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Charles R. Keyes

THEORY OF METEORITIC AGGLOMERATION AND THE ULTIMATE SOURCE OF THE ORES.

BY CHARLES R. KEYES.

At the present time unusual interest is taken by mining men in the subject of the origin of the deposits of the metallic ores, the extent of the world's supply, and the means of conserving them, for alarming as it may seem the end is already in sight.

Localization of ore-materials, or their formation into workable ore-bodies is now generally ascribed to the agency of waters circulating in accordance with well established geological laws and under peculiar geologic conditions. The circulatory currents may move through the deeper zones of the lithosphere below groundwater level, through the upper or vadose zone, or on the surface of the ground. In each zone there is a distinctive series of mineral concentrations.

The ultimate source of ore materials has been heretofore usually considered on the theory of a cooling terrestrial globe, according to the scheme imposed by the nebular hypothesis. The metals are thus assumed to reach the surface of the earth from a heated and perhaps metallic interior. There is another possible derivation of the metallic materials of the ores. Although the hypothesis has received since its proposal the support of distinguished authorities, from ore students it has not attracted the attention that it seems to deserve.

On the hypothesis of the origin of the planetary and stellar bodies through meteoritic agglomeration, as proposed by Meyer,* metallic substances in a fine state of division must be constantly falling upon the earth's surface. That portion of the stellar dust which falls upon the land areas mingles immediately, almost unnoticed, with the soil; and finally enters into the rocks which some geologists consider as the flotsam riding upon the heavy centrosphere. That part which falls into the sea goes to form the characteristic bottom-muds of the ocean. Whether falling on land or water the stellar-dust particles, on account of their high specific gravity and their prevailingly metallic nature, tend sooner or later to sink deeper and deeper beneath the lighter rock material on

*Beitrage zur Mechanik des Himmels, p. 157, 1848.

which from space they drop. Local conditions at or near the surface of the earth may reverse the usual direction of this migration so as to bring together the metallic materials into ore-bodies.

As aptly noted by Stallo, the general doctrine of meteoric agglomeration is in effect nothing more than a new statement of the law of parsimony, which forbids the unnecessary multiplication of explanatory elements and agencies. Exemplification of the logical principle has long been afforded by the various branches of science, and conspicuously by the new geology. The past history of the earth is accounted for in terms of what is continually going on around us. At no stage of the earth's record does genetic geology attempt to call into action forces other than those which are now at work changing the existing features of our globe.

In its main features Meyer's theory of meteoritic agglomeration is essentially identical with the planetesimal hypothesis of earth origin as recently and specifically set forth by Chamberlin.* Upon ultimate analysis, the meteoritic hypothesis is not so wholly novel and so radically distinct from the nebular hypothesis of Laplace as some of its advocates would have us believe. G. H. Darwin† has shown that the meteoric swarm is dynamically analogous to a gas; and in reality the laws of gases strictly apply to it.

At the present time the planetesimal hypothesis has especial attraction in its bearing upon the ultimate origin of the ores. It explains satisfactorily many phases of ore-genesis which have long remained enigmatical. It does away with the sweeping claim that ores owe their formation entirely to volcanic activities; and it suggests the vadose zone as the seat of the principal segregation of ore materials generally.

The meteoritic augmentation to the earth seems to be very much larger than it was once supposed to be. Something of the larger meteoric irons and stones has long been known; and our prevailing notions of extraterrestrial materials are mainly confined to these occurences. It is, however the constant and almost inappreciable shower of cosmic dust and particles falling upon the earth's surface that is of greatest consequence as a possible source of ore-supply.

The magnitude and persistency of the stellar dust shower ordinarily escapes notice. It is rendered visible in various ways. Hailstones are frequently found containing small particles of presumably meteoric iron. By the melting of snow in the arctic regions fine metallic particles composed mainly of iron, nickel, cobalt, etc., are obtained.

*Carnegie Institute Yearbook, No. 3, p. 208, 1905.
†Philos. Trans. Royal Soc. London, Vol. CLXXX, pp. 1-69, 1889.

The banded appearance of arctic glaciers is well known. Its main cause seems to be layers of fine dust and minute rock-fragments. Nordenskiold,* in particular, calls attention to the banded appearance of certain arctic snow-fields in which the dark zones were found to be due to minute black grains, most of which were found to be due to minute black grains, many of which were metallic in character. Chamberlin,† in presenting some fine photographic views of the fronts of Bryant, Krakokla and other Greenland glaciers, specially emphasizes the conspicuous banded appearance. While he incidentally states that the dark particles are "mainly terrestrial," he gives no data upon which he bases his conclusion; and he leaves it to be inferred that he regards at least a part of the material as perhaps meteoric in character. The myriads of dust-wells which the same author‡ describes in the surface of the great Igloodahomyne glacier seem to have like significance.

The great abundance of chondres in the abysmal deposits which cover the floor of the ocean is especially noted by Murray and Renard[1] in the reports of the Challenger expedition. These masses are largely composed of basic minerals, closely related to the earthly substance known as bronzite; and, with small doubt, appear to be of cosmic origin.

Some conception of the reality and importance of the heavenly swarm which is constantly reaching us may be gained when it is remembered how frequent and numerous are meteoric falls. In each 24 hours there are, according to Young[2] no less than from 15,000,000 to 20,000,000 of meteorites entering the earth's atmosphere.

The frequency of meteoric irons and meteoric stones in the arid regions of the globe, and especially on the high dry plateaus, is particularly significant in this connection. While such falls are probably not more common in those districts than elsewhere, the peculiar climatic conditions tend to give them prominence. The clear air, the cloudless skies, and the high altitudes contrast sharply with the thick atmosphere and prevailingly cloud-covered firmament of the sea coast of humid lands. In the high, dry regions, the frequency of meteoric manifestations immediately arouses the wonder of the sojourner from cloudy countries. The constant stream of light-paths across the heavens reminds one, every night in the year, of the November meteoric showers of other parts of the world.

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*Voyage of the Vega, p. 18.

†Journal of Geology, Vol. III, p. 568, 1895.

‡Ibid., p. 215.

[1]Narative Cruise H. M. S. Challenger, Vol. II, p. 809, 1885.

[2]Astronomy, p. 472.

Moreover, a dry climate appears to prevent rapid rock-decay. There is practically no such phenomenon as chemical decomposition of the rocks as it is known in the moister regions of the globe. The breaking down of rock-masses near the surface takes place mainly by means of insolation, which is strictly mechanical disintegration. Meteoric irons remain for years upon the surface of the desert without notable oxidation.

Again, the meteorites in such regions, instead of being immediately lost to view in vegetation, covered by soil, and subject to rapid chemical decay, as in humid countries, are left exposed on the surface of the ground through the constant removal by the winds of the lighter soils.* This cause affects, of course, all the larger rock-fragments, of whatever origin. The pebble mosaics which cover large tracts of arid plain, described by Blake,† by Tolman,‡ and by me,|| amply attest the extent of this remarkable phenomenon.

For peculiar reasons, meteoric masses are not easily recognizable in the pebble pavements. The majority of desert rocks are susceptible to notable discoloration and wind-polishing, which imparts to them a burnt and fused appearance. Travelers in the desert are prone to ascribe this characteristic of the rocks to volcanic action; and it is invariably one of the features of such regions which at once atttracts their attention. For example, in describing the general impressions gained in crossing the broad desert tract in New Mexico known as the Jornado del Muerto, Wallace§ says, "the portion I speak of appears to have served its time, worn out, been dispeopled and forgotten; the grass is low and mossy, with a perishing look—the shrubs, soap-weed, and bony cactus writhing like some grisly skeleton; the very stones are like the scoria of a furnace." Until they are broken in two the darkened rock-fragments give little suggestion of their real lithologic character.

The more basic rock-masses and larger rock-fragments which strew the ground throughout the arid regions are almost invariably coated by a black iron and manganese film which, highly polished by the wind-blown sands and dusts, gives every appearance of fusion. The aspect thus produced is not unlike that of the fused surface of meteorites falling in moist lands. Among such dark lacquered rock-fragments, it is with greatest difficulty that true meteorites can be distinguished. That they do occur abundantly nevertheless, is well shown by the rock-collections displayed at every cattle ranch.

Bull. Geol. Soc. America, Vol. XIX, p. 73, 1908.
†Trans. American Inst. Mining Eng., Vol. XXXIV. p. 161, 1904.
‡Journal of Geology, Vol XVII, p. 149, 1909.
||Ibid, p. 74.
§Land of the Pueblos, p. 140, 1888.

A notable instance of the exceptional frequency of meteoric irons in desert regions and one which has recently attracted wide attention from scientists, is that of the Canyon Diablo falls in eastern Arizona, first brought to notice by Foote.* Twenty miles east of that isolated and majestic pile of volcanics known as the San Francisco mountains and rising abruptly out of the vast even plain forming the general surface of the high plateau, is a low mound locally called Coon Butte. The center of this low elevation is occupied by a crater-like depression about 1,000 feet across. In the vicinity of this hill such large amounts of meteoric iron have been collected from time to time as to give rise to the fantastic notion that the crater was produced by an enormous meteorite striking the earth at this point,† the impact causing the fragments to be scattered about in all directions. As a matter of fact meteoric irons are no more abundant around Coon Butte than they are in other parts of the dry country, or probably in the desert tracts of the globe generally. At Coon Butte, a large company has been led into expending thousands of dollars in sinking shafts and in drilling for the suposed heavenly iron-body deeply buried in the bowels of the earth. The central depression itself is to all appearances a true volcanic crater of the explosive type;‡ but the accidental finding of many pieces of meteoric iron within it and about it has stimulated the immagination of observers, who have given undue weight to these occurrences as indicative of the origin of the crater. The occurrence of such meteorites instead of being special and novel, is general and wide-spread in desert regions. It is to these arid tracts of the globe that we must look for the greatest extension of our knowledge concerning meteoritic materials.

It is to the desert regions likewise that we must turn for information regarding the character of the rain of stellar dust. The remarkable prevalency of black-sand grains in the desert soils has generally escaped the notice of travelers. On the vast high plains of the dry Mexican plateau, metallic particles occur abundantly in soil, miles away from the mountains and from outcrops of igneous rocks. The plains are so level, the distances from the mountains so great, and the rain-fall so scanty as to preclude the easy transportation of these heavy particles by means of water; while their high specific gravity must prevent their movement by means of the winds. Yet after the severe rain-showers which occur at rare intervals, when little rills traverse the surface in all directions, considerable quantities of the "iron-sands" accumulate along the paths of

*American Jour. Sci., (3), Vol. XLI, p. 413, 1891.
†Smithsonian Misc. Coll., Vol. L, p. 461, 1908.
‡Bull. Geol. Soc. America, Vol. XVIII, p. 721, 1907.

the moving waters. A thorough chemical investigation of the composition of these sands would be highly instructive. The common black sands of placers appear to be in the main totally distinct; and their origin is usually traceable to decomposing igneous rocks. The metallic sand-particles of the desert soils necessarily long resist decay. Should these particles prove to be of meteoric origin, the fact would tend to make such estimates of the annual meteoric augmentation to the earth's volume as those given by Chamberlin and Salisbury* ridiculously inadequate. As it is their figures must be vastly too low.

The petrologic features of meteorites present many suggestive relationships to those of the igneous rocks of our globe. Among the common terrestrial rock of igneous origin there are usually recognized four main groups: the acidic, the neutral, the basic, and the ultra-basic. Among earth-rocks those of the last mentioned class are quite rare; but in the case of stony meteorites the rock species distinguished are very largely ultra-basic. Some of these mineralogic aggregates correspond, it is true, to some of the most basic of the terrestrial series; but the cosmical series begins with the earthly basic class and continues through the ultra-basic, of which limbergite and peridotite are the chief terrestrial examples, to yet unnamed series in which the metals form a larger and larger proportion.

So long ago as 1871, Meunier† recognized among the meteorites no less than 50 distinct lithologic types, most of which he later‡ described the microscopical characters and reported in them a wide range of metallic elements.

Among the metals occurring in meteorites are all of those found in the common ores. Gold and silver are the only conspicuous metals which do not yet appear to be found abundantly in meteorites. There are, however, good reasons why these two metals have not been reported more frequently; and other reasons why certain other metals seemingly occur only sparingly; so that the apparent absence of these elements in the composition of known meteorites does not preclude their derivation from this source.

As is well known, the relative abundance of chemical elements appears to be different in the terrestrial and siderial rocks. It is suggested by Farrington,|| however, that there is very good reason for believing this difference to be apparent rather than real. Only the crust of the earth

*Geology, Vol. I, p. 381, 1905.
†Geologie des Meteorites: Moniteur scientifique Quesneville, Feb. 1-15, 1871.
‡Bull. de la soc. d'hist. nat. d'Autun, t. XVI, 1893; also t. XVIII, 1895.
||Journal of Geology, Vol IX, p. 394, 1901.

is considered; and the analysis of meteoric material does not often show the true proportion of stony matter.

The introduction of meteoritic materials into rock-masses and their incorporation into ore-bodies are not intricate processes. On the theory of meteoritic agglomeration the original and often the immediate source of ore materials cannot be in nature so largely magmatic as it is vadose. Qualified in some ways and strengthened in others, the general arguments of Forchhammer, Sandberger, Winslow, Van Hise, and Bain assume a new interest and an added value. The main shortcoming, if such it really be, is merely in ascribing a sole, or principal, origin of the ore materials to rock-weathering, when a somewhat broader interoretation of the facts seems necessary.

It is not difficult to fancy the manner in which metallic substances of meteoritic origin may become incorporated with ore materials generally. After reaching the surface of the earth, both cosmic dust and the larger meteorites must mingle with the soil, more or less quickly oxydize, and enter by means of circulating groundwaters or otherwise, the deep-seated zone, in the same way as any of the heavier mineral particles liberated from the surface rocks through decomposition are supposed to do. The processes involved are essentially the same as for the changes and movements of rock-forming ore-materials. The distinction to be made is that instead of the ore material being derived from the breaking down of the rocks of the lithosphere; a very large proportion comes from extra-terrestrial sources.

Although there is probably no such universal sea of groundwater as that pictured by Van Hise, there is yet no reason for not believing that surface waters readily penetrate to the deep region, even to the zone of rock-flowage. The lithosphere thus represents merely the flotsam and jetsam of the globe through which the heavier materials may migrate, generally inward as individual particles, but occasionally or spasmodically outward, in connection with volcanic outbreaks.

In the course of the inward migration of ore materials temporary ore-bodies are often localized in the vadose zone chiefly. How much of these materials are of the recent extra-terrestrial origin and what proportion is the product of the rock-decay, is at present difficult to estimate. The meteoritic contribution has yet received insufficient attention. That it may be much more important than has been suspected hitherto is clearly shown by recent observations in desert regions. That this is the main source of vadose ore-materials now seems not unlikely. It is probable that most of the diffused metallic content of the sedimentary rocks is in reality immediately derived from meteoritic sources; for its derivation from the country rock of mining districts, especially in tracts far removed from volcanic activity has never been a very satisfactory explanation.