THE THEORIES OF ORE DEPOSITS.

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THE recent publication of the interesting chapter of Professor
Sandberger's work relating to mineral veins, in the Engineering
and Mining Journal (Vol. XXXVII, pp. 186, 198, 218, 219, 232,
233) has served to call renewed attention, on the part of Ameri-
can mining men, to the theories of ore deposits. The theory of
lateral secretion (infiltration, segregation, and impregnation) so
strongly advocated by Sandberger is very old, and has been a fa-
vorite one among American writers on the subject of mineral
veins, appearing even in the older text books, like Whitney's Me-
tallic Wealth of the United States, 1854, pp. 62–68, and Dana's
Manual of Geology, 1863, pp. 712–714. This theory appears to
have a direct connection with many other forms of ore de-
posits, besides true fissure veins, and to follow from a universal
law, intimately interwoven with the history of the rocks
of this globe. It is proposed here to point out this law and its
relation to ore deposits, and to call attention to the uncertainty
of conclusions drawn from the analysis of the wall rock and its
contained minerals. In order to do this, it is necessary to pre-
sent a brief but comprehensive view of the entire field.

Without entering at all upon the question of the source of those
rocks which have come from below the earth's surface, which are
known as eruptives, and which form a large portion of the
so-called metamorphic series, it is sufficient for the present pur-
pose to state that when they reach the exterior of the earth, their
condition is one not adapted to the circumstances in which they

are hereafter to exist.   For a time, at least, prior to their erup-
tion they have been placed in far different conditions from the
atmospheric ones on the earth's surface ; and, of necessity, there
will be a constant tendency on their part to conform to these
changed conditions.   This is manifested most conspicuously in
their loss of heat, and their passage from a liquid to a solid con-
dition.   When solid, it may be said that these rocks are in an un-
stable condition, in respect to their temperature, and also to the
chemical combinations formed on solidification.   Their chemical
arrangements, as manifested in their constituent glass and min-
erals, are such as to necessitate a transference to a condition in
which they are less acted upon by the agencies to which they are
exposed, on the earth's surface and this leads to a degradation,
dissipation, and loss of energy on their part.   In other words,
the rocks tend to pass from an unstable towards a more stable
state.   The rapidity of these changes depends not only
upon their chemical constitution, but also upon the special
circumstances in which the rocks are placed.   In the basic rocks,
or those containing much iron, magnesium, calcium, aluminum,
etc., the alterations are comparatively rapid, but in the acidic rocks
much slower.   If rocks of eruptive origin are studied under the
microscope these alterations can be readily traced from their
beginnings to the extreme changes, which are usually found to be
proportional to their age or some special condition.

It is these alterations which have led to the multiplicity of
rock names, and to the confusion of nomenclature ; lithologists and
geologists generally proceeding on the supposition that as a rock
now is, so it always was and always will be.   For example, the lava
flows of Keweenaw Point, which were once identical with the modern
basaltic lavas of Mt. Etna and Kilauea, are now designated, on
account of their alteration and age, as melaphyrs, diabases,
diorites, etc. ; andesite in its changed guise is designated as
propylite, diabase porphyrite, porphyrite, diorite, etc. ; rhyolite
as felsite, quartz porphyry, petrosilex, orthofelsite, etc. ; peridotites
or olivine rocks, as serpentine, talc schist, etc.

The propylite of the Comstock Lode is a striking example.
The present writer was the first to call attention to the fact
that the fortieth parallel propylites were altered forms of

pre-tertiary and tertiary andesites.[1]   The position then taken has
been fully confirmed by Dr. G. F. Becker[2], who unjustly appropri-
ates to himself the credit of this discovery, and is supported in
this appropriation by his colleague, Arnold Hague.

Dr. Becker further states that every rock in the district has been
taken for propylite when decomposed.

The above mentioned changes or alterations in rocks of the
same composition appear to be largely dependent upon the action
of infiltrating waters, and their rapidity seems proportionate to the
temperature.   These alterations appear to consist in general, of
molecular transferences or chemical reactions in the rock mass as a
whole, and are not confined to special minerals ; hence has resulted
the failure of theories of mineral pseudomorphism to explain *rock*
metamorphism or alteration—the pseudomorphic changes in the
rock mass being but the resulting accident of the greater and more
general metamorphosis.   In the process of alteration the original
glass of the rock is broken up, forming various minerals according
to its composition, while the original crystallized minerals are
changed to a greater or less degree ; the whole resulting in the
formation of quartz, various ores, anhydrous and hydrous silicates,
carbonates, etc.   In the course of these changes there is everywhere
seen a tendency to localize these secondary products, especially
the ores, which results in the removal of material of one kind
and the deposition of another in its place, or in the filling of fis-
sures and cavities in the rock.   It is not uncommon to find minute
veins in rocks, which, under the microscope, show variation in
their filling material as they pass through different minerals.   That
which has now been described as taking place in one rock takes
place in all, and frequently with various interchanges and reactions
between the different associated rocks.   If instead of minute fis-
sures to be filled and the alterations to be observed under the
microscope, we gradually pass to deposits visible to the unaided
eye, and to the joint or fissure planes affecting large masses of
rock, to cavities or to any condition of rock structure that will
admit of deposition of mineral matter, then whether we have ore
deposits or not seems to depend upon the activity of the altera-
tion and upon the amount and kind of matter stored.   It is well
known that valuable ore deposits are more apt to occur in regions of

[1] Bull. Mus. Comp. Zool., 1879, Vol. v, 281, 285, 286.

[2] Geology of the Comstock Lode and Washoe Districts.   1882, pp. 12-150.

eruptive and altered rocks. From what has been said the general alteration of rock masses, and the partial localization of their contained mineral matter by percolating waters, would appear to give rise to a large proportion of the ore deposits found in veins, segregations, and impregnations.

Instead of the mineral matter taken up by the percolating waters being deposited in the rock again or in contiguous cavities, it may be borne far away, appearing in spring, river, lake, and ocean waters, and in deposits laid down by them, precipitation taking place wherever the proper conditions exist.

If we start, as all geologists do, with the belief in an originally hot fluid globe, all rocks must have been derived, primarily, from fluid material. The detrital rocks would naturally partake of the characters and changes of the rocks from which their material came ; while in the chemically and organically formed rocks there can be readily suggested, in accordance with their special conditions of formation, agencies for the precipitation of useful ores throughout their mass,—the precipitated ores being gathered up subsequently by the percolating waters.

In order to draw any conclusions concerning the reliability of deductions regarding the source of the ore, based on the analysis of the minerals in the country rock, adjacent to an ore deposit, it is necessary to look into the question of the origin of these minerals. It has been found, that if the point of consolidation of rocks be taken as the reference point, their minerals naturally fall into three classes : 1. Those of prior origin—foreign. 2. Those produced by solidification (crystallization) — indigenous. 3. Those produced later by alterations in the rock mass, or by infiltration—alteration or secondary.[1] The first class can be conveniently separated into two divisions :

1. The minerals that are characteristic of the rock whatever may be its locality or age.

2. Those that are accidental, as for instance, fragments caught up during the passage through or over another rock.

Any rock may have in it all three classes or only one or two as the case may be. A few minerals may be cited in illustration : olivine, in the peridotites is an indigenous mineral, but in the basalts is foreign, although generally characteristic of them. Serpentine, when not an infiltration or veinstone product, is always a

[1] Bull. Mus. Comp. Zool., 1879, v, 277, 278.

secondary or alteration one. Hornblende in the recent andesites is foreign, but in the older forms, and in almost all the older rocks of every kind, it is either a secondary product or is a more or less altered mineral. The micas, feldspars and quartz occur as foreign, indigenous and secondary products. As a rule in the modern rhyolites quartz is foreign, but in the older rocks of this type — felsites and quartz porphyries—it is both foreign and secondary. All hydrous oxides and silicates and all carbonates appear to be alteration products.

As a rule the different modes of occurrence of these minerals can be readily distinguished from one another under the microscope by their characters and their relations to the rock mass.

Further, it may be pointed out that olivine, except in the more recent rocks, is found, as a rule, to be more or less altered to, or replaced by, serpentine, quartz, iron ore, carbonates, etc. ; augite by hornblende, biotite, chlorite, etc. ; and feldspar by quartz, kaolin, micaceous and chloritic minerals, etc.

These changes are so common that it is rare to find original minerals in the older rocks that remain unchanged.

Again, almost every mineral in rocks is found to contain inclusions of other minerals, glass, liquids, and gases, thus vitiating conclusions drawn from the chemical analysis of the mineral.

Since ore deposits are, in general, associated with altered or metamorphosed rocks, and occur in regions in which thermal waters have been active, the country rock would naturally be more or less changed, and sometimes completely decomposed. In the process of the formation of the ore deposit, it may happen that the ore material will be entirely removed from the adjacent rock, or this rock may have deposited in it ores which never existed there before ; or again, the ore material may have been brought from a distance by the percolating waters.

From the above it follows that chemical analyses alone, either of the country rock or of its inclosed minerals, lead to unreliable conclusions as to the source of the ores ; and hence it is an unphilosophical procedure to build any general theory upon such analyses.

If, by chemical analysis, any accurate deductions are to be drawn regarding the original source of the ores it seems necessary that we should select those rocks and minerals that are known to

be fresh, unaltered, and free from any foreign inclusions that would influence the result. Such materials could only be obtained from recent lava flows, recently formed limestones, etc., for no rock that has been exposed for a considerable length of time to the earth's meteoric agencies can, in the writer's opinion, be said to be in its pristine condition. Most analyses of such rocks have dealt too little in tests for minute quantities of such materials as comprise the more valuable ore deposits, to permit as yet any general conclusion to be drawn. The nearest approach we have to such analyses is in the meteorites, which are unaltered and which in composition and structure are closely allied to certain classes of terrestrial basic rocks.[1] These meteorites are found to contain copper, tin, nickel, cobalt, arsenic, zinc, manganese, chromium, and graphite.

While it would appear probable that the elements of the useful ores were often originally disseminated through the rocks with which they are associated and subsequently concentrated, by the agency of percolating waters, proofs that this theory is correct are yet wanting, the theory resting mainly on the observed structure of the ore deposits, their association and the alteration of the adjacent rocks.

Of all theories that have been proposed to account for ore deposits, there are few, which are not correct for some form of ore deposits in certain localities, while the practical use of these theories is to aid us in understanding the nature of the deposits, as a guide in their exploitation. The difficulty in the use of these theories lies in their abuse, through their indiscriminate application to all deposits. Our rule ought to be to study every deposit thoroughly, and after that study, not before, apply that theory which best answers to the observed conditions, since all theories ought to be generalizations or expositions of observed facts, with a prophecy for the future.

It is not doubted here that all ore deposits, not of a mechanical or eruptive origin, can be attributed to the general alteration and change in rocks, resulting from the general dissipation and degradation of the potential energy of the constituents of the earth's crust, in the universal passage of matter from an active state towards a passive and inert condition.

This general alteration manifests itself in a universal chemical

[1] Science, 1883, I, 127-130.

or molecular transference — a transference of material, leading to the segregation or localization of the ores in the places in which they are now found; it manifests itself in the deposition of mineral matter in the veins and cavities of the rocks themselves, in deposits from springs, in bogs, lakes, etc. From this it would follow that all ore deposits, not eruptive, are superficial phenomena as regards the earth, and dependent on its external agencies; although they may be deep enough so far as man is concerned. Again, few of these ore deposits would be expected except in regions in which percolating waters and their resulting metamorphism have been efficient agents ;[1] while the various forms of ore deposits would be expected to be associated with, and grade into, one another.

APPENDIX.

It has been thought that the writer's meaning in the above paper would be better understood, if some illustrations were added to show how the principles employed have been varied by him to accord with the special conditions observed in different localities.

Heidelberg, Feb. 14, 1885.

COPPER DEPOSITS.

In the famous districts of *Portage Lake* and *Keweenaw Point*, south of Lake Superior, the rocks consist of a mixed series of old basaltic lava flows and conglomerates traversed in part by fissure veins.

Locally the conditions in which the native copper is found in these districts give rise to four forms of deposits, known as :

1. *Amygdaloid Mines* in which some of the thinner lava flows (melaphyrs) are worked, the copper being distributed through them in an irregular manner.

2. *Ash-bed Mines* which are in reality the same as the *Amygdaloid* but in the "Ash-bed" the melaphyr is of a more irregular, open, and scoriaceous character.

3. *Conglomerate Mines* in which old sea-beach conglomerates are mined.

4. *Vein Mines* in which true fissure veins are worked.

All these deposits seem to the writer to have been produced by

[1] Whitney. Contributions to American Geology, 1880, Vol. I. The Auriferous Gravels of the Sierra Nevada of California. pp. 310, 331, 350, 356.

one cause—the action of percolating waters (whether thermal or not) in collecting the copper disseminated through the old basaltic lavas and concentrating it in whatever suitable receptacles existed in the lavas and their associated conglomerates, and in the fissures traversing them. Here the theory of "Lateral secretion" applies, not only to the copper, but to its associated gangue and amygdaloidal minerals.[1]

At *Cape D'Or*, on the Bay of Fundy, native copper occurs in relations similar to those observed on Lake Superior. Here, however, are found only the basaltic rocks (melaphyrs and diabases), and the copper is disseminated in part through them, and in part occurs in veins. As at Lake Superior the rocks are more or less amygdaloidal, and the preceding explanation is used here to account for the origin and concentration of the copper; which, however, has not been found at Cape D'Or in sufficient amounts to warrant exploitation.

The copper ores of *Newfoundland*, in the vicinity of Notre Dame Bay, are chiefly the yellow sulphide (chalcopyrite) associated with pyrite and quartz. These ores occur in connection with argillaceous and chloritic schists cut through by dikes and irregular masses of old basaltic rocks (melaphyrs and diabases), in all of which the ores are either disseminated or form gash veins. The theory of their origin adopted by the writer is as follows. During the eruptive activity, but after the principal portion of the basalt, if not all, had been extraversed, the action of percolating thermal waters on the eruptive rock and its adjacent fissured and broken sedimentary rocks led to the concentration and deposition of the copper ore, iron pyrites, and quartz in the places in which they are now found. As in the preceding cases the copper is supposed to have been brought up from the earth's interior by the basalt, at which time the ore was finely disseminated through the lava[2], and subsequently concentrated.

Copper ore occurs on *Waugh's River* in Nova Scotia about three miles from Tatamagouche Harbor, an inlet on the south side of Northumberland Strait. The country rock is a sandstone composed of granitic detritus, and contains clay, fragments of lignite, and other carbonaceous materials. Associated with this

[1] Bull. Mus. Comp. Zool., 1880, VII, 76-157; Proc. Bost. Soc. Nat. Hist. 1880, XXI, 91-103.

[2] Am. Journ. Sci., 1884, XXVIII, 94-104.

sandstone are intercalated beds of red shale, some of which is of so fine a quality that it has been used as a mineral paint. All these rocks dip N. 20° E. 26°. The ore is in nodules and lenticular masses composed of chalcocite or its hydrous carbonate (malachite) scattered through the beds of sandstone and shale. It is so associated with the carbonaceous materials in the rocks, that it is believed that the copper was collected by the percolating waters, precipitated and reduced by the organic matter, and thus collected into the masses found at present, many of which are now in part lignite and in part chalcocite. The change to the carbonate is, of course, a still further change, wrought through the medium of the percolating waters.[1]

ZINC.

During the mining excitement in Maine, in 1879–82, a mine was opened in the town of *Castine, Hancock County,* known as the Hercules. The country rock is a fine grained mica schist, much indurated and quartzose. In places it approaches, in character, quartz schist, and in others, a gneiss. The rock contains, in places, abundant pyrites. The dip and strike are variable, the former varying from south to 30° or 40° west, with an inclination of 75° to 81°. The country rock is traversed by small quartzose veins, carrying pyrite and sometimes sphalerite and it is more or less broken and jointed, part of the jointing being parallel to the foliation. When the jointings cross one another obliquely and also when parallel, if sufficiently close together, so that the rock has been crushed or finely divided, the percolating waters have deposited in the interstices more or less zinc-blende, iron pyrites, galena, tremolite and quartz, which in part replace the rock material. This segregating action of percolating waters thus gave rise to the local aggregations of mineral matter in the form of impregnations of the country rock, and of segregated veins. So far as the writer can learn, the above deposit is a fair sample of the majority of those heretofore worked in Maine.

GOLD.

Another of the Maine mines was on *Seward's Island,* town of

[1]Gesner's Remarks on the Geology and Mineralogy of Nova Scotia, pp. 139, 140; Am. Journ. Sci. 1828 (1), XV, 151–153; Trans. Am. Acad., 1831 (2), I, 289–292; Dawson's Acadian Geology, third editon, pp. 345, 346; Report of the Department of Mines of Nova Scotia, 1876, p. 63; 1877, pp. 48, 49; 1879, p. 13; 1880, pp. 75–77.

Sullivan, Hancock County. Here a fine grained argillaceous mica schist was cut by a diabase dike some forty feet in thickness, intruded approximately parallel to the bedding. Numerous segregated quartz veins cross this diabase and are locally limited to it. The quartz contains calcite, tremolite, chlorite, tetradymite and gold. The geological history appears to be, first, the formation of the sedimentary country rock, secondly, the intrusion of the diabase, and thirdly, the concentration (mainly from the diabase mass) of the vein materials, including the gold.[1]

MANGANESE.

At different times in past years, considerable work has been done in New Brunswick on a manganese deposit at a fall of the *Tete-a-gouche River,* a few miles from *Bathurst,* on the southern shore of the Bay Chaleur. The country rock is a reddish, fine grained argillite, much fissured and broken. The manganese ore (pyrolusite, wad, etc.) has been infiltrated along the fissures, apparently passing from above downwards, and making small irregular gash veins and pockets, the richest portion being in the upper part of the rock.

Another deposit of manganese has been worked at a locality four or five miles southeast of *Truro, Nova Scotia.* The country rock is a sandstone and shaly schist, quite indurated, folded and faulted. As before, the manganese ore is found deposited in fissures and pockets in the rock, and is infiltrated from above. This deposit, like that at Bathurst, is found on the side of a stream, to which, when cutting its bed, the formation of the deposit is probably due. In such cases as these, the theory of lateral secretion has no bearing, according to the writer's judgment.

IRON ORES.

The writer has given sufficient reasons in previous papers why he, in common with some others, can not regard the iron ores of the *Marquette District* of *Lake Superior* as coming either under the head of a deposit by lateral secretion or by sedimentation ; but holds that they are for the most part of eruptive origin. Those who have opposed this view have in general based their conclusions on theoretical grounds and not on the actual mode

[1]Bull. Mus. Comp. Zoöl., 1880, VII, 181.

of occurrence of the ores themselves. That the ores have been
subjected to mechanical and chemical action since the time of erup-
tion appears clear. This action has not only given rise to subor-
dinate mechanical deposits and to impregnations, segregations, and
minor veins, but has also been the means of the molecular re-
arrangement of much if not the whole of the ore.[1]

The iron ore of *Cumberland, Rhode Island,* has been shown by
the writer not to be a simple ore, but a rock composed chiefly of
titaniferous magnetite, feldspar and olivine. This ore appears to
be of an eruptive origin.[2]

The iron ore (magnetite) of *Port Henry* (Cheever Ore Bed) is
associated with and lies in a peculiar gneissoid rock composed prin-
pally of a clear, glassy, triclinic feldspar. This ore partakes of
the flexures of the gneiss and is in all respects to be regarded
as a sedimentary deposit; but whether it is to be regarded as
a chemical precipitate or a detrital accumulation the writer has at
present no opinion. The ore at times ramifies through the gneiss
in a way that only a chemical deposit or eruptive mass could, but
otherwise it has none of the characters of an eruptive. This
ramification then belongs to, or is the result of, chemical action,
yet it probably is not original, but a secondary result of chemical
agencies since deposition. Evidences of such action are com-
monly seen in the limestones in the vicinity, while its exciting
cause may have been the eruptive rocks (gabbros, etc.) which are
quite abundant in the vicinity.

The ores in this part of the Lake Champlain region have been
cited as proofs by analogy that the Lake Superior iron ores were
also sedimentary deposits, but such arguments are deceptive,
since the deposits in the two districts in question have nothing in
common in their structure, their relations to the associated rocks,
or in their apparent origin, beyond the fact that both are magnetite
and both are associated with old crystalline rocks.

In the vicinity of *Bathurst* boulders of iron ore (hematite and
jasper) were found in the bed of the *Tete-a-gouche River* which
closely resemble the associated hematite and jaspilite of the Mar-
quette District, Lake Superior.

[1] Bull. Mus. Comp. Zoöl., 1880, VII, 28-36, 66-76, 494, 495.—Proc. Bost. Soc. Nat. His-
tory, 1880, XX, 470-479.
[2] Bull. Mus. Comp. Zoöl., 1881. VII, 183-187.—Proc. Bost. Soc. Nat. Hist., 1881, XXI,
195-197.—Lithological Studies, 1884, pp. 75-81.

The origin of these boulders, or rather of similar ores, was found to be as follows : near the Peters River, diabase dikes had cut through the red argillite (see above, under manganese) indurating it and filling it more or less with iron ore.   This argillite when broken away and water-worn gave rise to the deceptive boulders mentioned above, which had thus an origin entirely different from the Lake Superior ore.

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