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On the Age and Continuation in Depth of the Manganese-ores of the Nagpur-Balaghat Area, Central Provinces. By L. Leigh Fermor, A.R.S.M., D.Sc., F.G.S., *Superintendent, Geological Survey of India.* (With Plates 1 to 3.)

IN *Memoirs, Geological Survey of India*, XXXVII, (1909), Chapters XIV to XVII, I have discussed somewhat fully the origin of the manganese-ore deposits found in association with the rocks of the gondite series (gondite being spessartite-quartz-rock).

Distribution of the gondite series.

The rocks of this series have been found in the following provinces, reading from west to east:—Bombay, Central India, Central Provinces, and Bengal; and probably in Rajputana also. The chief development of the series is in the Nagpur-Balaghat area of the Central Provinces, comprising the districts of Chhindwara, Seoni, Nagpur, Bhandara, and Balaghat; and it is from this area that most of the facts used in this discussion are derived.

Origin of the series.

The conclusions given on pages 364 and 365 of the work cited, as to the origin of the gondite series and the associated manganese-ores, are repeated here to save lengthy explanations:—

Conclusions as to the Origin of the Gondite Series and the Associated Manganese-ores.

The conclusions at which I have arrived in the foregoing pages are much more open to doubt than those regarding the origin of the ores of the kodurite series, the reason being the smaller amount of evidence obtained. The points that may be considered fairly certain are the following :—

1. The rocks of the gondite series are the product of the metamorphism of the less pure manganiferous sediments of Dhárwár age, the metamorphism of these sediments having taken place towards the end of the Dhárwár period.
2. A portion of the ores has been formed directly by the compression of the purest of the original manganese-oxide sediments.
3. Another portion of the ores has been formed by the subsequent alteration of the manganese-silicates produced by the above-mentioned metamorphism.

The points that are to be considered as more doubtful are put forth below. Even if they do not express the whole truth, I believe that they form an approximation to it; any way, together with the points given above, they form a working hypothesis that will suggest to a future geologist the evidence to look for in trying to put the theory as to the origin of these manganese-ore deposits on a surer footing.

4. The ores formed by the alteration of the rocks of the gondite series were formed by a combined decomposition and replacement of the gondite, spessartite-rock, or rhodonite-rock, as the case may be.
5. The alteration of manganese silicates to manganese-ores took place at the close of the Dhárwár period of folding, and hence in Archæan times.
6. The alteration took place at considerable depths, so that, taken in conjunction with the supposition that a portion of the ores are merely compressed manganese-oxide sediments, workable manganese-ores may be expected to extend in some places to as great a depth as the rocks of the gondite series.
7. The alteration was due to the attack on the manganese-silicate-rocks by waters containing either carbon dioxide or sulphuric acid, more probably the former; and also oxygen.
8. The carbon dioxide may have been a portion of that liberated in the conversion of original impure calcareous sediments into the quartz-pyroxene-gneisses of this area; and the oxygen a portion of that liberated in the conversion of original impure manganiferous sediments into the manganese-silicate-rocks.
9. A small proportion of softish and more or less porous ore has been formed since the rocks of the gondite series were exposed at the surface, and is probably still being formed.

Objects of this paper.

The *primary object* of this paper is to show that the majority of the manganese-ores of the Central Provinces[1] were formed in Archæan times; the word Archæan

[1] Manganese-ores are found in other parts of the Central Provinces besides the Nagpur-Balaghat area, *e.g.*, in the Jubbulpore district; but in this paper by the Central Provinces is meant the gonditic area, or Nagpur-Balaghat area, of the province.

being used, in the sense proposed by Sir Thomas Holland,[1] to include the rocks below what he calls the great Eparchæan Unconformity, *i.e.*, to include not only the most ancient crystallines, but also the Dhárwárs, and the gneissose granites, pegmatites, and other igneous rocks of post-Dhárwár age that are not intrusive with regard to the division of the pre-Cambrian rocks, known as the Puranas, lying above the Eparchæan Unconformity.

The *secondary object* is to indicate that, in all probability, these Archæan ores were formed at some depth below the earth's surface and not by any method of superficial replacement or concentration; so that the present position of the surface bears no particular relation to the depth to which the ores extend.

Ores formed in two ways.

Now the larger portion of the manganese-ores of the Central Provinces has probably been formed in the ways specified above in conclusions 2 and 3, those formed according to conclusion 9 being of little importance. That the ores formed by method 2 are of Archæan age needs no further proof here, since they must have been formed at the same time as the associated manganese-silicate-rocks (see conclusion 1). But that the formation of the ores produced according to method 3 took place in Archæan times by no means follows.

The difficulty is that at present there seems to be no way of determining what proportions of the ores are to be ascribed to methods 2 and 3, respectively. In many cases where the ores contain residual patches of gondite, spessartite-rock, or rhodonite-rock, the evidence is very clear that the ore has been formed by the chemical alteration, accompanied by replacement, of the manganese-silicate-rocks. But in cases where the masses of ore are pure and homogeneous, it is often impossible to say whether the ore has been formed by the completion of the process of alteration and replacement of the manganese-silicate-rocks (method 3), or whether we are dealing with masses of ore formed by the direct compression of original manganese-oxide sediments (method 2). Could it be shown that the larger proportion of the ores has been formed by method 2, the determination of the age of those formed by method 3 would be of much less importance. But this cannot be shown, and therefore the determination of the time of conversion of manganese-silicate-rock to manganese-ore—*i.e.*, the establishment or overthrow of conclusion 5 on page 2, becomes a matter of importance.

[1] *Trans. Min. Geol. Inst. Ind.*, I, p. 47, (1906).

Time of alteration of silicate-rocks to manganese-ore.

On pages 355 and 356 of the work cited it is shown, **on evidence derived from the Central Provinces, that the alteration must have taken place previous to the erosion of the present topographical features of the country**; but at the time this was written no evidence had been obtained from the Central Provinces showing at what particular past time or times, ranging from Archæan almost to recent, this change took place.

Nevertheless, the rarity of open spaces in the manganese-ore deposits of this area, and the compact characters of the ores, are held to indicate that the alteration took place prior to the last set of earth movements powerful enough to close up open spaces formed during the chemical changes by which the ores were formed. And [illegible]nce none post-Archæan earth movements of which we have [illegible] to have been powerful enough for this, judging fro[illegible] their effects on post-Archæan rocks, the non-cavernous nature of the deposits is held to be another piece of evidence pointing to the Archæan age of the alteration process (*l. c.*, p. 363).

Evidence at Jothvad, Narukot.

Further, there is at Jothvad, Narukot State, Bombay Presidency, a small hill of banded gneissic and schistose rocks, including members of the gondite series, invaded by apophyses of a porphyritic biotite-granite of presumed Archæan age; pieces of manganese-silicate-rock, of manganese-ore, and of manganese-silicate-rock passing into manganese-ore, are enclosed in the granite, showing that the manganese-ores of this hill were already in existence at the time of intrusion of the granite, and that, in so far as any of the ores can be shown to have been formed by the alteration of manganese-silicate-rocks, this alteration process dates back to Archæan times (*l. c.*, pp. 320, 321). And, arguing by analogy, it is held that the alteration of manganese-silicate-rocks to manganese-ores in the Central Provinces probably took place in Archæan times also.

Intrusives into the manganese-ores.

Many cases are known in the Central Provinces of acid intrusives (granites and pegmatites, and allied rocks), piercing the gonditic and associated manganese-ores (*e.g.*, at Ramdongri, Beldongri, Kacharwahi, Kosumbah). These intrusives frequently contain abundance of manganese-bearing minerals (*e.g.*, spessartite, blanfordite, and braunite).

But the manganese these rocks contain might have been derived either from the gonditic rocks or from the ores formed by method 2, and so cannot be taken as indicating the existence prior to the intrusion of these rocks of the manganese-ores formed by alteration. Further the fact that the igneous rocks are intrusive with reference to the manganese-ores cannot be regarded as conclusive evidence of the Archæan age of the ores formed by alteration; (1) because the ore invaded may be original ore formed by method 2, and (2) because the intrusives themselves are often partly converted by replacement into inferior ore, which might have been formed during the alteration of silicate to ore, or may be due to unimportant secondar[illegible]nges in the deposit subsequent to the main alteration.

[illegible]e when this alteration took place can never with certainty [illegible]ed as Archæan, unless inclusions of the partly altered manganese-silicate-rock can be found in the intrusive, or unless examples can be found in which the ore into which the igneous rock is intruded has manifestly been formed by the secondary alteration of manganese-silicate-rocks prior to the eruption of the igneous rock. (In this case [1] the process of alteration that has affected the manganese-silicate-rock, with its partial conversion into ore, will be found to end abruptly at the contact of the manganese-silicate-rocks and ores with the intrusives.)

In view, therefore, of the paucity of evidence relative to the age of these manganese-ores, it is very important to put on record some evidence similar to that of Jothvad obtained on a visit to the Gowari Warhona deposit in the Chhindwara district, in November 1908.

Gowari Warhona, Chhindwara district.

I re-visited this deposit on the suggestion of Mr. Hance, Manager of the Indian Manganese Co., Ltd., who reported that the deposit was showing signs of serious deterioration in depth. I almost expected to see a case of passage downwards from manganese-ore of good-quality into a zone of but partly-formed ore showing abundant remains of gonditic rocks. Such partly-formed ore does exist in this deposit, but I did not find the amount of it to increase with depth. Instead, I found that there was no deterioration in the quality of the ore apparent to the eye, and that the deterioration of the deposit with increasing depth was due to numerous intrusions of pegmatitic rocks, the eruption of which seemed

[1] *Cf.* (2) of previous para.