# LETTERS OF THE WORKING GROUP ON MANGANESE FORMATION OF INTERNATIONAL ASSOCIATION ON THE GENESIS OF ORE DEPOSITS

## REPORT

## ON INTERNATIONAL SYMPOSIUM ON THE GEOLOGY AND GENESIS OF PRECAMBRIAN IRON AND MANGANESE FORMATIONS, KIEV, AUGUST, 19—25, 1970

John Van N. Dorr, II

A symposium on the geology and genesis of Precambrian iron and manganese formations was held in Kiev, Ukranian SSR, in August 1970, under the auspices of UNESCO, the Ukranian Academy of Sciences, and the International Association of Geochemistry and Cosmochemistry. Papers were read and discussed in Kiev from August 20 to 25; most of the geologists attending the symposium thereafter went to Krivoi Rog to visit and observe the great iron ore deposits and complex structure and stratigraphy of that area. The organization of the symposium was most effectively handled by Academician N. P. Semenenko of the Academy of Sciences of the Ukranian SSR and his colleagues in the geological, geochemical, and geophysical community of the Ukranian SSR. Hospitality was warm and generous. Scientific communications from the western world were organized by Prof. Earl Ingerson, President of the International Association of Geochemistry and Cosmochemistry. Funds for travel to Kiev were supplied by UNESCO.

I was requested by Prof. Gyula Grasselly, President of the Working Group for Manganese of the International Association on the Genesis of Ore Deposits, to summarize the results of the Symposium with respect to manganese geology. The papers will be published in full in a volume of proceedings by UNESCO; inevitable delays in publication make such a summary desirable.

Most of the attention of the Symposium was perforce focussed on iron-formation and ore deposits. A number of interesting papers were read on several of the major manganese deposits of the world, however, and new information on geology and genesis was presented. In particular, papers on the Moanda deposits in Gabon, the Serra do Navio deposits of Amapá, Brazil, Moroccan deposits, Africa, and the deposits in Madhya Pradesh and Maharashtra, India, as well as a paper discussing the relations between iron- and manganese-formations in Brazil and Bolivia were of interest to manganese specialists.

Prof. Francis Weber of the University of Strasbourg described the manganese deposits in Gabon, which include the Moanda, the largest high-grade deposit of manganese oxide yet discovered in the world; he presented new information which clears away certain past misconceptions concerning the genesis of this great deposit. WEBER, who has worked for many years on this problem, showed that the oxide ores were derived by the weathering and oxidation of a zone of carbonate rock in the unmetamorphosed Francevillian (deposited about 1740 m. y. ago) of Gabon. This zone, revealed by drilling in a downfaulted block to be about 75 meters thick, averages about 13 percent Mn as carbonate; the original rock was a carbonate-rich black shale, slightly pyritiferous and poor in detrital components. An average of ten samples of [illegible] lows (in percent): $SiO_2$, 23; $Al_2O_3$, 6.3; CaO, 8.6; MgO, 4.3; $Na_2O$, 0.13; $K_2O$, 1.3; $TiO_2$, 0.17; P, 0.14; Fe, 2.5; Mn, 15; loss on ignition, 29.1. Organic matter is said to average about 6 percent, and iron is present as pyrite. The manganese is present as a complex manganese-calcium-magnesium carbonate.

Near the margins of the sedimentary basin in which this manganiferous carbonate protore was deposited, the manganiferous zone immediately overlies a 10-meter zone of iron-formation. In this iron-formation three facies are present, the sulfide, the carbonate, and the silicate. These facies are intergradational. The manganese content of the iron-formation is only about 0.2 percent; the iron content is about 31 percent.

The ore of commercial grade underlies large plateaus, the largest of which are the Bangombe (19 km² of mineralized area) and the Okouma (13 km² of mineralized area). These plateaus are at about 600 meters altitude and represent the remains of an erosion surface that was formed at the end of the Cretaceous or in early Tertiary time. Run-of-mine ore contains about 44 percent Mn, 4.4 percent Fe, 8.2 percent $Al_2O_3$, and 7.0 $SiO_2$. The ore is washed and screened, and the grade of ore marketed is about 50 percent Mn. Reserves are in order of 200,000,000 tons of washed ore.

WEBER makes a masterful analysis of the processes involved in the derivation of the oxide ores from the carbonate protores, too long for summary here. The discussion of the ultimate origin of the manganese and iron of the Francevillian necessitated a paleographic study of the whole sedimentary basin in which these and other rocks were deposited. WEBER postulates a compound basin, in one part of which volcanic rocks were abundant, in the other part of which the iron- and manganese-rich rocks were deposited, but in which volcanics of the same or older age are not abundant. He believes that the iron and manganese were of volcanogene origin, but transported long distances before deposition. Two types of volcanism are represented in the Francevillian; an early spilitic volcanism contemporary with the manganiferous deposits, although more than 100 km away from the larger concentrations of manganese, and an ignimbritic volcanism younger than the manganiferous beds. Naturally the spilitic type is thought to be the source of the manganese and iron. The high organic content of the rocks and the fact that the iron is present as sulfide, carbonate, and silicate and the manganese as carbonate both indicate a low Eh environment, which would facilitate long transport of metallic ions before precipitation.

PROF. SUPRIYA ROY of Jadavpur University discussed, in a beautifully illustrated paper the Precambrian manganese formations of India with particular reference to the effects of metamorphism. He showed that the syngenetic manganese oxide beds of India are in specific stratigraphic zones and are intimately interbedded with manganese silicate rocks in pelitic schists, quartzites, and carbonate rocks. No contemporary volcanic rocks are known.

The metamorphic facies of the manganiferous rocks ranges from the greenschist through the almandine-amphibolite facies, as shown by the enclosing pelitic rocks. Local contact metamporhism to the hornblende-hornfels and pyroxene-hornfels facies has been observed. Roy traces in considerable detail the mineralogical and textural evolution of the manganese minerals through the different metamorphic facies and subfacies. He considers that braunite is the first metamorphic mineral to appear; the mineral is stable to the sillimanite-almandine-muscovite subfacies. Bixbyite appears in the quartz-albite-epidote-biotite subfacies in association with hollandite and braunite and continues in the quartz-albite-epidote-almandine subfacies. Hausmanite, jacobsite, and vredenburgite (two-phase intergrowth) appear in the staurolite-almandine subfacies, continuing to the sillimanite-almandine-muscovite subfacies in association with braunite and bixbyite. Textures change with degree of metamorphism, ranging from colloform and fine-grained oxides in low-grade facies to granoblastic in the higher facies. Roy relates the mineral assemblages of the manganese oxide ores in different grades of metamorphism to progressive reduction of original higher oxide phases with relatively great $fo_2$, above those values prevailing in analogous iron-bearing systems and above values in similar rhodochrosite-bearing assemblages.

G. Choubert and A. Faure-Muret of the Museum of Natural History, Paris, presented a paper summarizing the literature on the Precambrian manganese deposits of the Anti-Atlas of Morocco. These deposits are both stratiform and in thin veins; there has been considerable disagreement as to the origin of the stratiform deposits, none of which is very large. The stratiform deposits, of which the Idikel and Tiouine are the best known, are remarkable for the large content of lead and BaO, the lead ranging to more than 2 percent and the BaO to more than 20 percent. Copper minerals are associated with some of the deposits.

Although the Idikel deposit is in Precambrian II rocks, or middle Precambrian, and the Tiouine deposit in Precambrian III rocks, or upper Precambrian, both are associated with continental and lacustrine sandstone, shale, and conglomerate. Manganese is present at transitional phases between the rock types in thin to moderately thick beds of no great lateral persistance. The Idekil deposit has variously been attributed to hydrothermal syngenetic, sedimentary syngenetic, and hydrothermal epigenetic origin; the present authors took no stand. The Tiouine deposits have been attributed by Bouladon and Jouravsky to a hydrothermal syngenetic origin, the manganese having been introduced into a lake by hydrothermal solutions and there deposited. The present authors consider that the deposit is hydrothermal epigenetic, the manganese minerals having replaced preexisting sediments.

There are hundreds of small vein deposits in the Precambrian III volcanic rocks of the Ouarzazate region, all small and none persistent in depth. The maximum known depth is about 100 meters; most are much shallower. The longest vein is about 800 meters; most are much shorter. Thickness is measured in centimeters or, rarely, decimeters; some short veins having dolomite gangue may be a meter or two wide. The veins are clearly epithermal epigenetic deposits closely related to volcanism.

The authors stress that the reason for the close relation between the predominantly rhyolitic volcanism and the formation of these manganese deposits is unknown. The rhyolites are very poor in MnO, and the vein deposits occur not only rhyolite but in other volcanic rocks and even in granite.

B. CHOUBERT discussed the manganese deposits in the Guianas and their relation to the fundamental structure of the shield area. With the exception of the Amapá deposits of Brazil, none of the deposits in the Guiana Shield have been economically successful, although the Matthews Ridge deposit in Guyana was worked for some years.

B. CHOUBERT points out that the Guiana Shield has two kinds of granites, one high in $K_2O$, the other, lower in $K_2O$, interposed between the high-potassium granites. The manganese deposits, which are all "gondite" deposits of ultimate sedimentary origin, are associated with the transition between the two types of granite, which CHOUBERT believes reflects the edges of ancient geosynclines. The manganese deposits are said to be associated with the volcanic sedimentary part of the old range between the geosynclines.

The "gondites" are present in thin lenticular beds in phyllite, quartzite, schist, and amphibolite of sedimentary origin. They are low in iron, containing one to two percent Fe, whereas the intercalated shale may contain as much as 10 percent $Fe_2O_3$, and some schists contain as much as 28 percent Fe. The "gondite" are everywhere associated with carbonaceous rock. The author states that there is no provable genetic relation between the ophiolitic rocks of the Guiana Shield and the manganese mineralization. He also states that there is no relation between the itabirite zones in the Guiana Shield and the occurrence of manganiferous zones.

The manganiferous zones are all thin, ranging to a meter or more in thickness, and consist of the common metamorphic manganese silicate minerals plus rhodochrosite in some deposits. These minerals have been oxidized to varying depths by supergene processes, and small low-grade deposits of the oxide minerals have formed. According to the author, the manganiferous zone at Matthews Ridge, the largest yet found in the Guianas proper, is some 30 km long (although not continuous) and 150—175 meters thick. It consists of thin layers of "gondite" alternating with barren rock consisting of chert lentils, carbonaceous phyllite, sandstone, and clays. Borings show impoverishment with depth; he states that in the first 30 meters the tenor declined from 40 to 12 percent Mn, and that enrichment ceased at the water table.

Three papers were presented on manganese deposits in Brazil. WILSON SCARPELLI, geologist and mine manager at the Serra do Navio mine, discussed the Serra do Navio manganese deposits on the south edge of the Guiana Shield, just north of the Amazon. This very important producing area has contributed more than ten millions of tons of high-grade ore to commerce, and reserves are substantial. The ores are weathering products of large lenses of rhodochrositic "gondite" intercalated into metasedimentary rocks of the Serra do Navio Group of the Amapá Series. The Serra do Navio Group overlies the Jornal Group, a thick, dominantly amphibolitic series of rocks of varying composition thought to be metasedimentary in origin.

The Serra do Navio Group consists of metasedimentary rocks deposited cyclically. They are divisible into three facies, quartzose, biotitic, and graphitic. Three cycles of deposition have been recognized. The quartzose facies is a metachert containing intercalations of calc-silicate and marble lenses. The biotite facies is a pelitic sediment now metamorphosed to a biotite schist with sillimanite, andalusite, and pink almandite. The graphite facies, which may contain as much as 20 percent C, is a metamorphosed carbonaceous clay. The manganiferous lenses are in the graphitic facies.

SCARPELLI made a very interesting and useful statistical analysis of 421 contacts between the facies to determine their gradational or nongradational nature and the relations between the rock facies. The analysis permitted the elucidation of the stratigraphic sequence of these highly folded and metamorphosed rocks. The cycles start with chert at the bottom, followed by the pelitic rocks now in the biotite facies, followed by the carbonaceous clays with which the protore was deposited.

The sequence indicates that deposition started in an oxidizing environment having pH greater than 7.5. The environment moved toward lower pH and considerably lower Eh as the pelitic material accumulated first to form the rocks now in the biotite facies, and then to pelitic rocks with very high organic carbon content and manganese carbonate lenses. An abrupt change in the environment then resulted in a new cycle of high Eh and pH, to be repeated at least three times. SCARPELLI suggests that these cyclical changes in environment are best explained by changes that would be produced on a shallow marine platform involved with periodic epeirogenic subsidence; this model fits the lenticular nature of the sediments deposited and their compositional variation. Radiometric dating indicates that the latest of three metamorphisms suffered by these rocks took place about 1750 million years ago.

The "gondite", composed of the usual manganese silicates dominated by spessartite, is principally on the edges of the manganese carbonate lenses and along strike where the lenses disappear. The high-grade ore formed principally from the rhodochrosite lenses; "gondite" produces less, and lower-grade, oxide ore. SCARPELLI points out that the ore is in a continuous process of secondary enrichment, being dissolved at the surface and reprecipitated at depth and laterally from the main ore zone. Unlike the situation described by B. CHOUBERT, supergene enrichment has proceeded at least 20 meters below the level of the master stream in the Serra do Navio area, although the major ore deposits are related to high-level erosion surfaces.

PROF. EVARISTO RIBEIRO, JR., of the University of São Paulo, discussed jacobsites from the Urandi manganese district, Bahia, Brazil. In the Urandi district, ores formed by the weathering of two types of protore, carbonate and oxide. The jacobsite formed from rather high grade metamorphism of the oxide protore; the mineral occurs with hausmannite. In areas where the grade of metamorphism is in the greenschist facies, neither hausmannite nor jacobsite are found. The magnetic properties of jacobsite facilitate prospecting by magnetic methods. RIBEIRO discussed at some length the mineralogical characteristics of the jacobsites found in the Urandi district; one slide showed native copper with jacobsite.

JOHN VAN N. DORR, II, of the U. S. Geoolgical Survey, discussed the relation between the different facies of Precambrian iron-formation in Brazil and the different facies of associated manganese deposits. He pointed out that oxide-facies manganiferous formations in Brazil are interstratified with oxide-facies iron-formation, which is by far the most abundant type of iron-formation in Brazil. Carbonate-facies and sulfide-facies iron-formation, on the other hand, do not contain interbedded manganiferous formation; manganiferous rocks that are possibly contemporary with carbonate-facies iron-formation are separated from the iron-formation in space, even though the carbonate-type manganese formations contain large quantities of manganese, as in Amapá and the St. João del Rey and Lafiete areas.

DORR also discussed the unmetamorphosed Cambrian and Ordovician oxide-facies iron-formation in western Mato Grosso and eastern Bolivia, which contains very large quantities of primary high-grade manganese oxide interstratified with the banded oxide-facies iron-formation.

PROF. H. J. KOARK of Uppsala University discussed the Precambrian sedimentary manganese deposits of Sweden. These polymetamorphic deposits have a very complex mineralogy and all belong to the upper sedimentary series of the Svekofennian shield, in which they form imbricate zones. KOARK compared the best-studied deposits, Nyberget, Långban, and Ultevis, in considerable detail. The deposits are thought to be sedimentary-hydrothermal; some addition of material and much modification of the deposits probably has taken place during the later metamorphisms.

DR. JOHN VAN N. DORR, II
US Geological Survey,
Washington, D. C. 20 242, U. S. A