ORE DEPOSITS

A DISCUSSION

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CONTENTS

Page.

Review by the Editor........................ 3

Discussion by S. F. Emmons........................ 17

Discussion by W. H. Weed........................ 20

Discussion by J. E. Spurr........................ 30

Discussion by W. Lindgren........................ 36

Discussion by S. F. Emmons........................ 42

Discussion by J. F. Kemp........................ 45

Discussion by F. L. Ransome........................ 52

Discussion by T. A. Rickard........................ 56

Discussion by C. R. Van Hise........................ 60

Discussion by W. H. Weed........................ 63

Observations by C. W. Purington........................ 68

A REVIEW.

The discussion on ore-deposits which appears in this pamphlet is a reproduction of the views expressed before the Geological Society of Washington, at two consecutive monthly meetings, early in 1903, as reported in the *Engineering and Mining Journal,* but it also includes some important corrections and amplifications of the material previously published. In a manner—timely and suggestive—it represents the latest opinions on a subject which is of perennial interest to all those who are engaged either in the academic or the practical pursuit of the ore-bodies valuable to man. The discussion gives particular prominence to the recent accentuation of magmatic differentiation as a factor in the distribution of ores in rocks; this is the reason why the advocates of the agency of water as a determinative process are not so prominent. Mr. Emmons, Prof. Van Hise and other authoritative writers have indeed taken part in the discussion and added largely to the value of it, but their purpose has been evidently more to warn against the exaggeration of a new motif in the geologic drama than to reiterate their own views fully until the new theories have been further substantiated.

The present position of the study—it is not yet an exact science—of ore-deposits is worthy of a brief review. It is summaried herewith in words whose repetition[1] seems warranted as an introduction to the discussion on which the present pamphlet is based.

Mining owes much to geology. This debt will, let us hope, be increased, for it is an honorable obligation. Science justifies herself to the commercial world by the practical aid which she gives to industry. Even those who delve underground for the metals upon which mod-

[1] From an article in the *Engineering and Mining Journal* of Jan. 18, 1902, entitled "Recent Progress in the Study of Ore-Deposits," by T. A. Rickard.

ern civilization depends are not without the realization that light has come to them in dark places.

Geology was not always a friend to mining. In its infancy it made wild statements which only perplexed an exceedingly venerable industry. Even to this day, in certain quarters, there is an unspoken idea that the young science stoops to commercialism when she concerns herself with matters which have to do with mining. A notable example can be instanced. The Geological Society of England was founded by the fathers of modern geology, by men whose names are household words, and among its records will be found the first presentment of the very foundations of the science to which the society is dedicated. I desire to emphasize the historic position and the splendid work, continuing to this day, done by the men who compose that honorable society, which represents all that is best in English geology, but such emphasis will also accentuate the extraordinary fact that, both as a body and individually, English geologists have severely abstained from developing that part of their science which touches most directly upon mining, namely, the study of ore-deposits. In striking contrast to this neglect of a most useful line of enquiry is the attitude adopted by the geologists of the United States, and more particularly by the organized corps of the Geological Survey. From its very inception, under Mr. Clarence King, the Survey has given the warm grasp of friendship to the miner, and during the past twenty-five years the distinguished scientific men who have done its work have contributed, not merely a few suggestions or iridescent generalizations, but the results of practical research of the most useful kind, which have formed the basis for a systematic study of ore occurrence.

Besides its own contributions on a subject of immediate economic importance, the Survey, by the separate writings of certain of its members, has given an impetus to the investigations of mining engineers and others who have collected data for the common fund of ascertained fact. The American Institute of Mining Engineers has served as a link to bring together the official and the professional mining geologists, the meeting of men working toward a common purpose by diverse paths having been facilitated by the fact that the distinguished secretary of the Institute was once a government official himself,[2] and is now the dean of the mining engineering profession.

The results of this co-operation are manifest. The literature of that branch of geology which deals with the genesis, structure and occurrence of ore-deposits is, in its modern aspect, distinctively American, and this can be said without under-estimating the inspiration given to the study of these problems by the writings of such men as Posepny, Vogt, Beck, De Launay and other European scientists.

During the past eighteen years the study of ore-deposits, in this country, at least, has received a marked impetus on three notable occasions. These three impulses toward advancement are associated with the names of Emmons, Posepny, and Van Hise. In the history of economic geology the publication of the Leadville monograph[3] marks a red-letter day. Of all reports on the geology of a mining district this one has had a value more directly measurable in dollars and cents. Whatever it may have cost, it is not too much to say that the work of Mr. Emmons and his assistants gave to Leadville an underground chart which has led to the discovery of bodies of ore valued at millions of dollars. And apart from its immediate aid to the mine-captains of one district, it proved a most illuminating guide to the men who opened up the Aspen, Rico and Ten Mile districts in Colorado. As a geological report made by a national survey, it marked a striking advance in its detailed deciphering of the underground structure of a very complicated region; for however interesting and suggestive the questions concerning the origin of ores may be, there is no doubt but that the unraveling of the structural relations of ore-deposits

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[2]This refers, of course, to Dr. Rossiter W. Raymond, to whom the mining industry, in its broadest sense, owes a debt which it is pleasant to remember.

[3]Monograph, XII. Geology and Mining Industry of Leadville, by S. F. Emmons. U. S. Geological Survey. Issued in 1886. An abstract, which stated Mr. Emmons' views quite fully, was published in 1882.

affords the more immediate aid to the miner, and in this respect the Leadville monograph is without a peer, before or since the date of its first distribution to the public.

Following up the Leadville monograph, Mr. Emmons studied the neighboring mining localities, and this resulted in the publication of several contributions to the science of ore-deposits. Among these papers may be instanced the essay entitled "The Structural Relations of Ore-Deposits,"[4] because it has proved extremely suggestive to the younger men who were at that time beginning to interest themselves in this branch of geological research.

The Leadville work gave a local application to those views upon the origin of ore-deposits which were, at that time, in course of ventilation in Europe by Professor Sandberger.[5] "Lateral secretion" under various forms and disguises became a dominant note in the writings of the years between 1883 and 1893. It was a narrow interpretation of a very wide phenomenon and, while the chemical side of the conception had a very evident fascination for the scientist, it did not recommend itself to those who spend much time underground. However, the objections which this theory presented to mining engineers led to the gathering of a good many new facts which paved the way for the favorable reception of Posepny's treatise,[6] in 1893. It is an interesting coincidence that three[7] different members of the Institute, in the course of papers descriptive of districts which they had severally studied, expressed disagreement with the then generally accepted lateral secretion theory. Each thought his attack was no better than a forlorn hope. It was a gratifying surprise to find afterward that the most important contribution of that year was a very telling criticism of Sandberger's views by so distinguished an authority as Posepny. But Posepny did not only destroy, he also built up, and if his structure bore signs of an extreme style of intellectual architecture, it was none the less a distinct improvement upon the makeshift which it replaced. It is true he set his

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[4]Vol. XVI., pp. 804-839. *Transactions* of the American Institute of Mining Engineers.

[5]Untersuchungen über Erzgänge. Wiesbaden, 1882.

[6]"The Genesis of Ore-Deposits." Vol. XXIII., pp. 197-369. *Transactions* American Institute of Mining Engineers.

[7]John A. Church, Arthur Winslow and the writer.

advocacy of ascending solutions against the lateral secretion theory of Sandberger, but that was the less important part of his contribution to science; he brought out the essential difference between the waters above the so-called water-level and those which circulate below that horizon, and he drew particular attention to the distinctive features of the former, which he then first called by the term now generally in use—namely, the *vadose* circulation. While the immediate result of his famous treatise was to stir up anew the controversy between those who variously advocated the agency of "lateral," "ascending" or "descending" waters as primarily responsible for the deposition of ores, a much better result ensued, since from the discussion of the general subject it became more and more evident that the word "circulation" was the key to the enigma, and that narrow insistence upon any one branch of that circulation was incompetent to explain the striking diversities of ore occurrence.

During the seven years which followed 1893 the pendulum swung steadily away from the lateral secretion theory —that is, the conception of ore-deposits as being derived from the wall-rocks of veins through the solvent agency of laterally moving waters—and the new ideas which Posepny had contributed led to the overhauling of old evidence with a particular regard to the distinction between the circulation of water in the vadose zone as contrasted with the deeper horizon. It became generally accepted that a large number of ore-deposits, more especially those containing gold and silver in association with sulphides of the baser metals within a matrix of quartz, had been laid down by ascending waters, and that enrichment took place, not from the wall-rock into the vein fracture, but by impregnation from the fracture outward into the encasing rock. During this period those of us who had the direction of mining operations were given an opportunity to chew the cud of philosophic reflection and to test the theories, which had been thus far developed, by observation underground. It is fair to say that then, as before, we had the same objection to the wholesale absorption of the latest scientific dictum, in that we found it too narrow to cover the multitudinous varieties of ore occurrence which were encountered in our work from year to year.

Then, quite unexpectedly, a new philosopher, of whom we mining engineers had only known vaguely as a distinguished authority on the obscure problems of metamorphism, came forward with a treatise which appealed to us from the very first on account of its striking originality. Professor Van Hise attacked the subject from an entirely fresh standpoint.[8] His essay is a deductive reasoning from physical and chemical principles; it is therefore in direct contrast to the induction from facts, which had hitherto been the method adopted by those who had investigated the problems of ore occurrence. For this very reason his work proved illuminating and suggestive along unexpected lines, and it stimulated the presentation of a new array of facts calculated to unravel many perplexities. Professor Van Hise avoided the old blunder of sacrificing a broad conception to a narrow theory. He took the underground circulation of water as one connected manifestation of natural activity, and emphasized the fact that in the formation of ore-deposits all the branches of that circulation may, at different times and in divers places, play a part. Two conclusions, however, he insisted upon, namely: that sulphide ores are generally deposited by ascending waters, and that secondary enrichment of such ore is effected, to very considerable depths, by the agency of descending waters.

In regard to the latter it is an interesting fact that other observers had for several years ruminated over the subject of secondary enrichment, and, prompted largely by the evidence obtained from the copper lodes of the Butte district, in Montana, each unknown to the other, had formulated certain views without, however, making their opinions public. The discussion of the matter by Professor Van Hise was accompanied by the simultaneous appearance of papers on that subject by Mr. Emmons[9] and

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8 "Some Principles Controlling Deposition of Ores," by C. R. Van Hise, Trans. A. I. M. E., Vol. XXX., pp. 27-117.

9 "The Secondary Enrichment of Ore-Deposits," by S. F. Emmons. Trans. A. I. M. E., Vol. XXX., pp. 177-247.

Mr. Weed,[10] so that soon we had an immediate secondary enrichment of a most pertinent aspect of the general inquiry. For it is obvious that the concentrations of the metals, whether due to ascending waters or otherwise, are particularly those which are of value to man, and that the investigations which concern themselves with the formation of bonanzas are of the greatest practical value to both the miner and the economist.

Thus, at last, geology in relation to mining reached a point where the most unbelieving utilitarian could not refuse to recognize its great economic value. There was a time when the disputation of the philosophers wearied the poor miner, who could not see how any of it would guide his pick amid the darkness underground. He felt like the Scotchman who was given claret and found it so thin a beverage that he complained that he could get "no forwarder" on it. Subsequently he was given a sip of Chartreuse and exclaimed: "Bring me a mug of that stuff." That is how the miner felt toward the last results of geological inquiry. It meant business.

It cannot be doubted that Prof. Van Hise's views of the subject, by inciting opposition no less than agreement, stimulated further investigation and cogitation over the obscurities of ore-deposition; and, human nature being what it is, opposition was more productive of enquiry than acquiescence, for it was an active motive in spurring investigators to the collection of fresh data. Within two years a group of valuable papers gave evidence of the studies carried on by at least three most capable geologists, who had carried forward the suggestions already published by Prof. Vogt, of Christiania,[11] soon after Posepny had presented his views to the American Institute of Mining Engineers, in the summer of 1893, as already related.

A change[12] had swept over the trend of scientific theory

[10] "The Enrichment of Gold and Silver Veins," by Walter H. Weed. Trans. A. I. M. E., Vol. XXX., pp. 424-448.

[11] In the *Zeitschrift für praktische Geologie* during 1893, 1894, 1895, 1900 and 1901.

[12] Editorial in the *Engineering and Mining Journal* of February 14, 1903.

in regard to the origin of ores. Not long before, students of the subject had been transported with the idea of water action, now they were asked to differentiate in magmas. Time had restored the balance. Ten years ago Prof. Posepny started a discussion which emphasized the importance of aqueous agencies in the distribution of ores; this was followed by an era of investigation into underground waterways, the effects induced by surface drainage and the maintenance of subterranean circulation by gravitative stress; this development of the science was fitly accentuated by the philosophic deductions of Prof. Van Hise, supplemented by the practical inference made on the subject of secondary enrichments by Messrs. Emmons, Weed and others.

During this period there were several investigators who chafed under the undue prominence given to aqueous agencies and demurred to the obvious neglect of a fundamental factor in the genesis of ore-deposits—a factor long recognized by the miner in his proverbial fondness for "porphyry" as a favorable association for rich mines. While our American authorities were waxing enthusiastic over the work of Posepny, Prof. Vogt was making a careful inquiry into the differentiation of rock magmas and had come to the conclusion that the normal terrestrial water circulation played a minor part in the primary origin of certain deposits, however much it may have affected their later concentration, from such portions of the magma as were rich in metals, along the contact with sedimentary rocks. When Prof. Van Hise elucidated the principles controlling the underground circulation of waters near the earth's exterior as the determining factor in the great process of ore formation, Prof. Kemp[13] pointed out that the greater number of deposits of gold, silver and copper ores, as known to-day, are near igneous rocks with which he believed them to be genetically connected. A discussion arose between Professors Van Hise and Kemp which served a most useful purpose and was followed with keen interest by the mining fraternity.

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[13] "The Rôle of the Igneous Rocks in the Formation of Veins," by J. F. Kemp. Trans. A. I. M. E., Vol. XXXI., pp. 169-198.

Before this interesting controversy occurred, Mr. J. E. Spurr, in his examination of the Yukon District, in Alaska,[14] had become impressed with the evidence of ore-segregation afforded by a series of closely related rocks in the Forty-Mile region, and in his report, published three years ago, he announced a radical departure from accepted views by describing the gold-quartz veins of the Yukon as the end-product of rock-segregation. This he explained as the result of a progressive increase in silicification, by means of which a basic hornblendic granite passes into a quartz feldspar rock, termed "alaskite"; the changes continuing until the alaskite resembles a quartzite and is only distinguishable from a typical quartz-vein by small porphyritic crystals of feldspar. Mr. Spurr holds that certain gold-bearing quartz-veins in the Yukon have originated by a process of magmatic segregation, and that they represent merely the siliceous extreme of the process, the final stage of which is marked by a magma so attenuated as to be described as highly heated water heavily charged with silica and other mineral matter, including gold.

These theories have been a stimulant to widespread observation. In the earlier part of last year Prof. Joseph Barrell published[15] the result of his researches into the physical effects of contact metamorphism, affording thereby certain data concerning the liberation of enormous volumes of gas due to the effects of igneous masses upon the sedimentary rocks which they penetrate. He gave also information concerning the mineralogic changes induced by metamorphism, affording valuable hints which other geologists have not been slow to utilize. Mr. W. H. Weed, the indefatigable observer that he is, has applied the views of Vogt and Kemp to particular occurrences of ore which he has examined, with the result, among others, that he has elucidated[16] the particular conditions which render the contacts of igneous and sedimentary rocks such a favorable *locus* for ore occurrence. This he has found

[14] "Geology of the Yukon Gold Belt," by J. E. Spurr. 18th *Annual Report*, U. S. Geological Survey, Part iii., p. 297, 1898.

[15] "The Physical Effects of Contact Metamorphism," by Joseph Barrell. *Am. Jour. Sci.*, Vol. XIII., April, 1902, p. 279.

[16] "Ore-Deposits Near Igneous Contacts," by Walter Harvey Weed. Trans. A. I. M. E., Vol. XXXII., read at New Haven, October, 1902.

to arise from the fact that the sedimentary strata are made porous by thermal metamorphism, which may be compared to the results produced by burning a clay into a brick. Finally, Prof. Kemp[17] has followed up his argument for the derivation of ores directly from a magma, and has pointed to the activity which vulcanism is apt to give to thermal circulation. His discussion of the distribution of the ground-water in mining regions draws attention to the confused ideas which exist concerning water distribution underground, a confusion due, I believe, to the fact that the ground-water level is artificially depressed by shafts and other mine workings.

In shaping the ideas of those engaged in the study of ore-deposits, one paper, as yet not mentioned, demands proper reference. I refer to Mr. Lindgren's essay on contact deposits[18] which appeared in 1901. This paper carries forward Vogt's views, previously expressed, as applied by Mr. Lindgren to occurrences of ore in the United States. It is a contribution which, while modest in its claims, has no doubt influenced to a notable degree the ideas of others, such as Mr. Weed, who have brought forward more comprehensive theories; and as a thoroughly scientific enquiry into an obscure matter, it forms one of the very best contributions to the discussion of ore-deposits. By throwing the weight of his researches against the water extremists, Mr. Lindgren gave strong support to the advocates of magmatic differentiation in its bearing upon the origin of ores; the influence of his work is plainly discernible in the discussion to which we now come.

This discussion took place at the regular monthly meetings of the Geological Society of Washington, a society composed largely of the members of the United States Geological Survey. At the meeting of January 14, 1903, Mr. Weed brought forward a genetic classification. It was discussed by Messrs. Emmons, Spurr and Lindgren.

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[17]"Igneous Rocks and Circulating Waters as Factors in Ore-Deposition," by J. F. Kemp. Trans. A. I. M. E., XXXII., read at New Haven, October, 1902.

[18]"The Character and Genesis of Certain Contact Deposits," by Waldemar Lindgren. Trans. A. I. M. E., Vol. XXXI., pp. 226-244.

Mr. Spurr offered an alternative classification. At the next meeting, held on February 25, the discussion was resumed with much interest in the presence of a strikingly representative gathering of geologists. Professors Van Hise and Kemp, who are non-resident members, were especially asked to be present, and the writer, who is not a member, was also most courteously invited to come and take part in the debate. It proved to be full of spirit. Mr. Emmons led off with a suggestive introduction, then Prof. Kemp spoke up for the rôle of the igneous rocks as against a too positive insistence upon the adequacy of meteoric waters; after him Mr. Ransome and the writer followed, taking a line of argument which went between the extreme views upon the subject. When Prof. Van Hise, as the exponent of the agency of meteoric waters, began an attack upon those who pushed the igneous theory too far, there was the keenest interest in his remarks. In his repeated request for criteria justifying the more recent views on magmatic differentiation, he was unusually earnest in his manner, insisting that his critics were too hasty in the promulgation of new theories. This prompted a sharp reply from Mr. Weed, and the personal element in the controversy threatened to dominate the discussion. However, Prof. Kemp, Mr. Lindgren and others offered a few friendly remarks and the debate was finally wound up with the feeling that it had proved most stimulating and suggestive.

In this debate it was seriously questioned whether the younger men were justified in publishing comprehensive theories on the evidence at present available. It was held by some that the premature statement of explanations, as yet not confirmed by sufficient data, would prove an obstacle to reliable testimony, by prejudicing the ideas of investigators in the field. One or two of the veteran geologists plainly deprecated anything approaching hastiness in the framing of generalizations from few facts, while certain active workers among the supporters of igneous views in ore-deposition were inclined to deny the claim of the advocates of meteoric waters to the possession of a demonstrated theory which could only be set aside by newer views based upon ample evidence. This is an interesting situation, such as has arisen before in the development of science.[19]

"Without speculation there is no good and original observation." This was said by the author of "The Origin of Species," himself a man who, as his friend Huxley said, "abhorred mere speculation as nature abhors a vacuum." These are statements which must be taken with an appreciation of the men who made them. Darwin held that true explanations of natural operations could only come from the painstaking sifting of a vast amount of evidence, some of which might be ill-assorted and even contradictory. He himself worked indefatigably for fourteen years on the species question before he even published an outline of his views, and he spent practically all the working hours of a long life in explaining, confirming and correcting his thesis. He, at first, had to face the charge of promulgating a theory based on insufficient data, but lived long enough to drive it home to the leading intellects of his generation. A theory is like a revolution, if it is made good it receives honor, if it fails to hold its own it becomes regarded as a mere unwarrantable disturbance.

Of late those of us who are interested in mining and in the technical knowledge which aids that industry have been stimulated from time to time by the projection across the intellectual horizon of a succession of theories explanatory of the origin of metallic ores. One theory has hardly been put to the trial of observation before another has collided with it, so that to-day a striking diversity of views claims our attention, and we are excited to a high degree of interest in the study of ore-deposits. Veteran authorities are inclined to deprecate the unseemly haste which appears to them to mark the publication of new ideas, and, pointing to the philosophic patience of the Lyells and Darwins of an older generation, who collected data for half a lifetime and ruminated over them for most of the other half before they came forward with well digested and splendidly supported explanations of natural

[19]The remarks which follow formed an editorial in the *Engineering and Mining Journal* of March 7, 1903.

phenomena, they feel justified in objecting to the confusion created by the simultaneous submission of numerous speculations of a revolutionary character.

We confess to a feeling of sympathy with both, and a keen appreciation of the aggressiveness of the younger men. "The scientific man accepts his limitations and does not expect to arrive at absolute verity. He observes, and when he has advanced far enough to begin to generalize, he formulates his ideas as an hypothesis to serve as a basis on which to work until some one has suggested something better." This was said by Huxley. He had been too long obstructed by the Mosaic cosmogony not to feel a bitter dislike of any artificial hindrance to scientific investigation; in his opinion a theory was to be respected so long as it served its purpose of directing observation along the right road, but as soon as it played the part of a barricade it behooved all seekers after knowledge to tear it down and proceed unhindered along the narrow way which leads to truth. This is not an unruly spirit, but sound common sense; it may indeed have fathered a few bastards like the *Bathybius* theory of Huxley himself or the "Polarity" of Edward Forbes, but it has bred a progeny of splendid philosophies, from the Nebular Hypothesis to Evolution.

Under the present dispensation of scientific research there are ten times as many investigators along any line of inquiry as there were fifty years ago. Conjecture, speculation and theory are enormously more active than they were in the days when geology lay in the cradle of Lyell's 'Principles.' It is useless to try to smother the eager voices which earnestly hasten to speak of that which they have seen. Let them speak out, and then correct them if they are wrong, disprove them if they are too hasty, so that out of the correction as out of the suggestion some truth shall come.

The fact is, that in dealing with such a tremendous subject as ore-deposition there will always be much concerning which we can never be certain. Inductive reasoning from facts will carry us down to the bottom of the mine, but deduction from principles must then carry the fairy wand of the scientific imagination, which finds a way into the depths where human eye will never be able to penetrate. Therefore, positiveness of statement is impossible, and a reasonable probability is the utmost goal of our unwearied seeking.

Ill-considered speculations are obviously undesirable, but it seems to us that the greater harm may be done by the failure to discuss the unverified hypotheses of the day. If a man is a fool, let him alone in his folly; but if a geologist, quickened by the acquirement of new evidence, hastens to formulate a conjecture, thank him for what is good in it and combat him for what is wrong. An erroneous hypothesis has before now led the way to the ascertainment of the truth. It is better than nothing to the seeker after order amid the maze of phenomena. Progress depends upon criticism of hypotheses, upon the sifting of facts, the elimination of fallacy until there only remains that residuum which is proved to be true. There is too little discussion on ore-deposits, and too much of essay writing. It is possible to criticise with penetration and yet to be polite. Such criticism is a compliment to the author and a gain to all who are interested in the subject. We advocate a free discussion of principles, a winnowing of fact from fancy, so that the solid observation may be separated from the light chaff of careless guess. To the miner, to whom the subject of ore-deposition is vitally important, it is of paramount interest that the authorities on the subject should come into the arena and discuss the principles at issue, to the greater glory of geology and the general enlightenment of the community.

It is for this reason that the discussion was published in the *Engineering and Mining Journal,* and it is for the same reason that the discussion is now reprinted with additions, in pamphlet form. There has been added a supplementary paper* by Mr. C. W. Purington, who submits considerations prompted by the foregoing discus-

*Which appeared in the *Engineering and Mining Journal* of June 6th, 13th and 20th, 1903.

sion and based upon his own observations in remote mining regions. Such observations are of the greatest value, for they afford the material needed to balance the tendency toward generalization, to which all of us are only too prone. The mining engineers who, as a rule, are shy of participation in open debate, possess opportunities, by the recording of observations made from day to day in the underground workings of mines, for collecting the facts upon which the theories of the geologist will be founded. At all events, they contribute the rough stones which the specialist will place in their proper position, adding thereto a cementing knowledge which shall bind together the sifted data into a firm and substantial material, fit eventually for the construction of that comprehensive theory which the miner and the geologist alike are seeking.

T. A. Rickard,
Editor of *The Engineering and Mining Journal.*

THE GENETIC CLASSIFICATION OF ORE-DEPOSITS

A PROPOSAL AND A DISCUSSION.

A tentative genetic classification of ore-deposits having been proposed by Mr. W. H. Weed, and submitted by him to those who would be likely to take a particular interest in the subject, a meeting of the Geological Society of Washington was held on January 14, 1903, with a view to eliciting a discussion upon the matter.

S. F. EMMONS. The debate was opened by Mr. Emmons, who recalled the conditions confronting Clarence King, when, in 1879, it fell to him to shape the policy that should direct the economic work of the Geological Survey. At that time but little progress had been made toward a clear understanding of the general principles of ore-genesis. King believed that systematic study of the important mining districts of the country would discover such general principles and result in material contributions to the then somewhat neglected study of ore-deposition.

Mr. Emmons continued: Investigations carried out by the Survey during the past twenty years have justified King's belief in the policy then initiated. The careful studies of many mining districts in this country has not only added directly to our knowledge of ore-deposits, but it has supplied a mass of selectively recorded observations that have made possible the recognition of such general principles as those enunciated by both Mr. Weed and myself in regard to secondary sulphide enrichment, by Mr. Lindgren with reference to metasomatic processes and contact metamorphism, and by Prof. Van Hise in connection with the circulation and action of meteoric waters. While a great deal remains to be done before the processes connected with ore-deposition are fully understood, there has undoubtedly been a great advance in this direction during recent years, and we are perhaps now in a position to discuss a preliminary classification of ore-bodies on the basis of genesis.

I desire to define my own position, since my views, as expressed in the first report on Leadville, have been misunderstood. In that report, being yet new to the study, I declined to discuss the *ultimate* source of the metallic minerals, but as regards the *immediate* source—that is, how they at last reached their present position—I said that the waters which deposited them were descending from the porphyry contact into the body of the underlying limestone, and did not come up through fissures in the Archean, as was then maintained by some mining engineers, who based their statements not on observation but on theory. I also stated my belief that the ores had been leached from the neighboring porphyry bodies. My statements with regard to these particular deposits have been construed to class me among the school of descensionists, and this construction still seems to hold among some writers. In point of fact, as shown in later writings, while recognizing that most deposits were formed directly by ascending waters, I differ from the ascensionists, especially as voiced by Posepny, mainly in believing that as regards their *ultimate* source the metallic minerals were brought from great depths to the vicinity of the surface or within reach of meteoric waters, rather in the magma of igneous rocks than in aqueous solution. Hence, in 1893, I welcomed Vogt's recent demonstration that certain iron ore-deposits had been formed by a magmatic differentiation during the cooling of igneous rocks, as a line of investigation that would prove fruitful in determining the probable ultimate origin of the material of our deposits; but I still believe, as I stated then, that most of our deposits in their present form are the result of a later concentration by circulating waters of meteoric origin. A pneumatolytic origin for a certain class of deposits, especially near the contacts of igneous rock with limestone, can be demonstrated by their mineral association, and it is very possible that some of the metallic contents of other deposits, where this mineral association is

S. F. EMMONS. wanting, may have originally been separated from an igneous magma by pneumatolysis. If, however, in the present condition of the deposit, the agency of circulating waters is the only one that can be actually demonstrated, and was the final cause, it seems to me that this origin should be the one to be recognized in the classification.

W. H. WEED. In his prefatory remarks, Mr. Weed emphasized the divergent views of those who maintained that most ore-deposits were the work of underground meteoric waters, which had derived their mineral contents from the rocks traversed, and those who held that the greater number of workable ore-bodies resulted from the gases and vapors given off from fused magma in the process of cooling. He firmly believed that igneous intrusions had furnished not only the heat for most hot waters, but also the mineral contents, either directly as differentiations or emanations, or through the leaching of the rocks by vapors and heated waters.

Mr. Weed remarked that probably everyone who had written or lectured upon ore deposits has felt the need of a systematic arrangement of his data, and has adopted some sort of classification. Such grouping was important because it facilitated discussion of the differences between ore-deposits, and lent itself to the orderly presentation of facts and descriptions. The provision..l classification which he submitted was an attempt of this kind. He owed much to the work of others, particularly of Vogt, Beck and Kemp, but he had aimed to give precedence to genetic distinctions, followed by those based on structure and on mineralogy.

Genetic Classification of Ore-Deposits.

I. Igneous (magmatic segregations.)
  A. Siliceous.
    a. Masses—Aplitic masses, Ehrenberg, Shartash.
    b. Dikes—Beresite or aplite, Berezovsk.
    c. Quartz veins, Alaska, Randsburg, Black Hills.

B. Basic.

a. Peripheral masses.
Copper.
Iron.
Nickel.

b. Dikes.—Titaniferous iron, Adirondacks, Wyoming.

II. Igneous Emanations. Deposits formed by gases above or near the *critical point,* e. g., 365° C. and 200 atmospheres for H_2O.

A. Contact Metamorphic Deposits.
Characterized by gangue consisting essentially of garnet, epidote, actinolite, calcite and other lime-alumina silicates.

a. Deposits confined to contact:
1. Magnetite deposits.
2. Chalcopyrite deposits, Kristiania type.
3. Gold ores, Bannock type.

b. Deposits impregnating and replacing beds of contact zone:
1. Chalcopyrite deposits—(*a*) pyrrhotite ores, (*b*) magnetite ores, Cananea type.
2. Gold tellurium ores, Elkhorn type.
3. Arsenopyrite ores, Similkameen type.

B. Veins (closely allied to magmatic veins and to division IV.).
a. Cassiterite—Cornwall.
b. Tourmaline copper—Sonora.
c. Tourmaline gold—Helena, Mont.; Minas Geraes, etc.
d. Augite copper, etc.—Tuscany.

III. Fumarolic Deposits. Metallic oxides, etc., in clefts in lavas. No commercial importance.
Copper.
Iron, etc.

IV. Gas—Aqueous (pneumato-hydato-genetic) deposits. Igneous emanations, or primitive water mingled with ground-waters.

A. Filling Deposits.
- *a*. Fissure veins.
- *b*. Impregnation of porous rocks.
- *c*. Cementation deposits of breccias.

B. Replacement Deposits.
- *a*. Propylitic—Comstock.
- *b*. Sericitic kaolinic.
  - Calcitic.
  - Copper silver.
  - Silver lead—Clausthal.
- *c*. Silicic dolomitic—silver lead—Aspen.
- *d*. Silicic calcitic—Cinnabar.
- *e*. Sideritic silver lead—Cœur d'Alene, Slocan, Wood River.
- *f*. Biotitic gold copper—Rossland.
- *g*. Fluoric gold tellurium—Cripple Creek.
- *h*. Zeolitic.

Structural types of above:
- *a*. Fissure veins.
- *b*. Volcanic shocks—Nagyag, Cripple Creek.
- *c*. Contact chimneys—Judith.
- *d*. Dike replacements and impregnations.
- *e*. Bedding or contact planes—Leadville, Mercur.
- *f*. Axes of folds.
  - Synclinal basins.
  - Anticlinal saddles—Bendigo, Elkhorn.

V. Meteoric Waters. (Surface derived.)

A. Underground.
- *a*. Veins.
- *b*. Replacements.
  - Iron ores—Michigan.
  - Copper ores—Michigan.
  - Lead.
  - Zinc.
- *c*. Residual.
  - Gossan iron ores.
  - Manganese deposits.

B. Surficial.
- *a*. Chemical.
  - Bog iron ores.

Copper ores.
Sinters.
b. Mechanical.
Gold placers.
Tin placers.
Sedimentary beds, iron ore, etc.

VI. Metamorphic Deposits. Ores concentrated from older rocks by dynamo—and regional—metamorphism.

In explanation of the foregoing scheme of classification, Mr. Weed said: The six primary subdivisions, as given by me, might be reduced to two: First, those of direct or indirect igneous origin, and, second, those due to aqueous agencies. As, however, there are intermediate types, I have deemed it best to make the subdivisions given. These six primary subdivisions have been arranged to show gradation from the magmatic segregation of original igneous rocks to the deposits directly or indirectly due to the emanations from igneous rocks up to those due entirely to aqueous agencies.

This classification practically ignores form as being a factor of economic but not of genetic importance. This point needs emphasis, since even the more recent writers on ore-deposits have grouped them into veins and irregular deposits. From a genetic standpoint, it is a minor detail whether ores are deposited in tabular form (veins) or irregular masses, such as characterize contact deposits. It is admitted that genetic considerations affect the shape and form of ore-bodies, but it is apparent that if, for example, hot mineralized waters ascending a fissure through flat sedimentary rocks may fill part of the fissure forming a vein, and at the same time replace limestone when these rocks form the fissure wall, and thus form so-called chamber deposits. Examples of this are not uncommon.

Thus it follows that a hard and fast line cannot be drawn for replacement deposits—a most important type and a distinction of vital importance to the miner. But my own experience confirms the observations of Mr. Emmons and others, that the veins formed by 'fissure filling' are accompanied by alteration and frequently by replacement of the wall-rock, and hence belong to both classes.

A careful study of the peculiar Black Hills gold deposits by Irving shows that the 'vertical,' a mere fissure traversing various rock formations, has been the feeder or conduit for mineral solutions—replacing congenial beds. Another familiar example is seen in the Rico, Colorado, deposits, as given by Mr. Rickard in his description of the Enterprise mine. At Cripple Creek the well marked vein is often an insignificant quartz thread, or even a fissure, though the rock for several feet on each side is altered, as described by Rickard, and carries high value in gold. Such fissures might readily be overlooked in mining, or, if discovered, adduced as proof of post-mineral fissuring of the deposit.* Such structural features are of the highest importance in the economic working of mines—a fact recognized, perhaps, but never fully appreciated until the presentation of Emmons' masterly treatise on the "Structural Features of Ore-Deposits," one of the earliest of the many contributions to the geology of ore-deposits, which have placed the mining fraternity under deep obligation to this author.

It should be understood that no argument will be attempted to prove the particular origin of any particular deposit, as such evidence would be out of place in the present paper. The localities mentioned are such as appear from a critical examination of the evidence by various trustworthy observers to illustrate the proposed classes. Whether they are of such character or not, is a subject for entirely separate inquiry and discussion. It is assumed also that the reader is familiar with the work of the well known writers on the genesis of ore-deposits, since it would be out of place to repeat the evidence presented by these authors, and readily accessible. It will be observed that the classification recognizes and enlarges upon the *magmatic segregation* and *eruptive after-action* groups of Vogt.

The first class embraces only deposits which are due to the differentiation of igneous rocks. These types of ore

*See Posepny's criticism of this; St. Avold. Trans. A. I. M. E., Vol. XXIII., p. 312.

deposits are but little known in this country and have been best studied by the Norwegian geologist, Vogt. Under the general term of magmatic segregations, I have distinguished masses from dikes. The first term embraces the irregular contact deposits of iron ores, copper ores and nickel ores, commonly associated with basic rocks, and due to extreme differentiation of these rocks. Besides masses, I have added the dikes which represent extreme differentiation products of the magmas, under different physical conditions, from the masses, the basic differentiations being titaniferous iron ores, examples being those of the Adirondacks and of Ontario, described by Prof. Kemp and by Prof. Adams, while recently Mr. Lindgren has described an example in Wyoming. Quartz veins, while not so generally admitted to be an extreme acid product of the differentiation of igneous rocks, are, I consider, now admitted by many geologists to grade into pegmatites and those aplitic rocks grouped under the name of alaskites, concerning the derivation of which there is no dispute. Van Hise records examples in the Black Hills which seem to show an orderly transition from pegmatite veins to normal quartz veins. The quartz veins occur farther away from the igneous core than the pegmatite.

The group is based upon so extensive a mass of evidence that it needs but little in the way of comment, save in explanation of the subdivisions adopted and the reasons therefor.

Ore-Deposits Formed by Igneous Emanations.—The second subdivision is somewhat different from anything heretofore proposed, and it is limited to deposits produced by the gases given off by highly heated igneous magmas. I may add that the term 'pneumatolytic,' which is used as synonymous with the term 'gas' in the classification under discussion, implies the action of heated gases and vapors upon solids. The evidence that ore-deposits are formed under such conditions, and not by ordinary waters or by steam and other gases at lower temperatures, is afforded by the mineral composition of the ores, and especially when examined in thin section under the microscope.

W. H. WEED.

Contact Metamorphic Deposits.—Deposits of this class occur at or near the contacts of intrusive granitic or porphyritic rocks. The characteristic minerals associated with the ores are garnet, epidote, vesuvianite, specular hematite and magnetite. These minerals are admittedly the typical products of contact metamorphism, and their nature and intergrowth show them to result from the action of water above the critical temperature. This water is believed to have been given off from the hot magma and to have been accompanied by metallic compounds, together with sulphur, fluorine, etc. At a temperature of + 365° C. and a pressure of 200 atmospheres or more, water can only exist as a perfect gas. The occurrence of the minerals mentioned and their manner of intergrowth show that they were, in large part at least, formed above the critical point of water, that is under pneumatolytic conditions, and that the sulphides of iron, lead, zinc and copper are of pneumatolytic origin. It has been shown by Joseph Barrell that in certain cases the metamorphism of the sediments is complete, and their recrystallization into contact metamorphic minerals had been effected before the consolidation of the igneous magma whose heat and vapors had caused the metamorphism. In such cases the still fluid magma was giving off aqueous vapor, which, according to physicists, was above the critical point, highly charged with fluorine and other mineralizing agents. This has been discussed by Vogt, so that detailed discussion would be out of place now. The subdivisions of this contact metamorphic class are based upon the occurrence of the ore along the contact of the igneous rock or in beds upturned and extending some distance from the contact, though generally underlaid by the igneous rock. A recognition of the latter type of deposit has been made by Vogt and Beck, but no separate place has been assigned to it. Inasmuch, however, as it has been found that the structural difference is one of importance, I have separated this type and used the term 'bed replacement' as equivalent to the 'strike deposit' of Beck. The individual types given under each heading are based upon mineralogical distinctions, which are the result of chemical differences in the mineralizing vapors and accorded, therefore, with ores of different character.

Pneumatolytic Veins.—The second class in the group of igneous emanation deposits are veins in which the fissure has simply been the channel for the vapors, and in which the impregnation of the country rock on each side of the fissure is essentially characteristic. Pegmatite veins have been recognized as of this general character, and the close relationship between pegmatites and the cassiterite veins of Cornwall is quite well known. To this I would add the veins characterized by tourmaline and copper, and those characterized by gold, pyrite and tourmaline. The latter are, so far as we know, new in the literature of ore-deposits, and I have but one example to present in which the similarity to the copper tourmaline deposit is very marked, the gold occurring solely in bunches of tourmaline disseminated through aplite, the example being near Helena, Montana, at the Winscott Mine. Near Tyson's Wells, Arizona, there is a very large amount of gold ore of similar occurrence, but without the tourmaline, the gold occurring in pyrite, and I doubt whether it belongs to this class or should be referred to magmatic segregations.

Fumarolic Deposits.—The third group of fumarolic deposits is of no commercial importance. It embraces deposits of ferric chloride, cuprous oxide and other metalliferous minerals formed in clefts about volcanic craters. Deposits of this kind have been observed by Geikie, Fouqué and other geologists, who have also analyzed the gases given off from these cavities and have made analyses of the deposits. They are assigned to a separate class because they occur at the surface of the earth, and the veins are fumarolic and not pneumatolytic, as the term is used by me.

Gas-Aqueous Deposits.—The fourth group embraces by far the largest in number of the commercially valuable ore-deposits of the world. Ore-deposits of this character are those which have been commonly assumed to be due to aqueous agencies, and it is well perhaps to emphasize the distinction to be made between the origin of these ore-de-

W. H. WEED. posits as understood by me, and the origin ascribed to them by Prof. Van Hise. According to Van Hise, ore-deposits due to aqueous agencies are formed from material gathered by circulating waters extracting the metal contents of the rocks traversed by them and depositing this material after the waters have been concentrated in trunk channels. While I admire the brilliant work of Prof. Van Hise in explanation of the movements and course of underground waters, I believe that the source of the metals is in most cases to be found in the vapors given off by the cooling igneous rocks, and in a minor degree to leaching of the rigid differentiated portions of cold igneous rocks by circulating waters. The difference is an essential one, since I believe that the waters are to be regarded as the vehicle, and not the agent, and that it is the mixture of the pneumatolytic gases with meteoric waters that formed the metal-bearing solution.

This conception of admixed igneous vapors and meteoric waters is not a new one, but a revival of the well-known theory of Elie de Beaumont and Daubrée. It is maintained that the igneous emanations which admittedly form contact metamorphic deposits are certainly capable of entering fissures traversing the cooling magmas and the rock surrounding them, where, although first under pneumatolytic pressures, and above the critical temperature, these conditions are rapidly modified, until reaching the zone of circulating ground-water the product of igneous emanations, both metallic and otherwise, mix with the ground-water. 'To this combination of agencies found in the ascending waters of regions of igneous intrusion, the formation of most metalliferous veins is probably due,' a final conclusion of Lindgren ignored when parts of the paper were quoted in support of the contention that inasmuch as most workable deposits were formed by water, they must have been formed by water *originally meteoric*.

Under the head of gas and water deposits, meaning by this title admixed gases and meteoric waters, I have placed two classes. The first are filling deposits, in which open fissures are filled by mineral crusts; secondly, replacement deposits, in which the primary fissure was a minor, though very important, structural feature, serving simply as the channel by which the solutions obtained access to the congenial rocks which they replaced. The term 'congenial' is used to imply a rock which is rapidly replaced by the particular waters acting upon them. At this point a distinction might be very properly made upon the basis of the chemical composition of the waters, and I have therefore indicated the subdivisions given by Mr. Lindgren, with which, in the main, I agree. Inasmuch, however, as the structural conditions which I have indicated in his table are not only of genetic, but of great practical importance, I have inserted them. They are the determining factors in the localization of the deposits, and if the chemical basis is adopted it would be necessary to recognize the distinctions *a* to *g* under precisely each one of the chemical subdivisions given.

Deposits Formed by Meteoric Waters.—Under the fifth group, that of meteoric waters, I would place those deposits in which meteoric waters have taken the metals in solution and have carried them to the place where they have become deposited as ores. This is my conception of the ore-deposits formed according to Prof. Van Hise's theory, of which the Mississippi Valley lead and zinc deposits are, according to his descriptions, typical examples. I do not deny the great importance of meteoric waters, nor the fact that such waters, when heated by igneous rocks, may produce hot springs, forming ore-deposits, but where the hot spring waters owe their heat to igneous rocks, it appears evident that they might also obtain their metalliferous contents from the gases given off by such rocks. If this classification is adopted, it will be necessary to remember that transitions from one group to the other could occur, and that when the igneous rocks have solidified they are still heated; that the motive power is furnished by them, and that the leaching of such rocks by the heated waters might furnish metalliferous contents.

The sub-group embraces sedimentary deposits, whose character is so well known that it is hardly neces-

W. H. WEED. sary to elaborate them. It is, however, wise to distinguish between those which are chemical precipitates and those which are of mechanical origin, the first being exemplified in the bog iron deposits and the second in gold placers.

Dynamo-Metamorphic Deposits.—These are similar to contact deposits in mineral character, but show in their structure and mineral paragenesis that they are the result of pressure, with a re-arrangement and concentration of material.

J. E. SPURR. Following Mr. Weed, Mr. Spurr said he had no need to state his sympathy for the ideas which assigned an important part in ore deposits to the action of igneous magmas, for, as Mr. Emmons had remarked, he had been the first of the members of the Geological Survey to recognize the importance of this agency, and, he believed, the first among American geologists. In 1895, in his report on the Mercur mining district, Utah, the observed facts had led him to formulate the following theories of deposition: First, that the Silver Ledge (for which the camp was first prospected) was due to the action of waters expelled from a porphyry sheet during the process of cooling, and circulating along the contact of the porphyry with limestone. Second, that the gold ores of the Gold Ledge (for which the camp became noted) were deposited at a subsequent period by vapors emanating from a deeper-seated igneous body. Later on he originated the theory of ore deposition by siliceous magmatic segregation, which was stated in a report on the "Geology of the Yukon Gold Belt," the field work of which was done in 1896 and the report written in the winter of 1896-7, while it was not finally issued till March 4, 1898. In this report he showed that the observed facts in the Yukon region pointed clearly to the explanation that the gold-quartz veins of that district were formed, in part at least, by direct siliceous magmatic segregation; and he suggested that the same explanation would apply to many other gold-quartz veins in other parts of the world. Still later, in 1900, in an article on "Quartz-Muscovite Rock from Belmont, Nevada, the Equivalent of the Russian Beresite," he described his critical microscopic studies on the origin of the peculiar granitic dike rocks at that locality, and especially of the blebs, segregations and veinlets in the rocks, reaching the con clusion that these represented the final stage of consolidation of the granitic rock. He also showed that the shaly limestone into which these dikes are intrusive had been metamorphosed near the contact by the same solutions which had formed the quartz veinlets in the dikes, and had become dense, hard siliceous rocks, impregnated with iron. The suggestion was also added that the ore-bearing quartz veins, found at this very locality, which were the one feature he did not have time to personally examine, were, to judge by the already published descriptions of their characteristics, very likely another link in this chain of phenomena, and that the ores were deposited at the same time and by the same agency.

All these suggestions were published before the first of the papers in the "Transactions of the American Institute of Mining Engineers," which had led up to the present discussion. It was therefore naturally gratifying to find that his views, in which for a long time he stood alone, were coming to be accepted.

In 1895, Mr. Spurr continued, he drew up a genetic classification of ore deposits, which he has slightly modified, with new light, from time to time. The present discussion has induced him to present it to the society.

Under the term juvenile spring* deposits, Mr. Spurr intended to classify ore-deposits formed chiefly by waters or waters and gases expelled from consolidating igneous rock, but deposited at a distance from this rock.

The term *stygian deposits* was offered as a general appellation for ore-deposits formed underground by waters of atmospheric origin.

The term *interstitial deposits* was adopted for the filling of pores in rocks, in place of the term *impregnation*

*The term originally proposed for this class of deposits was *solfataric* deposits, but this was abandoned as suggesting processes that were not meant; and the characterization by Prof. Suess, in a recent paper, of springs deriving their water directly from the exhalations of a solidifying magma as *juvenile springs,* suggested the substituted term.

GENETIC CLASSIFICATION OF ORE-DEPOSITS.

Order.	Manner of Formation.	Place.	Class.	Type.	Sub-Type.
Original (Formed during the Cooling Processes of Igneous Rocks).	Chemical (Deposited from solution).	Underground.	Basic Magmatic Segregations.		
			Siliceous Magmatic Segregations.	Gold-Quartz veins of Magmatic extraction. Ore-Bearing Pegmatites.	
			Contact Metamorphic Deposits.		
			Deep-seated Gaseous Deposits.	Tin Veins, etc.	
			Fumarolic Deposits.		
			Juvenile Spring Deposits.	Replacement Deposits.	
				Interstitial Deposits.	
				Filling Deposits.	Fissure Veins (Spaces of Discission). Cave-Deposits (Spaces of Dissolution).
Subsequent (Formed from cold rocks, sedimentary or igneous, by atmospheric waters).	Chemical.	Underground.	Stygian Deposits.		
		Surface.	Bog Deposits, etc.		
	Mechanical (Deposited from suspension).	Surface.	Placers.		
	Residual (Left by subtracting effect of mechanical and chemical actions).	Surface.	Residual Deposits.		
Transitional.	Chemical.	Underground.	Regional Metamorphic Deposits.		

deposits, which had no well-defined meaning, and partly of the term *disseminated deposits.*

The term *filling deposits* was proposed as a general name for deposits filling pre-existing cavities, replacing the term *crustified deposits,* proposed by Posepny.

The term *subsequent deposits* was proposed for ores which were not directly the result of igneous processes.

Regional metamorphic deposits were put in a separate division by themselves, as being distinct both from original and subsequent deposits.

It was interesting to note, Mr. Spurr added, that the least important subdivisions in this classification, between ore-deposits occupying spaces caused by rending and those caused by solution, were the primary divisions of ore deposits as proposed by Posepny. The next least important divisions in the classification, namely, replacement, interstitial and filling deposits, had also been regarded by many as the most important.

Under contact metamorphic deposits, Mr. Spurr understood ore-deposits brought about by the same agents which produced contact metamorphism in general. These agents were usually held to be both waters and vapors derived from the cooling igneous rock. He therefore believed that ore-deposits might be formed in different ways during the processes of contact metamorphism, and he did not limit this class of deposits to ores deposited by gases alone.

Defining his own position in the matter of theories of ore deposition, Mr. Spurr said: I desire to be classed neither with the ascensionists nor the descensionists, nor any other party; but I stand now, as always, for the principle that many different natural processes work together and singly to produce ore deposition. In my own experience I have never studied closely two ore-deposits which have had exactly the same origin, and the variety of causes to which ore-deposits have been ascribed in my writings are the result of careful study and reasoning in each case, and do not result from vacillations of opinion. For example, I showed in 1894 that the iron ores of the Mesabi range, in Minnesota, were the concentrations by descending surface waters from ferruginous (glauconitic) marine sediments. In my next important work, in Mercur, as already stated, I ascribed the orės directly to igneous emanations, both gaseous and liquid. In the Aspen monograph, I showed that the ores had been introduced from some foreign source by ascending hot springs, such as exist near Aspen at the present day. In regard to the Yukon gold quartz veins, my arguments for origin by siliceous magmatic segregation have already been mentioned. Again, in describing the ores of the Monte Cristo district, Washington (ores of lead, zinc, copper, etc., containing silver and gold), I found that the balance of evidence favored the explanation that the ores were deposited by descending surface waters in Pleistocene time, and that they have been concentratd from a disseminated state in the granitic rock (tonalite) in which most of the veins occur. In a district which I am at present studying (Tonopah) the evidence points to a different origin from any of the foregoing.

The solution of the problem why we differ in our conclusions one from another lies in the mental processes of each. Most of us see and have seen the same natural facts, but from them we may draw different conclusions or no conclusion at all. Just so much of nature is plain to us as we have capacity to understand. So it seems that the real advancement to be made in geology is not so much in searching after facts, which are commonplace and easy of access, but in examining and regulating our reasoning powers. There is danger in the heedless application of purely theoretical conclusions and hypotheses to concrete examples. Such conclusions, based on physical, chemical or mathematical principles, are usually the result of correct logic, but are dangerous, in that the premises are often assumed. The imposing statement of laws pertaining to a strange science impresses the geologist, and he is apt to believe that he has hold of something definite and invariable, which he can apply as a criterion in practical problems. Thus conceptions like those of the zones of fracture and of flowage, the sea of ground water, etc., may be used to decide questions. This is illogical, for the conceptions are not fundamental principles or axioms; and when they are confronted by natural phenomena, independently interpreted, one may be astonished to see how numerous and important the exceptions are, to say the least.

The method of deduction from preconceived theories, then, which led many of the by-gone geologists into error, has become replaced by the method of logical inference from observed facts, to which the actual progress of geology is chiefly due. Undoubtedly this latter is what one should strive to stick to. He should collect facts, assemble them, group them, and note the conclusions to which they point. This last stage in the process is all-important, and one of which the impartial carrying out marks the properly balanced scientist. Too often the conservative geologist assembles the facts, yet fails to note their meaning, or, if this is partly forced upon him, in spite of himself, he refuses to recognize it, with a clinging to what is old and a distrust of the novel, even though he may be rejecting the truth and harboring the error.

While, therefore, the method of observation and inference should be carefully applied to geological problems, and we must ever beware of forcing facts to suit our preconceived theories, yet it must be remembered that no man can go beyond his own mental depth in this process. It is a fundamental principle in logic that one cannot understand a conclusion or a law with whose elements he is not already acquainted. It is entirely a matter of the thinker, not of the facts investigated. An Arabic word leaves a blank in the mind of a Chinaman. You cannot argue with a cow, nor talk geology to a coal-heaver. To narrow down the application, a chain of logic and inference, based upon physical and mathematical grounds and pointing to a certain conclusion, makes no impression on the mind of the average geologist. If he accepts the conclusion, he does it because of the reputation of the arguer, and not because of the argument. Again, a line of argument based upon the behavior of rock magmas during the process of crystallization makes no impression on one who is unacquainted with this department of knowledge. Thus

J. E. SPURR. the correct process for the geologist resolves itself into the following: Preconceived theories for a special problem should be avoided, and the solution of the problem should be logically inferred from local facts; but the worker must have a broad knowledge of possibilities, else the conclusion will utterly escape him.

These remarks may not seem germane to the discussion, but I hold that they are the root of the matter. Illustrations are frequent and striking. Let a geologist bring out forcibly the principle of concentration of pre-existing ores by descending waters, and everybody sees cases of 'secondary enrichment.' The facts were there before, but everybody could not see what they meant, because they had no foreknowledge of the principle. Even improperly balanced minds permit this foreknowledge to distort objective impressions, and so they see enrichment of this sort where none exists. Let the geologist and the mining engineer, then, with the principles of the present discussion in mind, investigate and review both mines and literature, and a still closer agreement, and a steadier progress in real knowledge may be expected.

W. LINDGREN. Mr. Spurr was followed by Mr. Waldmer Lindgren, who said: A genetic classification is surely a great desideratum in the science of ore-deposits, and it seems as if we had arrived at a point when such a scheme might be tentatively advanced with profit, although, in view of the great diversity of opinion which still exists among prominent mining geologists, a general acquiescence in any one certain system is not to be expected for some time to come. The classifications of Messrs. Weed and Spurr are based on general principles, which, according to my view, are perfectly sound, and which I ventured to emphasize in 1900, at a time when the theory of almost exclusive concentration by atmospheric waters found few opponents in this country. I still adhere to the opinion that the majority of the metalliferous veins of the Cordilleran belts are due to gaseous emanations from intrusive magmas, released by decreasing pressure, mingling with surface waters and ascending as hot springs. Deposits exclusively due to atmospheric waters are no doubt very numerous, but chiefly, I believe, contain the more abundant metals, such as iron and copper. It cannot be denied that many of the arguments advanced by Professor Kemp and others against the extent and depth of the underground circulation of atmospheric waters are very strong and tend to diminish the universal application of Professor Van Hise's theory. It is unnecessary to discuss this problem here, since Mr. Kemp has taken up this question in considerable detail. The small amount of water in deep mines is certainly remarkable. I shall always remember my intense surprise, when visiting Przibram in 1881, to find the 1000 meter level of the Adalbert shaft, not only dry, but actually dusty. I would also like to call attention to the fact that in very dry regions, like Arizona, rain water may remain for several months to a depth of several feet in shallow shafts, while the water level of the country stands several hundred feet lower.

Regarding the details of the schemes proposed and the assignation by Mr. Weed of the various types of deposits, there may naturally be varying views, and indeed I understand that Mr. Weed considers these details as in part provisional. The first group of magnetic segregations contains the recognized groups of titanic ores and chromite, to which may be added some nickel deposits; but workable copper deposits belonging beyond reasonable doubts to this type are not, I believe, thus far recognized.

The class of siliceous magmatic segregations is earnestly advocated by Mr. Spurr and recognized by Mr. Weed by three, to my mind, very doubtful examples. Though admitting that quartz veins of this origin exist, I do not consider that proofs have been brought to show that they contain payable gold ores, and would, from my standpoint, strongly object to class the normal gold-quartz veins under this heading. They may very well be due to what Prof. Vogt aptly calls eruptive after-effects, but not, I think, to direct magmatic segregation. The

W. LINDGREN. distinction between these two things should be emphasized. The latter takes place in a mass of fused material with or without the presence of a subordinate amount of water; the former involves entirely predominating aqueous solutions or gases. It is admitted that there may be an intermediate stage between the two conditions and possibly the pegmatite veins may have been formed by magmas exceedingly abundantly charged with H_2O or by H_2O with an exceedingly large amount of matter in solution. As stated above, I agree with Messrs. Weed and Spurr in believing that a very large number of fissure veins are formed by the mingling of atmospheric waters with ascending emanations from cooling intrusive magmas. Among these emanations I believe that water prevails, but that along with it large amounts of CO_2, H_2S, and heavy metals in various combination are also brought up. In a forthcoming report on the Clifton Copper District in Arizona, I hope to produce convincing proofs of the direct causal connection of certain fissure veins with certain intrusive masses, and further bring direct evidence of the high temperature at which they were deposited.

The unimportant group of the fumarolic deposits, recognized by Messrs. Weed and Spurr, I would pass over with the remark that they are justly separated from the contact metamorphic or pneumatolytic division. It has long been my opinion that the words fumarolic and pneumatolytic should be applied to different things, and this view was expressed a few months ago in a paper on the gold production of this continent. Fumarolic emanations are vapors liberated from cooling magmas near the surface under slight pressure. It is true that the word pneumatolytic was first used by Bunsen in a general sense to cover all gaseous emanations from magmas, but as modified by Broegger and used by most modern writers, it has come to be applied to the action of perfect gases, that is, to substances above their critical temperature and pressure. If this definition is not accepted it would be better to adopt a new term for this conception.

W. LINDGREN.

This brings us to the group of the contact metamorphic deposits, which Messrs. Weed and Spurr both recognize as a prominent group. I believe I am not mistaken in saying that this class of deposits will be better known and its extent better realized a few years from now. Already the examples are multiplying and some important old mines are shown to belong to this division.

We are all agreed that the subject which has occupied our attention this evening is one of great difficulty and complexity, as always must be the case with questions relating to processes going on in a region concerning which we have but little direct information—that is, below the surface of the earth. It seems to me, however, that the only way in which the question relating to the direct emanation of metallic substances from igneous magmas can be determined is by the careful study of the contact metamorphic deposits and the igneous rocks which have produced them. We have here metallic minerals deposited in such intimate intergrowth with contact metamorphic minerals that their simultaneous origin, in cases where no subsequent alteration has taken place, can not for a moment be doubted. The direct relation of contact metamorphism to the igneous rocks which induce it has long been a well-known fact to petrographers, and the minerals we find in ore-deposits of this type are characteristically those which the world over are formed in sediments near bodies of intrusive rocks. The association is that of garnet, epidote, wollastonite and andalusite, with magnetite, specularite, bornite, pyrite, chalcopyrite, zincblende and other simple sulphides. The complex sulphosalts, such as the sulphantimonides, are not known, but tellurides occur in places, as shown by Mr. Weed. The action is always most intense at limestone contacts, while shales and sandstones are affected in a less extensive degree. Andalusite and epidote have not as yet been artificially reproduced by dry fusion or in the wet way; garnet and wollastonite only exceptionally by aid of chlorides and fluorides as mineralizing agents. Garnet, andalusite and wollastonite do not seem to be formed in nature by water except at high temperature. In the artificial reproduction of minerals it has been found that certain substances act as 'mineralizing agents,' that is, facilitate the crystallization of minerals not easily obtainable without them. They do not necessarily enter into the combination formed. Thus at comparatively low temperature sodium carbonate facilitates the formation of certain sulphides. These mineralizing agents act most energetically at high temperatures; among them are certain volatile compounds of silica, fluorine, tungsten, chlorine, boron and zirconium; and last but not least, simply water at a high temperature, the action of the latter apparently increasing at least up to its critical temperature. It seems probable that water at a very high temperature is necessary to produce the typical contact metamorphic silicates. With the ordinary increase in temperature in depth (1° per 30 meters) water would certainly be above the critical temperature (+365° C.) at a depth of 11,000 meters, and the requisite pressure (200 at.) would be obtained even under hydrostatic conditions at 2,000 meters. Under circumstances of intrusion at the latter depth the temperature at the contact would be at least 1,200° C. and would surely continue above 365° for long periods. Under such circumstances water could only exist as a gas along the contact.

The mere diffusion of heat is slow and it would take many years to produce a temperature of 365° at a distance 100 feet away from the supposed contact. But conditions change when we consider that the intrusive rock contained dissolved gases of various kinds, among which water above the critical temperature predominated. The intrusion cracked and shattered the surrounding cold rock, and through the fissures, as well as through the pores of the rock, these hot gases rapidly pressed outward, enormously increasing the heated zone and the zone in which chemical action was produced. The very varying width of the contact metamorphic zone in different rocks seems to confirm this view. The intensity of metamorphism is in proportion to the amount of the gases contained in the magma and to the shattering and porosity of the surrounding rock. We have to admit that in many cases temperature above 370° C. must prevail perhaps hundreds or even thousands of feet from the contact, and consequently the water must be in the gaseous state.

But many intrusions doubtless take place at less depth than 2,000 meters, and in this connection it should be emphasized that for intrusive conditions it is wholly inadmissible to calculate the pressure from hydrostatic conditions. The forming of laccoliths, which may certainly take place less than 2,000 meters below the surface, involves an enormous stress and I maintain as probable that in most cases the pressure all along intrusive contacts far exceed 200 atmospheres.

All this presupposes that the active agent is pure water. As a matter of fact, we actually have water charged with gases and other substances. The critical temperature of this mixture is not known, but is probably not greatly different from that of water. Carbonic dioxide, hydrogen sulphide and many combinations of fluorine, boron and chlorine have low critical temperatures and pressures and would certainly exist as perfect gases under the conditions promised. There is still another point in connection with this that I would like especially to emphasize at this time; in the existing text-books on geology and petrography we frequently find it stated that during contact metamorphism the altered rocks have received no important addition of substance. From recent studies of contact metamorphism in the United States, this statement should probably be greatly modified. It may be true that in many cases there has been but little additional substance, and that the metamorphism has simply been effected by the molecular re-arrangement of minerals by the means of fluid or gaseous water. In other cases, however, the indications are plain that an enormous amount of material has been given off by the magma. During a recent examination of the Clifton copper mines in Arizona, where extensive contact metamorphism has taken place in the limestones adjoining an intrusive diorite porphyry, some interesting relations have been observed. At the contact with granite or quartzite,

W. LINDGREN. no alteration is observed. At the contact with limestones, however, garnet and epidote develop on a large scale, and are associated with pyrite and chalcopyrite. There is a total thickness of about 800 feet of limestone. The lower part of the series is very siliceous, and the only pure carbonate of lime is found in some 50 feet of the upper part of the series belonging to the lower Carboniferous. The most extensive and complete contact metamorphism has taken place in this stratum of pure limestone. It has, over a large area, been almost entirely converted to lime-iron garnet, associated with some epidote and a little copper sulphide. This action clearly implies an enormous transfer of silica and iron from the cooling porphyry to the limestone.

Evidence from several other points tends at present in the same direction. I consider it practically proved that under certain circumstances cooling magmas will give off quantities of various substances such as water, silica, iron, metallic sulphides, and, in small quantities, fluorine and boron compounds. Important results regarding the genesis of ore-deposits will, I think, come from further study of these deposits. In many cases it will be impossible to prove the relative part which the atmospheric and the igneous waters play in the formation of a given ore-deposit, but I believe that, on the whole, the path for future advancement is laid in the direction indicated above.

On February 25, at another meeting of the Geological Society of Washington, held at the Cosmos Club, the subject of a generic classification of ore-deposits was again made the topic for discussion. Mr. C. W. Hayes presided.

The discussion was opened by Mr. Emmons, who said:

S. F. EMMONS. At the meeting of January 14, a discussion was commenced on genetic classification of ore-deposits, a discussion which could not be completed because of the limited time, and further because several of our members who were entitled to speak with great authority on the subject were not present; and it is proposed at the present meeting to resume the discussion and to give an opportunity for those members to express their views. It was not supposed at the start that a purely genetical classification would be one that could be adopted in practical work, and many of us feel that we know as yet too little about ore genesis to attempt such a classification as would have any finality; but we do feel that the presenting of one or more tentative schemes on this basis will have a useful effect in clarifying our ideas, in promoting an interchange of views, and perhaps also in helping us in our field observations by indicating phenomena that it is important to recognize in the course of underground studies.

Two tentative classifications were proposed at the previous meeting by Messrs. Weed and Spurr, in which the authors have given much greater importance to the direct action of eruptive agencies in producing ore-deposits than has hitherto been ascribed to them by most American writers on the subect. The question of the *ultimate* origin of the metallic minerals which go to make up our workable ore-deposits is one which involves much that is purely speculative and beyond the reach of actual proof or demonstration in the field. Moreover, it has been, as I conceive, a characteristic of American investigators on ore-deposits, as contrasted with their European colleagues, that they have based their conclusions with regard to genesis more on actually observed facts in the field than on laboratory studies and theoretical reasoning. For instance, as a pupil of Elie de Beaumont, I was taught that vein formations were the result of emanations from igneous rocks under the influence of certain mineralizing agents—the dying phases of eruptive activity. When, however, I took up the study of ore-deposits in the field, applying to that study the methods employed in the observations of other geological phenomena and endeavoring to keep my mind free from the bias of any preconceived theories, I failed for a long time to find any evidence that would support the igneous emanation theory in the deposits I had opportunities of studying. In the condition in which they were then found they appeared to me evidently the result of concentration by circulating waters. As to their ultimate origin, I conceived that the

S. F. EMMONS. greater part had probably been brought within reach of these circulating waters by igneous magmas as they proceeded upwards from the interior of the earth, but that these magmas had cooled and consolidated before the concentrations had taken place, since the rock-fractures which had afforded the trunk channels for the concentrating solutions were in most cases subsequent to that consolidation. In more recent years, when our field of study has widened and the number of workers (lamentably few in the early days) has greatly increased, actual field demonstration has become available that a certain class of deposits are probably the result of direct emanations from cooling igneous rocks, and others may be actual segregations in an igneous magma during the process of cooling. Such practical demonstrations of views that previously rested upon an almost theoretical basis have naturally excited great interest among students of ore-deposits, and it is eminently desirable that their field should be as widely extended as possible. On the other hand, it is wise to guard oneself against the attractiveness of what appears to be novel, and hence presumably an advance on previously conceived ideas, and not to confound speculative assumption with demonstration. Herein lies an actual danger in the effect of this kind of speculation. Men may be led to assume for a given ore-deposit, with regard to whose genesis they have really no direct evidence, an origin that accords with the latest speculative views, and such assumption may later acquire the standing of a demonstration.

Some of the instances which both Weed and Spurr quote as examples of the class of siliceous magmatic segregations come under this head. I have particularly in mind the quartz veins of Belmont, Nev., quoted by Mr. Spurr, since his statement is based upon my own observations made as far back as 1868. While I should be unwilling to state from a recollection of so far distant observations that such an origin is impossible, Mr. Spurr's statement is purely speculative, since he could not examine the veins in question; yet they are very likely to be quoted by some later writers as examples of this very doubtful class, in the same manner as Weed has quoted Spurr's Alaskan quartz segregations, of whose origin the latter seems to have equally little demonstrable proof. Whether it is justifiable to extend pneumatolytic agencies as far as these gentlemen have done depends primarily upon a question which it seems difficult to bring within the range of actual or even experimental demonstration; namely, whether igneous magmas as they come from the interior of the earth contain sufficient water to produce the phenomena observable in our ore-deposits. S. F. EMMONS.

In a recent paper on Hot Springs, Prof. Edward Suess, the eminent geologist of Vienna, takes the affirmative side of this question, dividing hot springs into those whose waters rise under hydrostatic pressure, and those that derive their waters from the interior of the earth, the latter being characterized by their intermittence. With regard to the steam emanating from volcanic eruptions, he comes to the following conclusion:

"Volcanoes are not fed by the infiltration of ocean water, but ocean water receives additions to its volume by eveiry (volcanic) eruption."

Prof. J. F. Kemp, of Columbia College, has been the first among American writers on ore-deposits to argue in favor of the sufficiency of the supply of water that may be furnished by eruptive magmas, and we shall be glad to learn from him any facts that may bear upon this question.

Prof. Kemp said: The early schemes for the classification of ore-deposits were chiefly based on shape and texture, after the fundamental difference between interbedded deposits and veins in fissures had been once established; but as time has gone on principles of origin have come more and more to the front. It is now a question of the relative importance which is to be assigned to geological structure on the one hand and to source of ore and agent of introduction on the other. Geological structure is generally safe and involves less assumption, but as regards derivation and agent we are now in a position to speak in some instances with assurance. While in the past at- JAS. F. KEMP.

tention has been specially directed toward the normal circulation of ground-waters of meteoric origin, more recently we have had emphasis placed especially on the igneous phenomena. To Messrs. Lindgren and Weed we owe a great debt in this particular, and especially to the latter for the formulation of the scheme of classification under discussion.

As a general principle groups in schemes of classification should be based upon certainties, and, so far as possible, should not be capable of two interpretations. We may set aside the group of igneous, magmatic segregations, as a type whose origin admits of no argument. Titaniferous iron ores are its most important representative. Corundum and chromite are known in the same relations. That the pyrrhotite-chalcopyrite ores are of this type is doubtful, as has been shown by Lindgren for those at Rossland, and recently for the Sudbury ores by one of my students, C. W. Dickson, in a thesis, which was read before the American Institute of Mining Engineers at the Albany meeting.

At the other extreme we may also set aside the superficial placers and related residual deposits, since they involve no uncertainties. For the rest we may start with contact deposits, especially as produced by the action of eruptives on limestones; and with pegmatites, which are certainly the effects of expiring igneous phenomena, and pass from these points of departure through veins and other forms of ores and reach the undoubted results of deposition from meteoric waters at the other extreme. In the interval between the extremes, where doubt arises as regards interpretation, it is best to fall back on the assured facts of attendant geological structure as the foundation of the type.

It is strange that the importance of contact zones of garnet, vesuvianite, wollastonite, epidote and copper ores with gold have gone so long without appreciation of their true nature. Although for some years correctly interpreted in Norway and described in the Norwegian reports, Mr. Lindgren's paper on the ores of the Seven Devils District of Idaho, and of others of related character, first brought them to American attention, but we have learned of many since, as at Cananea and San José, in Old Mexico, and San Pedro, New Mexico. With the last two I am most familiar, and at each there are acres of garnet rock which has been produced from nearly pure limestone by the addition of silica from the eruptive, undoubtedly while highly heated. The change at Cananea and San Pedro has followed individual beds for long distances, and no one can fail to be impressed with the enormous amount of silica which has been supplied in connection with watery vapor or its dissociated gases and probably other mineralizers. Had not this silica been caught and locked up near the eruptive, as it would not have been in walls of almost any rock other than limestone, we would have had very great veins produced in overlying strata. This is, in my opinion, the method by which many veins have been formed, even though the stimulating eruptive is not exposed to sight.

I have recently had the privilege of reading a very valuable contribution, recently issued, upon the "Gold Deposits of North America," by Mr. Lindgren, and submitted to the American Institute of Mining Engineers. In it he shows that after several geological periods —it may be even after geological eras—of no vein formation, the latter suddenly and for a brief period became very active, following igneous outbreaks. It then died away. Lindgren attributes the activity to the eruptive rock, and I think he is right. Eruptive rocks certainly accompany great upheavals, and extensive fracturing, and some may claim, with more or less reason, that they have merely furnished the propelling energy and the vein-minerals to circulating meteoric waters, but I incline rather to believe them not only the source of the energy and the minerals, but largely of the watery vehicle itself, a view that has claims to confidence, equal, if not superior, to those put forth for meteoric waters. Thus we find no vein-formation through enormous extent of time when conditions were favorable to meteoric waters, and suddenly the outbreak of eruptive rocks starts it up. I am therefore in full sympathy with the tendency shown in Mr. Weed's scheme of classification, and with the importance placed by it upon the igneous factors.

It may also be said that outbreaks of eruptives and great upheavals imply extensive fracturing of the rocks, and are thereby favorable to the circulations of meteoric waters, which, following down the fractures, gather up their burden of ore and gangue, and return to the surface perhaps being expelled by the heat of the eruptive. The period of vein formation would then last until the cavities were plugged and the meteoric waters no longer found entrance or exit.

There are, however, certain other general objections to attaching this relatively great importance to the meteoric waters as against the emissions of eruptive rocks. Thus fractured districts without eruptive rocks or fractured districts in old and long cooled eruptives are not uncommon, and yet extensive vein formation, while not unknown, is rarely seen. Meteoric waters are everywhere available, except in the arid districts, and the materials of the ordinary gangue minerals, such as silica, lime, and iron, are the universal elements of rocks, but vein formation as a matter of experience is rare. This operates to diminish the probability of the efficient action of meteoric waters, and throws toward the agent, which, almost without exception, visibly accompanies vein formation, the greater weight of importance. What was a coincidence, consequently rises to the dignity of a cause.

If now an observer greatly impressed with the extensive alterations and chemical changes wrought by meteoric waters in those portions of the crust of the earth which stand above the ground-water level and which are subject to a heavy rainfall, and still more by the extensive concentrations produced in the case of that most abundant and soluble of the metals, iron, and if this observer were to plead the cause of the meteoric waters for ore-deposits in general, he would naturally proceed as follows. And to him a believer in the greater efficiency of the igneous rocks would reply as likewise stated below. For convenience we may refer to the former advocate as M. W. (Meteoric Waters) and to the latter as I. R. (Igneous Rocks).

M. W. would state at the start that meteoric waters are the only waters entering into the crust of the earth or emerging from it, which cut any figure in the economy of Nature. Upon this sweeping, axiomatic principle his case would be especially based. But I. R. replies that abundant experience indicates that hot-springs are associated with expiring vulcanism, are particularly large in arid regions, are known in several cases to yield more water than the capacity of the catchment basin tributary to them, and are therefore fed by the emissions of cooling eruptive rocks, which, as we know from volcanoes, contain vast supplies of the elements of water. He would add that hot-springs have without much doubt been the great agents in the primary deposition of ores and gangue minerals in veins. JAS. F. KEMP.

M. W. would next postulate that gravity is the prime mover in the underground circulations of the meteoric waters, and that it is reinforced by the expansion of the waters from the increase in temperature with depth. The descending cold and heavy column forces up again the ascending heated and expanded column. I. R. replies that in the restricted areas of vulcanism, the energy afforded by highly heated bodies of igneous rock is vastly superior to gravity, above all as an expelling agent and especially through the production of steam. If, moreover, adds I. R., we calculate on the best experimental data, the head that would be produced by the heavier descending column of colder water to a depth of 10,000 feet, as against the ascending heated column, it is insignificant, and except so far as the water enters at a greater elevation than its point of emergence, gravity as a prime mover practically disappears.

M. W. would emphasize the universal presence of the meteoric waters, and of the normal increase in temperature with descent into the earth. Somewhat in the spirit of the Uniformitarian School of Geologists, he would urge the incomparable claims to confidence of the small, slow but widespread causes in the production of results. To which I. R. would reply that veins and, above all, veins rich enough in metallic minerals for profitable exploitation

JAS. F. KEMP. *are* the exception and *are* extremely rare, and that for this very reason they must have been produced by some local and exceptional cause. Whereas we find, as a matter of experience, no such widespread vein formation as would be implied by M. W.

M. W. would lay great emphasis upon the cavities, large and small, in rocks, would plot curves to show the wide area drawn upon by an uptake, natural or artificial, and would show that the deeper the uptake, the wider the tributary area, until depths were reached at which cavities become physical impossibilities, that is, at a maximum of 30,000 feet for resistant rocks. I. R. replies that actual experience in those mines which have reached considerable depths, say over 2,000 feet, and sometimes less, goes to show that the water, if impounded in the levels above, diminishes with depth, and that the lower workings are in positively dry rock and may be dusty, even in regions of heavy rainfall, and of synclinal structure. The few deep and wet mines are in regions of expiring vulcanism.

M. W. realizing from this that the very foundations of his elaborate argument are crumbling in ruins, hastens to "hedge" by stating that at the time of vein-formation and for its limited duration, the rocks were open and permeable, but that the deposition of mineral matter or "cementation" has plugged them and cut off the former supplies of water. I. R. then remarks the enormous restriction which this imposes upon the sweeping statements of the earlier presentation by M. W.; expresses his surprise that, even granting cementation, more water is not found, and insists that none the less the down-takes, in which, not cementation but solution prevails, ought to continue to afford water to the excavations. He insists that in the large way the permeability of rocks has been overrated, and he therefore falls back on the greater claims of igneous intrusions to confidence as primary causes. He contends that when the emissions and energy contributed by them ceased with their refrigeration vein-formation and water supply likewise ceased.

M. W. emphasizes the tremendous complexity of the problem; the difficulty of tracing waters to their real source; their deep vertical descents, their wide lateral wanderings, and their uprisings from the profound depths. He urges the need of criteria for whose even partial statements he looks to the publications of the future, and to whose complete collection many years of labor must be devoted. I. R. replies that if one starts with an assumption of agents and methods of precipitation, which can be applied to the cases in hand only with great difficulty, the complexity becomes something awful, just as the Ptolemaic astronomers were driven to endless cycles and epicycles in trying to explain on faulty assumptions, what the Copernican system rendered comparatively simple and intelligible. He urges that the advocates of the influence of the igneous rocks are doing for that branch of geology which relates to ore-deposits what Copernicus did for astronomy—and that is, they are bringing into the field agents which are comparatively simple and incomparably efficient.

There are other considerations regarding ore-deposits which are of importance and of interest, but which do not involve differences of opinion upon theoretical points. They need to be understood by the miner, but they are not fundamental; for example, the enrichment of veins near the water level or for short distances below it, by the leaching of the upper portions in the descent of the surface waters. Certain peculiar mineral aggregates are characteristic of these enrichments, such as chalcocite and the distinctive silver minerals, but it is also true that the richest ore in mines may lie 3,000-3,500 ft. down the slope or shaft, as at Przibram and Grass Valley. Nevertheless, geologists are under great obligations, more especially to Mr. Weed, for emphasizing these relations.

It must not be forgotten that in regions physiographically old, we have left only the stumps of veins which may have once extended considerably higher. At the same time, in connection with matters of genesis, the root is more important than the trunk and limbs.

In general, the more sound geology that can be worked into systems of classification and into terminology, the more helpful they will be to engineer and geologist. The

JAS. F. KEMP. closer we keep in touch with the miner and with the hard facts of his experience the more justification for the existence of geology. There is no geologist who may not profit by the experience of an observant and grizzled veteran of the pick and drill.

F. L. RANSOME. Mr. Ransome was the next speaker. He said:

In a recent paper on ore-deposits, Prof. Vogt has remarked that "the precise tracing of the boundary between eruptive after-action and the work of the underground waters, is a labor for the future." It is a question whether the genetic classification proposed at a recent meeting by Mr. Weed has in any way curtailed this field of future investigation. That the time is hardly ripe for a satisfactory genetic classification of ore-bodies is shown not only by the widely divergent views held by eminent students of the subject, but by the trend of the present discussion which insistently transgresses its implied limits, to concern itself with the underlying processes of ore-deposition, rather than with the grouping of accepted types of known origin.

I shall try to point out briefly what seem to me to be some objections to the plan of classification adopted by Mr. Weed and to illustrate these objections by reference to ore-deposits with which I am familiar.

The use of the critical temperature as a criterion of classification gives to the scheme an attractive appearance of precision, which, however, is more apparent than real. For it implies that contact metamorphism ceases and entirely different processes come into play the moment the magma cools below the temperature of 365° C. As a matter of fact, however, water (which is admittedly the chief agent concerned in mineralization) will still exist as a vapor below the critical temperature, provided the pressure be not excessive, and it is yet to be proved that substances given off from the magma above their critical temperatures are the only agencies capable of producing the minerals characteristic of contact zones.

While it is admitted that molten magmas contain various substances that may be given off in the state of gas or vapor when the magma is erupted near the surface, it is a debatable question whether the magma is so saturated with these substances as to give them off in abundance under great pressure, and above the critical temperature. The fact that granite when heated to 1,000° C. was found by Gautier to give off more than 100 times its own volume of gases and vapors shows that under the conditions of original solidification these gases were *retained* in the rock.

Part of the argument in favor of a pneumatolytic origin for certain ore-deposits is drawn from the well-known effect of mineralizing agents in the artificial production of minerals by synthesis. The mineralizing agent in most cases, however, either does not enter into the composition of the mineral formed, or does so in very small amounts. An ore-body, on the other hand, implies a local concentration of materials elsewhere very sparingly present in the rocks. It cannot be explained as the result of crystallization of material already provided, in the presence of some mineralizing agent given off from a contiguous body of molten magma. It implies extensive transfers of material, and it is this considerable concentration and transfer which I find most difficult to ascribe entirely to pneumatolytic processes, particularly when it is remembered that one of the characteristics of ordinary contact metamorphism is a surprisingly slight change in the chemical composition of the metamorphosed rock. The case of the garnetized limestone of San José in Mexico, cited in a recent paper by Prof. Kemp, is not clearly an exception to this statement. His argument for the original purity of the limestone, and the consequent introduction of material to form the garnet, is based upon smelter records. But it is not unusual to find that the metamorphism of an impure limestone is a clarifying process, resulting in the formation of garnet and pure crystalline calcite. Moreover, smelters as a rule seek the purest limestone for fluxing purposes. At Cananea, for example, where extensive garnetization of the limestone has taken place, the limestone for smelting purposes is brought from a distance and from a bed that cannot be taken as representing the original character of the limestone before metamorphism.

The entire subject of pneumatolysis is one of great interest, and there would seem to be here a field for extensive experimental work. The difficulties in the way of such experiments, involving great pressures, high temperatures and time, are formidable, but perhaps not insurmountable. It is one of many lines of scientific investigation awaiting the happy conjunction of the right worker and an available fund.

It is over the fourth class of Mr. Weed's table—the gas-aqueous or pneumato-hydato-genetic deposits—that there will probably be most difference of opinion. One may admit the action of pneumatolysis in the formation of some contact deposits and yet hesitate to extend the hypothesis to most of the deposits grouped under Class IV, which comprises the greater number of workable metalliferous ore-bodies. It is generally admitted that water has been the vehicle by which these ores have been deposited. So much may fairly be deduced from the observable facts. The question whether this water is mainly meteoric or has been expelled from solidifying masses of eruptive rock approaches, at present, the ground of speculation, and with the hypothesis that gases given off from igneous rocks are directly mingled with the ore-depositing solutions, that ground is fairly entered. My own limited experience has rather inclined me to the view that most of the ore-bodies grouped under Class IV have been formed *after* the solidification of the eruptive rocks with which they are more or less closely associated, and that the principal agent in their concentration and deposition has been meteoric water.

In the Sierra Nevada of California, in what is known as the Mother Lode District, the gold quartz veins belong to the sericitic-calcitic class as defined by Lindgren, and are Cretaceous in age. The great eruptions of granodiorite also belong to this same period. But the veins are distinctly later than the granodiorite, and in many cases occupy fissures in the latter rock. The granodiorite had therefore solidified before the ores were deposited, and any direct participation of pneumatolytic processes is barred out as far as known intrusive masses are concerned.

The San Juan region in Colorado has been frequently cited in illustration of vein-relationships, which, as far as that region is concerned, are entirely imaginary. Thus the authors of two recent papers discussing the relation between ore-deposition and igneous activity, have referred to the region as containing three distinct sets of veins, each set characterized by ores of different mineralogical character. As I have elsewhere shown, this distinction has no basis in fact, and is a case of hasty generalization from very incomplete data. The lodes of the Silverton quadrangle, in this region, which are generally associated with propylitic alteration of the country rock, are not only later than the great series of volcanic lavas and tuffs, but are later than the monzonitic intrusions that invade the volcanics. Many of the lodes occur in fissures which cut the monzonites and the mineralization took place subsequently to the solidification of all the eruptive rocks known in the region.

In the Rico Mountains, Colorado, there are some deposits in Devonian limestone, which consist of pyrite, chalcopyrite, sphalerite, galena and specularite, associated with garnet, wollastonite, chlorite and pyroxene. These, although not now observably in contact with intrusive rock, are probably to be classed as true contact deposits, and are possibly, in part, of pneumatolytic origin. But the lode and blanket deposits of this district are distinctly later in age than the intrusive masses of porphyry, and were formed after the solidification of the latter. The porphyry itself is often extensively mineralized.

The copper deposits at Globe, Ariz., originally pyrite and chalcopyrite, were deposited after extensive intrusions of olivine diabase. The ore occurs chiefly in limestone, quartzite and in the diabase itself. The ores in the diabase have the form of veins or lodes, and were evidently formed after the diabase had solidified and had been greatly faulted.

In the Bisbee District, Arizona, the principal ore-

F. L. RANSOME. bodies occur as replacements in limestone adjacent to an intrusive mass of granite porphyry, and related also to faults cutting the limestones and older rocks. The original ores, from which the workable bodies have been formed by oxidation and by sulphide enrichment, consist of pyrite and chalcopyrite. They occur chiefly in the limestone, but the entire mass of porphyry is altered and abundantly impregnated with pyrite, sometimes accompanied by chalcopyrite. Here again the mineralization is apparently later than the solidification of the only known eruptive rock to which it bears any relation.

In conclusion, I do not wish to deny that pneumatolysis may be an effective factor in ore-deposition, but there seems to be a tendency to carry this attractive and suggestive hypothesis a little further than the facts warrant. The few mining districts that I have studied have led me to regard the action of meteoric waters, usually heated and rendered physically and chemically active by masses of intrusive rock, as more important and more far-reaching than indicated in the proposed genetic scheme of Mr. Weed, which has provoked the present discussion.

Mr. Hayes then introduced Mr. T. A. Rickard, who had been invited by the society to attend the meeting in order to take part in the discussion. Mr. Rickard said:

T. A. RICKARD. It is evident that as yet there is no unanimity concerning the origin of ores, and until a certain degree of harmony of ideas has been attained no sysem of classification is likely to be generally accepted; nevertheless the classifications submitted by Messrs. Weed and Spurr have served a most useful purpose in crystallizing their own views on genetic principles and in affording a clear field for discussion on the part of those who hold different opinions. "All knowledge," says Locke, "consists in seeing likeness and difference." That defines classification; by means of it we shall be able to analyze existing conceptions of the process of ore formation, so as to separate the points upon which we agree from those which we dispute and from the much larger array of facts concerning which no one possesses precise knowledge.

The discussion has emphasized the divergence of views between acknowledged authorities. Formerly, when mining did not know geology, both suffered thereby; when geology was an arrogant youngster and mining only a blind digger, it was fashionable to impute to vague igneous agencies and unknown gaseous emanations the responsibility for the occurrence of ores. To this period, which lasted long, a sort of "dark ages" in the history of mining geology, there succeeded a recognition of the effects of water in depositing minerals within the earth fractures. Posepny's monograph represents the culmination of this philosophy, for when Prof. Van Hise elaborated his deductions from physical laws, the tide of opinion had already begun to turn by reason of the researches of Vogt. Kemp, Spurr and Weed have driven home Vogt's conclusions, and by observation and discussion they have advanced the theory of igneous agencies until the aqueous factor is almost driven to the surface. Van Hise claimed for his domain a depth which reached at least six miles into the interior of the earth, now the advocates of magmatic differentiation propose to confine the agency of free water to a shallow strip somewhere near the surface. The theory of an aqueous deposition of ores is thus threatened by an igneous intrusion of a very violent kind.

The agency of water was at one time underestimated, that of magmatic differentiation was not recognized until lately, and as each branch of the subject had been elaborated, the enthusiasm of its advocates has carried them beyond bounds. The swing of the pendulum just now is on the igneous side, by and by the pendulum will slowly fall back to a compromise of views, so that with each elaboration of this many-sided problem we shall gradually attain to a more comprehensive theory, capable at length of covering the multitudinous ways in which ores are found in nature.

The classifications proposed by Messrs. Weed and Spurr are extremely suggestive. To a large extent they are supported by the broad fact of an intimate connection between ore-deposits and igneous rocks. The miner's fondness for an environment of "porphyry" may not be well reasoned, but it is the result of wide experience. It expresses a general phenomenon. A phenomenon is a thing you do not understand.

During the past three years I have been collecting data upon the geological distribution of the precious metals in Colorado. It is a remarkable fact that in this single mining region the profitable mines, exploiting gold and silver ores, occur within every geological terrain from the Archean granite to a Tertiary conglomerate; at this moment mining is going on in terrains belonging to all the principal subdivisions of geological time and amid a variety of petrographic environment which includes nearly all of the principal sedimentary and crystalline rocks. In arriving at the age of the country enclosing these lodes it has frequently been difficult to consider the sedimentary apart from the intrusive igneous rock, and it is not too much to say that there is not a mining district, among the sixty-five which I have tabulated, in which igneous rocks do not occur in close association with the ore-deposits. Moreover, out of six hundred representative mines there are at least two hundred which have yielded ore from sedimentary rocks belonging to more than one geological period. Thus, any generalizations based upon the age or the composition of the country rock are completely shattered. This serves but the more to emphasize the fact, which is too general to be a coincidence, that the valuable ore-deposits are connected with the occurrence, in the vicinity, of intrusive igneous rock. I have been led to conclude that the deposition of ore represents the results of that thermal activity which is, as it were, the dying breath of volcanic activity, and that the dikes, sheets, cores and laccoliths were factors in stimulating the circulation of mineral solutions. Not that the igneous rock was the direct ore-carrier, but that it energized the chemical work of the solutions, and that it opened a subsequent passageway for such solutions, whereby they reached the *locus* of their deposit. As Mr. Emmons has observed already, it is likely that the igneous matter brought the metals within the region of water circulation, and that the actual concentration of ore which is exploited by man to-day was the result of the subsequent activity of the underground water system.

The dryness of deep mines and its bearing upon the general conception of the underground circulation has been emphasized by Prof. Kemp in a recent very suggestive paper. It is a question on which I have been collecting data for the past two years, for it is fundamental to any comprehensive theory of ore-formation. This brings me to a view of the subject which I have previously suggested. In discussing Posepny's paper in 1893, I used the simile of a domestic hot water system. Prof. Le Conte and Mr. Emmons have at various times referred to this analogy, as I used it, and I am therefore encouraged to apply it in a more comprehensive manner. Data afforded by mine workings indicate that a condition of rock-saturation does not persist indefinitely downward, but that there is a water zone, extending from the ground-water level for a further depth of several hundred feet. Below that horizon, which has limits varying with locality, whatever free water does exist is confined to definite channels, that is, vein-fractures similar to those in which we find the ore to-day. In depth we encounter vulcanism. Thus we have the elements of a circulatory system; heat at the base, a series of channels leading to surface and a reservoir of cold water at the top. It is not likely that gravitation is the main agent in giving movement to the underground waters; the decrease in density due to rising temperature must be offset against the friction of the rock walls, and it is probable that superheated water-vapor serves as the main propeling force, as is suggested by the testimony of volcanic action. Nor is it likely that the water is wholly of meteoric origin. Much of it, like other factors in vein formation is indirectly traceable to the sources of eruptive activity. Nor, again, must the simile of the hot-water system be taken too literally. Underground waters do not travel along pipes, but along fractures and those systems of fracture which are called sheer zones, affording no continuous free passage, but a path of circulation which

T. A. RICKARD. is sought out with difficulty and followed with that patience which "hardens the ruby in a million years." The geologist has a large account at the bank of Time and is entitled to draw upon it.

The deepest metal mines, in the Lake Superior region, are dry at the bottom; the deepest coal mines in Germany and England exhibit the maximum of dust; the deepest gold mine in the world does not need to use a pump; many mines in the dry regions of Australia are unhealthily dusty at a shallow depth; in the Transvaal, miner's phthisis is brought on by excessive dust in the air of the workings, —these facts speak for themselves. It is useless to speak of an indefinite water saturation in the face of them. Moreover, the heavy inflow of water in mines coincides usually with a comparatively shallow zone, the bodies of water encountered underground are eventually pumped out; so that there is plenty of evidence which is quite opposed to the conception of a water-soaked region of indefinite vertical extent. It is a matter which is worthy of consideration, because it affects the ideas which we form concerning the precipitation of ore from solutions in their approach to the surface.*

C. R. VAN HISE. The discussion was continued by Prof. C. R. Van Hise. He believed that in order to get a proper perspective and to appreciate differences of view, it would be well to first give a summary of points of agreement. Attention was called by the speaker to the fact that in his paper, published two years ago under the title of "Some Principles Controlling the Deposition of Ores," he had stated that the metals of some ores are directly derived from recent adjacent igneous rocks; that the ultimate source of all the metals of ore-deposits is the igneous rocks; that igneous rocks have an influence upon ore-deposits by contributing metals to them and by contributing solutions; they also produce important effects by heating solutions of meteoric origin and in forming the openings which may be followed by such solutions.

[1]This idea was subsequently set forth at greater length, under the title of "Water in Veins. A Theory," in the ENGINEERING AND MINING JOURNAL of March 14th, 1903.

C. R. VAN HISE.

As a basis for discussion the following provisional generic classification of metallic ore-deposits was submitted:

Metallic Ore Deposits.

- Sedimentary.
  - (a) Chemical precipitates.
  - (b) Mechanical concentrates.
    - (1) Residuary deposits.
    - (2) Stream deposits.
    - (3) Beach deposits.
- Igneous.
  - (a) Magmatic segregations.
- Metamorphic.
  - (a) Deposited from gaseous solution.
  - (b) Deposited from aqueous solution.
    - (1) Ascending waters.
    - (2) Descending waters.
    - (3) Ascending and descending waters.

Referring to the most recent classifications of ore-deposits, the placing of a large proportion of ore-deposits as of pneumatolytic, fumarolic, solfataric, and pneumato-hydato-genetic origin, was deprecated. The question was asked as to the criteria by which ore-deposits are known to be deposited by gaseous solutions.

The criterion which seemed to be of most weight to the speaker was the formation simultaneously with the ores of such heavy anhydrous minerals as garnet, pyroxene, wollastonite, tourmaline and biotite. For those ores which are deposited simultaneously with these minerals it is believed that they are deposited under the conditions of the deep-seated zone of rock flowage, and probably at temperatures above the critical temperature of water. It is further to be suggested that the frequent lack of definite boundaries for these ores and their dispersed distribution through rocks have a similar bearing.

If the question cannot yet be fully answered as to the criteria by which ores deposited by gaseous solutions are to be recognized, what shall be said as to the criteria by which such ores are divided into sub-classes? The placing of the various ore-deposits of many well-known districts in such classes as fumarolic, solfataric, pneumatolytic, etc., without giving the evidence for such distribution, seemed to the speaker to be premature.

The criteria by which ores deposited by aqueous solutions may be discriminated were briefly summarized. The more important ones were held to be the following:

First.—The material which has filled the numerous openings of great sandstone, conglomerate, amygdaloid and tuff formations, thus cementing them, is agreed by all to have been deposited by aqueous solutions. The evidence seems to be conclusive that the simultaneous filling of joint and fissure openings and the replacement of rocks by minerals like those of the cementation materials, are also the work of aqueous solutions. But here and there the fillings of various kinds carry a minute fraction of a per cent. of gold and silver, or a small per cent. of copper, lead or zinc, and are consequently ores. Such ores are almost certainly deposits from aqueous solutions.

Second.—The dominant gangue minerals which are deposited simultaneously with the great majority of ores, both in openings and in the wall rocks, are the hydrous silicates, such as the zeolites, the kaolinites, sericite and chlorite; the carbonates, such as calcite, dolomite and siderite; the oxides, such as quartz and hematite. These minerals are the same as those that do the general work of cementation. Moreover, they are the minerals which have been observed to be deposited by aqueous solutions at Steamboat Springs, Sulphur Bank, Boulder Hot Springs, Yellowstone Hot Springs and other localities. At some of these localities, notably at Steamboat Springs, Sulphur Bank and Boulder Hot Springs (described by Weed), small quantities of ores have also been deposited. Therefore, both observation of the actual work of aqueous solutions and the fact that the minerals formed are like those which have done the general work of cementation, lead to the conclusion that ores having the above-mentioned gangue minerals as associates, are the deposits of aqueous solutions. No observations have been made which support the view that ores having such gangue minerals are deposited by gaseous solutions. But the ores having such gangue minerals are the dominant class, and *it follows that the class of ores deposited by aqueous solutions is of greater importance than any other class, and probably of greater importance than all other classes.* C. R. VAN HISE.

Time does not suffice to discuss the sedimentary ores, nor more than allude to the igneous ores. In reference to the latter, it is well known that the corundum ores in certain corundum syenites are the direct products of magmatic segregation. Also, it is agreed by all that the titanic iron ores are produced by magmatic segregation. These ores, although large in total mass, are often low grade and are at present of little or no economic importance. The important point in this connection is that aluminum and iron are the two most abundant metals of nature. The fundamental law of chemistry, the law of mass action, is here applicable. In order to produce a titanic iron ore containing 60 per cent. metallic iron from a rock of medium basicity, such as a gabbro, it is necessary to suppose only that the iron has been multiplied seven or eight times beyond the original amount in the rock. It is, therefore, easy to understand why the processes of magmatic segregation produce such materials as titanic iron ore and aluminum ores. The production of ores other than of aluminum and iron by magmatic segregation is an entirely different matter. He who holds that ores of nickel, copper, gold, etc., are produced by magmatic segregation alone should determine the ratios between the amounts of these elements present in the original rocks and in the ores. When these ratios are determined one will be able to see whether or not the amount of segregation in these cases is comparable with that which we know to exist in the cases of the abundant elements where we can be sure of the nature of the processes.

The discussion was concluded by Mr. Weed, who said: W. H. WEED.

When the invitation to present a tentative genetic classification of ore-deposits was accepted, the scheme was reduced to its barest outline, and then sent to Mr. Spurr, and a large number of other friends, with a view to eliciting discussion. As a means of provoking discussion, it

W. H. WEED. has been eminently successful, and it has drawn out two other schemes of classification. The fact should be emphasized, however, that my genetic classification expressly disregards commercial considerations; it is based upon scientific data, and is intended to express the processes of ore formation. There may be but one example, and that of little economic importance in a class, but it is genetically as worthy of recognition in the classification as the great productive deposits mentioned by Van Hise. In presenting this scheme, my first attempt at a strictly genetic grouping, the limitations of time prevented anything more than a very general statement of the principles upon which it is based. In the table, certain ore-deposits were mentioned to show the nature of the deposits meant under certain types. Such references must be accepted as tentative, and as indicating that their character points to the origin predicated, to be confirmed or refuted by further study. For example, magmatic quartz veins have been recognized for many years. If, as Beck and Spurr maintain, these veins are sometimes gold-bearing, there should be a place for them in the classification. Beck* says: "The aplite dikes carrying the gold quartz veinlets mined at Berezovsk in the Ural Mountains, are genetically connected with the granite mass of Lake Shartash. . . . . The perfectly fresh stone-hewer's chips of this granite, which is there quarried for stair steps, door jambs, etc., are creditably stated to contain as much as one grain of gold per ton. If thus the intrusive stock proper is auriferous, it need not be wondered at that the subsequent outpourings from the same igneous hearth in the form of aplites, also brought with them a gold content which was concentrated in the quartz stringers. These quartz stringers have to be considered from the same point of view as regards their origin as the pegmatites."

Prof. Van Hise's concluding remarks indicate that the author of the proposed classification is expected to present detailed proof that each subdivision includes deposits of the origin indicated. This seems wholly unreasonable; for example, the igneous origin of certain copper and

*Richard Beck, "Lehre von Erzlagerstätten," p. 324.

nickel deposits is maintained by Vogt, who has presented detailed descriptions of the deposits, and these descriptions and theory have been accepted by numerous geologists of repute and quoted in text books. It is not incumbent upon the author of a classification, confessedly utilizing the work of all investigators, to present detailed proof of the correctness of the theories of well-known men. Adverse criticism would be merited were such work ignored. **W. H. WEED.**

As regards the criticism of the igneous origin of copper and nickel ores, the fallacy of Prof. Van Hise's argument lies in an appeal to mass action while disregarding relative solubilities. Nor is it evident why "differentiation" of copper and nickel is a very different matter from that of differentiation of iron ore. The mere fact that there is more iron in a rock than there is copper does not of itself and in disregard of solubility constitute a valid reason for the segregation of one and not of the other. Chalcopyrite and pyrrhotite are well known to be primary constituents of certain rocks, and the pyroxenites often carry 0.1 per cent. more of nickel oxide, so that twenty times this amount would constitute ore, as occurs at Webster, N. C. At the same time, it is recognized that there is not a copper deposit of demonstrated igneous origin yet known in this country.

Concerning the deposits made by igneous emanations, whose existence is so grudgingly admitted by two of my critics, the evidence of Aguilera, Kemp and Lindgren is rapidly accumulating, and it is confidently believed that as observers become better acquainted with the character of these deposits they will be able to recognize them, and many other examples will be found in this country and in Mexico.

"An attractive air of precision," to quote a phrase used in the recent discussion, is given to a citation by Mr. Ransome to the well-known California gold veins, as proof that because the veins cut the granodiorite that they must of necessity have no connection with this rock. I need only mention the classic tin-copper veins of Cornwall and Saxony, as well known examples controverting his contention. It is, however, well known to petrographers

W. H. WEED. that there is frequently a close genetic relation between basic and siliceous dikes and the granite rocks cut by them. To argue that veins cutting granitic rocks cannot be closely related both genetically and chronologically to them, is as unreasonable as to assume that the dikes mentioned are always proof of a distinct period of igneous activity.

In reply to Prof. Van Hise it appears to me very evident that a failure to recognize criteria perfectly plain to other equally competent observers is not a proper subject for argument. I am content in company with Geikie, Fouqué, Suess and Richard Beck, not to mention those who have supported me in this discussion. As Prof. Kemp has said, the scene shifters fill the stage in the "Principles controlling the deposition of ores." It is Hamlet, with Hamlet left out, and though the actors appear in the bill—the little classification presented to-night—they do not appear on the stage. Admitting as he does to-night that igneous emanations do form contact metamorphic ore-deposits, it is certainly reasonable to believe that the emanations could and do mingle with ground-waters, to which they not only contribute metallic substances to be deposited as ores, but also chlorine, fluorine, boric acid, etc. These mineralizers add immensely to the solvent power of said waters as a few drops of hydrochloric acid will sharpen the water in which calcite is dissolving, and such hot waters may add to their burden of precious metals by attack upon the rocks traversed. To quote the apt words of Suess: "The hot waters . . . accordingly cannot be anything else than the consequence of the degasification and cooling of a lava mass lying not far below the surface; emanations which are too feeble to cause a volcanic eruption or preparation for an eruption. It may be imagined that vadose infiltrations are carried up by the less hot springs, that is, that in descending, meteoric waters will meet hot water, which prevents further penetration. One may even imagine that in the course of an oscillation of the internal heat, that is to say, in case of diminished rise of heated gases, as is now the case in the Yellowstone, the vadose water is enabled to penetrate into a somewhat greater depth, and with a renewed rise of the hot gases

W. H. WEED.

these deeper vadose waters may even be taken up by them and a certain mixture ensue, thus vadose additions may cause subordinate features masking the true condition. But the essence of the phenomena, just as in the case of volcanoes, consists in the uprising of juvenile (primitive) material, the 'internal' supply or contribution from the depth."

It is true that the views now held are slightly at variance with former ones, but an intimate acquaintance with and study of the hot springs of the Yellowstone during the past twenty years, and the accumulation of facts upon rainfall and flowage, have led me to a belief in the statement just given, and to the conclusions of Suess, that ore deposits are the work of hot springs, and that hot springs are a waning phase of volcanic activity. It is hoped at some future day to present a fuller account of the evidence for this classification. It has fulfilled its mission in provoking discussion, and it now remains for us all to gather new facts whose study will either prove or disprove the correctness of the classifications which have been proposed.

OBSERVATIONS ON GOLD DEPOSITS*

BY CHESTER WELLS PURINGTON.

This distribution of ore deposits is a subject which presents to the mining engineer more of practical importance than does the discussion of the origin of ores. While not decrying the usefulness of the several views which are now the focus of so much comment among geologists, I would urge the necessity for collecting and publishing more data concerning the distribution of ores, together with their accompanying phenomena. In the present paper the purpose is to treat of the distribution and rock association of some gold deposits, the cases dealt with being for the most part those which have come under my personal observation. Although it is recognized that the recording of such observations forms but an elementary part in the working out of the profound science of ore deposits, it is hoped that some shreds of value may be found among these notes by those who shall later compile lists of the known gold occurrences.

In recent years, the accurate work which has been performed with reference to the testing of rock and rock areas, remote from metalliferous veins, has given convincing illustration of how widespread is the distribution of gold. Since the researches of Sandberger, no more able work has been done in the line of determining the minute quantities of gold and silver than that of Mr. Luther Wagoner,[1] whose results have recently been published. Mr. Wagoner has shown that granite, syenite, basalt and

*This carefully prepared contribution to the discussion on ore deposits was published in *The Engineering and Mining Journal* of June 6, 13 and 20, 1903. It is proper that it should appear as a part of the present pamphlet.

[1] Luther Wagoner, "The Detection and Estimation of Small Quantities of Gold and Silver." *Transactions* American Institute of Mining Engineers, 1901, Vol. XXXI, p. 798.

diabase, of the igneous rocks, and such material as Carrara marble and San Francisco Bay mud, representing sediments, contain gold in appreciable quantities. His specimens were selected without reference to the distribution of metalliferous provinces, and the work has thus a special value. It is possible that further investigation along the line of these experiments may show that the distribution of gold is practically universal.

Mr. T. A. Rickard, in one of his recent contributions[2] to the *Transactions* of the American Institute of Mining Engineers, states that the late Prof. Posepny criticized him for looking at every new conception in ore-deposition "from the sole standpoint of its immediate usefulness in mining." Mr. Rickard says that in the main he accepts the impeachment. One might almost go farther than this to-day and say that the writer on ore-deposits must confine himself to noting and speculating on those which have economic importance, or the mass of literature will soon become overwhelming. In the following notes, therefore, those occurrences of gold which have proven, or under future conditions may prove, of mining value, are referred to. Digressions are made from this general rule of treatment only in cases where the gold deposit of purely scientific interest offers special features for comparison with workable ore-bodies.

From the standpoint of personal observation, the recent paper of Mr. J. E. Spurr[3] has a special importance, and portions of it are to be considered as a distinct contribution to the assembly of information concerning ore deposits. Mr. Spurr has in this paper elaborated the theory advanced by him to account for certain of the gold veins of the Yukon District of Alaska,[4] and has cited numerous occurrences from other parts of the world in support of his hypothesis. As I understand Mr. Spurr he believes that the siliceous *relique* of large igneous magmas, as exempli-

[2] T. A. Rickard, "The Formation of Bonanzas in the Upper Portions of Gold Veins." *Transactions* American Institute of Mining Engineers, 1901, Vol. XXXI. p. 199.

[3] J. E. Spurr, "A Consideration of the Igneous Rocks and their Segregation or Differentiation as related to the Occurrence of Ores." *Transactions* American Institute of Mining Engineers, New York Meeting, 1902.

[4] J. E. Spurr, "Geology of the Yukon Gold Belt." 18th Annual Report United States Geological Survey, part iii, p. 300.

fied in the consolidated portions now visible at the earth surface, is more prevalent than has generally been called attention to. Further he maintains that in any large area of rocks, which is characterized by the occurrence of metalliferous deposits, the distribution of the gold-bearing veins is connected with the granite or siliceous, rather than with the more basic or iron-bearing portions of the mass. Instead of stopping with a granite as the final phase of a cooling and crystallizing magma, or with those forms of effusive lava, which are the surface equivalents of granites, he goes farther. He says that certain portions of the cooling mass may, if they find a sufficient opening, take the form of very siliceous dikes, which by the disappearance of the biotite, and the almost complete obliteration of the feldspar, become what he has called "alaskite." That further, by the disappearance of the feldspar, these alaskites may and do pass into quartz veins, containing precious metals as direct product from the cooling magma, and among these metals notably gold. In other words, he traces the origin of certain quartz veins directly from igneous magmas, by a process of magmatic segregation, and derives an auriferous quartz vein from an igneous siliceous dike.

Since the time of Hutton's observations on igneous rocks, and the experiments of Sir James Hall in the latter part of the eighteenth century, various writers have held to the igneous theory of veins. J. Brough Smyth[5] quotes, with a considerable amount of favorable comment, a work by Thomas Belt,[6] in which an igneous theory to account for the origin of auriferous quartz veins is given with such compactness that I venture to insert it here. After making the general statement that veins are explained by the theory that they are fissures which have been filled with molten silica containing entangled metallic vapors, he goes on to say that "the fusion of rocks in the bowels of the earth, and their subsequent consolidation supply the requisite conditions for the rending open of the superin-

[5]J. Brough Smyth, "Gold Fields and Mineral Districts of Victoria," 1869, p. 236.

[6]"Mineral Veins—An Enquiry into Their Origin—Founded on a Study of the Auriferous Quartz of Victoria," by Thomas Belt.

cumbent rocks, and the filling of the rents so formed with fluid matter, varying in composition according to the comparative depth from which it has been projected."

Although the ideas of the earlier investigators were to a considerable degree speculative, and in many cases not supported by the detailed observation which render the theories of present writers worthy of attention, still a consideration of Mr. Spurr's theory should include at least a mention of previously advanced theories which present analogous features.

Mr. E. D. Levat[7] has called attention to gold occurrences in East Siberia, which are apparently comparable to some extent with those which Mr. Spurr has found on the Yukon. I have not seen the East Siberian deposits, but shall beg indulgence to refer to them before proceeding to the description of localities personally visited. The descriptions given are evidently the result of much patient investigation on the part of the French engineer.

On a tributary of the Onon River, namely, the Khangarok Creek, in the Trans-Baikal region to the southeast of Irkutsk, on the border between Siberia and Mongolia, is situated the Blagovieshensk placer. This mine produced, in the years from 1868 to 1879, 491 poods, or over 8,000 kilograms, of alluvial gold. The gravel contains 0.25 per cent. of iron pyrite, which on being assayed was found to carry $40 to the ton in gold. The bedrock is a clay schist lying between two masses of granite on the east and west. The two granite masses are connected by a dike of aplite, according to Mr. Levat. He explains the occurrence of this rich placer from the erosion of the aplite, which contains the gold. He gives it as his opinion that the aplite was mineralized by a process contemporaneous with the disappearance of the mica from the igneous rock, and defines the aplite as a granite without mica.

In an entirely different locality, that of the Zeya River, a northern tributary of the Amoor River, Levat states his inability to find auriferous veins or other primary deposits to account for the existence of the rich placers there exploited. The country is for the most part schist and gneiss

[7] E. D. Levat, "L'Or en Sibérie Oriental," Paris, 1897.

in which beds of quartz are interstratified. There is a separate large detached mass of fine grained granite. In this granite, entirely apart from any other rock, occurs the placer deposit forming the Zholon Mine, one of the richest in the district. It is situated on the Zholon Creek, a tributary of the Zeya. In a length of 2.5 miles along this creek more than $7,500,000 in placer gold have been extracted.[8] The gold is not greatly worn, and is of moderate fineness of grain. The granite is characterized, especially in certain areas, by a schistosity, running nearly north and south, the minute planes being filled with a heavy iron oxide. No quartz is found, and there are no other signs of mineralization. No other rock occurs in the vicinity. The granite on assay yielded, even in its best mineralized portions, less than $1 to the metric ton in gold.

The above cases are cited as illustrations of the apparent direct connection of gold with granitic rocks in origin. One can hardly question, after seeing such instances in the field as Mr. Spurr and Mr. Levat call attention to, that there exists a genetic connection between siliceous rocks and gold, at least in some well-defined instances. Whether this connection of gold with siliceous provinces is of such general occurrence as Mr. Spurr believes, is a matter subject to some doubt, and worthy of investigation.

That rocks of a moderately siliceous character form a habitat for gold-bearing veins has frequently been remarked. So long ago as 1845 Mr. P. Tchihatchef[9] called attention to the fact that the occurrence of diorite is favorable to the occurrence of gold, and gave numerous citations from various parts of the world in support of this view. In 1866 Mr. P. P. Doroschin[10] advanced practically the same opinion. Undoubtedly the association is of very frequent manifestation. I am unable to believe, however, that either diorite or granite, in single occurrence, without the accompanying presence of the more basic rocks, are generally favorable to the segregation and subsequent deposition of gold.

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[8] From 1890-1894 this placer paid $2,000,000 in dividends.

[9] P. Tchihatchef, "Voyage Scientifique dans l'Altai Oriental," Paris, 1845.

[10] "Archiv für wissenschaftliche Kunde in Russland," vol. 25, 1866 (probable reference), work not accessible.

That a very large proportion of the known occurrences of gold are directly associated with silica in the form of quartz must be admitted. Until within very recently some investigators have claimed that an original deposit of gold without quartz was an unobserved phenomenon. Mr. Spurr, as I understand him, maintains that the derivation of a gold-bearing vein uninterruptedly from a siliceous rock is not only a possibility, but is a plausible explanation for many of the occurrences in nature. He eliminates the break in the continuity of phenomena which is a necessary accompaniment to the formation of a vein in a previously existing fissure. Without taking up here the various definitions of a vein which have been advanced, I would suggest that Mr. Spurr has rather overlooked the physical side of the question in his desire to lay stress on the chemical activity involved. If the occurrences to which he draws attention are quartz segregations, even though they contain sulphides of the metals, and are payably auriferous, they constitute a very exceptional class of veins, according to my understanding of the term. Indeed, I question if they should be classed as veins at all. I would therefore object to Mr. Spurr's views, as set forth, from two standpoints—one main, one subordinate. From the main standpoint, that siliceous rocks without the accompanying association of basic rocks, are not, in the majority of observed cases, favorable to the occurrence of gold; and from the subordinate standpoint, that fissure-veins formed by siliceous segregation in granitic magmas are difficult to conceive of from a purely physical standpoint.

The better to illustrate my meaning as regards the word vein, I cite from recent geological literature. Prof. J. F. Kemp, in his generally clear and useful paper, "The Rôle of the Igneous Rocks in the Formation of Veins,"[11] appears to me to use the term vein in an ambiguous sense, in his description of pegmatitic occurrences. Referring to certain cases in Connectitcut, he says, "Pegmatites grade insensibly into quartz-veins." Such a phenomenon, except in a very limited sense, is hard to reconcile with the accepted definition of a fissure-vein. Pegmatite de-

[11] J. F. Kemp, *Transactions,* American Institute of Mining Engineers, Vol. XXXI., p. 183.

posits undoubtedly occur with well defined walls. I am informed by Mr. Philip Argall that dikes of pegmatite, exhibiting sharp walls, occur well-defined in the granites of Gilpin and Clear Creek counties, Colorado. In a recent paper on the occurrence of mica in Brazil.[12] Mr. H. Kilburn Scott says, "The principal mica deposits are pegmatite veins, lenses or dikes, which occur in the metamorphic schists," etc., and states that the veins, running parallel to one another, from 20 ins. to 10 ft. in width, may be traced for long distances. Masses or bosses of quartz occur in the midst of these pegmatite veins. While granting the existence of pegmatite veins of considerable length and clear-cut definition, I maintain that they are exceptional, and that the normal pegatite occurrence exhibits the characteristic features of a segregation from the enclosing mass, its structure grading into that of the containing granite by a finer and finer crystallization.

For example at the well-known tourmaline deposit of Paris, Maine, the occurrence is a pegmatitic segregation in granite. The mass lies in the granite with no well-defined boundaries. It could not be defined as a vein or dike. The gangue minerals common to quartz veins occur in it, exhibiting many of the features of arrangement characteristic of such veins. Quartz crystals, arranged in comb-structure, and with open druses, even metallic sulphides, occur. I see no reason to doubt that the presence of gold in minute quantities might be established. In the midst of the Paris deposit occur many secondary and tertiary fractures, which appear to have been filled and refilled with quartz crystals. Some of these veinlets penetrate even the big crystals of black tourmaline, which I have seen 15 ins. in length, and 4 ins. in diameter. But taken as a whole, the occurrence is no more a vein than are the elongated blebs of magnetite, which compose many of the iron deposits in the gneisses of New Jersey. Veins in an extremely local manifestation are formed as a subordinate phenomenon in connection with pegmatite deposits, as illustrated at Paris, fulfilling all the requisite

[12] H. Kilburn Scott, "On the occurrence of Mica in Brazil and on its preparation for the Market," *Proceedings,* Institution of Mining and Metallurgy, April 23, 1903.

conditions of a pre-existing fissure subsequently filled by extraneous material. They are, however, in the majority of cases, of interrupted continuity, extremely irregular width, and except in rare instances, of negligible importance from a mining standpoint.

Mr. Spurr, referring to the deposits of gold at Berezovsk[13] in Russia, says the veins "generally stretch across the dikes at right angles to the walls and have been considered as filling 'fissures of contraction by Posepny.[14] This is probably correct,' for the veins follow the same lines as the 'columnar jointing' of dikes, which are due to contraction."

This explanation of Posepny's regarding the veins at Berezovsk appears to me, with all due respect to the views held by that renowned student, as probably highly incorrect. The country rock at Berezovsk, which is situated 7 miles to the northeast of Ekaterinburg, Perm Government, Russia, is a part of a large area of granites and metamorphic schists occupying the south central part of the Perm Government. At Berezovsk itself the country consists of a muscovite granite in more or less schistose bands, intercalated with mica schist. In the immediate vicinity of the village is an unusually large area of pure granite, of fine texture, while the associated schist is subordinate in amount. The schistosity of the whole runs north and south. To the west, but within the crystalline area, are patches of a peculiar rock, which has frequently a curious green color, and which is probably a metamorphosed dolomitic limestone. This consists of magnesite, siderite and calcite, and is called listvenite. The richest gold ore which has been worked occurs close to Berezovsk. The alternating bands of schist and granite have been at one time fractured by fissures having a direction N. 80° E., which, although they penetrate all the rocks except certain basic dikes, have their strongest manifestation in the granite.

[13] Berezovsk, pronounced Beryozoovsk, from the word Beryoza, birch tree.

[14] Posepny states that, although the fissures at Berezovsk cannot be ascribed to structural dislocation, nevertheless in the Pishminsk district (20 miles to the west), he found the gold quartz veins occupying the same position as in the peculiar Berezovsk granite, and suggests caution in referring the veins of Berezovsk to local filling from the granite. I did not see east and west veins in the Pishminsk District, but saw them at Moorzinsk, as noted farther on. See F. Posephy, "The Genesis of Ore Deposits," *Transactions* American Institute of Mining Engineers, 1893, Vol. XXIII, p. 266.

Into the fissures the gold-bearing solutions appear to have penetrated, resulting in the formation of the veins. In connection with the Berezovsk deposits occur bands of serpentine representing metamorphosed basic dikes. The quartz veins, which are rarely over 3 ins. in width, and from 6 ins. to 2 ft. apart, penetrate all the rocks except the bands of serpentine, and it is reasonable to infer that the basic dikes were the direct agents of mineralization.

In former times, when slave labor was employed, the Berezovsk deposit was developed by about 6,000 ft. of drifting and stoping, and I was enabled, through the courtesy of the present manager, Mr. Sokolof, tc inspect these old workings. The mine is at present worked in places, but the low-grade ores formerly extracted cannot now be profitably handled. It is stated that the richest of the small veins carried 1 oz. in gold, while the average for the ore as mined was 0.25 oz. The average of the entire stock or wide belt of berezite,[15] as proved by recent sampling, is 0.1 oz. in gold per ton, and it has been determined that appreciable though not workable amounts of gold occur throughout the granite area for a width of several miles. The ore taken from the selected portions of the leads now being worked, is milled by stamps, thirty in number, with accompanying amalgamation, followed by Chilean mills, and the tailings directly cyanided.

The granite, called in its more mineralized portions, berezite, consists of quartz, feldspar and muscovite. It is impregnated with iron pyrite, and is subject to much local silicification. The examination of the granite by Arzruni, referred to by Mr. Spurr, is susceptible of more than one interpretation. The disappearance of feldspar can take place normally by sericitization, as shown by Mr. Lindgren[16], and as I have tried to show,[17] and in the berezite deposit subordinate silicification has evidently occurred.

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[15]Mr. A. Karpinski states, (*Compte Rendu,*) Congrès Géologique International, 7 me. Session, St. Peterbourg, 1897, p. ccix, that berezite, "in its typical form, consists of muscovite and of quartz with a mixture of pyrite; it is a rock of secondary origin, formed by the transformation of microgranite and of granite."

[16] W. Lindgren, "The Gold Quartz Veins of Nevada City and Grass Valley," 17th Annual Report United States Geological Survey, pt. ii., p. 148.

[17] C. W. Purington, "Preliminary Report on the Mining Industries of the Telluride Quadrangle, Colo.," 18th Annual Report United States Geological Survey, pt. iii, p. 807.

I am inclined to disbelieve the efficacy of any tests which have been made on the Ural berezite, with the view of proving its primarily auriferous character. The difficulty of getting a piece of it which is not penetrated by one or more of the innumerable quartz stringers resulting from ore impregnation is great. The granite area itself is large, and the area of mineralization, so far as my observations have led me to believe, is very much larger. In a well sunk in the yard of Mr. W. E. Davidson in Ekaterinburg, decomposed greisen-like material was found, resulting from the disintegration of the schistose granite, on which the city of Ekaterinburg is built. I collected some of the material from the bottom of this well, and panned gold from it. I also panned gold from the decomposed material lying on the granite in the immediate outskirts of Ekaterinburg, and many little pits may be seen near the city, in the beds of the runs tributary to the river Isset, where the peasants have washed gold.

In the cuts of the Perm-Tiumen Railway, to the north of Ekaterinburg, exposures of the granite may be seen which appear fresh and unmineralized. But on close examination, pyrite crystals are generally visible, and quartz veins are not uncommon. Quartz veins and mineralized streaks, characterized by an oxidized appearance, may be seen penetrating the granite close to the cathedral in the town of Ekaterinburg in the public square situated between the telegraph office and the American Hotel. I give the above observations in order to indicate how widespread is the mineralization and how nearly impossible it would be to obtain a piece of this granite remote from the proximity of a quartz vein.

As regards the fissuring at Berezovsk, there is much evidence to show that the fractures are not of local development, and that the N. 80° E. fracturing, contemporaneous with another system which strikes N. 30° W., is of widespread areal[18] manifestation. In an open cut near the village of Berezovsk, the two sets of fissures, both sharply defined and carrying veins of auriferous quartz, may be seen. At other localities, from 5 to 75 miles dis-

[18] Note the observations of Posepny before recorded.

tant, for example at the Moorzinsk concession, 5 miles to the north, at emerald mines of the Crown Domain, 50 miles to the east, and in the Serebransk Dacha, 75 miles to the northwest, the fissuring, conformable in direction to that at Berezovsk, is so well exemplified that there can remain no doubt of its being a general and not a local phenomena. The data here given might be considerably extended, but the evidence, I think, is sufficiently strong to show that the direction of the veins at Berezovsk are determined by contemporaneous, widespread systems of fracturing, and it is justifiable to conclude that the provisional statement of Posepny regarding the origin of the fissures at Berezovsk is unworthy of consideration.

I have shown that at Berezovsk basic dikes occur which are themselves not penetrated by ore, but which have an influence on the values which are found in the veins of the granite and the schist. One cannot doubt that the granite must have been rigid to admit of fissuring. The basic dike intrusions occurred subsequently to the solidifying of the granite. The probability is that the ore-impregnation and filling were contemporaneous with, or directly consequent on, the intrusion of the dikes. The remarkable changes which have taken place in the bordering limestone, causing the change into listvenite, is another evidence of the widely manifested metamorphic action of the basic dikes. In short, the gold deposits in the vicinity of Berezovsk present nothing extraordinary. It appears to me an analogous occurrence to the Alaska-Treadwell Mine, on Douglass Island, Alaska.[19] There the mass or wide dike of sodium syenite has been mineralized throughout, consequent on the intrusion of a much later dike of basalt. I have examined many microscopic slides of the Treadwell ore, both of the rich and poor varieties, and have failed to find one case in which minute stringers of quartz connected with pyrite crystals do not occur. The deposit exhibits all the features of a shattered and subsequently cemented and impregnated mass. The Berezovsk deposit presents a near corollary to the Treadwell, the difference being that the

[19] G. F. Becker, "The Gold Fields of Southern Alaska," 18th Annual Report United States Geological Survey, pt. iii., p. 64.

dike rocks were considerably older at Berezovsk and the concentration of the gold values was considerably less. I have seen many of the openings on quartz veins in the Perm Government of Russia, and have reached the conclusion that, so far as the gold deposits are concerned, there has been a permeation to an extraordinary areal extent of gold-bearing solutions into a previously shattered and fissured country. The result has been, especially in the district of which the city of Ekaterinburg forms the approximate center, the formation, if it may be so expressed, of one great body of gold-bearing material, so low grade that it is not, except in certain very limited areas, of economic importance. The cause of this permeation is to be laid at the door of the basic dikes and stocks which occur in various parts of the region rather than to the rocks of granitic type which were earlier formed.

Taking the Ural as a whole, it is evident that the distribution of the gold deposits follows with a considerable degree of regularity that of the very basic rocks. At Miassky Zavod, on the Trans-Siberian Railway, in the Orenburg Government, where the gold deposits have proved exceptionally rich, as evidenced by the workings of many years, and where payable deposits are still operated, the region is characterized by a large area of granite with associated peridotite. Extending to the south, it is noticeable that the belt of peridotites, greenstone schists and porphyrites, making to the southwest, is characterized by the occurrence of gold as far as Verkni-Uralsk, a distance of nearly 100 miles. On the other hand, the belt of more acid crystalline schists, and the granite area to the west, are for the most part singularly barren of gold values. The only exception in the granite area in Kotchkar,[20] where in the midst of an immense area of granite, extending in all directions, occur two small stocks of peridotite cutting through it. The more southerly of these, which is about two miles in length, is marked by the occurrence of gold deposits, in veins far richer than the veins of any of the surrounding area. It is the direct influence of the perido-

[20] H. B. C. Nitze and C. W. Purington, "The Kotchkar Gold Mines, Ural Mountains, Russia," *Transactions* American Institute Mining Engineers, Vol. XXVIII., 1898, p. 24.

tites which has caused the auriferous values in the veins which now cut the enclosing granite. One has only to consult Sheet 139 of the Geological Map of European Russia, prepared by the Geological Committee of St. Petersburg (Vol. III, No. 2, 1886) to note the correlation of the iron-bearing rocks with the more prominent gold deposits. The occurrence of ilmenite, chromic iron, magnetite and other ultra-basic minerals at Miass, in the Ilmen Mountains, at Magnitnaia Stantsia, and other points in the gold belt, is not to be thrown out of consideration, when one is studying the association of the gold. At Miass I found it to be a well-proven rule of prospecting among the Kazak tributers or *"staratels,"* that there is a constant increase in the amount of placer gold, and presumably in the vein gold, from the granites and acid crystalline schists of the east toward the Igish Mountains on the west, which are composed of greenstone schist, porphyrite, serpentine and peridotite.

On page 39 of this paper, Mr. Spurr says: "By applying the idea of the change of segregated metals with the progress of general rock-segregation, some light on mineral association and succession may possibly be obtained. For example, in many districts of the world gold and platinum are closely associated in places. In these districts it is usual to find extremely acid and extremely basic rocks (complementary varieties) intimately associated, representing apparently an extreme stage of rock-segregation; and frequently, as in the Urals, the platinum is found to be derived from the basic rocks (peridotites), and the gold chiefly from gold-quartz veins in the siliceous ones (granite). This is one of the simplest cases."

I have already tried to bring out the fact that the gold in the Ural is for the most part dependent for its occurrence on the distribution of the basic rocks, and I am not inclined to believe that the platiniferous areas of that part of Russia, where gold also occurs, offer any exception to the general phenomena which obtain. I agree with Mr. Spurr that the association of gold and platinum deposits, which he assumes to occur in the Ural, represents one of the simplest cases of allied rock and metallic segregation, but it is scarcely justifiable to dispose in an off-hand manner of a great area of metalliferous territory in which occur some of the most remarkable mineral associations which have been met with in the known world.

In the Goroblagodat region of the Ural, the most important deposits of platinum occur.[21] The gold associated with platinum in these deposits is derived from the same general rock area. This area includes the basins of the Iss and Viya rivers, tributaries of the Tura. The rocks in it consist of diorite, gabbro, peridotite, serpentine, porphyrite, syenite and limestone. There is no granite within the area drained by the Iss, so far as has been determined, and it will be noticed on Prof. Zaitseff's[22] map, which I have reproduced,[23] that the basic rocks are in larger proportion in the platiniferous areas of the two rivers. The gold occurs in the placers of the Iss in the proportion of from 1 to 25 per cent. by weight to the platinum, while the ratio becomes more nearly equal as the distance from the source of the platinum increases. In the Tura, where the gravel is now worked by means of dredging, the proportion of gold to platinum is from 1-5 to 2-5 by weight. The source of the platinum has been determined to be in the rocks through which the Iss and Viya cut their beds, and it must be assumed that the source of the gold is in the same area. Prof. Zaitseff[24] in his detailed descriptions of the placers on the Viya River, in the vicinity of Mount Kachkanar, makes it clear that the proportion of gold is larger than in the Iss, and it is likely that this accounts for the larger amount of associated placer gold in the lower reaches of the Tura. As Mount Kachkanar is composed of peridotite entirely and as peridotite is the igneous rock in the vicinity far in excess of any other, it is reasonable to infer that the gold is more dependent on that rock than on any in the district. He refers to veins of quartz occurring in the region, and states that in many cases the gold and platinum exhibit

[21] C. W. Purington, "The Platinum Deposits of the Tura River System, Ural Mountains, Russia," *Transactions* American Institute Mining Engineers, Vol. XXIX., 1899, p. 3.

[22] "Die Platinlagerstätten am Ural," A. Zaitseff, Tomsk, 1898.

[23] C. W. Purington, *op. cit.*

[24] Zaitseff, *op. cit.*, p. 30.

little rounding, and could not have traveled far from the original source. In samples of the alluvial gold and platinum which I washed from the Tura[25] during the summer of 1902, there is no great difference in the amount of abrasion which the two metals have suffered. The platinum grains are rougher, as would be expected from the greater hardness. I would infer that the two metals are derived from sources not far apart.[26]

Another example of the association of gold and platinum is worthy of being cited. In the spring of 1901 I had the opportunity of examining a placer mine situated on Althouse Creek, a tributary of the Illinois River, in Josephine County, Oregon. The rocks of the district, which is drained by the Althouse Creek, are almost entirely of a basic nature, and a limited amount of diorite represents the only moderately siliceous rock. Serpentines and chloritic schists, with which is associated a considerable amount of bedded massive chrome-iron garnet,[27] are the prevailing rocks. Gold-bearing veins of irregular size and distribution cut these rocks, and are known to the miners as "pockety." It is from these veins that the gold of the placers is derived. In a clean-up of the placer gold at which I assisted, 50 oz. of gold were recovered, associated with which was 0.5 oz. of platinum, with some osmiridium. The gold exhibited the characteristic results of attrition, as did the platinum to a less degree, but it was evident that the sources from which the two metals had been derived were near at hand, and not greatly removed, one from another. The region of southwestern Oregon is pre-eminently one of basic rocks, with associated metal deposits, such as nickel, cobalt, platinum, which one would expect to occur in such an area. Many gold placers are worked there, and a few veins are being opened in the serpentines and chloritic schists.

Mr. Spurr says: "The intimate genetic connection of

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[25] From the Yerosalinski Placer, 4 miles above the bridge where the post road to Bogoslovsk crosses the Tura.

[26] Owing to the impurities which are combined with the platinum, its specific gravity, in its alluvial occurrence, may be reckoned as practically the same as that of the gold.

[27] Determined for me through the courtesy of Dr. Charles Palache, of Harvard University. This material has recently been referred to in several mining journals as jade.

these typical gold-quartz veins with distinctly basic rocks, such as those of the diabasic family, may be safely called exceptional." I make bold to maintain that the association of gold-bearing quartz veins of normal type with rocks of extremely basic character, from which often a genetic connection may be reasonably inferred, is by no means exceptional. In the Guianas of South America, one of the cases quoted by Mr. Spurr from Phillips and Louis (Ore Deposits), in support of his hypothesis, investigations have shown that the occurrence of gold is not dependent on the distribution of the granite, but on that of the diabase. Messrs. Quelch and Harrison, the geologists of the British Government at Demerara, informed me in conversation that the gold, at any rate in Demerara, is dependent on the diabase which penetrates the granite and the other rocks of the country in dikes. Mr. J. D. Harrison, in a published report,[28] says: "The acidic rocks of the district, whether gneiss, granite or porphyrite, do not appear to be the original sources of practically any of the gold of the auriferous gravels of the district, which have probably all been derived from the basic rocks, either the diorite, the older intrusive rocks now epidiorite and hornblende schist, or the diabase, or from parts of the acidic rocks impregnated with the metal by percolating water during their intrusions. The parts of the diabase rocks which are the richer in the iron ores and especially in pyrites are also the richer in content of gold."

In the spring of 1899 I had the opportunity of making observations in the gold fields of the Saramacca River in Dutch Guiana. The country was for the most part slate and schist, and the only igneous rock found over an area of 50 square miles was diabase. Auriferous veins were found in slate intercalated with the schistosity. The gold obtained in Suriname is mostly of alluvial character, and that of the Saramacca field is no exception. Little opportunity was afforded for noting the appearance of the veins. It is worthy of note, however, that in the richest of the placer ground which was examined the bedrock was dia-

[28] J. D. Harrison, "Report on the Geology of the Essequibo, Potaro, Konawaruk, and Demerara Rivers," Georgetown, Demerara, 1900, p. 69.

base. The peculiar rough and unworn appearance of the gold of the Guianas appears to preclude the belief that it has moved a great distance from its original habitat in the veins. The patchy character of its occurrence is also evidence along the same line. If one believes that this gold originated in quartz veins one must admit that it has traveled no great lateral distance, and may therefore argue with some reason from the underlying rock as to the nature of the rock which was originally associated with its veins.

In the Yenesei District of Siberia, to the east of the Yenesei River, and to the north of its tributary the Angara, I visited several of the principal gold-bearing areas in the summer of 1898. The country for the most part, on the Tala, Uderei and Boorovaya creeks, tributaries of the Angara, is slate and contorted schist, of argillaceous and carbonaceous character. There are smaller areas of sandstones and metamorphic limestone. The rocks are penetrated in all directions by quartz veins, from which it seems highly probable that the gold of the placers has been derived. These placers are now practically worked out, but in view of their not inconsiderable product (26,530 poods, or 434,030 kilograms, roughly, $225,000,000 in gold),[29] and the remarkably simple rock association, I consider the region worthy of mention in the present discussion. The only igneous rocks seen in the course of 300 miles of journeyings in the Yenesei District were basic rocks, resembling peridotite. On the Boorovaya Creek, at the property of Mr. Goodkof, 75 miles to the north of the river Angara, dikes of peridotite were seen cutting the slates, and large boulders of peridotite appeared in the gravel dumps. Boulders of this very basic rock were seen in many of the placers of the Uderei and tributary streams, but only in the instance cited was the rock seen in place. Granite was not found, and diorite only in a few instances. I am not, of course, prepared to say that large areas of siliceous rocks do not exist in the Yenesei District, but the alluvial material of the placers does not testify to their

[29] M. Shostak, "Gold Mining Industry of the Tomsk Mining District," Tomsk, 1896, p. 10.

presence. The evidence seems to point to the peridotite as the rock with which the gold was genetically connected, if one is to believe its origin due to the influence of any igneous rock.

As Mr. Spurr has himself called attention to the Appalachian gold region, it is proper to refer, in a discussion of his paper, to the interesting occurrence at the Haile Gold Mine in South Carolina, which has been several times described.[30] I have made several visits to this property, and no clearer case has come to my notice of the association of gold ore with basic dike rocks. Situated in an ear of hydro-mica schists, now silicified by the influence of the ore-bearing solutions, the principal mine workings are found to closely followed dikes of diabase. These dikes all cut the rocks, and it is in the silicified slate bands, directly in contact with the dikes that the best ore-shoots occur. As one gets away from the dikes, the values in the veins decrease. In the southern Appalachians in general, where gold-bearing quartz veins occur, dikes are almost a constant phenomenon. They are in mose cases of a basic character, those of siliceous make-up being exceptional.

In discussing the southern Appalachians, I would call attention to one statement made by Mr. Spurr in his general summing up. It appears to me that he has fallen into an error from the fact that he has failed to keep in mind the physical characteristics of a vein. He says: "It is recognized that the metals (in the Appalachians), though present, are constantly far less abundant than in the Cordilleran region." This is true. It is not true, however, as Mr. Spurr affirms, that a vein discovered in the Appalachians will "directly peter out." The chances are that ore found in the region will prove of very low grade, as at Dahlonega, or of a pockety character. The veins are, however, as continuous in length as in most mining regions, and they have in some instances been worked to a considerable depth. If in the southern Appalachian gold belt it is found that one of the intercalated lenses of quartz

[30] G. F. Becker, "Gold Fields of the Southern Appalachians," United States Geological Survey, 16th Annual Report, pt. iii, p. 306. Also H. B. C. Nitze and H. A. J. Wilkins, "The Present Condition of Gold Mining in the Southern Appalachian States." *Transactions* A. I. M. E., vol. xxv., 1895, p. 767.

in the schist or slates "peters out," the miner knows, or should know that by cross-cutting in the right direction, it is likely that another lens will be found, which overlaps the first in longitudinal extent. The tenor of the Appalachian deposits has been found to be of low grade, much lower than is the experience in the Rocky Mountains or in California. It is another thing, however, to affirm that veins give out. The Haile Mine, where it is the custom to keep development work some years ahead of the mill; the Ducktown copper deposits, and the zinc deposits at Franklin Furnace, are hardly examples of ore-deposits which have been found to directly peter out.

Sir Archibald Geikie, in his "Founders of Geology," says: "If geologists" . . . "could only be brought to realize that the addition of another paper to the swollen flood of our scientific literature involves a serious responsibility," . . . "how greatly would they conduce to the real value of the science which they wish to serve." If he who writes a paper on ore-deposits takes a responsibility, how much greater is the load assumed by him who adds to his own remarks promiscuous citation from the great body of past literature, in support of this or that hypothesis. Bearing in mind that unrelated facts are in themselves of no more use than are the separate parts of a steam engine, strewn about on the floor of a building, I still maintain that authors of the theories of ore-genesis, classifications of ore-deposits, and the like, should found their views more largely on the results of their own observations. Citations from previous literature, if confined within a narrower range, dealing with those occurrences of ores of which the author himself has been a witness, serve better their desired end. By such a concentration of literature would much of the speculative reasoning, of doubtful value, be eliminated from the discussion of the interesting science of ore-deposits. While not questioning the fact that Mr. Richard Beck[31] may have conscientiously recorded the results of his observations at Berezovsk, and the conclusions drawn therefrom, I am inclined to question the value of Mr. W. H. Weed's cita-

[31] "Lehre von Erzlagerstätten," 1891, p. 324.

tion,[32] thus at second hand, in support of his statements regarding magnetic quartz veins.

The San Juan region of Colorado has been quoted to a considerable extent by writers who have obtained their information by other means than direct and careful observation of its phenomena. As an example, Mr. Spurr says: "Prof. Kemp has called attention to the San Juan region in Colorado, where the different veins have been classified by T. B. Comstock as follows: 1. The northwest system with tetrahedrite. 2. The east and west with bismuth, and less often with nickel and molybdenum. 3. The northeast with tellurides and antimony, and sulphur compounds of the precious metals.

"The same writer cites, in this connection, the Telluride district in Colorado, where a heavy vein is cut out and faulted by a later one of different metalliferous character."

Referring first back to the writings of Dr. T. B. Comstock,[33] in the "Geology and Mineralogy of San Juan County, Colorado," I find that the above generalizations were made on certain veins occurring in a small area of what has since been termed the Silverton quadrangle of the United States geologic atlas. In view of the careful work recently done in that area by Mr. Ransome, of the United States Geological Survey, Dr. Comstock's classification can hardly be accepted as final. In the second paper of Dr. Comstock,[34] "The Geology and Vein-Structure of Southwestern Colorado," he very reasonably states that "it is not claimed that the opinions here expressed are such as can withstand the sifting to which other years of inquiry must subject them."

Referring next to the writings of Prof. Kemp,[35] quoted by Mr. Spurr, I find remarks as follows, in addition to the classifying of the veins above noted: "There are in this

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[32] "A further Discussion on Ore Deposits," ENGINEERING AND MINING JOURNAL, April 18, 1903, p. 595. Also *vide supra* p. 64.

[33] T. B. Comstock, "Geology and Mineralogy of San Juan County, Colorado," *Transactions* American Institute Mining Engineers, Vol. XI, 1882, p. 189.

[34] "The Geology and Vein-Structure of Southwestern Colorado," *Transactions* American Institute Mining Engineers, vol. xv., 1886, p. 256.

[35] J. F. Kemp, "The Rôle of the Igneous Rocks in the Formation of Veins," *Transactions* American Institute Mining Engineers, Vol. XXXI, p. 179. Also, "Ore Deposits of the United States and Canada," New York, 1900, p. 288.

district four sets of fissures, but only one carries the ores." . . . "In one instance the Smuggler vein is faulted by the Pandora, a later vein which does not carry ores sufficiently rich to be mined profitably." The above statements of Prof. Kemp are, as he states, partly inferred from my report on the Telluride quadrangle[36] of the San Juan region. But it seems to me that to interpret my conclusions that the northwest veins of the Telluride quadrangle are the more important ore-carriers into a statement that only one set of fissures carries the ores, is much like bending a fact to suit a hypothesis. I say nothing in regard to Prof. Kemp's conclusions, I object to his premises. Again the work on which my report was based was done in 1896, and I was limited geographically in my observations so as not to include the Camp Bird vein, which at that time was little developed. Prof. Kemp's paper[37] was published in 1901, and yet he quotes a statement of mine made five years before that the Pandora vein carries no ore. That is probably true, in the Telluride quadrangle. If Mr. Ransome's suggestion is correct, however, and I believe it is, that the Pandora and Camp Bird are an identical vein, it follows that the Pandora in the Silverton quadrangle has proven singularly productive in gold. This Prof. Kemp could have satisfied himself of had he been at the pains to make observations for himself in the San Juan. As it was, he attempted to support a speculation in regard to the origin of ores by the general application of a statement of mine which applied and was intended to apply only to a portion of the district under consideration. My statement was simply: "No remunerative values have, so far as has been ascertained, been found in the Pandora vein."[38]

I have shown in the Telluride report that there is good evidence that the majority of the veins of the quadrangle were formed at the same time, and from Mr. Ransome's statements in the Silverton bulletin[39] it is plain that he

[36] "A Preliminary Report on the Mining Industries of the Telluride Quadrangle, Colorado," 18th *Annual Report* United States Geological Survey, pt. iii, p. 745.
[37] "The Rôle of the Igneous Rocks in the Formation of Veins."
[38] *Op. cit*, p. 834.
[39] "A Report on the Economic Geology of the Silverton Quadrangle, Colorado, F. C. Ransome, *Bulletin* United States Geological Survey, 182, 1901, pp. 56, et seq.

does not regard a well-defined succession of ore deposition in that part of the San Juan as by any means proven. As for the contents of the veins, it is only necessary to refer to the published maps of the Telluride and Silverton quadrangles, and to look at the lists of ore and gangue minerals which have been found in the various mines to disprove any statements that veins having certain directions are characterized by certain minerals, and that those running at angles to them contain different minerals.

The San Juan region of Colorado is easily accessible, and all are at liberty to make such observations as they see fit in that classic laboratory of ore deposition. Those investigators who desire to make use of its phenomena in support of their views should avail themselves of an opportunity to visit the mines in person, rather than to quote, at second and third hand, observations which must have more or less of temporary value in a district which is so rapidly undergoing development.

The thorough and painstaking work of Mr. F. L. Ransome on the Silverton quadrangle can perhaps best be appreciated by those who have had experience in that part of the country. In summing up his observations on the fissures he says: "While many of the fissures in the Silverton quadrangle, including some which differ widely in direction, were formed at substantially the same time, there have been later periods of fissuring, also followed by vein deposition." . . . "This generalization, however, should not be taken too rigidly, as it is very probable whenever a prominent set of nearly parallel fissures were formed, other fissures intersecting the dominant set at various angles were produced at the same time."

The above quotation exhibits the moderation of statement characteristic of the conscientious observer, and partakes neither of the dogmatic certainty of the library theorist nor the hasty generalization of the geologist on horseback. To offer harsh criticism in the course of discussion of a subject so freshly explored as that of the distribution and genesis of ores is both unwise and unjustifiable. I make bold to suggest, however, that there are different ways of studying ore-deposits. To march hastily through a mine drift, and to scramble into a few show-off stopes under the necessarily hurried guidance of the mine foreman or shift boss; to visit one or two of the principal mines of a district in company with a large party whose ideas are for the most part preconceived or directed at the time by the temporary bias of one leading intellect; that is one thing. It is another thing to return alone, day after day, to the many workings of a great mine; to scan, by the light of a single candle, the momentous problems of vein phenomena. While not wishing to put muscular geology into the foreground, I maintain that he who climbs thousands of feet, over snow and rock slides, to an abandoned prospect, in order to determine points ill understood, may speak with more authority than he who contemplates the view from the beaten trail. The silent peak, where human environment no longer intrudes, affords a better vantage point for accurate gauging of the diagram of nature than does the rear platform of an observation car.

It appears excusable for one whose views have been attained in field work, frequently in regions hostile to human control, to protest when he finds subsequent investigators disregarding or misinterpreting his observations, ballasting the literature of ore-deposits with high-worded theories, and building hypotheses on unverified statements relating to parts of the world which they have never seen.