to ten of gold. Whenever I have had opportunity to compare the gold of an original or root-deposit with that of its derived placer, I have found the latter to be of greater fineness, that is, to contain less silver. I am strongly inclined to ascribe this phenomenon to the prolonged contact with water containing chlorides. The dull surface of placer-gold and its frequently spongy interior structure, as compared with the luster and solidity of "quartz-gold," favor this explanation.

Platinum-Placers.—Detrital deposits of platinum have been, until recently, particularly observed in the Ural only, from which the main supply of platinum was derived. Additional localities are now reported in the Altai district of Siberia and in Canada and British Columbia. In the Tulameen district, it is said, the hydraulic method of mining has been introduced for platinum. I have been unable to obtain detailed information concerning the features of these deposits.

In the Ural, and particularly in its most productive district, that of Niznyj Tagil, the conditions closely resemble those of gold-deposits. The richest platiniferous layers are on the true bed-rock. Platinum and its associates, palladium, nevjanskite and siserskite, being found to occur occasionally adhering to olivine and chromite, it was inferred that they were derived from the serpentine, which is itself a secondary product from olivine-rocks. More recently, platinum is said to have been found in an olivine-gabbro not yet metamorphosed; but whether the metal is a primary or an exotic constituent, can as yet scarcely be declared with certainty.

Formerly no other occurrence of platinum than the native metal was known; but now a platinum-ore has been found in the Sudbury district, Canada, namely, sperrylite, a compound of platinum and arsenic. Since this is certainly xenogenous, the question as to the original sources of platinum-deposits is advanced to a new phase by its discovery.

Tin-Placers.—In connection with the occurrence of tin as cassiterite in detrital deposits, the specific gravity (6.97) of this mineral, nearly equalling that of iron, and the great resistance which it offers to natural agents of decomposition, doubtless play the principal part. Of the numerous and various associates of cassiterite in its original deposits, none, except quartz, are equally able to resist decomposition; and the consequence is, that the detritus, both of weathering and of erosion, from the outcrops of such deposits, contains, besides the products of the decomposition of these other minerals, chiefly quartz and pieces of cassiterite. The latter, by reason of its high specific gravity, will tend to sink through the lighter detritus and be concentrated near the bed-rock.

The stanniferous detrital deposits of Bohemia and Saxony, as well as Cornwall, were long since exhausted; those of Australasia, the South Sea islands and South America are still worked. According to the special monograph of Dr. E. Reyer*, the richest layers are in

* *Zinn, eine geol.-montan.-historische Monographie*, Berlin, 1881, p. 208.

fact found at the bottom of the detritus, immediately on the bed-rock.

With regard to the geological age of the detrital tin-deposits, the rule stated for gold generally obtains, namely, they are for the most part diluvial, yet have sometimes been formed in earlier periods. Thus, at Platten, in Bohemia, a tin-placer, which has been worked under a bedded flow of basalt, and the detrital deposits of Annaberg in Saxony, which underlie the basalt of the Scheibenberg, were doubtless formed in Tertiary times.

The original or root-deposits of tin have been hitherto quite generally considered as very old formations, connected with the eruptions of granite and felsite-porphyry.

Recently, however, tin has been found in the Mesozoic limestones of Campiglio Maritima; and it has been shown, moreover, that the root-deposits of tin in Mexico and Bolivia occur in trachytes and andesites, erupted during the Cretaceous or Eocene. Dr. A. W. Stelzner has recently published a notice of the latter occurrence,* and promised a more elaborate description. He says (p. 533):

"The part played in geological history by the tin-ore of Bolivia, contrasts sharply with that which has been observed in the Erzgebirge of Saxony and Bohemia, and in Brittany, Cornwall, East India, Australia, Tasmania, and the United States of America, and which has hitherto been willingly regarded as the exclusive method of tin-occurrence. The Bolivian tin-ore does not constitute aureoles surrounding plutonic granite, and characterized by the contemporaneous presence of minerals containing boron and fluorine. On the contrary, it can only be considered as produced, simultaneously with precious silver-ores and sulphides of copper, iron, lead and zinc, by precipitation from mineral springs, which were connected in point of time, and perhaps also as effects, with outflows of Cretaceous or Lower Tertiary volcanic rocks."

c. *Hysteromorphous Deposits of the Older Geological Formations.*

Twenty-five years ago, at a time when no deposits of this kind were known, in an article on the continuance of ore-deposits (especially of gold) in depth,† I prophesied their discovery. They have since been observed in different gold-districts. I refer to the characteristic secondary deposits in quartz conglomerates, indicated by their stratigraphical positions and their contained fossils to be of considerable geological age. Such occurrences are often called simply cement-beds, as are the conglomerates of cemented gravel in recent placers; and it is difficult in cases where, as in Australia, this

* *Zeitsch. d. deutsch. geol. Gesellsch.*, xliv., 1892, p. 531.

† *Oesterr. Zeitsch f. B. u. H. W*, xv., 1867.

term is frequent,* to infer the age of the corresponding conglomerates. It is, however, in some cases unquestionable that these cements actually represent old formations—chiefly Palæozoic—and are therefore hysteromorphic products from still older primitive deposits.

Deadwood, Dakota.—One of the best described occurrences is that of Deadwood and Blacktail gulches, in the Black Hills of Dakota.† It is a conglomerate bed, passing upwards into sandstone, and belonging, according to the contained fossils, to the Potsdam sandstone (Cambrian). It is by no means a river-deposit; on the contrary, the fossils indicate a shallow marine basin. The series lies very flat upon crystalline schists; is at most 100 feet (30 meters) thick, and is covered by a layer of porphyry, which has most probably protected it from erosion. Fig. 100, a section given by Mr. Devereux (*l. c.*, p. 468), shows how the deposit is exposed and rendered accessible on the sides of Deadwood and Blacktail gulches, which cut through into the underlying schists.

The conglomerates of pebbles of quartz, schist, and hematite which lie at the base of this Cambrian series carry partly coarse gold, under such circumstances that there can be no doubt of its secondary origin. It came probably from the Homestake vein near by. The auriferous detritus is about 2 meters (6.6 feet) thick, and the portions next to the underlying rock are the richest; so we have here the relation of the "true bed-rock." If my theory be correct, that the gold reached this position by sinking through the lighter detritus, it might be said that the gold was deposited not *with*, but *after*, the detritus, and consequently that the Cambrian fossils do not prove the Cambrian age of the gold-deposition. Such an objection might perhaps have weight in other cases of the kind, but in this case, the bed being covered by a porphyry overflow, and hence not at all exposed to later deposits, the objection has no force.

The Black Hills contain representatives of the three principal types of gold-occurrence, namely, gold-bearing veins and ancient and recent detrital deposits. The paper of Mr. Devereux is also very interesting in other respects—for instance, with regard to the explanation of the differing fineness of vein- and detrital-gold, and with regard to the traces of chemical action in the detrital deposits.

* See, for example, Mr. Lock's *Gold*, etc., already cited.

† W. B. Devereux, "The Occurrence of Gold in the Potsdam Formation, Black Hills," *Trans. A. I. M. E.*, 1882, x., 465.

Australasia.—The data from Australasia concerning this class of deposits are less conclusive. In 1876 Wilkinson observed in the Talhawang district of New South Wales that the Tertiary detrital deposits received their gold from Carboniferous conglomerates. These conglomerates were associated with sandstones and slates, in which occurred a fossil plant peculiar to the Carboniferous of New South Wales. The gold occurred in pretty coarse, rounded grains, and on one occasion a nugget was found weighing 5 ounces (155 grammes). Similar conditions are said to obtain in the Hawkesbury rocks, at the North Shore, Sydney, at Govett's Leap, and in the conglomerates of the Coal-Measures in the southern district. Gold is also reported in the Coal-Measures at Peak Downs in Queensland, near Hobart Town in Tasmania, and in New Zealand.*

The question, whether these deposits of gold were really made simultaneously with that of the detritus in the Carboniferous period, may be decided by the circumstance that the conglomerates are or are not covered by Carboniferous strata. In the latter case, it is possible that the gold may have sunk into the gravel at a later period.

South Africa.—In South Africa, at Witwatersrand in the Transvaal, ancient detrital deposits have yielded a considerable gold-production. According to E. Cohen,† the Witwatersrand consists of sandstones (which resemble closely that of Table mountains at the Cape of Good Hope) and dolomites of high age—undoubtedly Palæozoic. Conglomerates of the same age, intercalated among these strata, occur in the vicinity of Johannesburg in several nearly parallel outcrops, and are for certain distances tolerably rich in gold. They are composed mostly of quartz pebbles, sometimes with fragments not entirely rounded, which are united by a strong, ferruginous, arkose-like cement. The quartz pebbles are sometimes porous and impregnated with hydrated ferric oxide, thus presenting the peculiar corroded appearance so characteristic of auriferous quartz. The gold occurs chiefly in the cement, immediately next to the pebbles. It is mostly coarse-grained, and sometimes even crystalline. The latter circumstance has raised the question whether the gold has not here been chemically precipitated, and hence, whether these are detritus-deposits at all. My standpoint in this discussion, as I have remarked at the end of the section on chemical effects

* Lock's *Gold*, etc., pp. 515, 516. See also R. Daubrée's "Note on Certain Modes of Occurrence of Gold in Australia," *Quart. Jour. Geol. Soc.*, 1878, xxxiv, p. 435.

† "Goldführ Conglom. in Sudafrika." *Mitth. d. naturw. Ver. f. Neupommern*, etc.

in the upper region, is like that of E. Cohen. I do not deny the presence of chemical influences in the detrital deposits, although I have personally not happened upon them. So far as I can judge from the treatises of A. R. Sawyer* and Charles A. Alford,† and from a specimen of the Witwatersrand conglomerate, kindly sent to me by A. H. Halden of Pietersburg, it is my opinion that the gold was mechanically brought into the conglomerates from still older auriferous quartz-veins occurring in the rocks which form the basis of this Palæozoic formation; and since the idea of a later entrance of the gold is excluded by the almost vertical position of the conglomerate beds near Johannesburg, I suppose the gold to have been deposited at the same time as the detritus. The greater part of the gold, as has been said, occurs in the cement. There are no vein-like deposits whatever in the conglomerate; and the only chemical changes which could be presumed are confined to the decomposition of pyrites and the segregation of its contained gold.

According to a foot-note in Phillips's *Treatise on Ore-Deposits* (p. 2), gold is washed out of granular conglomerates of the Lower Carboniferous at Bessèges, Department du Gard, France.

Bohemia.—In the region of Trautenau, in Bohemia, I observed at Gabersdorf and Goldenöls considerable traces of ancient placer-mining, partly in the valley-bottom, partly on the slope, which consisted of old Permian and Carboniferous conglomerates. These remains looked exactly like other gold-workings in Bohemia, and I could only explain their situation by supposing that this was another case of auriferous Palæozoic detritus. The same may be said of another enigmatical gold-occurrence, at Stupna in Bohemia, where in 1593 a gold of unusual fineness (0.954) for Bohemia was produced, and must have come from a detrital deposit. The ancient miners penetrated through bedded flows of melaphyre. The waste-dumps are composed of pebbles from Permian conglomerates. It is therefore possible that these mines were operated upon auriferous Permian conglomerates.‡

* "The Witwatersrand Gold-field." *Trans. N. Staffordsh., Inst. M. and Mech. E.* 1839.

† *Geological Features of the Transvaal*, London, 1891.

‡ F. Pošepný, "Ueber einige wenig bekannte, alte Goldbergbaue Böhmens." *Oesterr. z. f. B. u. H. W.*, xxxvii., 1889.

Description of Figures.

Fig. 1.—Erosion of a channel in rock-salt, at Máros Ujvár, Transylvania. I, impermeable rock; S, rock-salt; H, hydrostatic head of vadose circulation.

Figs. 2 and 3.—Course of vadose circulation, as affected by the nature of the rocks. S, soluble, I, insoluble rock; H, hydrostatic head; *a*, entrance, *z*, outlet; *a b c z*, natural curve of water-circulation, if I did not intervene; *a d z*, actual path under or over I.

Fig. 4.—Geode of *Eisenopal* (jasp-opal), showing the filling of a cavity in which air or gas is present, besides the liquid.

Fig. 5.—Diagrammatic representation of deposits in a limestone cavern. (Deposits white; empty space, black.)

Fig. 6.—Division of ground-water by fissures and permeable strata.

Fig. 7.—Conventional representation of an artesian well.

Fig. 8.—Spring-mounds at Arczó near Korond, in Transylvania.

Fig. 9.—Upward erosions in building-stone in the walled pit of a spring at Bourbonne-les-Bains.

Fig. 1

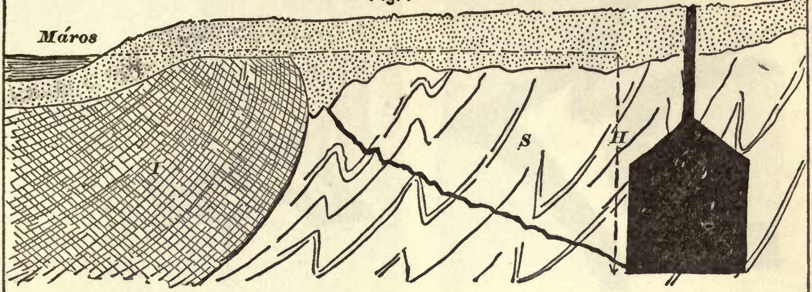


Fig. 2

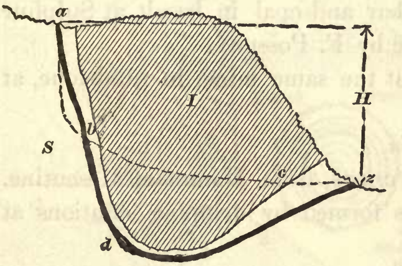


Fig. 3

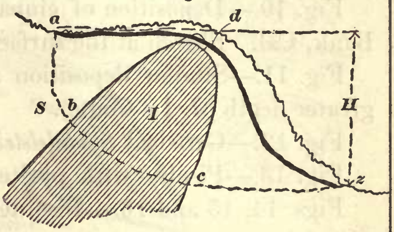


Fig. 6

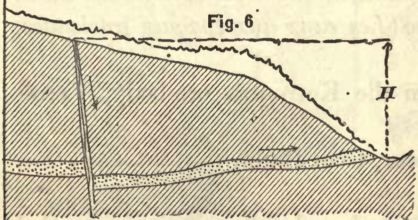


Fig. 7

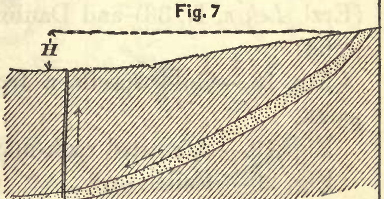


Fig. 4

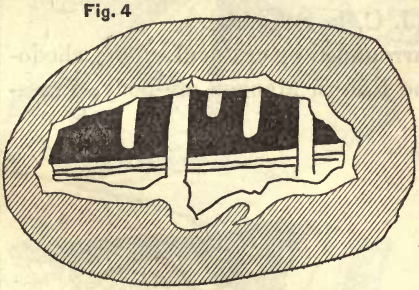


Fig. 5

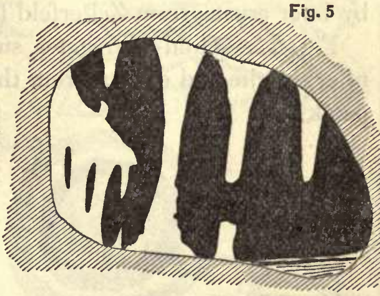


Fig. 8

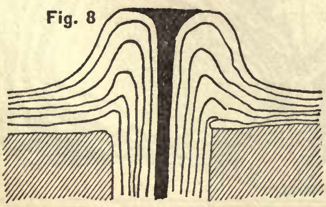
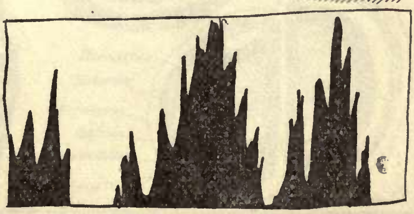


Fig. 9



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Description of Figures.

Fig. 10.—Deposition of cinnabar and opal in basalt at Sulphur Bank, Cal. Sketch at the surface by F. Pošepný.

Fig. 11.—Similar deposition at the same mine, in sandstone, at greater depth (J. Le Conte).

Fig. 12.—Carlsbad *Sprudelstein*.

Fig. 13.—Pisolite with pyrite crusts, from Hammam Mesoutine.

Figs. 14, 15 and 16.—Pisolites formed by dripping solutions at Offenbánya.

Fig. 17.—Sphere-ores, a correction of the illustrations of Cotta (Erzl. *Lehre*, I., 33) and Daubrée (*Les eaux aux époques anciennes*, p. 64).

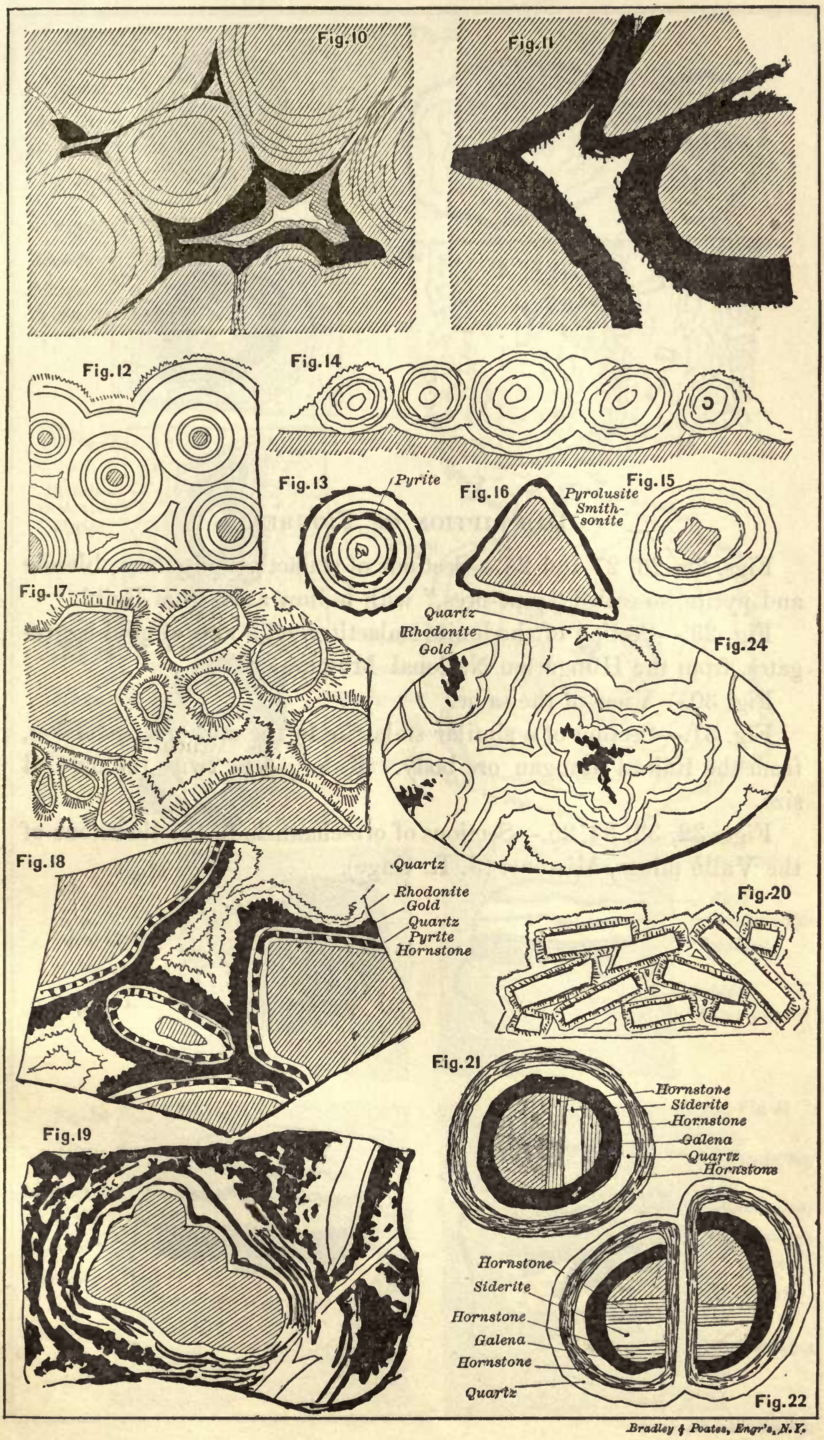
Fig. 18.—Gold specimen from the Katrontza ore-body, Verespatak.

Fig. 19.—A crusted rock-nucleus, from Raibl.

Fig. 20.—Boiler-scale.

Figs. 21 and 22.—Fragments of rock and older crusts, surrounded by later crusts, from Zellerfeld (J. C. L. Schmidt).

Fig. 24.—Gold-aggregates, surrounded by crusts of calcite, rhodonite, siderite and quartz, from the Rákosi Mangan ore-body, Verespatak.



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Figs. 25, 26, 27 and 28.—Sections of stalactites of galena, blende and pyrite, so-called "pipe-ores," with hollow axis, from Raibl.

Fig. 29.—Section of rhodonite stalactites, with axis of gold-aggregates, from the Hungarian National Museum.

Fig. 30.—View of the same.

Fig. 31.—Section of a similar stalactite in the author's possession, from the Rákosi Mangan ore-body. Enlarged to twice the natural size.

Figs. 32, 33, 34, 35.—Sections of ore-channels in the limestone of the Vallé mines, Missouri (J. R. Gage).

Fig.25

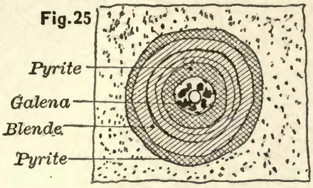
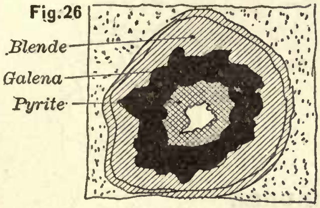


Fig.26



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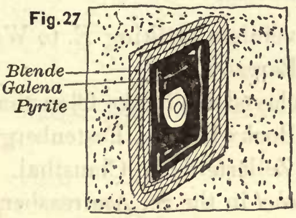

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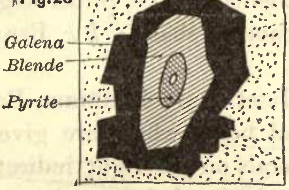

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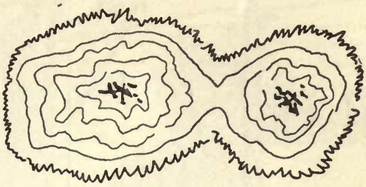

Fig.30

Fig.31

Fig.32

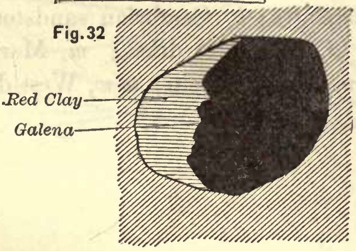

Fig.33

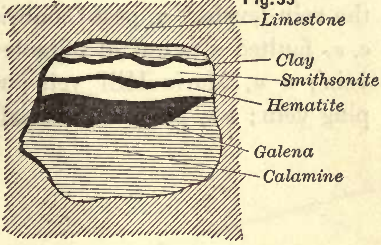

Fig.34

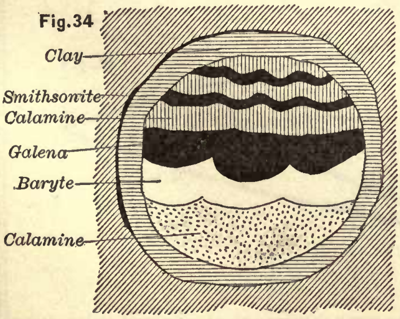

Fig.35

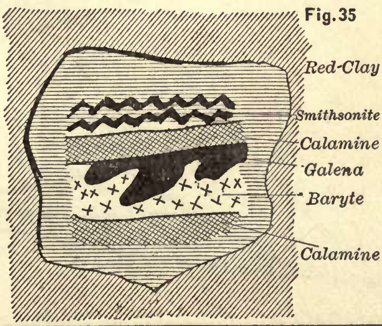

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Fig. 36.—Plan showing gold-bearing veinlets, striking E. to W., in granite (berezite) striking N. to S., at Berezov.

Fig. 37.—Network of veins and vein-clay-slates in the Clausthal district. Localities: *a*, Lautensthal; *b*, Bockwiese; *c*, Festenberg; *d*, Ober-Schulenberg; *e*, Wildemann; *f*, Zellerfeld; *g*, Clausthal.

Fig. 38.—Network of veins and *Ruschel* in the St. Andreasberg district. *Ruschel: a b*, Neufang; *a c*, Edellent; *d f e*, Silberberg; *f g h*, Abendroth Veins: *l l*, Samson (*i*, Samson shaft); *k k*, Bergmannstrost.

Fig. 39.—Section through the Franz Josef shaft, Przibram, Bohemia. A B, sea-level, heights above and below which are given in meters on the left. The Roman numerals on the right indicate the vein-levels. *a*, post-Cambrian slates; *b*, Cambrian sandstone; *c*, *c*, faulted stratum of adinole; *d*, *d*, diorite dikes; *m*, Martyr vein; *u u*, Marie Hilf vein; *v*, *v*, *v*, Sefcin vein; *w w*, West-dipping vein; *s s*, Franz Josef shaft.

Fig. 36

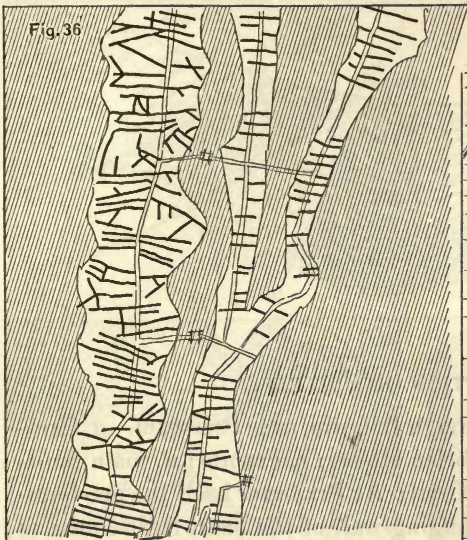


Fig. 39

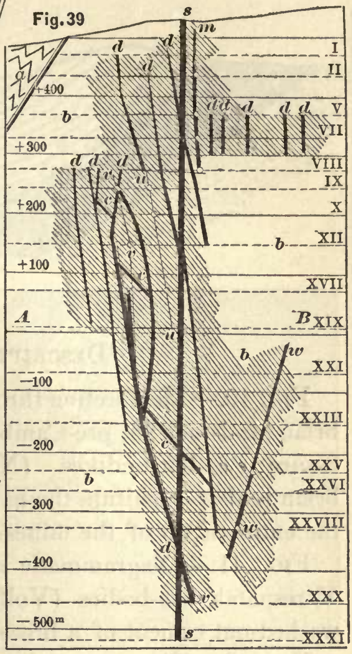


Fig. 37

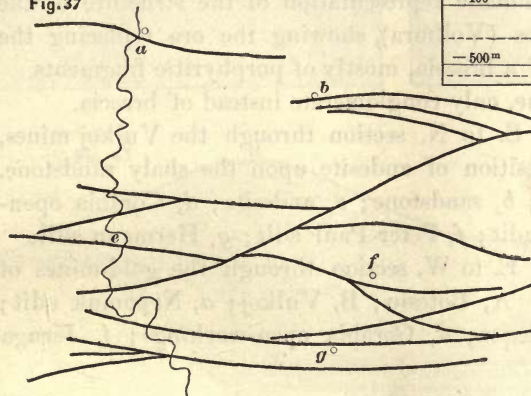
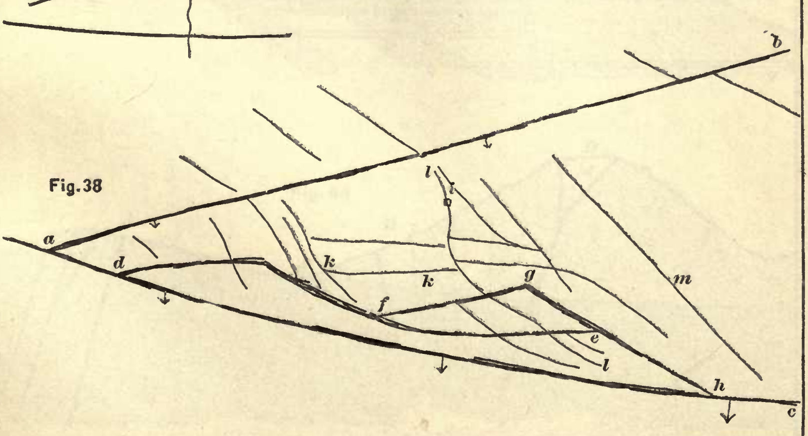


Fig. 38



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Description of Figures.

Fig. 40.—Ideal section through Bohutin, near Przibram. *a*, Cambrian sandstone; *b*, pre-Cambrian schists; *c*, granite; *d*, main fault-fissure; *e e*, diorite dikes. (Note: At Przibram itself the pre-Cambrian schists constitute the hanging-wall of the main fault-fissure to the entire depth of the mines—about 1100 meters, or 3600 feet.)

Fig. 41.—Diagrammatic representation of the structure of the Verespatak ore-bodies (Volbura), showing the ore replacing the washed-out cement of a breccia, mostly of porphyritic fragments.

Fig. 42.—The same, only conglomerate instead of breccia.

Fig. 43.—Vertical S. to N. section through the Vulkoj mines, showing the supra-position of andesite upon the shaly sandstone. *a a*, Nepomuk adit; *b*, sandstone; *c*, andesite; *d*, Corabia open-workings; *e*, Jeruga adit; *f*, Peter-Paul adit; *g*, Hermann adit.

Fig. 44.—Vertical E. to W. section through the gold-mines of Botesiu and Vulkoj. A, Botesiu; B, Vulkoj; *a*, Nepomuk adit; *b*, sandstone; *c*, andesite; *d*, Corabia open-workings; *j*, Jeruga vein.

Fig. 40

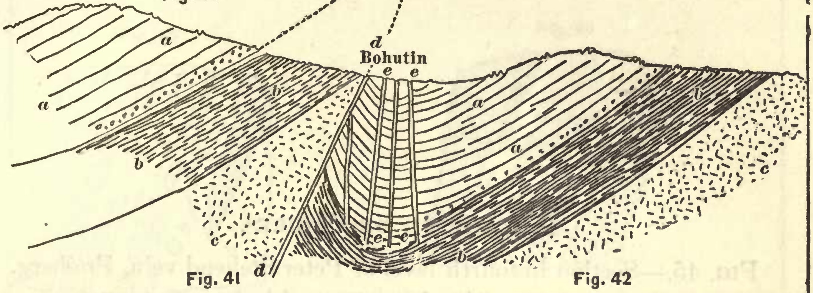
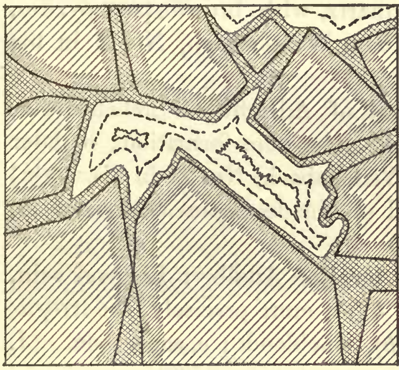


Fig. 41



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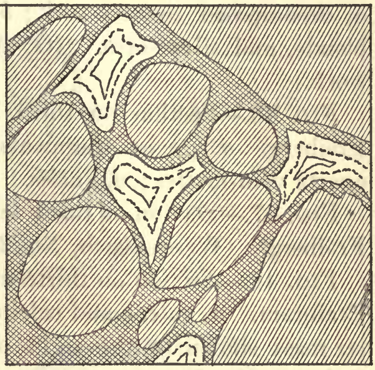


Fig. 43

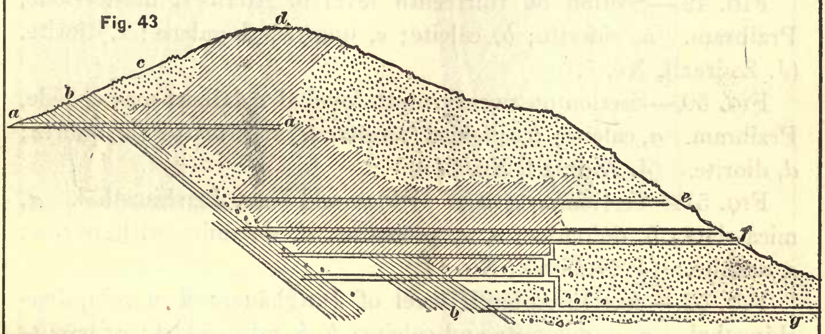
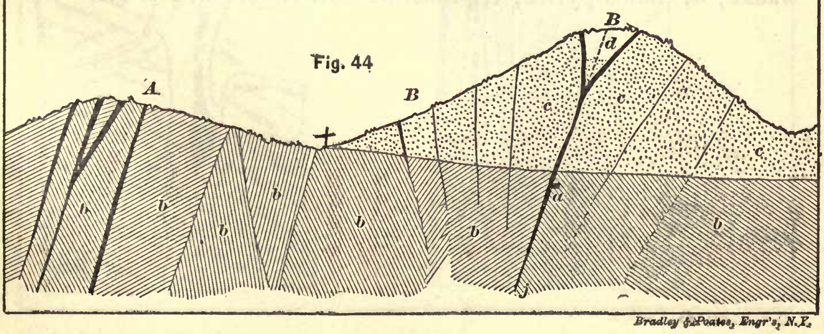


Fig. 44



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Description of Figures.

Fig. 45.—Section in fourth level of Peter Stehend vein, Freiberg. *a*, decomposed country-rock; *b*, quartz, with brown-spar, pyrites, blende, and silver-ores. (G. A. Von Weissenbach, No. 2 in his work.)

Fig. 46.—Section on third level of Adlerflügel Stehend vein, Freiberg. *a*, gneiss fragments; *b*, older vein-formation; *c*, later quartz vein-matter; *d*, gneiss. (Weissenbach, No. 21 in his work.)

Fig. 47.—Section on third level of Gnade Gottes Stehend vein, Freiberg. (Weissenbach, No. 22.)

Fig. 48.—Section on thirteenth level of Adalbert Liegend vein, Przibram. *a*, galena and calcite; *b* (or, more precisely, the irregular mass shown to the right of *b*), zincblende; *c*, sandstone. (J. Zadrazil, No. 52.)

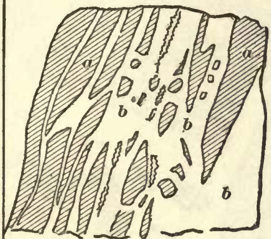
Fig. 49.—Section on thirteenth level of Adalbert master-lode, Przibram. *a*, siderite; *b*, calcite; *c*, quartz; *d*, galena; *e*, diorite. (J. Zadrazil, No. 5.)

Fig. 50.—Section on twenty-ninth level of Adalbert master-lode, Przibram. *a*, calcite; *b*, silicified (*verquarzte*) vein-matter; *c*, quartz; *d*, diorite. (J. Zadrazil, No. 21.)

Fig. 51.—Section on adit of Hildebrand vein, Joachimsthal. *a*, mica-slate; *b*, dolomite; *c*, *c*, proustite; *d*, dolomite with pyrite; *e*, uranite. (J. Nemecek, No. 11.)

Fig. 52.—Section on tenth level of Junghäuerzechen vein, Joachimsthal. *a*, *a*, dolomite and calcite; *b*, *b*, mica-schist; *c*, basalt-wacke; *d*, chalco-pyrite; *e*, proustite. (J. Nemecek, No. 5.)

Fig. 45



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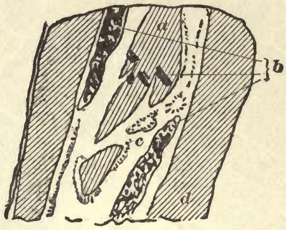
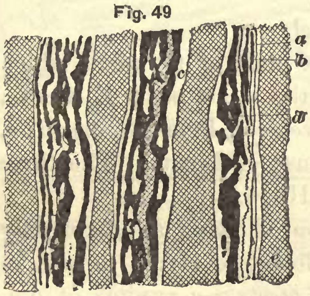


Fig. 47

Fig. 48

Fig. 50

Fig. 49



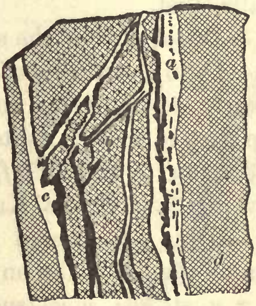


Fig. 51

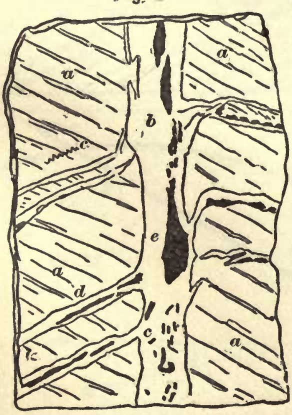
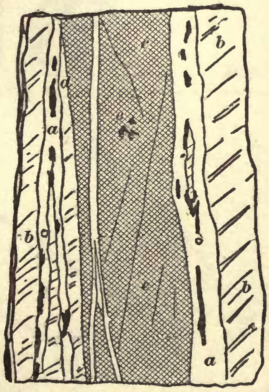


Fig. 52



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Description of Figures.

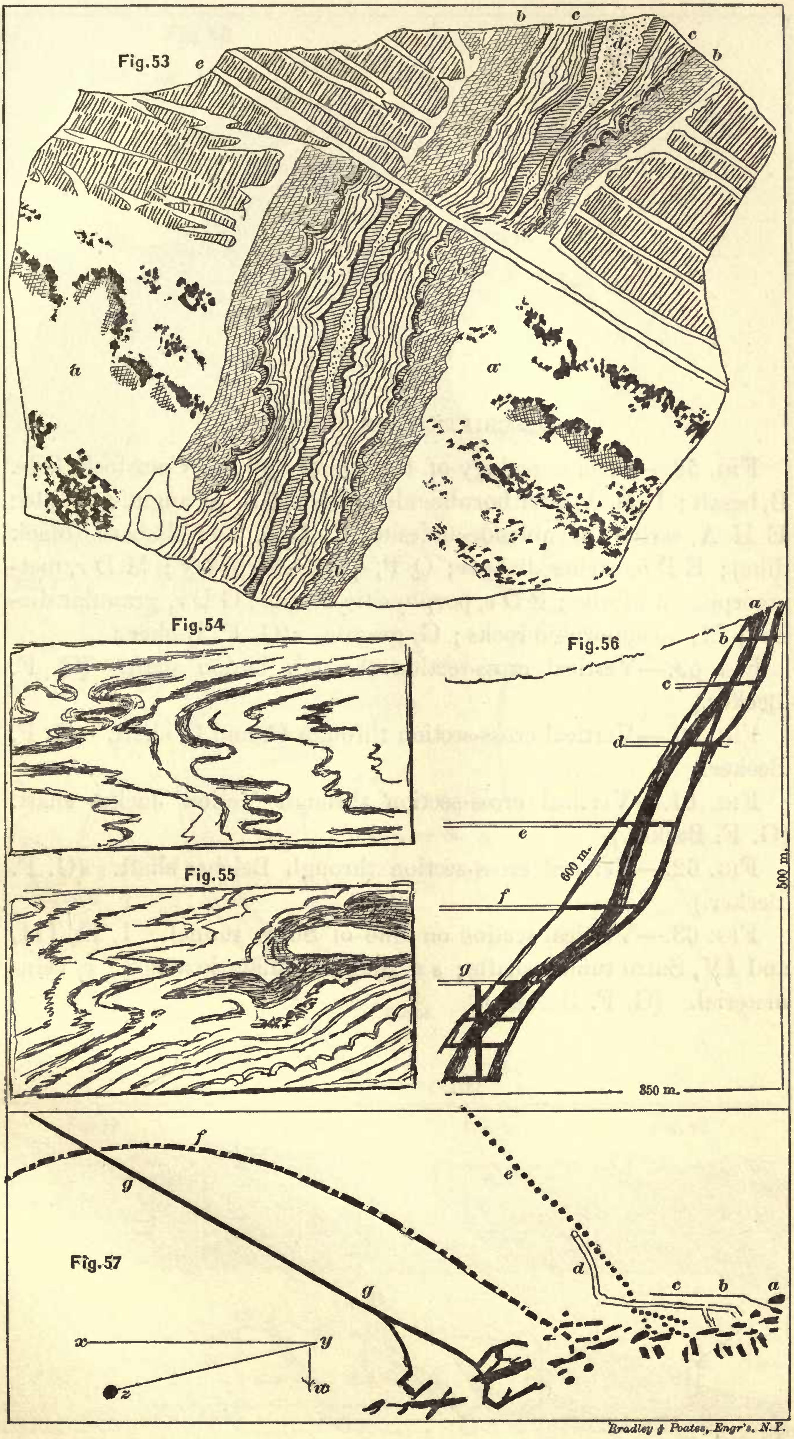
Fig. 53.—Specimen from the Drei Prinzen Spat vein, in the eighth level of the Churprinz Friedrich August mine, Freiberg, Saxony; $\frac{1}{6}$ nat. size; *a*, quartz with disseminated galena and blende, indistinctly crustified—from the older vein; *b*, fluorite with quartz; *c*, barite in thin crusts; *d*, gray earthy mass of the later vein, very distinctly crustified; *e*, the latest fault-fissure.

Fig. 54.—Copper-deposit at Prettau in Tyrol. Sketch of the roof of the Ottilie level.

Fig. 55.—Ditto; side of the same level.

Fig. 56.—Ditto; vertical section in the plane of the pitch, which descends nearly westward, the course of the strata being E. to W., and the dip steep to South. Adits and levels: *a*, Peter; *b*, Jacob; *c*, Marx; *d*, Johann; *e*, Kristof; *f*, Nikolaus; *g*, Ignatz. The three levels below *g* are the Ottilie, Karl, and Hugo.

Fig. 57.—Ditto; horizontal projection, showing approximately the position of the ore-bodies on the different levels: *a* to *g* as in Fig. 56; *x y*, strike; *y w*, true dip of strata; *y z*, pitch of ore-shoot.



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Description of Figures.

Fig. 58.—Surface-geology of the vicinity of the Comstock lode. B, basalt; L H A, later hornblende-andesite; A A, augite-andesite; E H A, earlier hornblende-andesite; L D *b*, later diabase (black dike); E D *b*, earlier diabase; Q P, quartz-porphyry; M D *r*, metamorphosed diorite; P D *e*, porphyritic diorite; G D *r*, granular diorite; M, metamorphic rocks; G, granite. (G. F. Becker.)

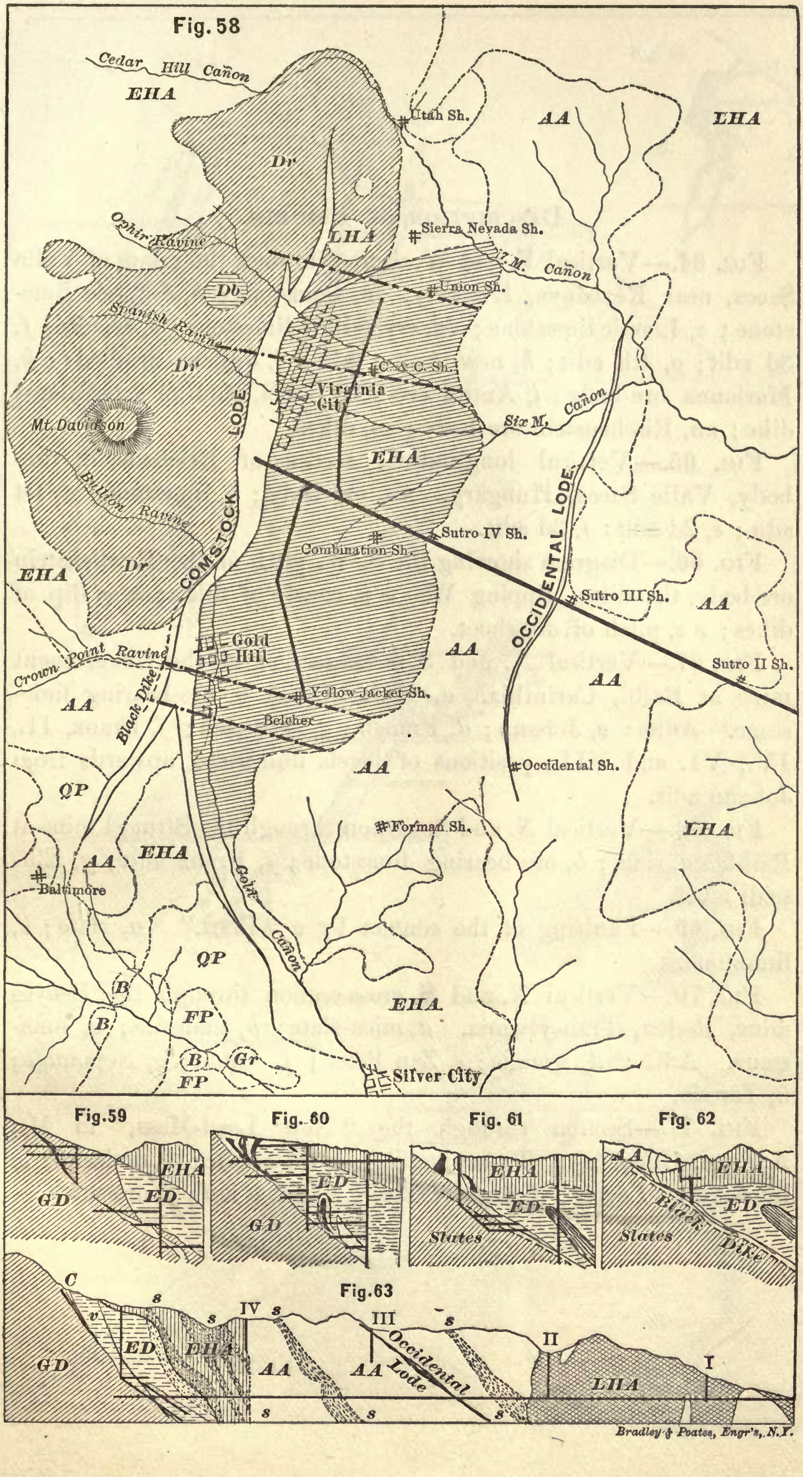
Fig. 59.—Vertical cross-section through Union shaft. (G. F. Becker.)

Fig. 60.—Vertical cross-section through C. and C. shaft. (G. F. Becker.)

Fig. 61.—Vertical cross-section through Yellow Jacket shaft. (G. F. Becker.)

Fig. 62.—Vertical cross-section through Belcher shaft. (G. F. Becker.)

Fig. 63.—Vertical section on line of Sutro tunnel. I, II, III, and IV, Sutro tunnel shafts; *s s*, lines of solfataric action; *v*, vein-material. (G. F. Becker.)



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Description of Figures.

Fig. 64.—Vertical E. and W. section through the mines of Valle Sacca, near Rézbánya, Hungary. *a*, sandstone; *b*, Jurassic limestone; *c*, Liassic limestone; *dd*, crystalline limestone; *e*, syenite; *f*, 3d adit; *g*, 4th adit; *h*, new Anton adit; *i*, Juliana ore-body; *k*, Marianna ore-body; *l*, Anton ore-body; *mm*, parallel intercalated dike; *nn*, Rischenstein ore body; *oo*, dikes.

Fig. 65.—Vertical longitudinal section of Reichenstein ore-body, Valle Sacca, Hungary. *nn*, ore-body; *b*, limestone; *d*, 1st adit; *e*, 2d adit: *f*, 3d adit.

Fig. 66.—Diagram showing the S. W. pitch of the Reichenstein ore-body, the dikes dipping W. *x y*, course of dikes; *x w*, dip of dikes; *x z*, pitch of ore-shoot.

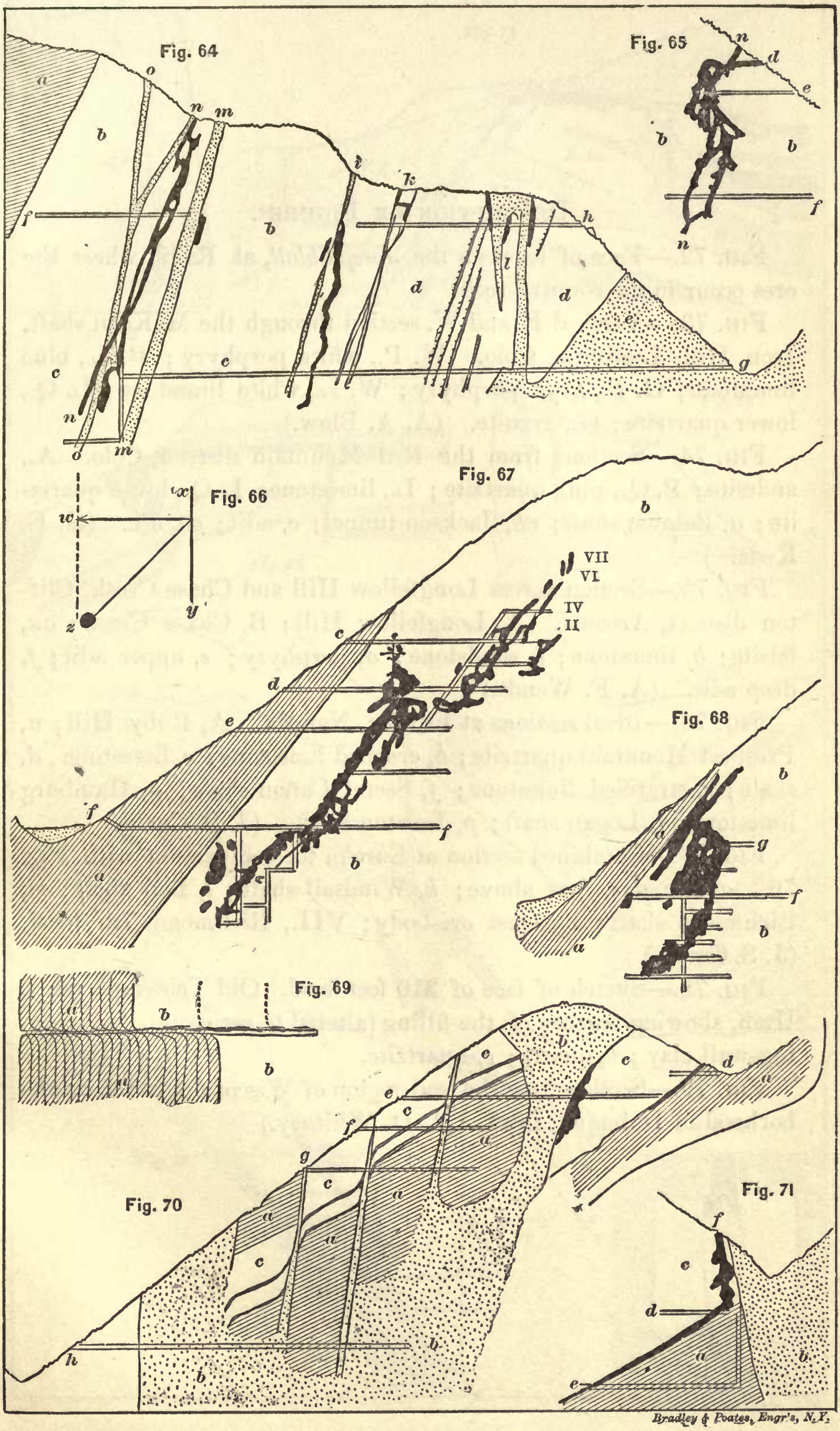
Fig. 67.—Vertical N. and S. cross-section of the Government mine at Raibl, Carinthia. *a*, Raibl slates; *b*, ore-bearing limestone. Adits: *c*, Johann; *d*, Frauen; *e*, Sebastian; *f*, Franz, II., IV., VI. and VII., positions of levels numbered upwards from Johann adit.

Fig. 68.—Vertical N. and S. section through the Struggl mine at Raibl. *a*, slate; *b*, ore-bearing limestone; *f*, Franz adit; *g*, Einsiedl level.

Fig. 69.—Faulting of the contact by a "Blatt." *a*, slate; *b*, limestone.

Fig. 70.—Vertical N. and S. cross-section through the Benyes mine, Rodna, Transylvania. *a*, mica-slate; *b*, andesite; *c*, limestone. Adits: *d*, Amalia; *e*, Zap Peter; *f*, Anton; *g*, Nepomuk; *h*, Teresia.

Fig. 71.—Section through the "New Lead-Mass," in Mt. Ambree, Offenbánya, Transylvania. *a*, mica-slate; *b*, andesite; *c*, limestone. Levels: *d*, Segen Gottes; *e*, Glück auf; *f*, ore-shoot.



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Description of Figures.

Fig. 72.—Face of level on the *Josephiblatt*, at Raibl, where the ores occur in the country-rock.

Fig. 73.—Vertical E. and W. section through the McKean shaft, Iron Hill, Leadville, Colo. W. P., white porphyry; B. L., blue limestone; G. P., gray porphyry; W. L., white limestone; L. Q., lower quartzite; G., granite. (A. A. Blow.)

Fig. 74.—Sections from the Red Mountain district, Colo. A., andesite; P. Q., pink quartzite; L., limestone; L. Q., lower quartzite; *a*, Batavia shaft; *ab*, Jackson tunnel; *c*, adit; *oo*, ore. (G. E. Kedzie.)

Fig. 75.—Section across Longfellow Hill and Chase Creek, Clifton district, Arizona. A, Longfellow Hill; B, Chase Creek; *aa*, felsite; *b*, limestone; *c*, sandstone; *d*, porphyry; *e*, upper adit; *f*, deep adit. (A. F. Wendt.)

Fig. 76.—Ideal sections at Eureka, Nevada. A, Ruby Hill; *a*, Prospect Mountain quartzite; *b*, crushed limestone; *c*, limestone, *d*, shale; *e*, stratified limestone; *f*, Secret Cañon shale; *g*, Hamburg limestone; *i*, Logan shaft; *p*, Lawton shaft. (J. S. Curtis.)

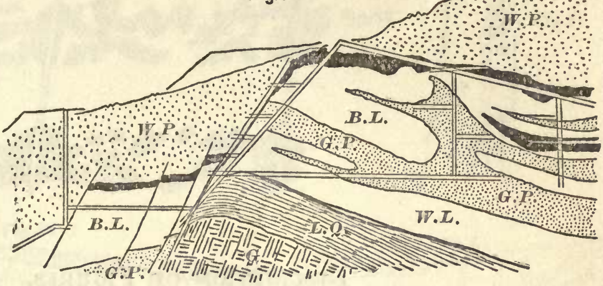
Fig. 77.—Combined section at Eureka for comparison with Fig. 76. *a*, *b*, *c*, *d*, *e*, *f*, as above; *k*, Windsail shaft; *l*, Bell shaft; *m*, Richmond shaft; *x y*, east ore-body; VII., Richmond 7th level. (J. S. Curtis.)

Fig. 78.—Sketch of face of 310 feet level. Old Telegraph mine, Utah, showing texture of the filling (altered to cerussite). *a*, hanging-wall clay; *b*, quartz; *c*, quartzite.

Fig. 79.—Section from the lead-region of Wisconsin, in the neighborhood of Dubuque, Iowa. (J. D. Whitney.)

Fig. 72

Fig. 73



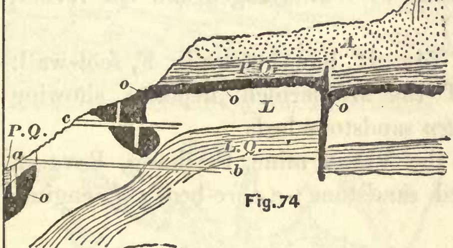
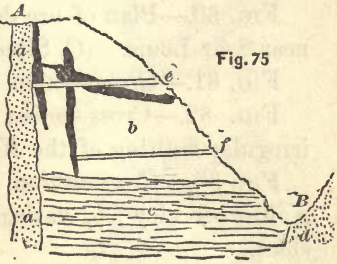


Fig. 74

Fig. 75



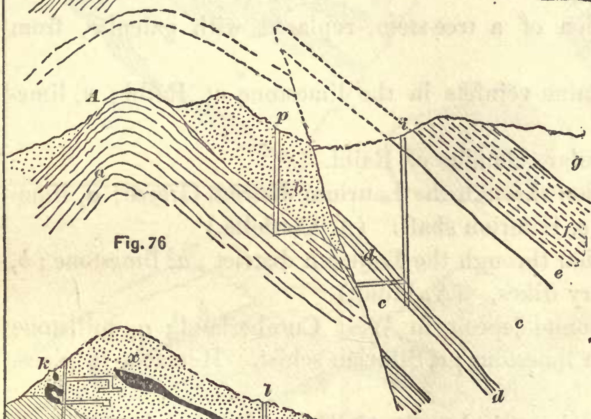


Fig. 76

Fig. 78

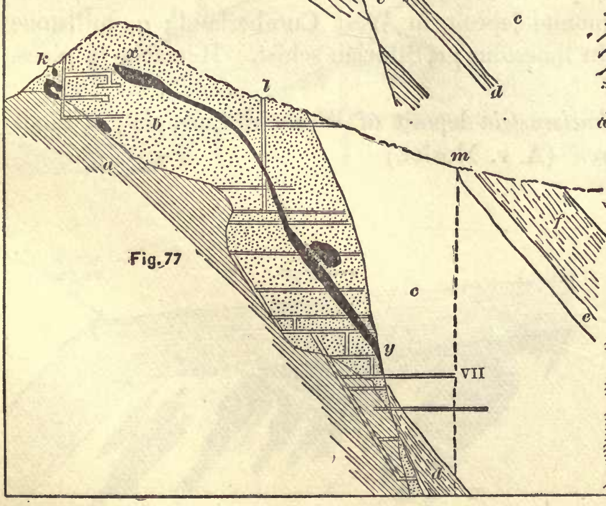
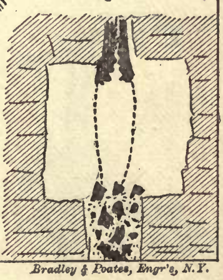


Fig. 77

Fig. 79



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DESCRIPTION OF FIGURES.

FIG. 80.—Plan of ore-deposits at Wallerfangen and St. Avold, near Saar Louis. (C. Simon.)

FIG. 81.—Cross-section of 81. H, hanging-wall; F, foot-wall.

FIG. 82.—Cross-section of the Mechernich deposits, showing irregular faulting of the *Knoten* sandstone beds.

FIG. 83.—Cross-section of the Vesuv mine, Freihung, Bavaria. *a,* Keuper clay; *b,* variegated sandstone; *c,* ore-beds; *d,* engine-shaft.

FIG. 84.—Section of a tree-stem, replaced with galenite, from Freihung.

FIG. 85. Calamine veinlets in the limestone at Raibl; *a,* limestone.

FIG. 86.—Cellular calamine of Raibl.

FIG. 87.—Section through the Laurium district, Greece; *a,* limestone; *b,* schist; *c,* Hilarion shaft. (A. Cordella.)

FIG. 88.—Section through the Laurium district; *a,* limestone; *b,* schist; *d,* porphyry dikes. (A. Huot.)

FIG. 89.—Limonite-deposit in West Cumberland; *a,* millstone grist; *b,* mountain limestone; *c,* Silurian schist. Hematite in place. (J. D. Kendall).

FIG. 90.—*Bohneisenstein*-deposit of Wochein, Carniola; *a,* limestone; *b,* iron-ore. (A. v. Morlot.)

Fig. 80

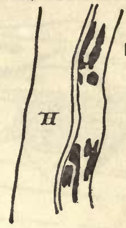
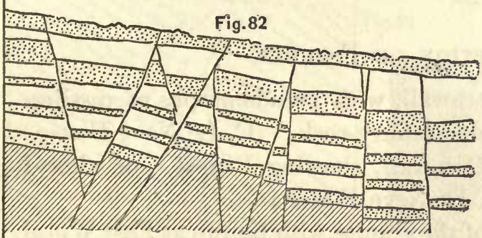


Fig. 81

Fig. 82



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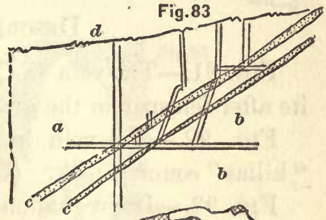

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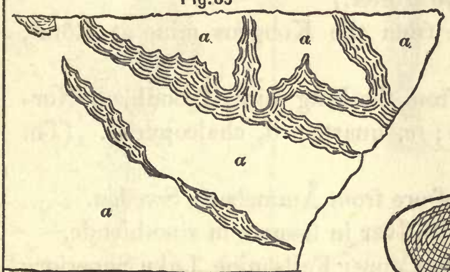
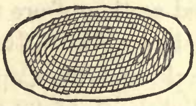


Fig. 86

Fig. 84



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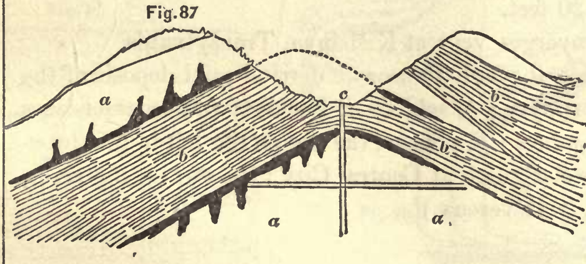

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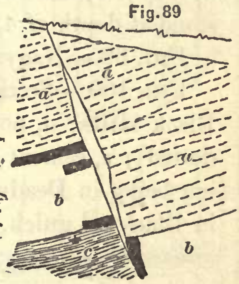
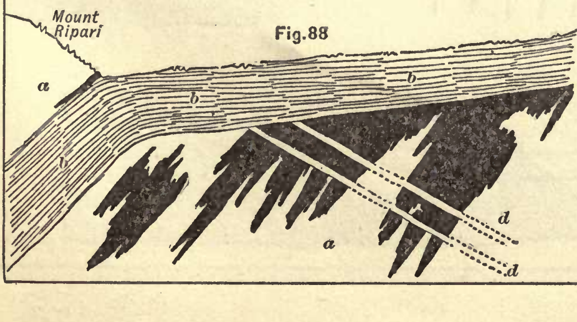


Fig. 88



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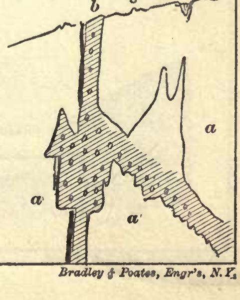

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Description of Figures.

Fig. 91.—Tin-vein in Cornwall, with pseudomorphs of cassiterite after feldspar in the granite country-rock. (C. Le Neve Foster.)

Fig. 92.—Tin-vein in Cornwall, showing "capel" or altered "killas" country-rock. (C. Le Neve Foster.)

Fig. 93.—Impregnation of the granite with tin-ore at East Wheal Lovell, Cornwall. (C. Le Neve Foster.)

Fig. 94.—Specimens of ore from the Kongens mine at Röras, Norway. (Th. Kjerulf.)

Fig. 95.—Specimen of ore from the Mug mine, Trondhjem, Norway; *a*, pyrrhotite; *b*, mica; *c*, quartz; *d*, chalcopyrite. (Th. Kjerulf.)

Fig. 96.—Polished section of ore from Åmmeberg, Sweden.

Fig. 97.—Ditto, showing leaf-silver in fissures in zinc-blende.

Fig. 98.—Section through the Copper Falls mine, Lake Superior; *a*, trap; *b*, ash-bed at depth of 80 feet; *c*, amygdaloid; *d*, sandstone at depth of 420 feet.

Fig. 99.—Nagynyerges vein at Kisbánya, Transylvania.

Fig. 100.—Section through Palæozoic detrital gold-deposit of the Black Hills; *a*, porphyry; *b*, schist; *d*, Potsdam (old contact-lines dotted); *e*, cement-mines; *ff*, placers, the one on the left in the drawing being in Deadwood gulch at Central City; the one on the right, in Blacktail gulch. (Devereux.)

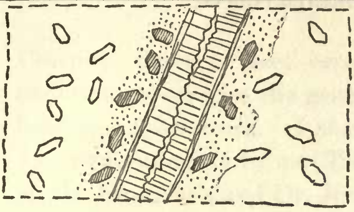


Fig. 91

Fig. 94

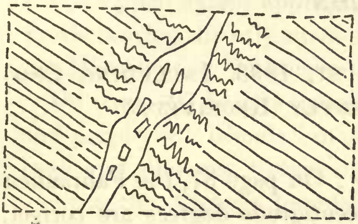


Fig. 92

Fig. 95

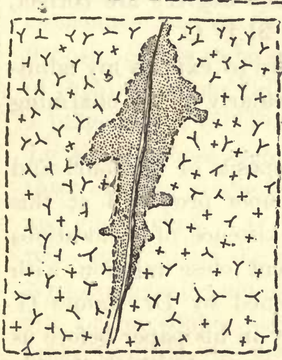
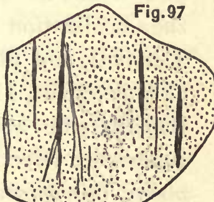


Fig. 93

Fig. 96



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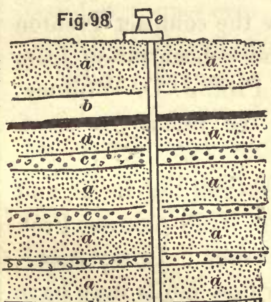

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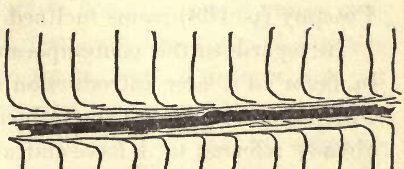

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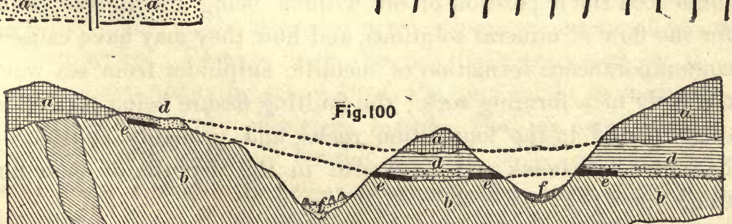

Fig. 100

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DISCUSSION

At the Chicago Meeting, August, 1893, Including Communications Subsequently Received.

R. W. Raymond, New York City: On page 37, the Fahrenheit degrees are incorrectly given. The centigrade degrees are correct, except as to No. 8 (Ophir), which should be 21.1° C.

W. P. Blake, Shullsburg, Wis.: I desire to express my admiration of Prof. Posepny's memoir, and particularly of the charming manner and spirit of the introduction.

With respect to his mention of the ore-deposits of Missouri and Wisconsin, reference may be made to my paper presented at this meeting (*Trans.*, xxii., 621), showing the existence of dislocations and breaks in the bedding, and their apparent close relation with the localization of the ore-deposits as claimed by Dr. James G. Percival, and also so claimed by Dr. Jenney in his paper before us (*Trans.*, xxii., 171). I have in my paper given reasons for believing that the zinc- and lead-ores in the strata above the compact Trenton limestones were formed by lateral secretion and concentration from above downwards, substantially as shown by Prof. J. D. Whitney, and not by the ascent of solutions through the fissures, as Prof. Posepny (p. 108) seems inclined to believe.

In regard to the contemporaneity of the ore and the rocks, and in favor of a later introduction of ore through fault-fissures, Prof. Posepny (p. 114) cites the influence of these fissures. In my paper, already referred to, I have endeavored to show how faults may have influenced the deposition of ore without being themselves channels for the flow of mineral solutions, and how they may have caused the contemporaneous formation of metallic sulphides from sea-water in the body of a forming rock; the faulting fissure being formed at an early period in the foundation rocks, and probably continuing to be a plane of break and movement in the deposits of later formation.

Arthur Winslow, Jefferson City, Mo.: The results of extensive and long continued studies, such as are here presented by Prof.

Posepny, deserve most careful consideration before one should undertake to criticise the general conclusions or judge of the broader bearings of his work. I shall not attempt anything of the kind. The remarks made by me (*Trans.*, xxii., 634, 735) in the discussions of Mr. Emmons's and Dr. Jenney's papers, presented at this meeting, are to a great extent applicable here; but I wish to add a few more words bearing directly upon Prof. Posepny's statements concerning the Missouri and Wisconsin ores.

On page 107 he says that while the deposits, away from the granite and porphyry "islands" of southeastern Missouri consist chiefly of lead- and zinc-ores, "other metals, such as copper, cobalt, and nickel, occur as the Archean foundation-rocks are approached." This circumstance, he says, is "an indication that the source of the lead-deposits also is to be sought in depth." Whatever may be the value of this indication, I do not think the facts as stated hold generally. I judge that Prof. Posepny reasons from his observations at Mine La Motte, where such conditions exist. At other points, however, these changes in composition are not observed as the crystalline rocks are approached. At Doe Run, a mine recently opened, work is prosecuted along the old water-worn pre-Cambrian surface of the Archean granite, among the conglomerate boulders themselves; and few or no copper-, cobalt-, or nickel-ores are found. Again at other localities, in St. Genevieve, Franklin, Crawford and other counties, copper-ores occur remote from any granite or porphyry outcrops and well above the basal beds of the Cambrian.

With reference to the Wisconsin deposits, our author seems to think the absence of ores, in the great thicknesses of limestones and sandstones which underlie the productive horizons, by no means conclusive as an argument against their deep-seated source, and suggests that the solutions may have come up through a passage not yet exposed, and even that fault-fissures and eruptive dikes may exist which have not been discovered. From the fact that he refers in this connection only to Whitney's report of 1862, I conclude that he has not had access to the later and more exhaustive works of Strong and Chamberlin. Perhaps with the full light conveyed by these reports and accompanying maps, Prof. Posepny might have attached more importance to the objections raised. For my own part I do not see how such a passage for the solutions as he suggests could possibly exist without its presence having been revealed and its course traced, through the widespread mining and exploring which has been conducted in this region during the past seventy years. Neither do I yet see how the solutions could traverse the intervening great thicknesses of water-soaked sandstones without becoming diffused, in great part at least. The failure to find such a passage and the absence of the ores in the beds assumed to have been traversed, though evidence of a negative character, is so strong that it becomes of almost positive value in support of the theory of lateral segregation.

T. A. Rickard, Denver, Colo.: The distinguished author of this paper has referred to the Leadville monograph of Emmons, as "epoch-making." This judgment has been anticipated, I believe, by most of us. It serves, however, very well to recall the fact that the publication of that particular monograph marked the high tide of the lateral-secretion theory, which owed its importance more to the fact of its acceptance by certain distinguished geologists than to its incomplete demonstration by Sandberger.

What Prof. Posepny said of the work of our American geologist we can say, with even greater force, of his present contribution. His dissection of the theory promulgated by Sandberger is most effective. The sympathies of the miner are with him in that demolition of the lateral-secretion theory; for the latter was an explanation which never found much favor underground, with the miner, but had its stronghold in its own particular *habitat*, the professor's *sanctum*. Here I would throw out the suggestion to my fellow mining engineers, whose business is to observe rather than to theorize, that these distinguished scientists must, after all, look to the men who spend much time underground for the accumulation of evidence whereon to found their hypotheses. If the genesis of ore-deposits is to be unravelled, more particularly if this study is destined to be capable of further practical and economic application, it must be through the gathering of facts and not the mere building of theories. Prof. Posepny has very properly pointed out that Sandberger's views gained many disciples because they permitted extensive generalizations to be made above ground, and in comfort, but did not so much require a descent underground and the making of observations under conditions of discomfort. Therefore, I would say, let those of us who have the opportunity aid in the elucidation of truth by the collection of the facts and observations without which speculations regarding the origin and formation of ore-deposits are worse than vain.

Prof. Posepny emphasizes the fact of the ascension of mineral solutions. I venture to suggest that these terms—"ascending," "lateral," and "descending"—may all be applied to mineral solutions at various periods and under various conditions. It is the great fact of *circulation* which covers all. The water which comes up must have first gone down; its original descent was as necessary to the process of ore-formation as its subsequent ascent. When and where in its journeying it became a solvent and when and where it became a precipitant—that is what the miner wants to know. The ultimate formation of an ore-deposit is dependent more upon conditions favoring precipitation than upon those determining solution.* Prof. Posepny points out more than once, that the two great factors which increase the solubility of all substances are heat and pressure. We know by observation that these conditions are increasingly obtainable as we go downward. The deep region is one that favors solution, just as the shallow zone, because it is characterized by lessened heat and diminished pressure, favors precipitation. It is this simple fact which helps to explain the ordinary non-persistence of ore in depth. It is this which explains the comparatively late origin of ore-deposits. The general non-persistence of ore in depth is a fact capable of proof, the comparatively late origin of most ore-deposits is a hypothesis which is founded upon observation and confirmed by the consideration that the older geological formations were at some time overlaid by an enormous thickness of later sediments and therefore existed under conditions favoring solution, and not that precipitation to which ore-deposition is more directly due.

One more point I would wish to refer to. Prof. Posepny demonstrates that at Przibram the metal of the ore-deposits could not have come from the eruptive rock in the immediate vicinity of the lodes. This is most interesting. For many years we have been accustomed to references to dikes and other bodies of eruptive rocks as being the source of the precious metals of certain lode-formations. In fact, a "dike" was almost as necessary as a "true fissure-vein," a good climate, plenty of timber, fine scenery and other factors, which, in a prospectus, are requisite to the making of a good mine. In my Bendigo paper† I have already suggested that the vicinity of eruptive rocks need not necessarily indicate that they were the source of the metals but that their extrusion afforded the heat which made the underground waters active. I would add that the contraction, due to cooling, following the extrusion of a sheet or a mass of igneous rock

* Reference is intended particularly to the metals. † *Trans.*, xxii., 289.

may have afforded a line of least resistance or—as Prof. Posepny would put it—"a line of maximum circulation."

In closing I would express the indebtedness which we must all feel to Prof. Posepny for so extensive and so valuable a contribution. In my own case I would express it as the gratitude of an apprentice to a master.

HORACE V. WINCHELL, Minneapolis, Minn. (communication to the Secretary): It is an interesting fact that the opinions here so ably advanced by Prof. Posepny were partially stated as long ago as the end of the seventeenth century. A few quotations from "An Essay towards a Natural History of the Earth," by John Woodward, will make this plain. I quote from the third edition, published in 1723, the date of the first edition being 1695.

"That there is a perpetual and incessant circulation of water in the atmosphere; it arising from the globe in the form of vapour, and falling down again in the form of rain, dew, hail and snow. That the quantity of water thus rising and falling is equal; as much returning back in rain, etc., to the whole terraqueous globe, as was exhaled from its vapours. That tho' the quantity of water thus rising and falling be certain and constant as to the whole, yet it varies in the several parts of the globe; by reason that the vapours float in the atmosphere, sailing in clouds from place to place, and are not restored down again in a perpendicular upon the same precise tract of land, or sea, or both together, from which originaly they arose, but any other indifferently" (pp. 132, 133).

As to the cause of the circulation of waters beneath the surface of the earth he speaks as follows:

"That there is a nearly uniform fire or heat disseminated throughout the body of the earth, and especially the interior parts of it; the bottoms of the deeper mines being very sultry and the stone and ores there very sensibly hot, even in winter, and the colder seasons. That 'tis this heat which evaporates and elevates the water of the Abyss, buoying it up indifferently on every side, and towards all parts of the surface of the globe; pervading not only the fissures and intervalls of the strata, but the very bodyes of the strata themselves, permeating the interstices of the sand, earth or other matter whereof they consist, yea even the most firm and dense marble and sandstone. . . . That this vapour proceeds up directly towards the surface of the globe on all sides, and as near as possible, in right lines, unless impeded and diverted by the interposition of strata of marble, the denser sort of stone, or other like matter, which is so close and compact that it can admit it only in smaller quantity, and this very slowly and leisurely.

"That where the vapour is thus intercepted in its passage, and cannot penetrate the stratum diametricaly, some of it glides along the lower surface of it, permeating the horizontal intervall which is betwixt the said dense stratum and that which lies underneath it. The rest passes the interstices of the mass of the subjacent strata, whether they be of laxer stone, or of marle, or the like, with a direction parallel to the site of those strata, 'till it arrives at their perpendicular intervalls" (pp. 136, 137).

Woodward entertained the idea that "the whole terrestrial globe was taken all to pieces and dissolved at the deluge,"

"That at length all this metallick and mineral matter, both that which continued asunder, and in single corpuscles, and that which was amassed and concreted into nodules, subsided down to the bottom; at the same time that did the shells, teeth, and other like bodyes: as also the sand, cole, marle, and other matter whereof the strata of sand-stone, cole, marle, and the rest are for the most part composed; and so were included in, and lodged amongst, that matter. . . . And the case of metalls and minerals being the same, 'tis for that reason that in some places we now get iron, or vitriol, but no copper or alum: in others we find these, but not those: and in others both these and those, and perhaps many more. . . . Thus we sometimes see whole strata compiled of metallick and mineral nodules: others of pebles, and of flints, without the interposition of other matter. . . . Thus likewise we find strata consisting almost entirely of common salt: others of ochre: and others of several metalls and minerals, tin, lead, vitriol, nitre, and sulphur promiscuously, without any considerable mixture of coarser terrestrial matter."

Of the origin of veins he speaks in these words:

"That the metallick and mineral matter, which is now found in the *perpendicular intervalls* of the strata, was all of it originaly, and at the time of the deluge, lodged in the bodyes of those strata; being interspersed or scatter'd in single corpuscles, amongst the sand, or other matter whereof the said strata mainly consist. That it was *educed thence* and *transmitted into these intervalls*, since that time; the intervalls themselves not existing till after the strata were formed, and the metallick and mineral matter was actualy lodged in them; they being only breaches of the strata, and not made till the very conclusion of the catastrophe, the water thereupon immediately withdrawing again from off the earth.

"That the water, which ascends up out of the Abyss, on all sides of the globe, towards the surface of the earth, incessantly pervading the pores of the strata, I mean the interstices of the sand or other matter whereof they consist, detaches and bears along with it all such metallick, mineral, and other corpuscles which lye loose in its way, and are withal so small as to be able to pass those interstices; forcing them along with it into the perpendicular intervalls; to which it naturally directs its course, as finding there a ready exit and discharge, being partly exhaled thence up into the atmosphere, and partly flowing forth upon the surface of the earth, and forming springs and rivers.

"That the water which falls upon the surface of the earth in rain, bears also some, tho' a lesser, share in this action; this, soaking into the strata which lye near the surface, straining through the pores of them, and advancing on towards their perpendicular intervalls, bears thither along with it all such moveable matter as occurs in those pores in much the same manner as does the water which arises out of the Abyss with only this difference, that this passes and pervades none but the superficial and uppermost strata, whereas the other permeates also those which lye lower and deeper. (*The vadose and deep underground circulations of Posepny.*) . . .

"That therefore the metalls and minerals which are lodged in the perpendicular intervalls of the strata do still grow [to speak in the mineralogists' phrase], or receive additional increase from the corpuscles which are yet daily borne along with the water into them. Nay they have grown in like manner ever since the time of the Deluge, in all such places where those intervalls are not already so filled that they cannot receive any more: or where the stock of metallick and mineral corpuscles, originally lodged in the strata, is not quite exhausted, and all borne thither already. . . .

"That the metallick and mineral matter which lyes in the bodyes of the strata does not grow, . . . but on the contrary, hath been diminished and lessened by so much as hath been conveyed into their perpendicular intervalls, and as hath been brought forth upon the surface of the earth by springs, rivers, and exhalations from the Abyss, since that time. That notwithstanding there have and do still happen, transitions and removes of it, in the solid strata, from one part of the same stratum to another part of it, occasion'd by the motion of the vapour towards the perpendicular intervalls of these: and in the laxer strata, such as sand, clay, and the like, *from the lower ones to those which lye above them*, and even to the very surface of the earth" (pp. 208–216).

Although the paragraphs quoted lead us to infer that Woodward thought veins were filled by the mechanical transportation of matter in small grains, yet there are in other places indications that he also had an idea of their formation by the deposition of minerals from solution. Thus, nearly a century before Werner and Hutton, were expressed ideas which were the results of long and careful observation and study which, though tinged with the theological and so-called philosophical doctrines of the day, were yet true to nature and of universal application, and which strike us as extremely valuable and original when put in modern logic and phraseology.

John A. Church, New York City (communication to the Secretary): I cannot agree with all the *dicta* of Prof. Posepny's valuable paper. He says (page 13, and see page 68) that in fissures "only the places remaining open would permit an active circulation of solutions and a regular deposition from them." The idea of deposition in a free space runs through the whole of the paper and is applied not only to the ore-deposits of the vadose circulation but with equal uniformity to those of the deep circulation. Such ideas seem to me to be incompatible with the crushing pressure which all agree must be found at depths of 10,000 and 15,000 feet. We have in metasomatic replacement an explanation of ore-formation which accords so well with the conditions supposable at great depth that it seems unnecessary to add to it a requirement that is certainly contradicted by those conditions.

I believe I was the first in this country to ascribe the formation of an important vein (the Comstock) to metasomatic alteration, which I then called "substitution," the term metasomasis being suggested in the same year. The character of the Comstock ore forbids the supposition of deposition in an open space; for it is not quartz but a mixture of quartz and fragments of the wall-rock. In the opinion of experienced men more than half of the rich ore mined from the heart of the great ore-bodies was "porphyry," and at least the proportion was great. My conclusion was disputed by Mr. Becker; but one of the surest advances which vein-geology has made in the last fifteen years has been the steady growth of the idea that the thickest ore-bodies may have been formed by the replacement of masses of wall-rock fragments, or by the spread of siliceous replacement from a narrow crevice through the walls.

In deep-seated formations this method of deposition is necessarily supposed; for there are not only no open spaces there, but the situation is not even what I conceived it to have been in the Comstock. Nearer the surface there might be partings which, though minute, would be real openings, while at great depth such partings must be so closely appressed as to be no more than mere breaks of continuity.

The tendency of opinion in this country is toward metasomasis acting upon masses of crushed rock in crevices which they completely fill; and I find nothing in Prof. Posepny's paper which need cause a retreat from this view.

Prof. Posepny appears to place great reliance upon the appearance of the ore and the walls enclosing it and I suppose it is because deep seated deposits in limestone have some strong resemblances to those of the upper circulation, that he concludes that the former must be laid down in "spaces of dissolution," like some of the latter. To me these facts point rather to an identity of active agent than to identical circumstances of its action. To make my meaning clearer I will recall some well-known facts and theories.

We know that the limestone rocks, in proportion to their amount, carry more ore-bodies than the siliceous rocks, though the latter have actually the greater number. The suitability of limestone for the deposit of ores is usually made to depend upon its solubility in water charged with carbonic acid, which is supposed to be derived from the soil by descending waters. It is carried into the interior of the earth and again discharged, for the earth being a closed vessel already full of water into which a new supply is constantly poured, it is clear that as much must be discharged into the atmosphere by springs as the atmosphere supplies by rain. I find fault with the usual view upon this subject, which apparently assumes that the deep waters must be highly charged with CO_2 derived from the surface. On the contrary it seems to me that the discharging water must bring out as much CO_2 as it takes in, for neither water nor gas can be lessened in quantity except by the comparatively small amount that enters into fixed combinations in the rocks. Since the solubility of gas in water is increased by pressure we must suppose that the dissolved CO_2 remains with the water that absorbed it throughout the whole range of circulation and that there cannot be any discharge of surface CO_2 in the interior. Yet we know that large quantities of CO_2 are discharged from the earth as gas not dissolved in water, besides that which is dissolved; and this gaseous discharge must be in excess of the CO_2 carried in. May we not find the source of this excess in deep-seated metasomatic replacement?

The operation of solutions whose composition we do not know can be judged only by their effects. When metasomatic replacement takes place in limestone it is generally assumed that lime carbonate goes into solution, while its place is taken by the ore-substances, that is to say, that the action is molecular substitution and not atomic; but it is conceivable that the change should begin by an interchange of acidic elements—that SiO_2 should drive out CO_2. Subsequent changes might remove the lime silicate by another process of substitution, since it is more soluble than silica; but the point is that CO_2 would be liberated, and though the original ore-solution were free from CO_2, it would immediately become charged with that agent and exert the well-known dissolving power of carbonic acid solutions. In this way a solution which would have but feeble power in other rocks may in limestone set up a chain of reactions that would intensify its effects. These considerations lead to interesting conclusions.

We have a source of CO_2 in rocks, however deep-seated, and consequently effects may be produced at any depth, which simulate those of surface-waters, though probably without the production of caverns. Since the mode of solution is the same, the appearance of the walls lining an ore-body and the appearance of the ore itself may be almost precisely the same as in the vadose region.

Limestone contains the elements for self-destruction, since the breaking up of one lime-carbonate molecule may cause the solution of another; and, as this cannot be said of any other rock, we reach a possible explanation of the comparative frequency of ore-bodies in limestone. The dolomites would, of course, present similar reactions.

There are two questions which are distinguished, even in the difficult study of veins, by the obscurity which hangs over them. One is the selection of a favored stratum for ore-deposition. In some situations the solutions, before reaching the stratum of actual ore-deposition, must have passed several strata suitable for their action, if they had possessed from the beginning the power of solution which they showed ultimately. I believe this objection has been urged against the lateral-secretion theory as applied to Leadville. Ore-solutions exhibit a selective power which is extraordinary in a water fully supplied with dissolving qualities, but quite explicable in a solution which lacks this power. I suppose it is impossible at present to determine why the rocks now exposed at Leadville were selected for attack by the solutions; but I think it is comprehensible why that action, however extensive, should be localized by the development and action of CO_2 in the neighborhood where it began.

An obvious consequence of these considerations is that the aqueous circulation of the earth becomes, through the medium of metasomasis, a means for restoring to the atmosphere accumulations of carbon that represent the organic life of past times.

The second obscure question is logically one which ought to be answered before we discuss the origin of ores at all. It is the secondary alteration of already-formed ore-deposits. I have no doubt that some of the deep-seated deposits which we see are actually a product of the vadose circulation. Formed ten thousand feet below, they have been raised until they are now ten thousand feet above the sea-level, and, during the immense period through which they have been subjected to the surface circulation, they have not only been re-arranged but may have actually lost their ancient origin. Even the rock in which they were deposited may have been removed and the ore transferred to another member of the series. Structural facts may prove deep-seated deposition, but actually the ore-bodies we see are often in whole or in part hysteromorphs. This is especially true in limestone deposits. Though these facts are well-known, they do not exert the controlling influence upon opinion which I think they deserve, probably because of the extreme difficulty of separating the primary from the secondary phenomena. No writer that I have seen has given to this subject half the importance which a mining engineer must give it.

I cannot agree with the author in giving so much importance to crustification, as he describes it. Certainly a banded structure can arise from the replacement of fragments arranged in layers by pressure and friction, as well as in many other ways, and does not prove deposition in a cavity, whether filled by water or air. He has misunderstood me in saying that I found crusts of quartz alternating with calcite in the Justice mine (Comstock). I said the thick masses of calcite in that mine rested on a thin layer—an inch or two—of quartz; but this is not crustification in the author's sense. My view of that occurrence was that an insignificant quartz seam, probably belonging to the last period of the Comstock, was first produced, and that the calcite was formed by replacement of the wall-rock at a later period. There is not the least evidence of deposition in a cavity. If there is crustification, that appearance does not have the significance which our author gives to it.

I have not attempted to particularize the many points in which I find myself in agreement with the author; and since my remarks have been rather in criticism, I desire to express in conclusion my high appreciation of his admirable treatise.

S. F. Emmons, Washington, D. C. (communication to the Secretary): Prof. Posepny's paper, or treatise, as it rather deserves to be called, is a most important contribution to the theory of ore-deposits. His wide personal observation of most of the important mines in so many different parts of the world and his critical acumen as an observer, combined with his long continued studies of the subject, give to his words an exceptional authority. Whatever might be said, therefore, in praise of his article (and it would take much time to say it all) would hardly add to its value. But the very high quality of his work renders any errors in it exceptionally hurtful, and I shall therefore confine my remarks mainly to what seem to me to be erroneous teachings, and to points in which I differ with him either wholly or in part. I would first say, however, that to the greater part of the views put forth in this paper I most heartily subscribe, especially to those on underground circulation, and on the great rarity of ore-deposits which have been formed contemporaneously with the enclosing rocks.

It is well known that for some years past there has been a very warm discussion between Posepny and Stelzner on the one side, and Sandberger on the other, in regard to the derivation of the material of ore-deposits, the former holding to the ascension, the latter to the lateral-secretion theory. Without attempting to determine the merits of either side of the controversy, which it would be unwise to do without examining personally the deposits in question and their geological surrounding, one is inclined to believe that the views of either of such able geologists must have scientific value, whether one or the other may be proved to be erroneous in a particular instance.

I regret, however, to see this controversy brought into what should be a broad and impartial discussion of the facts of nature, and to detect in certain cases what appears to be a tendency on the part of Prof. Posepny to adopt a rather forced construction of these facts, in order to make them support his views rather than those of Sandberger.

The lateral-secretion theory, which Posepny ascribes to Sandberger, is much narrower than that which I, and I think most American geologists, hold. It confines the derivation of the vein-contents to the wall-rock in immediate contact with the deposit; whereas, in my view, a derivation from rocks within reasonable proximity, as opposed to a source at unknown depths ("in the barysphere"), would constitute lateral-secretion, and ore-bearing currents may in such cases have had an upward, downward, or lateral motion according to differing local conditions of rock-structure. Prof. Posepny himself admits, in his admirable discussion of vadose or shallow and deep underground circulation, the possibilities of such lateral-secretion when he describes the latter (p. 26) in the following words:

"The ground-water descends in the deep regions also through the capillaries of the rocks; at a certain depth it probably moves laterally towards open conduits, and reaching these, it ascends through them to the surface."

The distinction between the action of surface and that of deep-seated waters is an important one in the study of ore-deposition; but I do not think that Prof. Posepny is justified in assuming, as he does, that only ascending waters are capable of depositing ores. Futhermore, the necessary derivation of metallic minerals by these ascending waters from the "barysphere" seems too far-fetched. At what depth the barysphere will be found, meaning thereby the part of the earth's interior where the rocks have a much higher specific gravity than those that come under our observation, is purely a speculative question; but as our surface observations extend over a thickness in round numbers of about 100,000 feet of rocks, and show no appreciable difference of specific gravity between the deeper and more shallow rocks, except such as is due rather to different degrees of density than to heavier mineral constituents, it seems safe to assume that such a barysphere must exist, if at all, at such great depths as to be beyond the reach of any mineral-bearing waters. If such a zone rich in heavy metals exists in depth, as there is some reason to believe, my own view, as expressed in my paper read at this meeting, is that the heavy metals which constitute the ore-deposits were brought up from it into the outer crust of the earth by the various eruptive rocks, and were partially concentrated in certain parts of these eruptive rocks, by differentiation during the process of cooling. In this view I agree with Vogt, whom Prof. Posepny mentions (p. 134) in a somewhat slighting manner. I differ with Vogt, however, in that I consider the greater part of our ore-deposits, all certainly that have come under my limited observation, to be due to further concentration, perhaps many times repeated, both chemical and mechanical; and I am entirely at one with Prof. Posepny in considering their final concentration into their present form to be due to the action of circulating waters.

Prof. Posepny's belief in the capabilities of an ascending current of heated waters or thermal springs seems to me, in some instances, as exaggerated and unreasonable as his rendering makes Sandberger's disbelief, in the instances he cites. He quotes a single observation by Nöggerath in 1845 on the finding of vertical channels in limestone 8 to 35 inches in diameter, near Aachen, which are supposed to have been eaten out by the ascending spring-waters, and from this draws the wide-reaching conclusion that ascending waters may actually force their way up through rock masses without the necessity of pre-existing cracks or channels. Among instances where he uses this explanation to account for the formation of an ore-deposit the most remarkable is that of Laurium (p. 124) where the ore-deposits as shown by the diagrammatic section (Fig. 87) are funnel-shaped bodies extending outward from the contact of flat-lying schists into subjacent and superjacent limestones, that is both upwards and downwards. My own explanation of this section, deduced by observations in limestone-deposits in this country, would be that the ore-bearing currents circulating along the contact-planes had eaten outward into the more soluble rock, upwards from the upper contact, and downwards from the lower contact. But Prof. Posepny explains the funnel-shape of the ore-bodies on the upper contact as produced "by the pressure of the ascending solutions." The lower contact he offers no explanation for, but says "it is perhaps somewhat ideally sketched."

It is unprofitable, however, to discuss deposits which neither of us have seen; for nothing is so liable to misconception as the description of ore-deposits one has not seen by a person with whose qualifications and accuracy of observations one is not familiar. This is shown in Prof. Posepny's remarks upon the Leadville deposits, in which he concludes that I must acknowledge that my views in regard to the downward course of the ore-bearing solutions were incorrect, because several mining engineers have shown them to be untenable. It does not seem to occur to him that the views of a mining engineer (who is not necessarily a geologist) based upon studies of a single mine or set of mines would be of less value as applied to such theoretical questions than those of a trained geologist who had made a study of all the geological conditions and mines of a district. Of the three articles quoted by him, that of Mr. Freeland offers no opinion upon the subject in question. Both this and Mr. Rolker's article were written before my monograph was published, otherwise Mr. Rolker would have found his objections on these points foreseen and accounted for there (p. 490).

In the summer of 1890, I spent nearly two months at Leadville studying the recent developments with the special purpose of testing the correctness of my former deductions, and Mr. Blow accompanied me through the workings of North Iron Hill with which he is so familiar. While I naturally found many details of geological structure which were not, and could not have been, correctly represented on the underground sections accompanying my report, I found no reason to change my views of the manner of formation of the ore-deposits, and I convinced myself (and I think Mr. Blow also) that his objections were based on a misapprehension of certain geological phenomena. It were too long to give here all the results of my observations, which I regret that circumstances beyond my control have as yet prevented me from publishing. I will say, however, as bearing upon this point, that in no case did I find any convincing evidence of the action of ascending solutions. The ore-bodies occur in two general forms, either on the approximately horizontal contact-planes of porphyry and limestone, or along nearly vertical fissures crossing the limestone beds. In either case, wherever the form of the ore-body was such as to throw any light upon the probable direction of the ore-forming currents, it showed that they must have descended, for they all terminated more or less in a point or wedged out downwards.

Before discussing this further, it may be well to repeat my statement given in the monograph (p. 379) which has evidently been overlooked or misapprehended by my critics. I say, with regard to the *immediate* source of the ores:

"1. That they came from above. 2. That they were derived mainly from the neighboring eruptive rocks.

"By these statements it is not intended to deny the possibility that the materials may originally have come from great depths, nor to maintain that they were necessarily derived entirely from eruptive rocks at present immediately in contact with the deposits."

I do not maintain, as many have assumed, that the ore was derived from the white porphyry. I do not pretend to be able to determine what particular body of porphyry it came from. The objection of Mr. Blow that it could not have come from the white porphyry because this is not all decomposed (*not*, "not at all decomposed," as Prof. Posepny puts it), is based upon a misapprehension of what constitutes decomposition. If Prof. Posepny will read the description of the eruptive rocks in my chapter on rock-formations, he will see that all the Leadville porphyries are more or less decomposed within this district; when Mr. Cross and I were making our geological studies we had to go several miles away before we could find a specimen of unaltered white porphyry for microscopical study.

My contention with regard to the ores of this district, as opposed to the theoretical views of Prof. Posepny and those of his school, would not have been essentially affected, however, if it had been shown that the solutions had ascended to reach the *locus* of the present deposits. The fissures across the limestone which gave access to the solutions forming the ore-shoots of North Iron Hill described by Mr. Blow are, as I showed in my monograph, faults with only a few feet of displacement, and can extend to only limited depth; in some cases their lower limit could be detected. The great faults which extend several thousand feet in depth are not ore-bearing, except in so far as ore has been dragged into them in the movement of their walls, one upon the other. But the extent in depth, even of these great faults, must be extremely limited as compared with the distance of the barysphere. I believe that the eruptive rocks originally brought up the heavy metals from the depths into the general region in which the ores are now found. Some of these eruptives still contain over four per cent. of them, in spite of all the leaching to which they have been exposed. The ore-deposits are concentrations of these materials by deep underground waters, flowing along natural channels, and depositing along those which admitted a comparatively free flow, as compared with a capillary circulation. Such a flow may have been upward, downward or lateral, according to varying structural conditions. The ascending solutions which Prof. Posepny contemplates, however, could not have formed ore-bodies of the form of those found in Leadville; and it was for that reason that I laid stress upon the evidence of their probable downward course.

As regards the phenomena of "crustification," I may not have been explicit enough in stating its absence. In my original examination I searched in vain for any evidence of it. In my second examination, almost entirely in bodies of unaltered sulphides, I found overwhelming evidence that the ore was not deposited in preexisting cavities, but by metasomatic replacement of the limestone. In the great bodies of the A. Y., Minnie and adjoining mines not only could every detail of the granular structure, joints and cleavage of the original limestone be detected at times in the sulphide ore, but even the cracks in the top of the ore-body through which the ore-bearing solutions had descended were often visible. In abandoned drifts, where the limestone dust had accumulated on the walls, one would have supposed the walls to be all limestone until the breaking off of a fresh fragment by the hammer showed the metallic gleam beneath.

G. F. Becker, Washington, D. C. (communication to the President from Newport, R. I.): The paper of Prof. Posepny is a very valuable contribution to the science of ore-deposits, and deserves a more careful critical discussion than I am able to assist in giving to it at this time, in the absence of facilities for reference to authorities, etc. A few general observations, therefore, must suffice at present to indicate my views.

The theory of the substitution of ore for rock is to be accepted only when there is definite evidence of pseudomorphic, molecular replacement. Prof. Posepny is very clear on this point (p. 12), and I have insisted upon it in my memoir on quicksilver-deposits and in a paper on quicksilver about to be distributed. Prof. Posepny appears to me, on the other hand, to lay too much weight upon the structure which he calls "crustification," as indicating exclusively the filling of open cavities and the absence of replacement. Metamorphic processes are very frequently accompanied by the formation of layers similar to stratification and crustification, and, indeed, from similar causes. Strata are distinguishable only because the circumstances of deposition undergo more or less marked variations, and the banded structure of agate or hematite is also due to variations in conditions of deposition such as the strength of the solutions, or the rapidity of their flow, or temporary changes in the composition of the fluid. It appears to me that the banded structure attending metamorphism, as a matter of observation in many cases, is due to entirely similar causes. Thus a mass of iron immersed in a copper-solution will precipitate the copper as a laminated mass, unless great precautions are taken to secure uniformity of temperature, etc. In short, lamination is an ordinary attendant of processes of deposition, whether by replacement or otherwise, whenever they are so slow as to be subject to changes of condition. Hence crustification seems to me an insufficient guide to genetic diagnosis.

The indications of replacement which I should rely upon are twofold: crystalline pseudomorphosis and the irregular enlargement of fissures in the replaced mass. Of the latter, Prof. Posepny gives a good illustration (Fig. 85). As for pseudomorphosis, it has a very important bearing on the work of Mr. Emmons and of J. S. Curtis, for it appears to be thoroughly well established that galena forms pseudomorphs after calcite; and, therefore, the theory of replacement of limestone which they advocate is to say the least possible. The studies of these observers at Leadville and Eureka tend to show that replacement has been the chief process; but so far as I can recall their remarks they do not assert the entire absence of deposition in pre-existing openings; so that even if crustification were an infallible sign of filling, the detection of crusts (Posepny, p. 104) would not invalidate their position. Another objection to Mr. Emmons's views is expressed by Prof. Posepny in the sentence (p. 99), "It is difficult to believe that metasomatic processes could produce such pronounced ore-shoots as those described at Leadville." I cannot share this view, for replacement, like solution, must occur along fissures or channels, and metasomatic ore-bodies will present analogies in form to the open spaces of caves of solution.

It seems substantially certain that open cavities in limestones can form only above the permanent water-level of a country, since in such a country the water below this level must be approximately saturated with calcium carbonate. On the other hand, replacement may take place at any depth. Now, in the Great Basin, the Tertiary and Early Quaternary were very wet periods, and if the Eureka limestones have been excavated by surface waters, the excavation and subsequent ore-deposition, according to Prof. Posepny's view, must be crowded into the late Quaternary. The present precipitation of that region would seem insufficient to bring about much cave-formation, while a greater precipitation would raise the water-level. Thus, so far as Eureka goes, the hypothesis of subsequent filling raises distinct, though perhaps not insuperable, difficulties as to the formation of the cavities.

The foregoing notes should be reinforced by examples and citations which I cannot now furnish.

F. M. F. Cazin, Hoboken, N. J.: If I venture to add a few lines to Prof. F. Posepny's treatise on the genesis of ore-deposits, my justification is derived from practical work done and consequent opportunities enjoyed in a region, to which the learned author personally has remained a stranger, and of which in existing literature no such account is available, as would afford to him the powerful argument in favor of his theories really presented by the region itself, to a degree of importance beyond any other mentioned by him.

The region to which I refer furnishes a demonstration of the xenogenous origin of ore-deposits, heretofore considered as idiogenous, which I may properly call gigantic, and which is equalled nowhere on the face of the earth, as far as known. I refer to the region so tersely described by James Douglas (*Trans.*, xix., 694), in these words:

"In the Appalachian chain from Vermont to Georgia, there are imbedded in the crystalline schists large masses of pyrites, some consisting of ordinary bisulphide of iron but most of them of pyrrhotite, and all carrying more or less copper."

There is, on the long stretch from Vermont (Mr. Douglas might have truly said "from Canada and Maine") to Georgia, no older mine, and none with more important development on the ore-deposits thus described, than that which has been called by State-legislative act "the Vermont Copper Mine." Its history began before the world knew about copper on the shore of Lake Superior. For many years it produced at the rate of 3,500,000 pounds of copper per annum, and, with adequate improvements, could do so to-day. I have seen its developments on a deposit dipping 24° N.E. to a distance of 2350 feet from the surface, and to a vertical depth below sea-level of several hundred feet, the lateral expansion of stopes ranging between 50 and 350 feet. Having been connected with this mine from early in 1882 to June of 1888, I have had opportunity to search for the origin of the ore-body there exploited.

Having discovered unmistakable local evidence as to the true nature of such origin, it remained to ascertain the identity or uniformity of effect from identical causes on other deposits falling under the description above quoted; and it was not difficult to establish such identity and harmony.

At a distance of ten miles in a northerly direction another mine in the same geological position, at Corinth, offered evidence leading to the same conclusions, and in a southern direction at a distance of four miles, the Strafford mines, and at a further distance of sixteen miles the Pompanoosuc mine, all similarly situated, demonstrated the same effects under similar causes. And a visit to many other localities within the Huronian Appalachian region could confirm only the conclusions, to which the observations in the Vermont mine had been leading me.

Except as to dip, topography and shape of workings, Fig. 56 in Prof. Posepny's paper might well serve as the image of the Vermont ore-deposit, represented on a vertical plane along its dip. And Figs. 54 and 55 may well serve as a representation of horizontal and vertical planes, as they are seen inside and outside of the Vermont, Corinth and Strafford mines, where the designs shown in these figures not only occur in dimensions varying from a few fathoms to many hundreds of fathoms, but also in varying material. In the mine, this consists of the sulphides of iron and copper, and outside and at distant points therefrom, in an admixture of carbon-matter (graphite) in the country-rock. This rock is a micaceous schist, the graphitic part varying in proportion from a mere trace to 100 per cent., becoming marketable plumbago in many localities, though without sufficient extent, as a rule, for exploitation.

But it is not on the similarity of design between sulphide and carbon admixtures in the rock alone, that my conclusions were built, as a description of the mine will further show.

In their lateral expansion the ore-stopes in the Vermont mine present a figure very similar to the one presented in Prof. Posepny's Fig. 93, if the longitudinal extent be assumed as 2350 feet, with the lower part broadened. But similar figurations are also presented on a smaller scale, where in quarries the rock is laid bare on one of its dark seams.

The roof and floor of the Vermont ore-deposits are virtually impenetrable to water ; the mine at 1000 feet vertical depth being dry. But there is uncovered at a distance of a few hundred feet from the outcrop an almost vertical cross-fissure or fault (without perceptible faulting), filled with calcareous spar containing sparsely distributed small seams of galena, which cross-fissure allows a few hundred gallons of water a day to percolate into the workings. Some of this water finds its exit through an abandoned adit. Where it reaches the surface, and where its flow is slow, allowing evaporation, it deposits a slime of virgin-white carbonate of lime; and as it passes down into the valley, it deposits for miles a mixture of carbonates of lime and iron, giving to the creek-beds their peculiar coating of color, as a result of atmospheric reduction of the iron carbonate.

The ore of the Vermont in its mineral character has one main peculiarity, which is common to the deposits as described from Canada to Virginia and Georgia, namely, that quantitative analysis shows neither the figures required to constitute the one of its components as ferro-sulphide, nor those required to show it as ferri-sulphide, these figures varying all the way between those applying to FeS and those applying to FeS_2.

The structure of the ore is the same as that of the graphitic rock, with the same variations in the ore as to contents in sulphides, as there are in the country-rock as to contents in carbon-matter. That in no case I have met with a nucleus of carbon in a body of sulphides, I have attributed to a full completion of the metamorphosis.

Yet another feature is common to the ores of the described deposits. For a long distance on the northern part of these continental deposits, wherever they occur in the Huronian schists, their ores carry nickel in proportions varying from a mere trace in the copper-metal made therefrom to an available percentage in the ore itself.

Although much disinclined to draw generalizing conclusions from isolated geognostic phenomena, I claim justification in the case at hand for the following conclusions, because the evidence is such as repeats itself on a large area, and once understood presses itself upon our attention, so as to be no longer ignored:

1. The iron and copper sulphides occurring in the Huronian crystalline schists on the eastern part of the North American continent have locally displaced carbonaceous matter, where faulting of strata aided water-circulation, such water containing sulphate salts of the metals in solution.

2. The metamorphic action of absorbing mineral carbon and of setting free CO_2 is continuous to the present day.

3. The product of such action extending below sea-level being observable in lines nearly parallel with the coast-line of an entire continent, and showing equal peculiarities in composition on the entire line, it is reasonable to assume oceanic action.

It is true that the ocean of our period evinces the presence of copper only by its presence in maritime organisms. But when, on the shores of a once existing Triassic sea we find embedded in massive but porous sand-rock an entire palm-vegetation, that has turned into copper-glance, as my eyes have seen it (compare p. 120 of

Prof. Posepny's paper), then we may well assume the presence of a perceptible quantity of copper in a Triassic sea, though not necessarily sufficient to destroy animal life. It is even a matter of time only for an ocean like the one of our own period to provide Pecillopora and Heteropora corals with their copper, or to be the means of metamorphosis of carbon-deposits into copper-sulphides in part; the percentage of copper in these deposits being in general not above three per cent, of the deposits as a whole.

I find a further justification for stating these facts and the conclusions to which they lead in the circumstance, that the learned author, although mentioning the occurrence of graphite in crystalline schists, does not mention that this graphite anywhere accounts for the origin of ore-beds.

The description of the Sudbury ore-beds deals with a case far more complicated than those considered by me, because there Huronian strata similar to those met at the different mines in the Appalachians, have been disturbed by more recent dioritic eruptions, which subjected the pre-existing ore-beds to a new partial or second metamorphosis, by which the true state of affairs is very materially obscured, misleading the describers into the untenable assumptions, so justly controverted by the learned author. Had he been informed of the facts, as I have described them above, the author of this eminently interesting and progressive essay on the genesis of ore-deposits would have been able to knock the last crutch from under the theory of an eruptive origin of the ore-deposits at Sudbury and elsewhere in the crystalline rocks of the Huronian period.

I take this opportunity to furnish, on another point, information for which Prof. Posepny apparently calls (p. 121).

A few months only after my report on the Nacimiento copper-occurrence was published, with the consent of those interested, in the *Engineering and Mining Journal*, Aug. 7 and 14, 1880, the United States surveyors, who were commissioned by the Surveyor-General of New Mexico to survey the twenty-one mining claims described by me, were driven off these claims by a numerous band of jumpers, who had swarmed into those parts as the usual *avant-garde*, indicating, as stormbirds the storm, the approach of a new railroad line in those remote parts. To reinstate the legitimate owners either brutal force or litigation had to be employed. The ill-success of other copper-enterprises in New Mexico, though quite foreign to all natural conditions, caused them to resort to neither. When, in 1891, I again visited the upper Rio Grande valley, I found on the platform of the railroad-station at Bernalillo, N. M., about a car-load of the precise cuprified palm-vegetation formerly described by me, showing that there had survived some activity at Nacimiento; but, as stated in my first report, profitable operations are possible only on a scale like that on which lead is obtained from a similar sand-rock at Mechernich in Rhenish Prussia.

DISCUSSION

At the Virginia Beach Meeting, February, 1894, Including Communications Subsequently Received.

T. A. Rickard, Denver, Colorado (communication to the Secretary): The paper of Professor Posepny was printed so short a time before the Chicago meeting that it could not receive at that meeting the thorough discussion, based upon careful study, which its great importance and value deserved. In the remarks which I made on that occasion, I could do little more than express, with others, our thanks to the distinguished author for this admirable treatise on a subject of such general and permanent interest. Further examination of it has confirmed the opinion that its appearance marks an epoch, particularly in this country, in the study of ore-deposits, and their origin, and has led me to feel that our appreciation of it will be best expressed in aiding its purpose and widening its usefulness by the free contribution of facts and interchange of views which it invites.

I have, elsewhere,* expressed some dissatisfaction with the new names introduced in this paper; and it has seemed to me, also, that the classification of ore-deposits, which it proposes, is unnecessarily complicated. From the stand-point of a mining engineer, we have had, in my judgment, no classification more practical and sensible than that suggested by Dr. Raymond, twenty-five years ago (outlined on page 6 of Professor Posepny's paper). If any modification of it be permissible, I would suggest the following:

I. Surface-Deposits.
 A. Due to mechanical agencies.
 B. Due to chemical agencies.

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* *Eng. and Min. Jour.*

II. Inclosed Deposits.
- A. Bedded.
  - *a.* Contemporaneous, in origin, with country-rock.
  - *b.* Subsequent, in origin, to country-rock.
- B. Not bedded.
  - *a.* Due to dislocation.
  - *b.* Due to impregnation.

Surface-deposits have no regular form, and are, therefore, distinguished primarily by their origin. Class A would be typified by gold-bearing placers, and Class B by deposits of bog iron-ores.

When we come to inclosed deposits, we find an extreme complexity; but, we readily recognize that some are conformable to the bedding of the country-rock, while others are independent of it. We can further distinguish those which are of contemporaneous origin, such as the coal-beds, from those which were formed after the deposition of the country-rock. To this class belong ore-deposits which have replaced beds of limestone; and another pretty example is afforded by the Bendigo saddle-reefs, which are conformable to the anticlinal curves of the country-rock, but were clearly formed after both the original sedimentation and the subsequent folding.

Among the non-bedded deposits there is no limit to diversity of structure and of origin. We recognize, however, that the fissure-veins which cut across the bedding, but retain a definite position due to their formation along lines of original dislocation, may be distinguished from the irregular impregnations, due as much to the chemical composition of the country-rock as to its structure. These two types, however, are forever intermingled. It is seldom, indeed, that an ore-deposit has not some features, however faint, of form and structure dependent upon those of the country-rock, while, on the other hand, it is not often that a fissure-vein is found which does not exhibit, in places, a lack of definition, due to metamorphic action upon its inclosing walls.

In the discussion of the origin of fissures, Prof. Posepny has touched upon a point which has been the subject of frequent debate. I fully believe that dislocation accompanies the formation of a fissure, and that a movement of its walls is often evidenced by slickensides and striæ. Yet, this has been questioned by one or two members of the Institute who are known to be both accurate and experienced observers. The question at issue is a vital one, if we desire to obtain a clear idea of the mode of formation of mineral veins. It has been denied that the striæ and slickensides observed upon the walls of lodes necessarily prove that movement has taken place; but it has never been clearly shown what other agency did form them. Prof. John A. Church has discussed this matter in a most interesting way,* and has pointed out that slickensides may be formed, not only by rubbing but also by "deformation, as when a plastic substance like clay is forced through an opening," and again by deposition in fine parallel lines. Recently, Prof. Daubrée has experimentally proved that gases under high pressure are capable of producing striæ upon rock-surfaces.† It is true that a distinction is made between striæ and slickensides, but I look upon the two as the work of the same agency. In the former case we have coarse rubbing due to large particles, and in the latter, fine polishing due to minute particles. There is no doubt, however, that certain structures are called striæ, which are to be ascribed to causes other than those usually supposed to produce striæ and slickensides. As I write I have before me a large piece of rock, the surface of which exhibits fine parallel lines, which, at the mine (the Hillside, in Yavapai county, Arizona), were called striæ. The rock was part of the casing of a cavity found in the hanging-wall of the lode, which traversed a quartzose talc-schist. Its surface has been covered‡ by a series of siliceous coatings, doubtless deposited by the mineral-bearing waters which circulated over it. The precipitation took place along certain parallel lines, probably marking the direction of flow of the circulating waters, and the resulting appearance is to be regarded as a pretty example of a variety of crustification, but, coming as it does from a lenticular hole, cannot have been due to rubbing caused by faulting.

In the accompanying drawing (Fig. 1), reproduced from a sketch made underground, the cavity above referred to is marked A. There are two others, B and F, of the same kind. D is a seam 6 inches thick, of white talcose gouge, lining the footwall, and separating it from C, which is the lode itself. The latter is 15 to 18 inches wide, and consists of quartz, iron pyrites, zincblende, and a little galena, very much intermingled, and carrying gold and silver in almost equal proportions. The lode itself reproduces to a noticeable extent

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* *Eng. and Min. Jour.*, April 30, June 11 and 18, 1892.

† *Bull. Soc. Géol. de France,* 3 serie, Feb., 1891, t. xix., p. 313. *Compt. rend Acad.*, t. cxi., séances du 24 Nov. et 4 Dec., 1890. *Compt. rend. Acad.*, t. cxii., séance du 19 Jan., 1891.

‡ As shown by viewing the broken edges of specimens.

the structure of the country-rock which it has replaced. The cavities in the hanging-wall are also surrounded by talc-schist, which is mineralized to such a degree as to constitute "low-grade ore." The vein cuts clear through the foliation, nearly horizontal, of the talc-schist and the alteration of the country-rock, while most marked in C, extends to a varying distance on either side.

Not infrequently the quartz of a lode has striated markings which

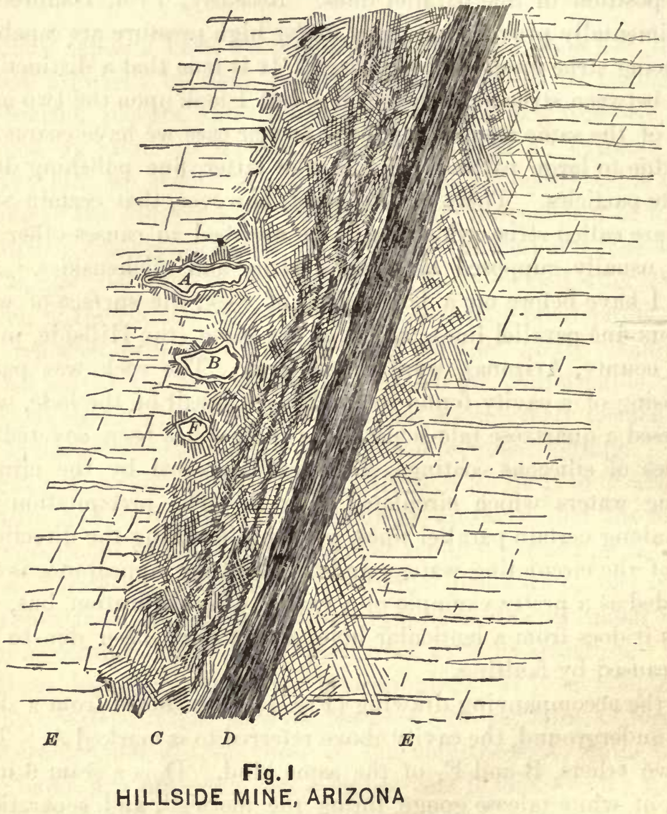

Fig. 1
HILLSIDE MINE, ARIZONA

are but the negative of those occurring on the wall-rock.* In such cases the quartz is sometimes entirely solid and unbroken, suggesting that it was deposited upon the previously striated surface, and that it has not only replaced the substance but also reproduced the structure of the rock once inclosed by the fissure-walls. On the other hand, one instance may be cited where it seems necessary to suppose that movement took place subsequently to the deposition of the

* Instances of such are to be seen in the gold-quartz veins of California.

quartz. At the 1800-foot level in the Great Extended Hustler's mine* at Bendigo, Australia, the quartz lying against the hanging-wall of the reef exhibited a surface as smooth as polished ivory, but distinctly grooved, and also marked with fine, dark lines, parallel to the grooves. The latter had, I believe, an origin similar to that of ordinary striæ, while the dark lines were due to the grinding of particles of pyrite observable in the quartz. Though this quartz seemed to the eye as hard as adamant, it would readily crumble away when pressed between the fingers. It had been crushed to the consistency of common table-salt, which, save for the presence of occasional crystals of pyrite, and for its highly polished surface, it much resembled.

Objection has been raised to accepting the occurrence of clay, striæ and slickensides as necessary evidence of faulting, because they are occasionally absent where movement may be supposed to have taken place. In such instances, it is reasonable to infer that they have been destroyed by agencies identical with those to which the lode-formation is due, namely, the replacement of country-rock, often in a crushed and shattered condition, by ore, through the metamorphic action of percolating solutions.

There is a fanciful notion current among miners that a smooth wall and a thick gouge are the necessary adjuncts of a productive "true fissure-vein." Experience does not confirm this belief. A defined wall and a soft seam of clay are naturally welcome to the miner, because they facilitate the actual breaking down of the vein-stuff; but they are no more characteristic of productive than of barren lodes.

The irregularity in the dip of some veins has been cited as disproving the possibility of their formation along lines of faulting. Occasionally mine-workings show that the dip of a vein is reversed; and the formation of the fracture which it occupies cannot be referred to a continuous line of movement, because that would have involved the shearing-off of the opposing angle. But it is not necessary to suppose, nor do facts suggest, that lodes are generally formed along continuous or single lines of movement. As Prof. Posepny has well shown, it is the study of the circulation of underground waters which affords the key to much that is perplexing in ore-deposition. In such cases as are here referred to, it is rational to suppose that the mineralizing solutions searched out the easiest way which offered itself. They did not necessarily percolate along a single definite straight line of fissuring, but often deviated from it,

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* See *Trans.*, vol. xx., 512 *et seq.*

whenever it afforded a less ready passage than was offered by other fractures which united with it or crossed it. An instance which occurs to me as I write, is furnished by the Seven-Thirty mine at Silver Plume, Colorado. The lode consists of a system of veins carrying rich silver-ore. The most productive of which is that which bears the name of the mine. It rarely has any considerable width ; it is often only a thread traversing the coarsely crystalline granitoid gneiss and porphyritic microcline granite of the region. At the third level, about 280 feet from the surface, there is a very marked irregularity in the course of the vein, presenting some interesting features, which the accompanying sketch (Fig. 2) will help to explain.

From the shaft eastward for several hundred feet (A to B) the vein carries ore; but its width is small and irregular. The lode widens rapidly at B, where it also meets with a sudden deviation in its course. At a first glance, this looks very much like a fault, but subsequent examination will correct such a view. The fissure continues in a straight line from K to L, after the ore has swerved to

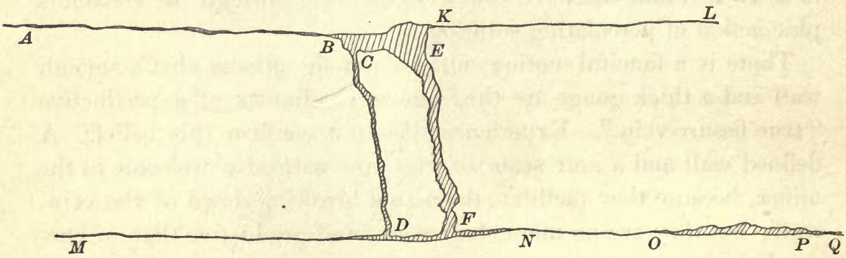

Fig. 2
SEVEN THIRTY MINE, COLORADO.

the south. Instead of maintaining its eastward course, the ore is disposed in two cross-veins, CD and EF, nearly at right angles with that course, which unite with a fissure, MQ, similar in character and parallel in strike to that from which they sprung, AL. Both AL and MQ are continuous so far as they have been followed in the mine-workings. The walls are well-marked, even after they cease to enclose ore. The cross-veins CD and EF lack well-defined boundaries. The western branch, CD, is a streak, about 3 inches wide, carrying ore of a tenor of 300 ounces of silver per ton, while the eastern branch, EF, is larger, about 1 foot wide, and carries ore of lower grade, about 100 ounces per ton. The latter is accompanied by much more galena than the former. The distance between the two is 10 feet; their length is 44 feet. The country separating them is not noticeably altered or mineralized.

This is not an instance of faulting; the ore is found in connection with a system of fractures AB, CD, EF and MQ, the varied structure and arrangement of which modified the circulation of mineralizing solutions, and so brought about the irregularity in the deposition of the various minerals comprising the ore. The mineralizing waters met with diverse conditions. From A to B the fissure was tight, and its boundaries were distinct, limiting the circulation to a narrow channel; hence a small streak of ore was found. At B the shattering of the country-rock accompanying the formation of the cross-fractures, CD and EF, offered facilities for the ready penetration of the solutions and for chemical interchanges. From C to D and from E to F the irregular fracture across the foliation of the country-rock produced irregular but rich streaks of ore. On meeting with the other main line of fissure the solutions again found well-defined boundaries which put a check to the metamorphic replacement of the country-rock, and it was not till the conditions changed (at O), that a notable width of ore was again deposited.

Many supposed faults found in mine-workings are really of this character. There has been a deviation in the course, and a marked diminution or increase in the amount of ore-deposition, because the mineralizing solutions have circulated along those fractures which presented the easiest passage and offered the conditions most favorable to chemical interchanges.

Returning to the subject of striae, slickensides and clay-seams, I must say, that while the questioning of accepted theories is wholesome, and the views quoted above deserve respectful consideration, it seems to me that observed facts warrant the general belief that these phenomena have usually been produced by the rubbing of two faces of rock which have undergone movement; and I do not sympathize with those who consider that the ordinary explanation is far-fetched. We know that the rock-formations of the upper earth have undergone movement, for this is proved by all geological investigation. Further, we have every reason to believe that movement among beds of rock of unequal flexibility must cause some to break. Facts confirm such a belief. Again, every break must be coincident with a movement; for a fracture can hardly be said to exist until made evident by movement however slight. At any rate a fracture unaccompanied by movement would not give the relief required by a series of beds exposed to such strain as necessitated a rupture. Such movement must be accompanied by friction, due to the tendency to smooth down the irregularities of the two opposing rock-faces.

Where movement has once occurred, a line of less resistance is established, and a repetition of movement is likely. The result is to break small particles from off projecting points and so form a dust which water makes into mud or clay, also to scratch the surfaces in contact, forming striæ, and to polish them, forming slickensides. Why therefore deny the probability, even the necessity, of the movement of the walls of a fissure, and why endeavor to give to the markings of rocks underground an origin other than the one which would certainly be ascribed to them if they were found on rocks* at the surface?

The pages which Prof. Posepny devotes to an inquiry into the conditions governing the flow of underground waters are among the most valuable of his treatise. His explanations will do much to clarify our conceptions of the mode of behavior of underground waters, and will doubtless suggest further inquiry in the same direction. The word "circulation" is the key to the whole matter. There has been a tendency to speak of descending, lateral and ascending currents, as though the one adjective would cover the manner of movement of all mineral solutions. An ascending flow was supposed to have formed this lode, descending that one, while others again, steering a middle course, have imagined that ore-formations derived their origin from solutions having a lateral flow. In each case a narrow view of the subject is both unphilosophic and unscientific; it has too often been the obstacle to progress in this branch of geology. One great fact confronts us, and that is circulation.

The distinguished author is himself carried away by his prejudices, and in the latter portions of his treatise† allows his ascensionist views to lead him too far and in part to forget the very forcible teaching given in the earlier pages. Much will be done to explain the many puzzling and apparently contradictory features exhibited by the ore-deposits of different regions if we remember that mineral solutions both descend and ascend, that occasionally they may have an approximately lateral flow, and that in each instance their circulation is governed by a diversity of ever-changing conditions.

Water must first descend in order to afterwards ascend. The known density of the earth precludes the supposition that its in-

* No one questions, for instance, that the scratching seen on boulders from a glacial moraine are the result of rubbing due to movement.

† As at the bottom of page 52.

terior contains any reservoirs of water; the sinking of deep wells and bore-holes has indicated that at a comparatively short distance from daylight the temperature is so high that water could not exist as such, but would be dissociated into its constituent gases; while actual mining exploration has shown that in the deepest mines there is less water encountered in depth than in proximity to the surface. These facts all confirm the every-day observation that underground waters originate from the rain and snow precipitated from the atmosphere.

We may compare the circulation of water up and down, through the earth's rocky exterior to that of the ordinary heater in a house. The water circulates because, when hot, it rises through the length of pipe, and, when cool, it falls back to be reheated. Using this analogy to explain Nature's operations, we have at one end the condensation and precipitation of moisture due to a fall of temperature, while at the other, and deep down in the earth's rocky confines, we have a heat which sends the water back to the surface. In this matter of ore-deposition we are not concerned with the two ends of the circuit. We have no particular interest for the moment in that part of the water-circulation which intervenes between its elevation by evaporation from the earth's surface and its return as rain; nor, on the other hand, can we see what goes on at the other end of the circuit. We can only guess what conditions obtain and what phenomena occur at depths inaccessible to man. All our investigations must concern themselves with the intermediate stage, that stage which is most particularly marked by the transition from higher to lower temperatures, and, inversely, from increasing to diminishing pressures. It is the nice adjustment of these conditions which, on the one hand, favors precipitation, and, on the other, compels solution. To the miner, therefore, it may appear most important to investigate those factors which bring about precipitation, because to them must be ascribed the immediate agency of ore-deposition. It would simplify his ideas if he could speak of an upper zone of precipitation, where the temperature is low and the pressure light, in contradistinction to a lower region of solution, where the heat is great and the pressure intense. Such attempts to separate the locality of the two processes, however, must not be carried too far. Precipitation has no sooner ceased than solution begins. It is the excess of the one over the other which causes the deposition of ore in one place and its removal to another. Similarly, in our talk of "primary" and "secondary" deposits of ore, while some such distinction may be necessary for the purpose of explaining differences of immediate origin, we must not fail to recognize that all the ore-deposits within the ken of man are essentially secondary. There has been nothing original since the world was first evolved from chaos. We have to deal with a continuous rearrangement of material. The ore of one place came thither by removal from another. Whether it be present in minute microscopic particles or in blocks as big as a house is a distinction more economic and commercial than scientific and philosophic. The decomposition of one mineral is required for the composition of another. Ore-deposits are in their nature concentrations, whether by the mechanical accumulation of disintegrated fragments of older deposits or by the local regathering or segregation by chemical agencies of minerals previously widely and minutely disseminated, or finally by the addition, bit by bit, through mechanical and chemical force, of the matter brought from above or below by circulating waters.

The frequent occurrence of thermal springs in the neighborhood of later eruptive rocks is very properly emphasized by Prof. Posepny, and is of immediate importance to the student of ore-deposition because the eruptive rocks are in turn found so often in close association with lode-formations. That thermal springs, eruptive rocks and ore-deposits are intimately inter-related in their origin is generally accepted. In this connection I may be permitted to contribute some additional facts.

Besides the localities quoted by Prof. Posepny, I would mention the Hauraki or Thames gold-field, in the North Island of New Zealand, where a good opportunity is offered for the study of this subject. In the Coromandel peninsula of the North Island, there is a gold-bearing belt extending for nearly a hundred miles, from Cape Colville to Te Aroha. The prevailing country-rock consists of Tertiary eruptives, through which patches of Carboniferous slate occasionally appear. There are thermal springs scattered throughout the region. At the principal mining center, the Thames, the escape of carbonic acid gas has often caused a temporary cessation of work in the mines. There are soda-water springs in the vicinity of the Thames. At Te Aroha, at one end of the gold-belt, there is a group of celebrated medicinal hot springs. This last locality is connected by a continuous chain of thermal springs with Rotomahana, about 45 miles distant, the famous hot-lake region, the pink and white sinter-terraces of which were known for their beauty throughout the world, until Mt. Tarawera broke out in sudden eruption and destroyed them in 1884.

Veins of gold-bearing quartz, recent eruptive rocks, thermal springs, dying solfataric action, and active volcanic force, are all intimately associated in this corner of the world.

At the Thames, the leading mining town of the island, bodies of gold-ore of unusual richness have been found. In 1871, the Caledonia mine produced 10 tons of gold and paid three million dollars in dividends. In 1878, at the Moanataeri, 5400 pounds of quartz yielded 14,600 ounces of gold. The prevailing country-rock is an andesite breccia, traversed by zones of decomposition, in which the gold-veins occur. At Rotorua, in the hot-lake district already referred to, the plain is in part covered with fragmentary andesite. This material is usually loose and unconsolidated. Near the edges of the fumaroles, which are numerous, it has, however, become cemented, and then very much resembles the country-rock of the mines. The rims of the fumaroles also exhibit products of decomposition, which are similar in character to those observed in the lode-channels at the Thames, and which, because they are soft and granular, have been termed "tufaceous sandstone." Quartz closely resembling that of the gold-veins of the mines can also be seen to be deposited around certain of the fumaroles and hot springs referred to above. My examination of the ore-occurrence and vein-structure, though incomplete, led me to conclude that the deposition of the gold and its associated minerals had followed certain lines of altered country-rock which had been exposed to the effects of dying but lingering solfataric agencies.*

Another district which affords evidence to help us in studying this subject is that of Pontgibaud, in south-central France, among those volcanic peaks of Auvergne which have been rendered classic by the work of Poulet Scrope. The silver-lead lodes of this district have been very extensively developed, and their geological structure has more than once received notice at the hands of competent observers.† The country-rock consists of gneiss and mica schist, penetrated by dikes of granulite.‡ The lodes are of later date than the dikes, but older than the Pliocene flows of basalt which cover their croppings.

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* See also "Certain Dissimilar Occurrences of Gold-Bearing Quartz" by the writer, in the *Proceedings of the Colorado Scientific Society*, for 1893.

† *Annales des Mines*, M. Guényveau, 1st series, t. vii., p. 162 to 188. MM. Rivot and Zeppenfeld, 4th series, t. xviii., p. 137 to 257, 361 to 446. Also recently M. Lodin, April, 1892, in a paper entitled, "Etude sur les gites métallifères de Pontgibaud," also published in the *Annales des Mines*.

‡ If it were in our West it would be called "porphyry"—a term which has gradu ally been losing its distinctive meaning through careless use.

The period of their formation is considered to have been between the middle Miocene and the middle Pliocene, very probably contemporaneous with the extension of the acid eruptives of Mont Dore, which took place at the beginning of the middle Pliocene. The lodes generally follow the veins of granulite, and are productive only when so associated. When the dike-rock in which the lode occurs is most feldspathic, the metalliferous filling is most valuable.

In this region mineral springs are abundant, and the escape of carbonic acid gas has frequently put a temporary stop to underground work. This applies particularly to that part of the district through which the river Sioule flows between the town of Pontgibaud and the mines at Pranal. Often, while fishing along the stream, I have noted places where there is a constant escape of carbonic acid gas from its bed to the surface. At Pranal there appears to be an intimate connection between the lode-fissures and the volcanic vents. One of the mineral veins has been traced to its connection with what appears to be a vent of the extinct volcano of Chalusset. Powerfully carbonated springs exist close to the mines and on the slope of Chalusset.

In both of the two districts above cited, the one in New Zealand and the other in France, note has been made of the escape of considerable quantities of carbonic acid gas. It is scarcely necessary to emphasize the fact that this is a most common and powerful agent in bringing about changes in rocks and minerals. The action of carbonic acid, and of the alkaline carbonates which it forms, have been recognized by all petrographers. To it we owe the salts occurring in ordinary mineral springs; to it are due the pseudomorphic replacement of feldspar with chlorite*, and the alteration of olivine into serpentine, and of limestone into dolomite. Even at ordinary temperatures, carbonated waters extract magnesia from complex sili-

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* And the chlorite afterwards gives place to tinstone. This is a subject much studied by Mr. Richard Pearce, at a time when its importance was not so well recognized as now.—See "The Influence of Lodes on Rocks," *Proceedings of the Mining Association of Devon and Cornwall*, September 8, 1864. Mr. Pearce directs attention to the difference between the granite encasing the lode and that found at some distance from it. He makes note of the joints in the granite, and remarks upon the difference in the minerals found in two well-marked systems of joints having contrary directions. He shows that the changes observed in the rock adjoining the lodes have their origin in the lodes. Emphasizing the metamorphism of the granite he shows that the lodes consist essentially of altered granite, the most important alteration being the replacement of the feldspar by chlorite, by tinstone and by schorl. He discards the idea of an igneous origin of the tin-ore, and

cates. In this way, biotite loses magnesia and iron, becoming converted into muscovite.

The subject of the close association of ore-deposits and igneous rocks is a most important one to mining engineers. The detailed geological surveys of several of the most productive mining districts of the West, carried out during the past few years, have done much to emphasize the relation which seems to exist between bodies of eruptive rocks and deposits of gold- and silver-ore found close to them. It has become the fashion, especially since the publication of Emmons's masterly monograph on the Leadville region, to suppose that the precious metals of the lodes were derived from the leaching of the adjacent eruptives; and some mining engineers have gone so far as to consider the neighborhood of dikes necessary to the occurrence of a productive lode. This latter notion may be classed with the supposition, now slowly passing away, which, not long ago, was so strong, that a "true fissure-vein" was the only permanent depository of the precious metals.

In the United States, in Europe, and in most of the Australasian mining regions, the close association of dikes, or other forms of intrusive eruptive rocks, with lode-formations is so marked, that it is not surprising to find such rocks considered as necessary adjuncts to the occurrence of valuable ore-deposits. But, generalizations are proverbially dangerous; and, that this is an illustration of the proverb, the following facts may show.

The gold-mining region of the province of Otago, in the South Island of New Zealand, is confined, for the most part, to a great series of foliated quartzoze schists of an age considered Archæan by some,* and Silurian by others.† These rocks have an enormous thickness over a large area; the thickness has been estimated at 50,000 feet, while the area is fully 10,000 square miles. This has been a very successful gold-mining region, although the gravel-deposits have, so far, been more productive than the quartz-veins. The lodes have certain well-marked structural peculiarities, resulting from the foliated arrangement of the country-rock which they tra-

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declares that aqueous agency alone can satisfactorily account for the changes in the rocks and the formation of the lodes. He expresses the belief that the subject of the metamorphism of the country-rock, if "diligently investigated, must assist in explaining some of the laws which regulate mineral deposits." This was said thirty years ago!

* "On the Foliated Rocks of Otago," Professor F. W. Hutton, F.G.S. *Trans. of the New Zealand Institute,* vol. xxiv., 1891.

† "The Gold-Fields of Otago." *Trans.* A. I. M. E., xxi., 412.

verse. In a previous contribution, incidental reference was made* to the fact of the remarkable absence, in this auriferous area, of eruptive rocks. It is interesting to recall so marked an exception to what is often held to be a general rule.

That the quartzose schists of Otago are simply altered sedimentary beds of very early geological age, there is little reason to doubt. The quartz folia are arranged along the lines of original sedimentation, and not along cleavage-planes. It is a case of "stratification-foliation," as distinguished from "cleavage-foliation."† The only rock likely to be a metamorphosed eruptive is the chlorite schist of Queenstown.‡ The mining regions of Otago do not exhibit any of the phenomena of contact-metamorphism; and the changes which have been produced may be ascribed to what we call "regional" metamorphism, a vague way of describing those alterations which are forever taking place in rocks wherever there is heat and pressure, alterations which are, therefore, most evidenced by the oldest rocks, which have necessarily been overlaid by a great thickness of later-deposited formations.§

A treatise which covers so wide a field as that of Professor Posepny, can, of necessity, devote but scanty attention to some mining regions which, to those who know them, appear to afford important evidence on the subject of ore-deposition. In this regard, it is to be regretted that Professor Posepny does not seem to have had his attention drawn to certain very excellent geological reports contained in the blue books of the mining departments of Victoria, New South Wales, and New Zealand. Australasia has many object-lessons to offer to the student of economic geology, and the Colonial geological surveys have published several accurate and most interesting descriptions of them.||

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* *Trans.*, xxi., 413.

† Prof. T. G. Bonney uses these terms in the *Quarterly Journal of the Geological Society*, vol. xlix., part 1, p. 95.

‡ As pointed out by Prof. Hutton. *Op. cit.*

§ I do not lose sight of the fact that igneous rocks may become schistose by metamorphism, especially through pressure, as a dolerite becomes a hornblende schist. There is no reason to suppose that such a metamorphism has occurred in these rocks of Otago.

|| I would more particularly instance *The Geology of the Vegetable Creek Tin-Mining Field*, by T. W. Edgworth David, and the recently published *Special Report on the Bendigo Gold-Field*, by E. J. Dunn, together with the numerous observations made by R. L. Jack, in Queensland; H. Y. L. Brown, and H. P. Woodward, in South Australia; G. H. F. Ulrich, and F. W. Hutton, in New Zealand; Wilkinson and Liversedge, in New South Wales; Murray, Sterling, and Howitt, in Victoria.

In concluding this contribution to the discussion of Prof. Posepny's paper, I may be permitted to express again the belief that his destructive criticism of the lateral-secretion theory is most opportune, and that his investigations into the flow of underground waters will do much to illuminate our views of the methods of ore-deposition. At the same time, I cannot but hold that the accumulation of facts and observations will show that neither the lateral, nor the ascensionist, nor any other one narrow theory can cover the multitudinous diversity of the ways in which ore-deposits are found to occur.

R. W. Raymond, New York City: Concerning Mr. Rickard's proposed classification, I beg to say, while recognizing its convenience for mining engineers, that it cannot be considered as a substitute for that of Prof. Posepny, for the simple but conclusive reason that it is not genetic. Its fundamental division is based upon the position of the deposits, which should be, in a genetic classification, a subordinate consideration; and the most profound genetic distinction presented by nature, namely, the distinction between contemporaneous and subsequent formation, appears in this scheme as a division of the third degree, affecting only inclosed bedded deposits. If I were inclined to criticize names, as Mr. Rickard has elsewhere done with regard to Prof. Posepny, I might point out that the word "contemporaneous" does not describe coal-beds, which Mr. Rickard mentions as typical examples of it. Whatever may be said of a coal-bed, it is not contemporaneous in origin with the country-rock above it or below it. But this is a small matter. The point I make is much more important, namely, that the classification itself is neither based on genetic distinctions nor on any other logical arrangement. I say this all the more frankly, because, as Mr. Rickard declares in complimentary phrase, he has largely followed the classification given by me in 1869. But that was, as Mr. Rickard's is, merely a convenient miners' arrangement. Now that Prof. Posepny comes forward, proposing for the purposes of science, not of mining, a truly genetic classification, a critic may fairly demonstrate its logical defects and suggest remedies, or declare remedies to be impossible. In the latter case, his contention would be that a genetic system cannot be constructed, and that the attempt had better be abandoned. But to say that one prefers, as a mining engineer, the handy non-scientific arrangement of ore-deposits hitherto in use, is no criticism at all. It is as if a botanist, considering a natural system in botany, should sap that it was discouragingly complicated, and that he preferred the simple and convenient arrangement of Linnæus, by which one could identify a species from the number of petals and stamens and other arbitrary signs.

H. V. Winchell, Minneapolis, Minn.: While heartily agreeing with the frequently-expressed opinion that Prof. Posepny's paper is a masterly and exceedingly important discussion of ore-deposits, it still appears that there may be room for differences of opinion on some points. Indeed, they necessarily follow from such decided statements on so important and interesting a subject.

Those of us who live in the Lake Superior region are wont to believe that we have some conception of the meaning of the term "ore-deposits." We can, and frequently do, point with pride to the great value of our production of iron-ore and the fact that we furnish nearly two-thirds of the total product of the United States. It is an industry employing about 30,000 miners and involving capital to the amount of fully $100,000,000. But when we come to treatises on ore-deposits we are always disappointed. We find that, while speaking generally and theoretically, iron-ore deposits may be mentioned, yet when it comes to critical discussion, and the illustration of theories by examples, they are omitted. We are constrained to protest that "ore-deposit" does not signify merely a vein of gold-, silver- or lead-ore or a stockwork of tin- or zinc-ore, but that hematite and magnetite form ore-deposits of a commercially important and genetically highly interesting class.

The value of the raw iron-ore produced in this country in 1889 was equal to the value of the gold bullion produced in the same year. And if we take the value of the pig-iron, which more nearly corresponds with bullion in the degree of removal from the raw material, we find it equal to the value of the gold and silver combined. And yet our author dismisses the entire subject in a couple of pages, and of Fuchs's and DeLaunay's 2000 pages only two are devoted to the most important iron-ore district on the globe.

It would not be fair to suggest that iron-ores are overlooked because they do not seem to be explainable by the theories adopted for other classes of deposits. If that were the case, all the more need of giving them attention. It is more probable that it is because of the recentness of their development and the comparatively scant literature on the subject in the libraries of our foreign colleagues.

That the circulation of waters carrying different chemical reagents is the all-important factor in the genesis of ores, as we find and mine them, is clearly shown by Prof. Posepny, and is accepted by the majority of writers on the subject. But the prominence which is given to ascending waters and the insignificant effects ascribed to descending solutions will not find such ready acquiescence. It seems likely that ascending waters are the more likely to be effective and to predominate below the ground-water level than in the vadose circulation. But it can be conclusively demonstrated that many of the immense iron-ore lenses of the Lake Superior region owe their present state of concentration, even to the depth of many hundreds of feet, to the action of the descending waters. Aside from the Mesabi range, the proofs lie partly in the following well-known facts :

1. The ore is a product of concentration *in situ,* whether the original rock or lean ore was an oxide, a silicate, or a carbonate, or whether it was oceanically or otherwise precipitated.

2. The ore-bodies have the shape of highly-inclined lenses, and frequently have an unaltered "capping" of jasper partially covering their upper ends.

3. When this capping is present, it can be traced downward into the ore through changes which are clearly the result of oxygenated atmospheric waters.

4. The downward course of the waters is further shown by the protecting action of dikes and other impervious barriers, below which the ore is not found.

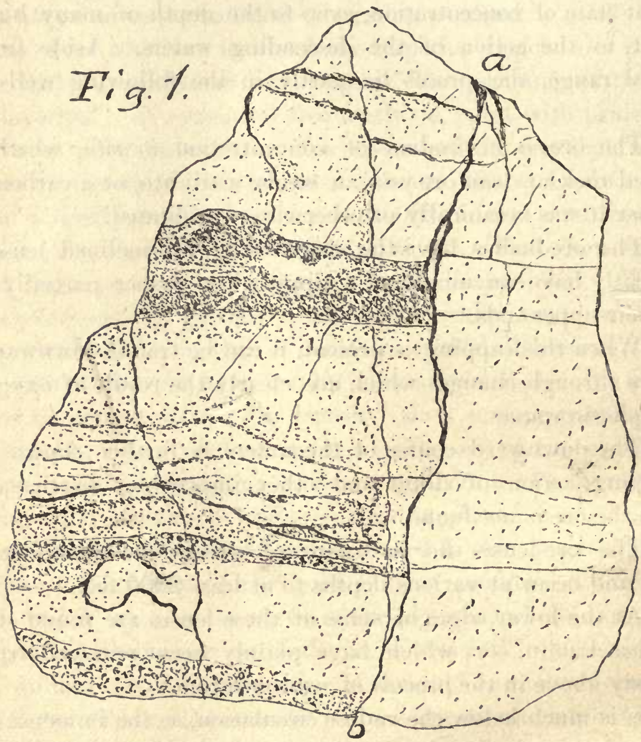
5. The ore-lenses lie in basins of greenstone-schists or other rocks, and occur at various depths to at least 2000 feet.

6. At the lower edges of some of these lenses are found deposits of silica, kaolin, etc., which have plainly been removed from the ore-body above in the process of concentration.

This is much below the vadose circulation, as the immense pumping engines and the rivers of water which they throw the year round testify ; but it is an instance of the formation of ore-deposits on the largest scale by descending waters.

The circumstances are somewhat different on the Mesabi range, but the proof is no less clear that the ore has been formed by solutions percolating downwards. There the mines lie along the south side of the continental divide or water-shed, from which waters flow north to Hudson Bay and south to the Gulf of Mexico. They thus occupy the highest regions of the northern part of the State. Moreover, the shape of the strata, and the presence of a conglomerate beneath them, indicate that there was a shore-line there when the rocks were deposited. These facts, with the comparatively undisturbed condition of the strata, lead us to believe that the conditions have remained during many geological ages as they were originally and as they are now, viz., such that the inevitable direction of water-circulation would be downward and following to a certain extent the gentle dip of the rocks to the south.

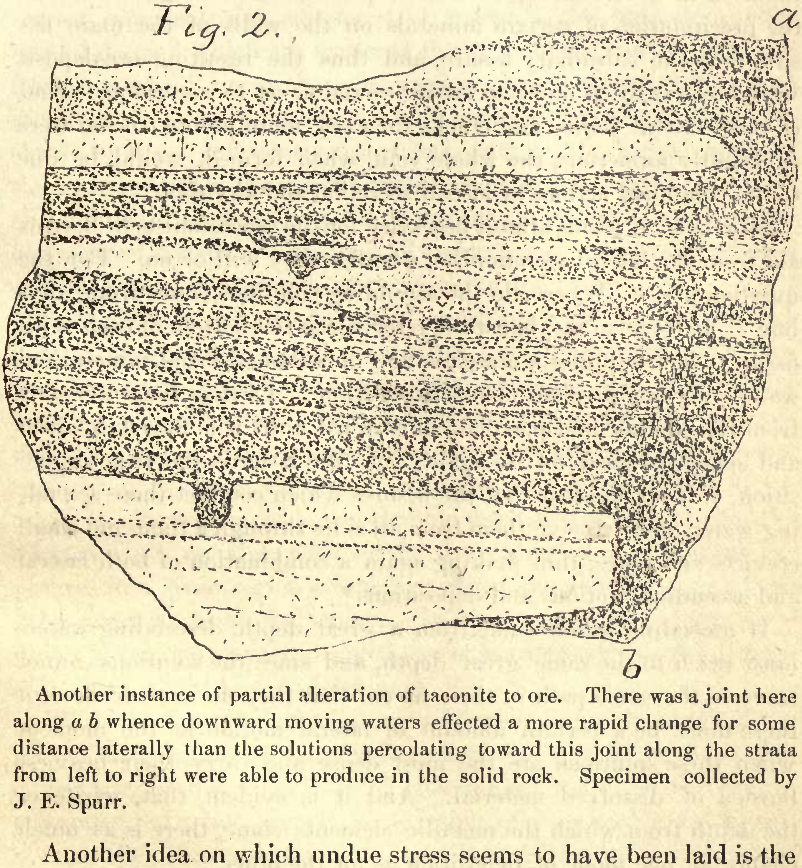
Although of remarkable magnitude and chemical purity, these



Taconite from the Mesabi range changing to iron-ore by solutions moving from left to right. *ab* is a fault line which conducted the descending waters downward and prevented the right half of the specimen from undergoing the ferrification which is seen in the left half.

deposits are essentially surface-products and are at present largely above the ground-water level. The processes of replacement by the removal of silica, and of concentration by the addition of sesquioxide of iron, can be seen in progress in a hundred places. The rock which undergoes this change is a gray, reddish or greenish chert ("taconite") banded with iron-ore. Figs. 1 and 2, taken from specimens from the Mesabi, illustrate the change mentioned, and show the downward course of the ferruginous solutions.

Since we have here examples of iron-ore deposits, both above and below the ground-water level, which have been formed by descending waters, the thought naturally arises that the solutions may not have been so universally ascending in the case of other mineral deposits, as our author would have us believe.



Another instance of partial alteration of taconite to ore. There was a joint here along *a b* whence downward moving waters effected a more rapid change for some distance laterally than the solutions percolating toward this joint along the strata from left to right were able to produce in the solid rock. Specimen collected by J. E. Spurr.

Another idea on which undue stress seems to have been laid is the correctness of the "ascension theory," and the absolute error of that of "lateral secretion." A consideration of these two ideas leaves me with the impression that they are not in reality so diametrically opposite that if one is true the other can have no scintilla of truth in it. In the deep region the circulating waters are supposed to be under considerable pressure, from which they escape by flowing in the direction in which they meet the least resistance.

Even if the solution were on the whole ascending, still it must often happen that cracks and fissures would be encountered, leading in a lateral direction into some main fissure, full of ascending waters under slightly less pressure than that behind the waters which entered laterally. In that case it is also quite likely that there would be a different chemical reaction at or near the junction of these two circulating fluids from that produced by the action of either one of them on the rocks through which it passed. This might result in the precipitation of certain minerals on the walls of the main fissure near the subsidiary fissure, and thus the resulting ore-deposit would owe fully as much to lateral secretion as to ascension. And if these lateral joints and cracks (or even more porous rocks) were sufficiently numerous, the whole vein, when formed, would be due to the combined actions of lateral secretion and ascension.

Moreover, it seems almost necessary for the ascensionists to borrow aid from the lateral secretionists, whether they will or no. For the question arises: Where do the ascending solutions come from, anyhow? Is there an inexhaustible reservoir at the bottom of each vein-fissure, which supplies a ceaseless flow of carbonated and mineralized waters carrying precious metals in solution? Or does the water start from the surface and percolate downward until it is forced by heat and generated gases to rise again? If the latter is the true supposition, is it not evident that the fissures which conduct these ascending waters must receive them from all sides through a thousand small crevices and pores, thus making again a combination of both lateral and ascending motions and depositions?

If ascending waters come from a great depth, descending waters must reach to the same great depth, and since the solutions cannot traverse the same path in their ascent that they do in their descent there must be a certain amount of lateral motion at the moment when these solutions are the most dense and carry their heaviest burden of dissolved material. And it is evident that, whatever the depth from which the metallic elements come, there is as much chance for one mode of deposition as for the other.

SECRETARY'S NOTE.—The remaining contributions to the discussion published in this volume were presented at the Bridgeport Meeting, October, 1894, or issued with the papers of that meeting, having been received before the Florida Meeting of March, 1895.

PROF. POŠEPNÝ (communication, translated by the Secretary): First let me express my warmest thanks to all those who have so favorably judged my paper on the "Genesis of Ore-Deposits," and likewise to those who have taken this occasion to bring forward, whether in support of my views or in opposition to them, various observations and opinions, whereby our knowledge of ore-deposits has been unquestionably increased.

It is exceedingly difficult—indeed, almost impossible—to make a correct comprehensive statement of a subject, the separate fundamental data of which are scattered throughout the world; and my treatise must, of course, be considered as merely an attempt in that direction, inspired by the purpose of contributing to this theme an element not yet sufficiently recognized, namely, the logical application throughout of the genetic principle. As I indicated on p. 8 of this volume, I expected as a result neither a simplification of systems nor a direct benefit to practice. My object was, irrespective of such considerations, to approach more nearly to the truth.

A single observer may be able to establish a few more or less important facts; but the great mass of the knowledge required he cannot personally possess. In the most favorable case, government institutions, established to benefit single nations, or scientific or business associations, may procure accurate knowledge of the mineral resources of separate countries, and these may be combined to increase the knowledge of a considerable territorial complex; but the question still remains, whether the developments and natural exposures in a given region are really typical and conclusive as a basis for general scientific deductions. In this respect, an international union of such endeavors, devoted to the advancement of this branch of geology would be a decisive gain.

When the United States Geological Survey began the study of the geological relations of ore-deposits, there was ground for hope that a new era in the knowledge of this subject would be thereby inaugurated. In fact, several monographs of inestimable value concerning the most important ore-deposits had been published, when, for reasons unknown to me, the whole activity of the survey in this direction was interrupted—an event much to be lamented.

Yet a monograph can give only what is revealed by the developments accessible at the time it is written; and since mining continually makes new exposures, and for the most part obliterates the old ones, a complete scientific inquiry should involve provision for the repeated examination of a given mining district, and for publication, at intervals of, say, five or ten years, of the new knowledge thus acquired.

It is scarcely to be doubted that the investigation of the genetic relations of a thing is necessary to complete our knowledge of it, and that this inquiry is therefore obligatory as a part of the study of anything which we desire to know exhaustively. Dr. Raymond (discussion at the Virginia Beach Meeting, p. 209) has defended the introduction of this principle into the science of ore-deposits, for which I thank him heartily.

Messrs. W. P. Blake and A. Winslow have controverted my views concerning the original source of the lead- and zinc-deposits of Missouri and Wisconsin, condemning at the same time the similar views brought forward at the same Chicago meeting in the paper of Dr. W. P. Jenney. Since I am personally acquainted only through a tourist's journey with the relations of these deposits, which extend over so large a region, and am, moreover, not master of the wide literature of the subject, I must leave the defence of the principles asserted to Dr. Jenney, and will here simply refer to his reply, contained in the present discussion.

With regard to Mr. Winslow's observations, I must confess, that I am acquainted neither with the mine at Doe Run nor with the publications of Messrs. Strong and Chamberlin. But I know that concerning every region where lead- and zinc-ores occur in limestone and dolomite, the two opposite theories as to their origin invariably appear; and that in terranes consisting of structural plateaux, with nearly undisturbed position of strata, the representatives of the view that these ores were deposited simultaneously with the country-rock have the great advantage that the conditions of stratification are in their favor.

Besides the paper here in discussion, I have lately devoted to the deposits of lead- and zinc-ores in soluble rocks a special treatise,* in which I have compared the occurrences of such deposits in plateau-regions with the conditions obtaining in mountain regions, with already disturbed stratification. This publication originated in an address delivered by me at a miners' congress in Klagenfurt, that is to say, in the center of a mining industry based upon mineral occurrences of this class.

In order to counteract a conception based upon local conditions, I have placed side by side the various alpine occurrences of Carinthia

* "Ueber die Entstehung der Blei-und Zinklagerstätten in auflöslichen Gesteinen."—*Jahrb. d. k.k. Bergakademien,* 1893.

with those of the plateaux of Upper Silesia and North America, illustrating them, according to my custom, with drawings of the typical features. Among others, the occurrences in Sardinia and in the North of England are discussed, and use is made of recent literature concerning the Upper Silesian plateau. In this place, I can only remark, that some of these occurrences in the mountain terranes carry evident traces of the subsequent derivation of the ores from below; and that this fact alone is an argument for the similar origin of the plateau-deposits, which so closely resemble the former in all other respects.

The treatise I have mentioned does not include the observations made by me in the spring of the present year, upon the analogous deposits of Laurium in Greece, which are likewise in a structural plateau; but I can assure the reader that the developments of that region also indicate the derivation of the ores from below.

So far as Mine la Motte is concerned, I can attach no great weight to the observations which I made there, upon a hasty journey. Nevertheless, the specimens of ore disseminated in sandy dolomite which I brought away show distinctly upon the surfaces, after polishing, the secondary intrusion of the ore into the country-rock.

With regard to Mr. T. A. Rickard's criticisms, I would observe, that formerly the theories of ascension, descension and lateral secretion were generally spoken of, without the assignment of any cause for the assumed movements of the subterraneous liquids. I think, however, that I have secured some definiteness of conception by showing the actual descent of the vadose circulation and the ascent of the deep circulation, and by interpolating the lateral movement between the two. This gives reality to the processes formerly conceived abstractly, and makes it possible to discuss them.

Mr. Rickard observes that, with reference to the formation of ore, I have laid special emphasis upon *ascending* mineral solutions (p. 176 of this volume). I meant to do this, however, only with regard to the sulphides. These certainly were not produced from the *descending* solutions, which carry oxygen now, as they unquestionably did in former geological periods also, and which invariably decompose sulphides wherever (as is the case in the vadose zone) they come into contact with them. With regard to the sense in which I use the terms *ascending* and *descending*, I will say something below.

Mr. Rickard suggests (*loc. cit.*), that since the increase of pressure and temperature favors solution, while their decrease favors precipitation, precipitated ores are to be expected rather in the shallow zone; and that this might explain the circumstance that (as he believes) ores do not continue in depth. Without going into the latter question in detail, I would point out that the conceptions of shallow and deep are only relative, and that in my discussion I could only have in mind the conditions existing at the time of the formation of the ores, and not at the present time. What was once shallow may now lie very deep, and *vice versa*. In this respect, the character of the ores is, I think, the decisive fact. Oxidized ores must have become such in a zone then shallow, and original sulphides must have been deposited in a zone then deep, and beyond the reach of oxidizing agencies. For the present, only the extreme of these processes can be clearly recognized; but it is not impossible that future studies in this direction may distinguish the characteristics of the intervening stages of formation, such as the deposits made during lateral movements of the mineral solutions.

It would certainly be a step backwards, to allow the established characters of the two extremes to disappear under the general term "circulation." In my description of the vadose circulation I have pointed out that, notwithstanding its course at the ground-water level appears to be almost horizontal, and notwithstanding an actual ascent of the liquid may be locally brought about by siphon-action, nevertheless a decided prevailing descent can be proved for the vadose currents. The terms "descending," "ascending" and "lateral" are not applied to a portion, but to the whole line of the current; and to its cause, as both theoretically and empirically determined. I cannot admit that this is "a narrow view of the subject," likely to hinder progress in this branch of geology; on the contrary, I believe it expresses a series of observed facts, calculated to increase our knowledge.

Mr. Rickard seems to look at every new conception in this department from the sole standpoint of its immediate usefulness in mining, and not to reflect that the scientific investigator has simply to seek the truth, without regard to such considerations. His criticism might have been more favorable in some particulars (*e.g.*, Virginia Beach Discussion, p. 202, with reference to p. 52 of my paper), if I had taken pains, in many cases in which I was speaking of "ore-deposits," to explain that under this phrase, used for brevity, I was referring to deposits carrying metallic sulphides.

Mr. H. V. Winchell complained, at the Virginia Beach meeting, that under the head of ore-deposits, the deposits of iron-ore are too often either meagerly or not at all considered. This complaint would be well-founded as against a report on the mineral resources of a given region, in which the economic importance of the deposits is a controlling element; but it is scarcely just in its application to a paper like mine, which was intended only to give single instances in illustration of certain genetic theories. The reason that iron-ore deposits generally receive comparatively little attention in genetic discussion is, I think, the simplicity of their conditions, the knowledge of which is to some extent assumed to be familiar, so that authors interest themselves much more in the discussion of the more complicated occurrences, which have rarely, as a rule, been correctly interpreted.

I am indebted to Mr. Winchell for making good my omission by adding to my paper his account of iron-ore deposits known to him. Since the deposits he cites consist of oxidized ores only, they may well have been formed by an originally vadose circulation. I must, however, point out that some iron-ore deposits may be of idiogenous origin. Thus, I consider the oölitic structure of some deposits (*e.g.*, those of hematite in the Silurian of Central Bohemia) as a sign of their original deposition in the basin. I have had, however, far too little to do with these deposits to be able to determine more closely the significance of the remains of brachiopods (*e.g.*, orthis shells), which occur, transformed into hematite, together with the oölites.

The iron-ore beds of the Silurian basin of Bohemia have a certain analogy with those of the Huronian basin of Michigan, especially as regards the length and continuity of their outcrops and their connection with tufas of the eruptive rocks. In the latter, as is indicated by the beautiful pseudomorphs of chlorite after garnet, considerable metamorphosis must have taken place.

Concerning the Mesabi iron-ores, I am indebted to this critic for the illustrations of two specimens which he has published. They, indeed, suggest reflections as to their probable genesis, upon which, however, I do not trust myself to venture at this time.

In reply to Mr. Winchell's criticism that, while laying unnecessary emphasis upon the correctness of the ascension-theory, I appear to concede to the theory of lateral secretion not an atom of truth, I beg to observe:

1. That I deem lateral secretion, in the sense in which it is defined by Professor Sandberger, to be possible only in the zone above the ground-water-level, and, therefore, in the formation of oxidized ores only, and not for sulphide-ores.

2. That I am, indeed, obliged (as I have shown on page 26) to assume a lateral movement of liquids in the deep zone. But this is a region in which present processes cannot be directly observed, and, therefore, no clues to the conditions of deposition are found. Hence, I was not able to describe such conditions in my paper. It is possible that, in the course of time, conditions of deposition may be discovered which can best be explained in this way. I have not yet encountered such a case.

The same is true as to regions in which the two extreme branches of the subterranean circulation take on a lateral course. The case supposed by Mr. Winchell, in which a deposit can be ascribed to ascension and also to lateral secretion, I do not clearly understand, since a physically weaker current is not capable of displacing a stronger one. While the extreme forms of circulation—that is, both the ascending and descending branches—possess a pronounced character, it must be expected that the character of the branches connecting these extremes will be less distinct.

Mr. John A. Church does not agree with me regarding ore-deposits in open spaces as a very frequent phenomenon, and expresses the opinion that open spaces cannot exist at great depths (such as 3 to 5 kilometers). I must remind him that in order to establish the first proposition the most important observations of a great number of observers for more than a century must be disproved. He cannot have failed to notice that ore-deposits of that form which has been relatively most thoroughly studied, namely, fissure-veins, consist predominantly of separate crusts, often marvellously distinct, covering what were once the walls of the fissure-space. Even if his proposition be confined to deposits of great thickness and extent in depth, which are deemed to have been formed (as, for instance, the Comstock lode, which he has studied) by substitution, replacement or metasomasis, he cannot possibly deny the existence of other thick and deep deposits, the structure of the ores of which evidently represents the filling of open spaces. For instance, some of the Przibram veins, which have been worked to the depth of more than 1100 meters, and the ore of which often exceeds 10 meters in thickness, must certainly be reckoned as wide and deep; yet the ores from their deepest portions do not differ in the least, so far as structure is concerned, from those which occur in the shallower parts. Both regions present fragments of the country-rock of all sizes, surrounded by the vein-material. Moreover, these fragments surrounded by quartz usually predominate in one or the other of the crusts of the vein-filling.

Mr. Church seems to allow small value to the observations which it is possible to make upon the ores themselves and the adjoining country-rock. This is equivalent to the rejection of the only means of obtaining data concerning their probable genesis. It is difficult to discuss such an objection, particularly in its bearing upon the phenomenon of crustification, which I consider one of the most important genetic factors, and concerning which I will speak further in connection with my reply to other critics.

Mr. Church declares the Comstock vein-mass to be the product of substitution—that is, of metasomatic alteration—and denies entirely that it is a fissure-vein. He says I have misunderstood him in saying (p. 85 of this volume) that he found crusts of quartz, alternating with calcite, in the Justice mine. The passage to which I referred was the following: *

> "The ore of the Justice is not quartz but calcite, with but an insignificant amount of silica, and it is noteworthy to find these two components of the lode dispersed in that banded arrangement, which is another of the accepted proofs of a true fissure-vein. The quartz is always on the propylite and the calcite on the quartz; but there is no comparison in respect to quantity. The quartz is always insignificant in thickness, never reaching a layer more than an inch or two, so far as noticed, except in the dyke-vein, while the calcite forms masses which are several yards in thickness," etc.

Why is this not what I call crustification? It is certainly conceivable that the Comstock was formed by the opening of a space of discission at the contact of diorite and diabase, the filling of this space by the deposition of silica and carbonate of lime from solutions, and the repetition of these processes until the deposit had attained its present thickness. There is, for example, in the collection of the University of Vienna, a large slab from the Adalbert vein at Przibram, showing a series of thin galena-veinlets, the crystals of which meet in the axis of each several veinlet, showing that each was separately filled, and hence that the process of opening and filling, regarded with reference to the Adalbert vein as a whole, was repeated many times, until the aggregate thickness of about one meter, shown by this slab, had been attained. The Comstock might have been formed likewise by repeated opening and filling, only the several fillings would have to be thicker, and (since the material varied little) the result might be too indistinct to attract the attention of the miner.

Mr. Church regards the ore-body of the Justice mine as a deposit

* *The Comstock Lode*, etc., by John A. Church, New York, 1870, p. 173.

separate from the Comstock; but it is, nevertheless, a branch of the Comstock lode, and certainly has an analogous origin.* The occurrence of a crustified portion, which I think the text of Mr. Church's description indicates, possesses, therefore, significance for both branches of the Comstock.

By crustification, however, I do not mean merely a "banded structure." This may indeed originate, as Mr. Church says, in various ways, but crustification cannot; for true crusts are predominantly chemical precipitates, the crystal-aggregates of which present a certain arrangement. For instance, the quartz-crystals usually stand perpendicular to the former cavity-wall, directing their pyramidal surfaces towards the central druse. Incrusted fragments exhibit the same crusts as the cavity-walls, which is, at the same time, an additional proof of the existence of an open space, etc. It is true, that among these chemical precipitates there sometimes occur mechanical sediments, such as frictional detritus, which may be enveloped by one or another of the crust-substances; but, this is by no means a case under Mr. Church's statement (p. 183 of this volume):

"Certainly, a banded structure can arise from the replacement of fragments arranged in layers by pressure and friction, as well as in many other ways, and does not prove deposition in a cavity, whether filled by water or air."

Pressure and friction can give rise to no arrangement of xenogenites in separate crusts; in other words, no crustified quartz and calcite filling, such as I suppose to exist in the Comstock. I possess, for example, besides the ores from the Consolidated Virginia bonanza, mentioned in my paper (page 85), some quartz specimens from the 1500-foot level of the Belcher mine, in which separate dark ore-bearing zones may be distinguished, running parallel with each other, even to the repetition of minute undulations. This is, I confess, not such a convincing case as that of the specimen shown in Fig. 53 of my paper, which exhibits numerous successive crusts of baryte, fluorite, etc., no thicker than paper; or those of the Raibl specimens, which consist of thousands of thin layers of zincblende (whence the name *Schalenblende*); but it indicates, at least, the probability of a similar origin. It is, of course, not in every ore-deposit that such incontrovertible proofs as those last mentioned are found and preserved for science.

* See Becker's *Geology of the Comstock Lode*, p. 30.

Mr. Church points out (pages 182 and 183 of this volume) that metasomatic processes effected in limestones through the expulsion of the carbonic acid by a stronger acid, may also explain the exhalations of carbonic acid so frequent in certain localities. I much prefer, however, to avoid the adoption of such a purely speculative standpoint, and would only suggest that, upon that view, the enormous volume of such exhalations in volcanic regions would require us to conclude that in those regions immense masses of limestone are undergoing the metasomatic process referred to.

As regards, finally, the subsequent alteration of the original ore-deposit, which, according to Mr. Church, partially passes into hysteromorphism, it is undoubtedly true that mineralogists, devoted to the study of pseudomorphs, have collected already valuable data in this field; yet, I think, prolonged investigation will still be required before general deductions can be profitably discussed.

Mr. S. F. Emmons, whom I have to thank warmly for his favorable judgment upon several portions of my paper, naturally does not concur in the views I have expressed concerning Prof. Sandberger's lateral-secretion theory, to which he was himself at one time more or less committed.

He objects, for instance, to my reference to the barysphere. This is a part of my conception of our planet as consisting outwardly of several successive, and more or less connected, spherical envelopes—atmosphere, hydrosphere, biosphere, lithosphere, and barysphere—of which only the exterior ones are open to our direct observation. In discussing the mutual reactions of these great geological factors, which we may briefly call aggregate-spheres, it is unavoidably necessary to refer to the barysphere, which is beyond our observation; and, according to my habit, I have used this term in speaking of the source of the heavy metals. It is true, the term is only a device to avoid questions still unsolved; but the same may be said concerning the phrases "unknown depths," or "unknown sources in depth," which have a similar meaning.

It seems to me, that Mr. Emmons and others of my critics have not correctly understood my statements concerning the several branches of the underground circulation; and I therefore beg permission to make my meaning clearer, even at the cost of a little repetition. For this purpose, I will take for illustration, not an ideal case, but conditions actually existing, namely, those developed at Przibram, concerning which there exists an abundant literature, shortly to be increased (in the second volume of my *Archiv für praktische Geologie*) by a monograph of my own.

The Przibram district lies, in round numbers, about 500 meters above sea-level, and the mine-workings extend, as is well known, to more than that distance below sea-level. The ground-water level is but a few meters under the surface. The deepest adit drains the mines to about 100 meters; and everything below that level is strictly deep workings, from which the water is lifted to the adit-horizon. A comparison of the water raised from different levels shows that the largest quantities come from the upper ones, and that the amounts diminish with increasing depth, so that at about 300 meters below sea-level no water remains to be raised, the ruling rock- and air-temperature of about 23° C. (74° F.) at that depth sufficing to evaporate the small existing quantity of water. This is certainly a striking proof that the water encountered in mining is of atmospheric origin.

The ore-deposits are steeply-dipping fissure-veins, which are mined by reason of their richness in silver (about 5 per cent., or 50 kilos per metric ton—or say 1458 ounces Troy per ton of 2000 pounds avoirdupois). Even in the neighborhood of the surface the sulphides predominated, but were mixed with a great variety of beautiful minerals, which have made Przibram famous among collectors, and most of which, according to the results of the investigations of F. A. Reuss and others, are of secondary origin. It cannot well be doubted that this alteration is due to the oxidizing properties of the liquids coming from the surface. But this variety of minerals is confined at Przibram to the upper zones. Since mining has penetrated to lower levels, its product has been mainly only rich argentiferous galena, with accompanying zincblende, etc. The diminution in secondary minerals, so far as it can be determined, seems to follow closely the progressive diminution, in depth, of the quantity of surface-waters.

Concerning the origin of the secondary alterations, there is (as Mr. Church may be pleased to know) no doubt at Przibram. The only question at issue concerns the explanation of the original vein-filling, consisting of sulphides. This must have come, of course, from some rock as a source; and on this point views are at variance.

1. Professor Sandberger at first conceived that this filling came directly from the country-rock (*Nebengestein*). The technical term *Nebengestein* is more definite, perhaps, than "country-rock." It means literally the rock alongside, or the country-rock or wall-rock immediately in contact with the deposit. In this sense, it is impossible to conceive of any other process than that of lateral secretion, which could make the *Nebengestein* the source of the filling; and I

have attempted in my paper to show the improbability of such a lateral secretion of such a filling.

2. Mr. Emmons, in his paper on "The Geological Distribution of the Useful Metals in the United States," read at the Chicago meeting (*Trans.*, xxii., 53), has connected the derivation of the various metals of different deposits with the observed geological conditions of that country, discussing the metals, iron, manganese, nickel, tin, copper, lead and zinc, mercury and gold and silver separately. In his criticism of my views in this field (pages 185 and 186 of this volume), he has taken occasion to express a general statement for all ore-deposition. According to his opinion, the metallic constituents were derived by lateral secretion from rocks within "reasonable proximity;" and "ore-bearing currents may in such cases have had an upward, downward or lateral motion, according to differing local conditions of rock-structure." This latter expression I would like to amend in accordance with the fact that, while the local conditions of rock-structure indeed influence the movements of liquids, the true causes of the upward, downward and lateral motion, as explained in my discussion of this point, lie outside the particular rock-structure.

I would invite Mr. Emmons to take the standpoint sketched on pages 51 and 52 of this volume, in the depths of the Przibram mines, and see how he would get along with his assumption of lateral movement. And I must repeat that it is not so much the local direction of the currents, as the general character and cause of the flow which should be kept in view.

The general phenomenon of descending currents in the Przibram mines is clearly subsequent to the formation of the ore-deposits; and the existence of lateral movements of the vadose circulation which could form these deposits is inconceivable. Let us see, then, whether such movements could occur in depth, in the sense defined by me on p. 26 of this volume, and quoted by Mr. Emmons.

We should be forced to assume that the open vein-channels had not extended much deeper than the point (500 to 700 meters below sea-level) at which I have invited Mr. Emmons to stand, and also that there was no special upward tendency of the waters filling these channels. A lateral continuous movement would be only possible if there was something "in reasonable proximity" which would consume the moving current, or force it back to the surface. To expect this phenomenon in a terrane already traversed by channels reaching to the surface is irrational. In the only conceivable sense, it would merely make the lateral movement an incidental part of a general upward circulation. But this favors my view of the ascent of mineral solutions from greater depths than have yet been reached in mining, *i.e.*, from "unknown depth," as Mr. Emmons expresses it, or from the barysphere, as I have expressed it. He also, by the way, assumes the origin of the heavy metals from the barysphere (or "from the depths," as he prefers to say), and goes so far as to intimate that I would make the theory more plausible by allying it with that of Vogt, according to which a process of so-called differentiation, during the cooling of the eruptive rocks, has concentrated their metallic contents in certain regions more or less accessible to our observation. For my part, I must wait until Vogt's ideas have assumed a more solid form; but I cannot help suspecting that Mr. Emmons favors them principally because they bring the concentrated metals in eruptive rocks within the reach of lateral secretion, as a forming process for ore-deposits.

Mr. Emmons doubts my conclusion, based upon Nöggerath's observations, that waters rising under pressure are capable of creating a channel for themselves in soluble rocks. In this connection I must refer to the difficulty encountered in explaining the cavities containing pipes of ore in soluble rocks. In my monograph on Résbánya,* published when Nöggerath's work was unknown to me, I was forced to assume, as the cause of the formation of the cavity, the downward vadose currents, and as the cause of the filling, on the other hand, the ascending currents of the deep circulation; in other words, two processes, representing the extremes of circulation, and successively acting along the same line. Such a dilemma may be presented by any ore-deposit in limestone. Indeed, I became acquainted subsequently with instances indicating that the two processes of cavity-forming and cavity-filling may have been sometimes almost simultaneous.† I was greatly pleased when I learned of Nöggerath's observations and deductions, and I took pains at that time to acquaint Mr. Emmons by letter with the consequent change in my own views. The observation, as I convinced myself in 1885, cannot now be verified, for the whole place at Burtscheid is completely built over; but Nöggerath was a highly conscientious ob-

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* *Geologisch-montanistische Studie der Erzlagerstätten von Rézbánya, in S. Ungarn.* Published by the Hungarian Geol. Soc., Budapest, 1874.

† See my paper in *Jahrb. der k. k. Bergakad.*, 1893, p. 18, "Ueber die Enstehung der Blei- und Zinklagerstätten in auflöslichen Gesteinen," especially Fig. 14, Pl. III.

server, and there can be no doubt of the correctness of his statement of the facts. Moreover, the phenomenon is, *a priori*, inevitable. If the highly dilute currents of the vadose circulation, descending by gravity, can eat out their own channels in salt or limestone (as is shown at p. 19 and other places in my paper), all the more might such effects be expected from waters ascending under pressure and more highly charged with reagents. Fig. 9 of my paper, showing the wedge-shaped spaces of corrosion described by Daubrée from Bourbonne-les-Bains, with their summits directed upward, gives actual proof of this.

My reference to the wedge-like form of certain deposits at Laurium was based on an ideal profile. In the spring of the present year (1894) I personally visited the district, and strove to secure more accurate drawings of the position and form of the deposits. I must confess that I was not able to find any such drawings, and I must therefore submit to the rebuke of Mr. Emmons. So far as I know the literature concerning the Laurium district, the only accurate drawings are those of the French company in the treatise of A. Cambresy.* (I take this opportunity to correct a typographical error in the pamphlet edition of my paper. Fig. 87 was taken, not from Cordella but from Huot.)

With regard to the essential difference of opinion concerning the Leadville deposits, I may observe that the reason I ventured to discuss that district without having personally studied it, is to be found in the magnificent monograph of Mr. Emmons, the interesting conditions which it describes, and its contradiction of current views as to the origin of the Leadville ores. Passing by all corrections and criticisms on points of minor importance, I wish only to keep in view this essential difference of opinion, and to inquire what were the convincing reasons which led Mr. Emmons to assert in this case a descent of the mineral solutions.

He separates the sources of the metallic substances into "immediate" and "ultimate." The latter, by reason of their purely speculative nature he does not discuss, but devotes himself to the former. Without being able to doubt that these substances originally came from great depths, and without being willing to assert that they came wholly from the country-rock actually adjoining the deposits, he believes:

1. That they came from above.

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* "Le Laurium," par A. Cambresy, *Rev. Univ. des Mines*, 3 ser., t. vi., 1889.

2. That they were derived chiefly from neighboring rocks.

With regard to the first of these propositions I can find in his elaborate monograph no tangible proofs whatever, only conclusions deduced from certain observations. The shape and position of the ore-deposits, whether of those at the contact between porphyry and lime, or those in the limestone, afford no conclusive proof of descending mineral solutions as their source. Indeed, this is disproved by the fact that the deposits were originally sulphides (as they are now shown still to be at greater depths), and such sulphide-deposits cannot be asserted to have been formed by solutions descending from the surface (unless such an application should be made of the case cited on p. 98 of my paper, namely, the reduction to sulphides by means of organic matter). The interior structure of the deposits and of the country-rock, so far as they are described in the publications on the subject, likewise fail to furnish any conclusive proof of this assumption.

In his re-examination of the mines in 1890, Mr. Emmons found, even in the original, unaltered sulphide-ores, no crustification, from which he concludes that in this case there has been no deposition of ore in open spaces, but a metasomatic replacement of the limestone. It is to be hoped that investigations on this point will not be wholly abandoned in future. Mr. Emmons mentions also his recognition of the granular structure, joints and cleavage of the original limestone in the sulphide-ores of the A. Y. and Minnie mines, and speaks of the cracks in the top of the ore-body, "through which the ore-bearing solutions had descended." This is clearly, as stated in this form, an expression of opinion. A detailed and purely objective description, particularly if accompanied with drawings, would be highly valuable, and might constitute the tangible proof, the absence of which I have pointed out. Mr. Emmons gives us ground to hope for further observations in this direction, based upon the latest developments of the mines. For the present, however, it cannot be said that we have any decisive proof from the interior structure of these deposits.

The facts described in the literature concerning Leadville may be equally well used in support of the ascension-theory. As I have remarked (page 98 of this volume), the ores were at first conceived to occur at the contact between porphyry and limestone, or confined to the lime; but afterwards it became clear that not the whole contact-surface as such, but only certain zones of it, could be regarded as the principal centers of the accumulation of ore.

These ore-shoots, lying in and near the contact-plane, were the channels of which the mineral solutions availed themselves. A parallel is thus furnished to various other ore-deposits; for instance, the zinc- and lead-deposits of the Alps, the shoots of which are near a contact of soluble with insoluble rock, and pursue the same direction as the stratification.* For the establishment of this analogy, credit is due to the mining engineers who have published their observations at Leadville, and, as Mr. Emmons observes,† have rendered valuable assistance in enlarging our knowledge of the facts as developed by mining.

The text of Mr. Emmons's great monograph on Leadville shows plainly (p. 572) that, under the impression produced by the first publication of Professor Sandberger, the author deemed the ascension-theory to have been already completely overthrown. He assumes that the type of a vein, as described by earlier authorities, is a purely ideal conception, and does not exist in nature. To show that these writers had before them, on the contrary, a real condition, I have cited the developments at Przibřam. If we substitute, in that case, for the space of discission the spaces occupied by the Leadville deposits, the situation, as concerns the question of the direction of the ore-bearing circulation, is not altered. The flat dip of the ore-shoots and the solubility of the country-rock at Leadville are scarcely decisive as to this question. Nor does the depth thus far attained in Leadville mining afford conclusive evidence. In my judgment, therefore, notwithstanding the differences between Przibram and Leadville, the same inference must be drawn in both cases as to the direction of the ore-bearing circulation. In other words, Leadville must be declared to be no exception to the general rule that ore-deposits carrying metallic sulphides have been formed by ascending solutions.

Whether the metallic contents were derived wholly or predominantly from the eruptive rocks adjacent to the deposits or occurring within a certain distance, is an independent question.

Mr. G. F. Becker's criticism (page 189 of this volume), having been prepared without opportunity for a thorough combination of authorities, is considered as preliminary only. It deals, as does that of Mr. Emmons, in the main, with metasomatic forma-

* See my treatise (1893), already cited, on the "Origin of Lead- and Zinc-Deposits in Soluble Rocks."

† Page 188 of this volume. See also "The Mining Work of the U. S. Geol. Survey," *Trans.*, x., 412 *et seq.*

tions, without reference to formations in open spaces, and, contemplating the former exclusively, seems to disparage the emphasis which I have laid upon crustification as a clear proof of the filling of open spaces. According to his view, the recognizability of successive deposits is dependent upon incidental local circumstances, but the instances he gives do not appear to me adapted to prove his proposition, that crustification may be produced by other causes than that which I have assigned.

The banded structure of agates, so far as I have had opportunity to study it, is a genuine crustification. It exhibits incrusted nuclei, stalactites, and other formations characteristic of deposition in an open space, quite independently of the question whether changes in concentration or rapidity of circulation or in the substances contained in the solution were the occasion of precipitation. In like manner the precipitate formed upon a piece of iron immersed in a solution of copper sulphate is a genuine crust, the iron serving as the cause of the precipitation; and the circumstances of such a precipitation in a space filled with solution, though the process take place above ground, present some analogies with underground conditions.

A party of mine-thieves once entered by night an old and extensive mine in Transylvania for the purpose of blasting off and carrying away an exposed mass of gold-ore. The shot opened a hole into an old working (*coranda,* in the Roumanian language), and one of the miners crawled through. The immensity of the space in which he found himself astonished him greatly, but his exclamations of wonder were cut short by the crowing of a cock, which revealed to him that he stood under the night sky, in a great surface-*coranda* or open quarry, which covered the whole area of the mine. Under some circumstances, therefore, it is clear that underground and above-ground are not so very far apart!

A mineral solution standing in a laboratory-beaker, exposed to the air, may practically represent, from our standpoint, a subterranean space, the lower part of which is filled with liquid and the upper part with gas, as I conceived it on p. 22 of my paper.

Mr. Becker doubtless means, by the examples he cites, to argue that the banded structure may originate also through replacement of the idiogenites by xenogenites. This may be true, but his instances do not support the hypothesis; for the pseudomorphosis of galena after *calcite* is not a replacement of *limestone* by galena. Moreover, not every "banded structure" is a crustification.

Mr. Becker names two sorts of indications of replacement, namely, crystalline pseudomorphism and the irregular enlargement of fissures in the replaced mass. I beg to say, that on pp. 14 and 15 of my paper, I have mentioned several other signs, such as the retention of the structure of the original mass; the transformation of fossils into ore; the occurrence of remaining nuclei of the original rock, etc., and that I also suppose a metasomatic process to have taken place, when the evidence is merely negative, that is, where indications of cavity-formation, in other words, crustification, are absent. But I have found deposits where the indications of both processes occur side by side, as, for instance, at Rodna, in Transylvania. It was at this place that I had the opportunity, thirty years ago, to demonstrate the metasomatic origin of an ore-deposit. Since that time, however, I have never visited the locality, and have received only superficial data concerning further developments. Outside of calamine-deposits, I have not encountered in my later explorations any cases of metasomatic formation; and I have been led to attach ever-increasing importance to the deposits formed in open spaces, the list of which, as known to me, has been continually growing, while their definite characteristics have become more and more unmistakably clear. Any difference of opinion which has arisen, as a consequence, between my American colleagues and myself, must be left to the judgment of investigators who are equally familiar with both classes of ore-deposits.

My statement, "It is difficult to believe that metasomatic processes could produce such pronounced ore-shoots as those described at Leadville," must be explained from the standpoint I have taken as to the origin of cavities in a soluble rock. On p. 19 of my paper, I have shown that, before the origin of the cavity, the rock-pores or interstices are filled with saturated solutions, and that a line of maximum flow must be subsequently set up between the point of entrance and some point of minimum resistance, along which line solutions not yet saturated, finding access to the rock, may ultimately dissolve out open channels or cavities. These will then possess a shape extended in one general direction, such as we encounter almost always in ore-deposits in soluble rocks. The Leadville mining engineers have established such a form for the Leadville deposits; and Mr. Becker has also found it in the quicksilver-deposits studied by him. If I have correctly conceived the formation of these ore-shoots, they should show some indications of free cavity-formation, even when they have been produced in part by the replacement of the original rock.

Finally, as regards the Eureka deposits, I seem to have been misunderstood. I did not assert that the spaces originally occupied by the Eureka ore-deposits had been formed by surface-waters. I merely said (in accordance with Mr. J. S. Curtis) that this was the case with the caves, which accompany the ores altered and redeposited by the action of surface-waters.

Mr. F. M. F. Cazin has called attention to an American example, furnished by the Vermont copper-mine, in which graphite (or organic matter, the remains of which are now represented by graphite), may have reduced the ore-bearing solutions. Mr. Cazin cites the fossil palms converted into copper-glance, in the Trias of Mexico, as proof that the copper was originally dissolved in the Triassic ocean, though perhaps in too small a proportion to injure animal life. With regard to that I must observe that these palms probably occur in a fresh-water basin, from which the character of the ocean of the period cannot be inferred; nor, *vice versa*, can the traces of copper found in corals be adduced as indicating the probable presence of copper in such a basin.

R. W. RAYMOND, New York City: The labor and pleasure of translating Prof. Posepny's contributions having fallen to me, I have taken special interest in the discussion which they have elicited; and I venture to believe that an attempt on my part to summarize the results thus far attained may be useful as a help to the further discussion which I trust will ensue, and will not be deemed an arrogant assumption of the position of a judge, which is as far from my intention as it is beyond my capacity.

No amount of latitude in such a discussion is reprehensible if it elicits new facts; for the accumulation of accurate data is really more important than the mere iteration of argument, and a new fact, however remotely collateral in its bearing, may turn out to be of inestimable value. In this connection, however, it should be noted that the fact is valuable in proportion as it is not merely the expression of an opinion. When we are told by some authority that he "found unmistakable evidences" of this or that, we are simply asked to accept his conclusion, which might or might not have been our own upon the same phenomena; and the weight we give to the fact of his opinion as indicative of the real facts behind it, which are what we want, depends upon our confidence in him, not only as an observer, but also as a reasoner. In my judgment we should be grateful to Prof. Posepny for the emphasis he has laid, not only in this paper but in many preceding publications, upon the supreme importance of what he has called *rein objective Darstellungen,* a phrase which I have weakened in my translations by rendering it "accurate descriptions," in the fear that the term "objective," used in that sense, would be misleading. In this connection I may remark, that when the admirable paper of Prof. Posepny was sent to me, it bore a title which would have been, literally translated, "Subjective Views on the Genesis of Ore-Deposits," the author meaning thereby to indicate modestly that he offered his paper only as an expression of the opinions to which he had been led by his own studies, and not as a statement of the settled results of science. I took the liberty of objecting to this title, on the ground that "subjective" views might be construed as opinions simply "evolved from the inner consciousness," without any foundation whatever in observed facts; and as a result of this correspondence, Prof. Posepny permitted the use of the simpler title, accompanied with such introductory explanations as would relieve him from the imputation of dogmatism.

Accepting, however, his use of "subjective" and "objective" as connoting statements respectively affected or unaffected by individual opinion, we cannot but appreciate and share his desire for "purely objective" reports of observed facts in the field of his studies. And, since it is extremely difficult to convey an "objective" description in writing, the superiority of a careful drawing (not an "ideal" diagram, though that has its uses, and is often a better vehicle of description than words) is clear. Prof. Posepny has practiced his own doctrine by illustrating his paper with numerous drawings, and, I may add, he has unconsciously enforced that doctrine by betraying his own doubts and difficulties in the interpretation of mere verbal and partly "subjective" descriptions, given by other authors.

The misunderstandings thus occasioned may be left to settle themselves through mutual explanations, such as have been made, more or less fully, in the course of this discussion. It need only be added here that Prof. Posepny's conscientious and frank declarations as to the limits of his personal observation and his careful references to all authorities cited, constitute a safeguard against error, a full guide to further investigation and a model for our imitation.

But the chief questions of interest to us, I think, are these: What are the characteristic and valuable contributions made by this paper to the theory of the genesis of ore-deposits? and, What are the definite issues on which Prof. Posepny's views differ from those of other observers, as the latter have been represented in this discussion?

Under the first head I think we may regard as pre-eminent the masterly exposition of the subject of underground circulation and the distinction established between the vadose and the deep circulation, the former actuated mainly by gravity and conditioned upon the relative position of the surface-outflow, the latter complicated by the effects of capillarity and pressure due to heat. This distinction supersedes the vague terms "ascending" and "descending," though the author has employed these terms, in accordance with popular usage, and has thereby incurred some unnecessary criticism. For it is really not of the slightest importance to the general theory of this subject whether a given mineral solution was moving horizontally or up and down when it produced a given precipitate. The only significant question is whether it was *on the way* up or down; that is, whether it belonged to the one or to the other branch of the underground circulation. The third view, namely, that such a solution might belong neither to the vadose downward circulation nor to the deep upward circulation, but to a "lateral secretion," Prof. Posepny practically declares to be inconceivable. As I understand his argument (or rather, perhaps, as I would state my own view, which I think to be in substantial accordance with his), it may be expressed as follows:

1. The aqueous solutions underground must be conceived either (*a*) as moving on a general downward course, as parts of the vadose circulation, above ground-water level, or (*b*) as penetrating still deeper into the rocks below drainage-level (the barysphere), or (*c*) as rising from those depths under pressure, overcoming gravity, towards or to the surface; or (*d*) as standing (held by capillarity or otherwise) in rocks, whether above or below the drainage-level, and not participating in the circulation at all.

2. Concerning the condition (*a*), which is most open to our obserservation we know a great deal. We know, for instance, from an overwhelming number of observations, that the solutions of the vadose circulation are oxidizing, and that (apart from the, probably rare, re-formation of sulphides by the action of organic matter) they do not precipitate sulphides, but, on the contrary, attack and decompose them.

3. Concerning (*b*), we know nothing by direct observation, but are forced to believe, and justified (by Daubrée's experiments, etc.) in believing, that such a movement actually takes place.

4. Concerning (*c*), we have the evidence derived from hot springs, etc., which has convinced all observers that there is in fact such an ascending circulation, whatever may be their conclusions as to the

depth of its origin or the degree of its agency in forming mineral deposits. The ascension-theory postulates concerning it only that it comes from depths below drainage-level, and is not moved merely by siphon-action, ultimately due to gravity.

5. Concerning (*d*), it may be said that solutions thus held without participation in the general circulation, while they may affect internal changes in the rocks they occupy, cannot begin, *until they begin to move*, a process of redistributing and concentrating by precipitation elsewhere the substances they hold in solution.

6. Moreover, solutions in the condition (*d*), though not participating in the general circulation, must have reached their *locus* by means of that circulation. They must be conceived as having been a part either of the downward or of the upward branch, or, in other words, as arrested portions of the circulation.

7. Whenever they begin to move, they must join one or the other branch of the circulation; and the deposits they may make must be the result of the laws of that branch, operating upon the nature of the solutions, this in turn being partly dependent upon their original source.

8. There is, therefore, no room for a hypothesis of ore-concentration and deposit in bodies of considerable size by "secretion," independent of circulation, or for a cycle of circulation, complete in itself, yet not participating in the general phenomena described. For continuous currents must come from somewhere and go somewhere; and neither inflow nor outlet is provided, except by the conditions of the general underground circulation, as described.

9. From this standpoint it is clear that the source of the substances carried in solution by a current must lie somewhere in the path which that current has traversed. If the theory of lateral secretion means no more than the assertion that the mineral solutions which have precipitated ore in a given fissure or space have traversed and leached some rock before entering that space and that this rock adjoined or lay in "reasonable proximity" to the space of deposition, it would mean, as to the first proposition, nothing that anybody denies; while, as to the second proposition, it would be a somewhat vague assertion, requiring definite proof in each case, and not entitled to the dignity of a general theory.

10. But the theory of lateral secretion, however it may have melted away under the fire of criticism, originally claimed more than this. Prof. Sandberger says:*

* *Untersuchungen über Erzgänge*, von Fridolin Sandberger. Wiesbaden, 1882, *Erstes Heft.* pp. 3, 4.

"The so-called descension-theory of Werner is purely neptunic, and regards veins as exclusively filled from above downwards by the deposition of ores from liquids, without answering the question, whence these liquids derived their metallic contents. The descension-theory remains good to-day for all cases where, in higher-lying rocks, those substances can be with certainty traced, which have collected as ore-deposits in cavities and fissures in lower-lying rocks, not originally containing them. If the ores are accumulated in fissures, they possess all the characters of fissure-veins. So far as my knowledge of ore-deposits goes, the filling of fissures by ores which can be clearly proved to have filtered in from above is not very frequent; but such fillings of irregular cavities are common."

After mentioning as an excellent instance the lead- and zinc-deposits of Raibl (which Prof. Posepny has discussed with very different conclusions), and declaring that he is at present concerned specially, not with such deposits, but with true fissure-veins, Prof. Sandberger proceeds to state as follows the ascension-theory, which he says, "still counts many adherents," and which he proposes to controvert:

"The ascension-theory assumes in all cases that the ores occurring in a vein-fissure were derived either not at all, or only in part, from the immediately adjacent country-rock (*aus dem unmittelbaren Nebengestein*), but on the contrary, from greater depths, and have been introduced into the fissures either by ascending mineral springs or by sublimation. The substances deposited in the veins should therefore be different from those of the adjacent rock, and should only occur in the latter as lateral impregnations from the fissures."

Confining himself to the supposed agency of ascending mineral springs, the author asserts that such springs would not, and in fact, do not, deposit minerals in their channels, and discusses at some length the case of Sulphur Bank in California, which he declares to be the only instance apparently contradicting his view. He argues against the conclusions drawn by others from this instance, and concludes as follows (p. 17):

"If, then, the only region in which it has been deemed possible to assume the filling of vein-fissures by ascending mineral springs as a process now going on, furnishes no trustworthy proofs for this assumption, what remains? In my opinion, only the leaching of the country-rock which bounds the fissures by seepage-waters which have penetrated it, and which deposit the dissolved materials as ores and gangue in the fissures of the same (or, in exceptional cases, the nearest neighboring) rock.* This is the so-called lateral-secretion theory in its most prosaic form; and it is this to which I have been so distinctly led by many years of observation and investigation that I am forced to consider it applicable to most ore-veins."

* "Nach meiner Ausicht nur Auslaugung des die Spalten begränzenden Nebengesteins durch Sickerwässer, welche dasselbe durchdrungen haben, und die gelösten Stoffe als Erze und Gangarten in den Spalten des gleichen oder ausnahmsweise auch in solchen des nächsten Nachbargesteins."

11. It is clear that this theory contemplates the exclusion of the agency of waters rising from below drainage-level. That there are such waters, is an admitted fact; and it must be also admitted that they are under pressure great enough to overcome gravity and friction. All fissures accessible to such waters, they must necessarily occupy; and it seems to follow inevitably that all fissures extending below drainage-level must be filled, up to that level at least, with waters either in actual circulation on their way upward, or temporarily arrested and confined. "Seepage" into such spaces is inconceivable.

12. On the other hand, currents under pressure would necessarily penetrate into the pores and interstices of the rocks bounding their main channels, and the deposit in such rocks of minerals carried from the fissures is more probable *a priori* than the deposit, in the fissures, of minerals dissolved from the adjoining rocks. The opposite would be true if the fissures did not contain water, a condition which can only be assumed when there is a lower outlet, that is to say, only in the zone of vadose circulation.

13. The advocates of lateral secretion must state, at least, their conception of the way in which "seepage" can take place from a porous solid holding water into an adjoining space also filled with water, and under higher pressure. That practically no interchange between the two will take place, even if the pressures are equal, is shown by the occurrence of fresh-water springs along our coast, separated by a few feet of sand only from the salt waters of the sea. It is often popularly supposed that the sea-water has been deprived of its salt by "filtration" through the sands; but the real fact is, that the mass of the sea bars the path of a circulation which would carry the spring-water into it, and the spring seeks another way to the surface, where it emerges perfectly fresh. The intervening sands are doubtless filled with brackish water, but this takes no part in the circulation, and therefore carries no salt into the channel of the spring. If the Atlantic Ocean cannot "seep" salt into a spring of fresh water, how could a rock, not included in the path of a continuous circulation, impregnate any portion of that path by its "seepage?"

14. Again, it is conceivable that gash-veins, and other spaces wholly within a given rock-mass, may receive concentrations of mineral by "seepage," though even in this case, if the process is to result in considerable accumulations of mineral, it must be a long-continued one, supported by an inflow and outflow; in other words,

it must be a part of a general ascending or descending circulation. And since the ascending circulation involves a pressure from the fissure towards the wall-rock, that is, in the wrong direction for "seepage," it follows that, except in the vadose region, and apart from highly exceptional conditions, the products of the leaching of any given rock-mass are not likely to be found predominantly in adjoining fissures.

15. The theory of lateral secretion, therefore, is essentially confined to the region of the vadose circulation; and those who would apply it to the origin of deposits containing sulphides must be prepared to maintain that those sulphides have been deposited from solutions moving downwards or laterally, under the influence of gravity, in other words, surface-waters. Prof. Sandberger does not hesitate to accept this alternative, although he does not perceive, apparently, how it confines the sphere of his theory. According to his view, the metals are disseminated in the country-rocks and silicates, and these rocks contain also sulphate of soda, and other soluble alkaline sulphates, as well as chloride of sodium, all of which, he supposes, are converted by organic matter into alkaline sulphides, which transform the metallic silicates into metallic sulphides.

16. But this explanation encounters two serious difficulties. In the first place, it is opposed to the overwhelming evidence that the downward circulation does not characteristically deposit sulphides, but attacks them; that it does not characteristically contain alkaline sulphides, but alkaline carbonates and free carbonic acid and oxygen. In the second place, the explanation breaks down in the presence of fissures filled with sulphides, extending far below any present or conceivable past drainage-level. The sulphide ore-deposits in such fissures, at the greatest depths attained by mining, show no structural differences or other indications of a different origin, as compared with sulphides in the levels above. There is a change at water-level, but it is notoriously a change from oxidation above, to absence of oxidation below, that level.

17. The lateral-secretion theory, therefore, so far as it is true at all, is no more than a subordinate division of the theory of the formation of deposits in open spaces above drainage-level; and even here, it is neither necessary nor plausible, as the explanation of deposits which continue downwards, and must be referred, as regards their lower portions, to a deep source. Such deposits may have been altered in character and even in form, in the vadose region; they probably originated in the deep region.

18. On the other hand, the hypothesis of ascending waters as the vehicle of solution and deposition does not exclude the idea of the leaching of any rock traversed by such waters. It indeed assumes such a leaching as having taken place somewhere. But, as opposed to the theory of lateral secretion (modified to lateral circulation) it assumes the rock immediately adjoining a vein-fissure (when the fissure continues deeper) to be the least likely, not the most likely, source of the metallic ores. And on this point it appeals to the phenomena of crustification. Nothing is plainer than the evidence afforded by the successive crystalline crusts of an amethyst geode, for instance, that the deposition took place first upon the walls of the cavity, afterwards upon the crust thus formed, and so on towards the central druse. The very first deposit evidently covered the wall with an impermeable layer; and the material for all succeeding deposits must have come (as the sections of many geodes show visibly that it did come), through a passage from without the mass of the geode. In like manner, the crustified filling of a fissure-vein cannot well have come from the walls of the vein at the place where the first crust deposited would necessarily close those walls. The crusts have been deposited from a solution between them. The central druse was not first formed, and then pushed out by successive deposits behind it, as the bark of a tree is thickened. The solution depositing the crystals in successive crusts must therefore have been part of a current; and its entrance and exit can scarcely be sought, as a rule, in the walls it has crusted. A side-fissure, entering through either wall, is, of course, not impossible or uncommon. But it cannot be assumed to exist, without proof. And when such a thing is actually found, its effect upon the vein is so marked as to raise a strong presumption that the normal source of the vein-solutions was not in that direction.

19. Prof. Posepny has laid much emphasis upon crustification, as he has defined that term. I think he is right in so doing; and I may remark incidentally that his use of new special terms (which has been objected to by some), is justified, in this case, as in other cases, by the greater precision of thought thereby secured. The disadvantage of a preference for ordinary and familiar words, when such words may have many meanings, is illustrated by the manner in which Prof. Posepny, on the one hand, and his critics, on the other, have been misled by the ambiguity of "banded structure." He interprets "banded structure," or equivalent expressions, in some of the authorities he cites, as meaning crustification, and they say

that banded structure may arise in several ways, intimating thereby that crustification is not a sure proof of deposition upon cavity-walls. The verbal misconception being corrected, it seems to me that there is no difference between the parties on this head.

20. The assertion that a current is necessary for the deposition of such crustified accumulations is not to be construed as excluding variations in velocity, or occasional stoppages and intermissions. The objection of Prof. Sandberger, that mineral springs do not, as a fact, deposit solid substances in their channels, seems to be based upon the conception of such springs as ascending with unvaried velocity, as if through pipes of uniform diameter. Even pipes, as Professor Posepny reminds us, have been known to receive interior incrustations; but the probability of such deposits is much increased when the effects of variations in the nature and size of the channel are taken into account. *Mutatis mutandis*, the analogy of the deposition of sediments by a running stream is available here. As sands and clays, carried in suspension where the current is most rapid, are dropped where it is checked through widening of the channel, or from other causes, so the deposits of a mineral circulation will naturally be greatest where the movement is slowest, or is even temporarily arrested altogether; and they will be reduced to a minimum, other things being equal, where the current is most rapid. The phenomenon of distinct crustification, in fact, requires the hypothesis of a relative quiescence of the menstruum. And instances are not wanting underground in which the widening of the vein-fissures, or the change to a flatter dip, has apparently favored the deposition of ore.* The ascension-theory does not exclude these obvious considerations. All it asserts is, that the portion of solution entering a given space, and depositing therein a precipitate, must thereafter escape and give place to another portion of solution, if the process is to be repeated; and that, with regard to deposits of sulphides, formed below drainage-level, the only escape is ultimately upward. But the phenomena of crustification in veins afford, in

* On the other hand, increased width of "vein-matter" has often been due to a splitting of the fissure, and the enclosure of fragments of country-rock, which is afterwards more or less transformed into gangue, or remains as horses in the vein. Or, such increased width may be (as in the Cornwall tin-mines) the result of a mineralization of the country-rock beyond the limits of the original fissure, producing a mass of altered rock impregnated with ore (the *Zinnzwitter* of the Germans). In such cases, while the aggregate of mineral deposited is doubtless much greater than it would have been had the solution passed through the narrow fissure only, the richness of the material is reduced by the admixture of gangue and rock.

my judgment, another argument against the theory of lateral secretion. Namely, it is well known that the crustification, even in typical fissure-veins, is not everywhere distinct. If it can be observed, with its characteristic central druse, in one part of a vein, it is held (properly, I think) to be (in the absence of evidence to the contrary) a proof that the similar ores of other parts of the vein have been similarly deposited. The absence of crustification in some places may be explained, on the ascension-theory, by the varying speed of the current, and the varying nature and dip of the walls, as affecting the deposition of adherent crystalline crusts. The chemical or physical causes inducing precipitation may simply produce a suspended precipitate, to be subsequently deposited as a sediment. But if lateral secretion has produced crustification, such as is observed in fissure-veins (as I think, with Professor Posepny, that it has not) then that structure, it seems to me, should be more uniformly distinct in such veins than it is. For the conception of lateral secretion into a fissure excludes the conception of a current under higher pressure, already occupying that fissure; and the local interference of such a current with the quiet process of crystallization is therefore out of the question.

21. The comparatively small amount of mineral matter contained in the ascending springs of the deep circulation, originating below drainage-level, is to my mind some indication that they have already deposited somewhere the larger part of the substances they have held in solution. They are never saturated solutions. As we find them, they contain what we may suppose to be only remaining traces of the metallic constituents which they may (we may almost say must) have carried at greater depths, temperatures, and pressures. Is not the presence of these minute remainders really an evidence of the larger amounts once present, and therefore of a precipitation *en route?* In connection with this question, the probable conditions of the deep zone must be borne in mind, such as, not only the increased solvent power of the waters of that zone, but also the probable slowness of their downward progress, which is practically (according to Daubrée) a seepage, and which must favor the formation of saturated solutions.

22. In reply to this suggestion, the question may be raised, how the deposition of ores, extending almost or quite to the surface, is to be accounted for, if the solutions now encountered below drainage-level, are already so nearly exhausted as to be capable of comparatively little further precipitation. Without forgetting that the most

dilute solutions may still give precipitates under chemical or physical changes of condition; and that such precipitates, however insignificant, may attain a considerable aggregate amount by long-continued repetition, I think the more comprehensive answer to the above question is found in the conclusion to which we are led by the ascension-theory, that deposits carrying metallic sulphides, though they reach the present surface, were formed mainly below the influence of the vadose circulation, and therefore under conditions such as may now obtain at depths beyond our observation.

23. This suggests another point, to which Prof. Posepny has called attention, and which was acutely recognized by Cotta, many years ago,* namely, the fact that speculations upon the relation between the contents of mineral veins and their depth are largely vitiated by the vagueness and uncertainty of the element of depth, as estimated by comparison with the present surface. In most mining regions there is unquestionable evidence of great denudation, which has probably removed from the surface a larger mass than has been penetrated anywhere by mining. It seems impossible, therefore, to argue as to the continuance of ores "in depth," meaning thereby beyond 1000 or 2000 feet from the present surface, when that surface itself may have been 10,000 feet underground at the time the ores were deposited. We may imagine that the ascending waters in a vein now rich in metallic deposits "from the grass-roots down," once continued their upward course to the *former* surface, emerging as dilute solutions; or never reached that surface intact, but encountering the vadose circulation, became a part of it; and, in either case, precipitated less and less metallic matter as they ascended. Conversely, we may reasonably imagine that, if we could retrace the course of a mineral spring coming from the deep zone, it might lead us back to the region where it had deposited the treasure of which it now exhibits, at most, only faint remaining traces. And what we might thus fairly imagine concerning an actual spring might be equally true of the channel of a former spring now closed altogether, or occupied only, under changed conditions of altitude and drainage, by the vadose circulation—that is to say, of a fissure-vein, comparatively barren or lean at the present surface. In other words, the present surface is an arbitrary section, cutting off the veins. Those which it happens to intersect in their richer portions, are naturally the ones which are developed by mining. Those which it shows to

* *Die Lehre von den Erzlagerstätten*, Freiberg, 1858. Part I., p. 129.

be locally barren, are naturally not thus developed, unless local experience supports the hope that they will improve in depth. Such a local experience is doubtless the foundation of the maxim which Cornish miners have carried throughout the world, that "a fissure-vein grows richer in depth," a proposition for which, as a general guide for mining (apart from the effects of surface-waters, which may be sometimes impoverishing), is without foundation in experience. For although a comparatively barren fissure may be, and has often been shown to be, the upper part of a vein carrying rich ores below, there is no general law that it must be so; and, moreover, there is no way of determing *a priori* the depth of the barren zone, measured from the present surface.

24. On the other hand, while the varying positions of the present surface prevent generalization as to the relations of ore to "depth," it is unquestionably possible that there may be, in a given fissure, a relation of that kind. The ascension-theory neither asserts nor denies such a supposition. Mr. Rickard's suggestion that the deeper zone must be the region of solution, and a higher zone the region of precipitation, is speculatively reasonable enough; but it amounts to a proposed subdivision of the barysphere into two regions; for the deep zone which Prof. Posepny has called the barysphere includes everything below our observation, and it is in that zone that both solution and precipitation are supposed to have taken place to form the deposits of metallic sulphides. In our ignorance of the conditions of that unknown region, it is scarcely possible or necessary to frame hypotheses concerning them. The practical bearing of Mr. Rickard's suggestion lies in his connection of it with an alleged general phenomenon of the impoverishment of veins in depth, as shown by experience in mining.

25. As to this alleged general phenomenon, I would say first, that even if it were proved, it could hardly be ascribed to the cause suggested by Mr. Rickard, namely, the predominance of solution in lower zones and the confinement of precipitation to higher ones, because the depths reached in mining are not great enough to warrant such a deduction, and also because the instances (such as Przibram) of rich ores continuing for great vertical distances, and down to levels among the deepest ever opened by mining, contradict the hypothesis.

But it must be confessed that there is much evidence which seems to corroborate Mr. Rickard's statement as to the exhaustion of mines in depth. This evidence needs, however, to be carefully collated and critically sifted, before it can be accepted as the indication of a natural law.

a. In such an inquiry all cases must be rejected in which oxidized surface-ores have been mined down to water-level, and the mine has been abandoned by reason of treating the refractory sulphides. In many such cases the oxidized ores are actually richer (*e.g.* in gold) by reason of the alteration they have undergone; but this is not pertinent to the question of original deposition.

b. The abandonment of mines by reason merely of the increased cost of deep mining must be also set aside as affording no evidence on this subject.

c. The fact that in mining a bonanza is traversed, and a relatively barren zone occurs below, does not necessarily indicate a relation between barrenness and depth. The occurrence of a bonanza very frequently involves barrenness of the neighboring portions of the vein. That this is the case on a horizontal line is abundantly proved. An instance in point is furnished by the Bullion mine situated on the Comstock lode, between mines which have produced many millions. The expenditure of millions on the Bullion never produced, so far as I know, a ton of profitable ore. Why should not a similar alternation of rich and barren places occur in the vertical line? The cost of exploration in depth, and particularly in sinking, naturally discourages mine-owners; and the abandonment of an operation under such circumstances really proves nothing.

d. In any case of alleged impoverishment of a vein in depth, not only the actual depth below the present surface, but also (so far as it can be estimated) the probable amount of denudation which the surface has undergone, should be taken into account.

e. The nature of the ore also may have a distinct bearing upon this inquiry. It is my impression that of the loose and vague evidence thus far accumulated, a large part refers to gold-ores, and particularly to free gold in quartz, as "giving out" in depth. I remember that in my last conversation with the late Joshua E. Clayton, a close and conscientious observer, he told me that he had personally examined numerous quartz-veins, occurring all along the flanks of the Sierra Nevada, and had found in every case that the veins, as exposed in the deep cañons cross-cutting them, hundreds of feet below their outcrops on the mountains, were poorer in gold than at the higher level. This testimony is valuable, and it may be that it indicates a general law as to such gold-veins; but it must be borne in mind that some of the California gold-mines have been worked deeper than any cañons have cut the veins. Yet, on the other hand, many of the deep gold-mines of the State have been ultimately abandoned.

26. Mr. Rickard's suggestion has a practical side of great importance. Namely, although, in my judgment, there is no established general law, discouraging the exploration of a vein in depth, so long as the fissure continues well-defined, and especially if it carries any thread of ore, it is undoubtedly the case that mining explorations are too much confined to sinking and drifting, and that there is too little cross-cutting for parallel fissures and ore-bodies. To some extent this is one of the results of our absurd United States mining law, which lays so much stress upon the "apex" and the "lode;" but the mistaken practice of neglecting cross-cuts into the country-rock is not confined to mines operated under that law.

27. Another important point in Prof. Posepny's paper is his proposition (based on Nöggerath's observations in the main, but not lacking other support) that open spaces of dissolution may be formed by ascending as well as descending currents. Since the process of solution depends upon the character of the liquid agent, this is only saying that some ascending waters may be able to dissolve portions of the rocks they traverse; and that if such rocks belong to the class represented by limestone, such currents may produce in them caves and channels, comparable to those notoriously produced by the descending waters. I confess, this seems to me a reasonable proposition, however meager may be the proofs thus far adduced. And I cannot understand, at all events, how opponents of the ascension-theory should object to it; for they do not deny that there are such things as ascending mineral springs, and that these springs hold in solution such substances as carbonates and free carbonic acid. What they deny is that these springs deposit anything in their channels. In that case, they must dissolve without redepositing; and the evidence that they have actually excavated channels underground is afforded by their constitution. They bring the evidence of their guilt with them. To reply that they are part of the vadose circulation only, and hence, no matter what their local direction, belong to the descending branch, is not permissible; for springs encountered at great depths in mining have the composition required to make them active solvents. How can it be doubted that the hot waters of the springs encountered in the Bohemian mines (see Nos. 1, 2 and 3 of Prof. Posepny's table, p. 38), which contain "a notable quan-

tity of free carbonic acid," would, if they traversed limestone, excavate cavernous channels in it?

28. Moreover, there is reason why a liquid solvent under pressure, occupying a space in a soluble rock, should eat its way upward rather than downward or laterally—namely, because the insoluble portions of the rock, loosened by the action of the solvent, fall away from the roof of the cavity most easily and completely, leaving fresh surfaces open to further attack. Whoever has visited, as I have done, the salt-mines of the Salzkammergut, in the Austrian Tyrol, where salt is extracted by *Sinkwerke*,* and has observed how the great underground rooms, repeatedly filled with water under pressure, *travel upward* through the mass of the saliferous rock, as their roofs are attacked and dissolved, while their floors are relatively protected by the fallen insoluble *débris*, can scarcely doubt the possibility of the formation of spaces of dissolution by ascending waters. One variety of this extraction—*viz.*, the so-called "continuous watering," employed in some of the mines—presents a still closer analogy. In that method the water is not introduced periodically into each *Sinkwerk*, to be withdrawn when saturated, and wholly replaced with fresh water for further solution. On the contrary, the flow of water is made continuous, fresh water being admitted at one point while saturated brine is conducted away at another. It is true that the actual flow of the current is downward, the fresh water being admitted above and the brine drawn off below; but this is not an essential feature of the process itself. The actual progress of excavation by solution is upward, and the essential condition is the presence of a pressure sufficient to cause the solvent to penetrate the roof. That being secured, the roof is mainly attacked, the side much less, and the bottom scarcely at all.

29. Prof. Posepny's "Theory of the Sinking of Heavier Constituents," as applied to the distribution of gold, etc., in placers, is a valuable addition to our knowledge of such deposits. It is highly desirable that our members engaged in placer or hydraulic mining should give us the results of careful observation upon the conditions presented by the gold-deposits of this country, Few of them have done so thus far, and the field is full of interesting data not yet put into shape for preservation. I am inclined to think, for instance, that "the hypothesis of a natural concentration in running water," which Prof. Posepny disparages, and for which he proposes to sub-

* Described in Serlo's *Leitfaden zur Bergbaukunde*, 4th ed., Berlin, 1884, vol. i., p. 611 *et seq.*

stitute the theory just mentioned, would find some support in the phenomena of many American placers, where the gold is concentrated not only on a false or true bed-rock, but in distinct channels along that plane, so that the placer-miners, for many years, have pursued the tortuous channels of "pay-dirt," leaving large areas unworked, which, for some reason or other, did not pay, though they were equally "in the gulch," and had the bed-rock under them, like the rest. I do not mean to deny the possible agency of such a concentration by gravity in loose sands and gravels as Prof. Posepny has postulated, but I fancy it would be hard to explain the distribution of the gold in many of our American placers except by including among its factors the action of running water. If I am correct in this impression, I may venture to consider the case as one in which Prof. Posepny's heaviest artillery can be turned back upon him; since his theory of "settling" may be called a sort of dry "seepage" or secretion by gravity, and my view may be considered as the assertion that, here as elsewhere, there is no deposition without circulation.

Concerning the differences of opinion developed by this discussion, I think it may be said that, upon closer examination, they are not important, except as to the explanations of certain districts and ore-deposits which Prof. Posepny has rather deduced from the writings of others than based upon observations of his own.

With regard to nearly or quite all of these instances, our own experts are not agreed, so that Prof. Posepny has respectable backing for his views, whether they turn out in the end to be correct or not. Certainly he has presented them with a conspicuous absence of dogmatism, and they have been received on the part of our members, I am happy to say, with the respect due to the merits of a veteran authority, and with gratitude for the generosity which has enriched the *Transactions* of the Institute with one of the most important contributions to technical science ever made through that medium.

F. M. F. CAZIN, Hoboken, N. J.: Bergrath Posepny rejects my assumption of the presence of copper in the Triassic sea, claiming that the evidence adduced does not hold good, and observing in support of his view, "that these palms," the cuprified fossils of which are found in the "coarse yellow sandstones and conglomerates overlying the red beds of the Trias," "on the junction of the Trias with the Cretaceous,"* "probably occur in a fresh-water basin."

The fossil in question is identical with "Podozamites crassifolia,"

* J. S. Newberry, *Report on the Expedition of* 1859, pages 117 and 118.

described* as occurring in the State of Sonora.† Palms cover at this date a narrow belt along the northern coast of South America, disappearing in the interior. The location of the Nacimiento copper-belt is one, from which the Cretaceous sea retired last of all on this continent. Its waters at this date are shed into the Gulf of Mexico, with no indication anywhere of a pre-existing barrier. I am acquainted with the English and North German Wealden formation, having mined in it; but, as J. S. Newberry did not, so I did not, find a trace of evidence for assuming a sweet-water formation at the Nacimiento copper-deposits.

My assumption, therefore, stands on proper ground, unless more than a probability to the contrary be offered.

If ever J. S. Newberry's and my own observations as to the geological position and normal character of the deposits in question have been objected to on the ground of actual local observations, I am ignorant of the fact.

JOSEPH LE CONTE, Berkeley, Cal.: All geologists, but especially students of the phenomena of metalliferous veins, are under deep obligation to Bergrath Posepny for the very lucid exposition and abundant illustrations of these phenomena contained in his admirable treatise on the "Genesis of Ore-Deposits." Like the previous treatise of Sandberger, though taking an extreme opposite position, it must powerfully revive the interest of students and observers in the purely scientific theory of metalliferous veins. Although read at the International Engineering Congress of the World's Fair at Chicago, in 1893, it has only very recently fallen under my eye. As I have thought much, and published somewhat on this subject, I beg leave to say a few words in the way of criticism on this masterly work.

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* *Ibid.*, p. 145.

† It is one of the various strange things observed in geological reports, that are the compound work of many—that, although J. S. Newberry prominently and repeatedly refers to the palm-fossils of Nacimiento, his plates show naught under that head, but do show a true image of these "palm-leaves," described as collected in "quite a number" by Mr. Redmond from "the Triassic strata at Los Broncos, Sonora," a locality not visited by the expedition of which the report is made. I may mention as an amusing coincidence, that at Prof. Newberry's and at my time there was at Nacimiento a silver-smith, who hailed from Los Broncos, Sonora, and who, whenever in his trade he needed copper, smelted it in a miniature crucible on a miniature Mexican forge with accordion-shaped bellows, using as his material for copper the fossil palm-leaves of Nacimiento, of which within easy walk from his door he could pick up all he was in need of, and of which he kept on hand "quite a number."

All, I think, will agree that one of the chief merits of the work consists in the clear distinction which the author draws between what he calls the *vadose,* or superficial, and the *deep* circulation of underground water; the water in the one case containing air, and therefore oxidizing; in the other, destitute of air, and therefore, non-oxidizing; the one circulation driven by gravity alone, the direction of the current being determined by the place of outflow, the other driven largely by heat received in the lower parts of its circuit, and the direction of its current being mainly upwards.

We are all, I think, especially pleased with the significance he finds in, and the importance he attaches to, the oxidizing and non-oxidizing effects of these two circulations respectively. It follows, from this view, that metallic sulphides are not deposited from the waters of the vadose circulation, unless under the exceptional conditions of the presence of excess of organic matter; and therefore, that the presence of metals in the form of sulphides is usually a sign of deposit from ascending currents of the deeper non-oxidizing circulation.

Most of us, I think, too (and I among the number), will agree with him, as against Sandberger, that since great deep fissures are not empty, air-filled spaces, but are necessarily filled with water, deposits in them cannot take place by seepage or oozing, or lateral secretion from the immediate bounding-walls. Also, that the phenomena of crustification or ribbon-structure of vein-contents seem to negative such a mode of filling as is supposed by Sandberger; that this structure does not indicate a filling by oozing and trickling of waters containing soluble matters, down on a free surface, but rather a deposit in successive layers inward from water contained in the fissure.

For all this, and very much more which I cannot repeat here, we are under many obligations to Bergrath Posepny. Nevertheless, I cannot but think that he carries his ascension-views much too far; that in his zeal against the extreme lateral-secretion views of Sandberger, he has gone to the other extreme of ascensionism; and that a truer view than either may be found in one that shall combine and reconcile these two extremes.

The evidence of the extremeness of his views is found, and indeed, is embodied, in his use of the term *barysphere.* As contrasted with *lithosphere,* this term can only mean a region in the interior of the earth, the materials of which are heavier, because more metalliferous, than the superficial lithosphere visible to us. From such a metalliferous barysphere, he thinks, all the metals of ore-deposits (with trifling exceptions) are derived. It is true, that in his reply to objectors, he speaks of his barysphere as only the equivalent of the "unknown depths" of other writers; but, it must be remarked, that this latter term, while open to the objection of indefiniteness, does not, necessarily, carry with it any implication of a region peculiar in its density and in the abundance of its metallic contents, although it is doubtless often used with this implication. The word barysphere, on the other hand, fixes definitely an idea which has long floated vaguely in the minds of many writers on this subject. It will, therefore, form the central point of my criticism.

I.—Is there a Barysphere within Reach of Circulating Water?

It is true, that the earth increases in density from the surface towards the center, and probably to the very center itself. This is shown by the fact that the mean density of the earth is more than double that of the superficial parts. It is true, also, that the increasing density, while certainly due, in part, to condensation by increasing pressure, is probably also due, in part, to difference of material, and especially to the presence of metals, as sulphides or native, in greater abundance in the interior parts. It is true, therefore, that the deeper parts of the earth are certainly heavier, and probably more metalliferous, than the superficial parts. In a word, it is true that there is a barysphere, and probably in the sense used by Posepny, as being more metalliferous. But how deep must we go to find this barysphere? Let us see.

Taking the density of the superficial parts of the earth (or what Posepny would call the lithosphere) at 2.5, and the mean density of the earth as a whole at 5.5 (Posepny accepts these figures), and assuming the simplest rate of increase, viz., a uniform rate, then an actual density equal to the mean density of 5.5 would be reached at the depth of 1000 miles, and the central density would be 14.5* This is an increase of 3 in 1000 miles. At the depth of 100 miles, therefore, the increase would be 0.3 and the density only 2.8. Is it at all probable that we ever have circulating water coming up from any such depth as 100 miles? And yet, 2.8 is only about the den-

* By mathematical calculation based on the above conditions, an actual density equal to the mean density of 5.5 is reached at depth of $\frac{1}{4}$ radius from the surface. Multiplying this gain of 3 by 4 and adding the surface density of 2.5 makes a central density of 14.5 ($3 \times 4 + 2.5 = 14.5$.)

sity of our more basic eruptives, and therefore, wholly undeserving the name of a barysphere. Circulating water may possibly come up from as deep as 10 miles, but, at the same rate of increase, the density there is only 2.53—an increase over the superficial density wholly inappreciable. Dr. Raymond, interpreting Posepny, defines the barysphere as all that interior region, the circulating water of which would not come up at all without the aid of heat. Does this mean all but the superficial region traversed by the vadose or oxidizing circulation? If so, it cannot be far from the surface, and the term barysphere, as applied to it, is surely wholly inappropriate and misleading.

But it may be answered that all this reasoning is based on the assumption of a *uniform* rate of increase of interior density; while in fact the great mean density of the earth may be explained by the existence of a highly metalliferous shell at no great distance beneath the surface and therefore within easy reach of circulating waters. To this view I make the following objections:

1. All our general reasonings concerning the cause of the great mean density of the earth, whether (*a*) condensation by increasing pressure, or (*b*) arrangement of materials of a primal fused earth according to their relative specific gravities, would make the increase progressive to the center. In fact it is hard to conceive the conditions under which a dense metalliferous shell a little way beneath the surface could be formed.*

2. We have abundance of materials coming up in eruptions from depths as great as circulating water is ever likely to reach, and yet these materials show no such density and metalliferousness as is implied in the term barysphere.

But again, it may be objected that I greatly underestimate the depth which may be reached by underground water. This brings up an important but difficult question. Is there any limit to the depth to which meteoric water may penetrate? If so, what determines the limit and where is it? These are questions which science is probably not yet prepared to answer definitely. I once thought,

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* Of the two causes mentioned above, the first would probably produce increase at an increasing rate and put the place of density equal to mean density deeper than $\frac{1}{4}$ radius down. The second might give rise to any kind of rate according to the relative amount of the different kinds of metals; but not improbably to a decreasing rate and put the place of mean density higher. The combination of these two would make an indeterminable rate; but something like a uniform rate is as probable as, perhaps more probable, than any other.

that since the pressure of a water-column increases uniformly with the depth, while the elastic tension of steam in contact with water increases with increasing heat at an increasing rate, so as to develop a logarithmic curve, there must be a depth at which the tension of steam would be equal to the downward pressure and that at that depth would be found the limit of underground water; and I expressed this conclusion in my *Elements of Geology*, page 99. Further reflection has convinced me that the conclusion is unwarranted. Such a limit would undoubtedly be reached if the increase of tension continued to follow the same law indefinitely. But it is now known that at a certain temperature, called the critical point, steam has the same density as the water from which it is formed. At this point, therefore, it may be regarded as either steam or water indifferently, and under the slightest change of temperature it takes the one form or the other. Beyond this point it is no longer steam in contact with water, but dry steam, which we know follows an entirely different law. Now the critical point of water is about 700° F. and the tension of steam at this point is about 200 atmospheres. Taking the increase of underground temperature at 1° for 53 feet, or 100° per mile, the temperature of 700° would be found at the depth of seven miles. But the pressure of a water-column there would be about 1100 atmospheres. The tension has not yet even nearly reached the pressure; and, as the law changes here, it would seem that the tension would never overtake the hydrostatic pressure at all. Therefore, if the undergronnd water is limited at all in its downward course, as is probably the case, it must be limited in some other way, probably by increasing compactness of material, under the increasing pressure of superincumbent rock, which, by closing up the pores would inhibit further penetration, or would make it easier for the water to come up again in ascending currents.

I think we may reasonably conclude, therefore, that whether there be a limit to underground water or not, it is certain that below a certain moderate depth, say 8 or 10 miles, such water cannot be circulating; for beyond this the compactness of rock under superincumbent pressure would be such, that while capillarity and weight of water-column might still urge further movement, passages sufficiently open to allow currents of circulation could not exist.

We may assume, then, that the limit of circulating water cannot be more than 10 miles in depth. Below this, water may indeed penetrate by capillarity and by weight of its own column, but such water does not enter into ordinary circulation, although it may come up in volcanic eruptions and indeed supply the force of such eruptions. Still, below this again, and even to the very center, there may possibly be what Fisher calls *constituent* water, *i.e.*, original water occluded in the primal fused magma of the earth, still present in the interior and coming up in volcanoes and (according to him), the cause of their eruptions. If there be such, it is not circulating water in the ordinary sense, and therefore may be left out of account in this discussion.

Underground water may be conceived, therefore, as existing in three possible conditions, but more and more doubtfully in the order named :

1. Circulating meteoric water. This of course is certain. It probably extends but a few miles (8 or 10) below the surface.

2. Meteoric water, but not circulating. The existence of this is probable. I have been accustomed to call it "volcanic" water, because it is a probable source of the eruptive force of volcanoes.

3. Constituent water, originally occluded in the primal magma of the incandescent fused earth, and still occluded in the materials of the interior. This, Fisher thinks, is still escaping, and in doing so, fuses its way towards the surface, and finally emerges in volcanic eruptions. This, of course, is very doubtful.

Of these three, if they all exist, we are concerned, I believe, with the first only.

We have assumed 10 miles as the limit of circulating water, and therefore the limit of depth from which metals may be derived. But at that depth, as already shown, there is no "barysphere" in any intelligible sense of that word. For the difference in density and in metalliferousness between the rocks there and those at the surface is quite inappreciable. We have, in fact, much material coming up from this very region, and therefore know its density. Our more basic rocks are indeed far denser and more metalliferous than the average of that region, having acquired greater density by differentiation from an average magma representing that region.

I believe, therefore, that the greater abundance of metallic ores in solution in ascending waters is the result, not of the greater abundance of metals in their lower courses, but of the greater *heat* which they take up in that part of their course and the greater *pressure* to which they have been subjected there. Both heat and pressure greatly increase the solvent power of water upon the feebly soluble metallic sulphides. Thus heavily freighted, the waters lose, in ascending, both heat and pressure, and therefore deposit abundantly in their upward course. In a word, ascending waters are rich in metallic contents, not because they have traversed a barysphere, but *because they have traversed a thermosphere.* With equal heat and pressure, I am convinced, they would get as much metal from our more basic rocks here at the surface as they now do from the hypothetical barysphere. These ascending waters are non-oxidizing, not because they have never seen the air, *i.e.*, are not meteoric, but because they have exhausted their oxidizing power by previous oxidation of metals, of organic matters, and other oxidable substances in the upper parts of their downward course.

II.—Vadose *vs.* Deep Circulation.

Again, I think, Posepny draws much too sharp a distinction between his two kinds of circulation; not indeed as to their oxidizing and non-oxidizing properties, but as to the force of circulation in the two cases respectively. In his anxiety to distinguish them sharply, he speaks as if the forces of circulation in the two cases were entirely different, being gravity or hydrostatic pressure in the once case and heat and capillarity in the other. Now nothing can be more certain than that hydrostatic pressure is the *fundamental* cause in both cases alike; although heat, by lightening the ascending column and thus disturbing the hydrostatic equilibrium, is the *immediately determining* cause in the latter. As Mr. Rickard, in the discussion, has justly pointed out, the effect of heat in the underground circulation is exactly like its effect in determining circulation in a system of house-warming pipes.

Again, Posepny lays much stress on *capillarity* as an additional force urging forward the circulation. But surely this cannot be so. Capillarity is indeed a powerful force, urging water to where there is none, but an equally powerful force fixing it where it is. So far from assisting, it powerfully impedes circulation, and, where it is strong enough, inhibits it altogether. Dry clay is a powerful absorber of water, but, when once wet, it becomes impermeable to circulation.

In fact, Posepny sometimes speaks of the deep barysphere circulation, as contrasted with the vadose circulation, in such terms that one is left in serious doubt whether he regards the former as meteoric water at all; and yet he speaks of it as circulating. Sometimes it seems as if he regarded his vadose water alone as meteoric and his barysphere water as some other kind of water coming up from the deep interior of the earth, like, for example, the constituent water of Fisher. Such water, if there be any such, might indeed be conceived as coming up from a metalliferous barysphere, such as he supposes. But this would be escaping water, not circulating water. If he means anything like this, it ought to be distinctly stated, for it changes entirely the ground of the discussion, and much that I have said above would be wide of the mark. For my own part, unless we adopt Fisher's view, I believe that we never have any water coming up which has not previously gone down. This is what is meant by circulation, but I cannot think Posepny can mean that his deep circulating water is not meteoric; and I therefore say nothing more on this head.

III.—Leaching of Wall-Rock.

Again, although I fully agree with Posepny and his brilliant expositor, Dr. Raymond, that crustification, when it is well developed, indicates deposit from within, by ascending waters already occupying the fissure, and not by laterally incoming water depositing in the act of incoming (in the manner of seepage-water in empty cavities), yet I cannot agree with them in thinking that the pressure of such ascending water would necessarily or even usually prevent the incoming of lateral currents from the wall-rock. It is doubtless true that the ascending water in the fissure is under higher pressure than *precisely similar* water on the outside; for, in addition to the hydrostatic pressure determined by the height of the outlet, it is also under hydraulic pressure in proportion to the velocity of the upward current. But the water saturating the wall-rock is also, of course, under heavy hydrostatic pressure. And when we remember the slowness of the ascending current (which is a necessary condition for deposit), and therefore the slight excess of the pressure over that measured by the height of its outlet; and when we remember further that the ascending water is *hot* while the wall-water is *cooler*, and therefore denser, we may well doubt whether the pressure of the ascending or the lateral waters will be the greater, and therefore whether the current will set outward or inward. The pressure of the ascending water is greater by virtue of its motion, but that of the wall-rock is greater by virtue of its greater density. It seems not unreasonable, therefore, to conclude that sometimes and in some places the current would set outward, and sometimes and in some places it would set inward. In many places, doubtless, the wall-rock is not saturated. In such places, of course, the current would set outward by capillarity, as well as by pressure, until saturation is reached.

Of course, also, impediments to upward flow, brought about by filling of the fissure by deposit or otherwise, would increase the interior pressure, and would cause an upward ramification and outflow in many places at the surface.

Although the analogy is by no means perfect, yet, by way of illustration, the ascending fissure-current, with its freight of dissolved matters and its tributary drainage from the country-walls, may be roughly compared to a main river with its freight of suspended materials and its lateral tributaries. In such a stream, the tributaries usually discharge freely into the main river, increasing its volume, though perhaps diminishing its percentage of freight; but sometimes, by the greater pressure of flood-waters, the main stream may back up the tributaries until equilibrium is restored. So in the case before us, the main ascending fissure-stream, with its freight of dissolved matters, usually receives tributaries from the wall-rock, although, by defect of pressure of the latter or increased pressure of the former, the main current may overflow into the wall-rock. Again, in both cases, the percentage of freight is usually greatest in the main stream, and therefore the deposits by diminished velocity and carrying power in the one case and by diminished heat and pressure and solvent power in the other, are heaviest there, although, sometimes, heavy deposits occur also in the back waters. Again, in both cases, while the tributaries increase the volume of the current, they usually diminish the percentage of freight, although sometimes the reverse may be the fact. Finally, as rivers, when obstructed by their own deposits, may reach their final destination by inverse ramification and through many mouths; so ascending fissure-currents, obstructed by their own deposits, may branch upward and reach the surface by many exits. This, however, can be seen only in ascending currents still depositing, as in the cases of Sulphur Bank and Steamboat Springs. In most cases this part of their course has been carried away by erosion.

In a word, there seems no reasonable doubt that while usually the main deposits have been brought up from below, yet the tributaries from the country-wall do contribute, and sometimes in an important degree, to the metallic contents of the veins. This seems well-nigh proved in those cases given by Sandberger and Becker, in which analyses, especially selective analyses, find notable quantities of the required metals in the more basic minerals of the country wall-rock. To discredit the obvious inferences from the results of a method so much in accord with modern science and substitute a roundabout process of secondary leachings by vadose circulation of primary impregnations derived from a hypothetical barysphere, as Posepny does, must be regarded as a return to the speculative methods of early writers. Again, in cases like the lead-ores of Missouri and Wisconsin, where there is no evidence of disturbance or of igneous agency of any kind, is it not more rational to derive the metals from the wall-rock, though probably from its deeper parts, than from an unknown barysphere?

IV.—A More Comprehensive Theory Needed.

In conclusion, I cannot but think that the views brought forward in 1883 in my paper on the "Genesis of Metalliferous Veins" (*Am. Jour. of Sci.*, vol. xxvi., p. 1, 1883), although I would perhaps now modify them slightly on some points, still represent well the present condition of science on this subject. Those who have read that paper will remember that it is an attempt based partly on my own investigations of the phenomena of metalliferous vein-formation now going on at Sulphur Bank and at Steamboat Springs, and partly on a general survey of the whole field, to embody a comprehensive and rational theory, avoiding extremes on both hands. In it I devoted considerable space to combating the extreme lateral-secretion views of Sandberger. I did so because, on account of the recent appearance and signal ability of his treatise, it seemed likely to do harm by carrying scientific opinion too far in one direction. If it had been Posepny's treatise instead of Sandberger's, I should have felt equally compelled to combat it, and on the same ground. Posepny quotes freely from my papers on "Sulphur Bank" and on "Steamboat Springs," but not from that on "Genesis of Metalliferous Veins." Whether he has seen it, I do not know.

There has always been, and still is, a strong tendency to extreme views on this subject. On the one hand, ascensionists would derive all metals from a mysterious metalliferous region—a "barysphere," and so strong is their advocacy that even when analysis finds the required metals in notable quantities in the wall-rock, they discredit the obvious inference by suggesting a secondary leaching of materials deposited there by primary baryspheric currents. On the other hand, the lateral-secretionists would derive metals not from ascending currents at all, but wholly from direct secretion from the immediate bounding-walls; and so strong is their advocacy that even when the deposit of metals from hot ascending currents is proved by direct observation, as at Sulphur Bank and at Steamboat Springs, they seek to throw discredit on the obvious inference in regard to all metalliferous veins, by giving many cases in which hot springs do not deposit any metals. My paper was an earnest attempt to combine what is true in each, and thus to reconcile these extremes by a more comprehensive view, which explains their differences.

According to my view, the source of metals is, indeed, on the one hand, by leaching, but not by lateral secretion; on the other hand, not from a hypothetical barysphere, but from the wall-rock; though, again, not from all parts alike, but mainly from the deepest parts, and even from below the deepest parts, of sensible fissures. As in the case of many other disputes, I believe both sides are right and both are wrong. Ascensionists are right in deriving metals mainly by ascending currents from great depths, but wrong in imagining these depths to be an exceptionally metalliferous barysphere. They are wrong also in not allowing subordinate contributions by lateral currents from the wall-rock higher up. The lateral-secretionists, on the other hand, are right in deriving metals by leaching from the wall-rock, but wrong in not making the main source the thermosphere.

In the uncolored light of a more comprehensive view, many of the difficulties and obscurities of the subject disappear.

1. Ore-deposits, using the term in its widest sense, may take place from many kinds of waters, but especially from alkaline solutions; for these are the natural solvents of metallic sulphides, and metallic sulphides are usually the original form of such deposits.

2. They may take place from waters at any temperature and pressure, but mainly from those at high temperature and under heavy pressure, because, on account of their great solvent power, such waters are heavily freighted with metals.

3. The depositing waters may be moving in any direction—up-coming, horizontally moving or even sometimes down-going, but mainly up-coming, because by losing heat and pressure at every step, such waters are sure to deposit abundantly.

4. Deposits may take place in any kind of water-ways—in open fissures, in incipient fissures, joints, cracks and even in porous sandstone, but especially in great open fissures, because these are the main highways of ascending waters from the greatest depths.

5. Deposits may be found in many regions and in many kinds of rocks, but mainly in mountain-regions and in metamorphic and igneous rocks, because the thermosphere is nearer the surface, and ready access thereto through great fissures is found mostly in these regions and in these rocks.

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[NOTE.—In this Index the names of Contributors to the Discussion are printed in small capitals.]

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