

MANGANESE DEPOSITS IN THE RIDING
MOUNTAIN AREA, MANITOBA

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Presented in partial fulfillment of the requirements
for the Master of Science degree in the University
of Manitoba.

March, 1941.

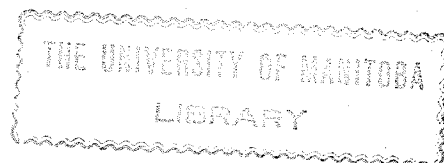


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Abstract

Several bog manganese deposits were discovered in the Riding Mountain area in Manitoba during the spring and summer of 1940. A study was made of the known deposits to determine the grade of the occurrences, a possible source of the manganese oxides in the bog deposits and the possibilities of locating other manganese occurrences. Samples of the bog manganese, of spring waters from which the manganese oxides have apparently been precipitated, of the Odanah shale in which the deposits occur, and of "ironstone" nodules found in the Odanah and Riding Mountain shales were gathered in the field and later analyzed. In addition to chemical analyses of the above-mentioned samples, several polished sections of the manganese oxides were prepared and studied under the microscope, thin-sections of nodules were examined, and spectrographic analyses of both nodules and bog manganese were made.

The manganese deposits are irregularly distributed along the bases of steep slopes where they have evidently been deposited by springs issuing from the hills. Some of the occurrences are intimately associated with wet bog material; others are mixed with fractured shale. In the latter type of deposit selective screening removed a portion of the shale and increased the manganese content of the sample. The better grade occurrences vary in areal extent from approximately 40 to 1,000 square feet and in maximum thickness from 8 to 42 inches. Dried material passing through a $\frac{1}{4}$ inch screen contains from about 25 to 50 per cent manganese. The occurrences are typical wad or bog manganese and polished sections indicate that pyrolusite forms the greater part of the deposits.

Manganiferous nodules are the source of the manganese in the deposits. These carbonate nodules are found scattered throughout the shale forming the bedrock of the area. Waters circulating through the shales leach manganese from the nodules and deposit it in the form of oxides near the spring openings.

Although no large occurrences may be expected, several small ones of high grade could supply chemical grade material or manganese in a form suitable for use in the brick industry. Possibilities of finding other deposits are considered favorable where springs are found emerging from the hills in areas where Odanah and Riding Mountain shales containing manganiferous nodules make up the bedrock formations.

MANGANESE DEPOSITS IN THE RIDING
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Introduction.

Manganese is today considered one of the most important strategic minerals on the North American continent. The term strategic is used by Roush¹ "to designate a mineral or metal the domestic supply of which is insufficient to meet the demands, regardless of whether that demand be industrial or military...." As the steel industry is of prime importance and as manganese is so essential in the manufacture of steel, it is quite obvious why manganese is such a much-sought metal. Up to the present time, no satisfactory substitute has been found for ferromanganese in the deoxidation of steel.

In normal times the chief sources of supply have been the deposits of Russia, India, the Gold Coast, Brazil and Cuba. As a result of the present war, some of these sources have been cut off, and shipping difficulties have interfered with the normal flow of manganese ore from the remaining sources. At present Brazil and Cuba are the main sources of supply for Canada and the United States. As in the previous war the decreased source of supply and high oceanic freight rates have given impetus to the search for

1) Roush, G. A.: "Strategic Mineral Supplies", p.3. (1939)

manganese on this continent and to attempts to develop known low grade deposits. Since 1918 production of manganese in the United States has averaged less than 8 per cent of the consumption. All the remainder of the supply has been imported, either as manganese ore, or as ferromanganese or other alloys. In Canada the production of manganese is almost negligible. Accordingly when manganese was reported found in the Riding Mountain area in Manitoba great interest was shown.

During a part of the summer of 1940 the known deposits were examined by the writer for the Mines Branch of the Manitoba Department of Mines and Natural Resources. A study was made to determine a possible source of the manganese oxides in the bog deposits and the possibilities of locating other manganese occurrences. Analyses were made of samples gathered in the field to find the grade of the deposits and the nature and amounts of the impurities.

History of Manganese.

Manganese, probably in the form of naturally occurring manganese oxides, is known to have been in use as far back as early Egyptian times. At that time and since, it has been used in the glassmaking industry, primarily as a decolorizing agent. When chlorine came into wide use as a bleaching agent about ten years after its discovery by Scheele in 1774, manganese ores were used to a considerable extent in the manu-

facture of that substance. It was not until 1839 that manganese was used in the manufacture of steel, and twenty-one years later that ferromanganese was first produced for commercial use. About 1883 R. A. Hadfield, of Sheffield, England, conducted the first successful experiments and tests of manganese steel. At present about 95 per cent of the manganese ore produced is used for metallurgical purposes; the remainder is consumed in the chemical and non-metallurgical industries.

Manganese Minerals.

Harder² lists 103 minerals containing manganese; only a small number of these are considered as ores of manganese, which are mainly restricted to the oxides. The commoner manganese ore minerals are described in the following list:

Psilomelane-- $MnO_2 \cdot (Mn, K, Ba)O \cdot nH_2O$; or H_4MnO_5 --is usually regarded as colloidal MnO_2 with the various impurities adsorbed. It is a bluish or greyish-black mineral, with a brownish-black streak, a hardness of 5 to 7, and a specific gravity of 3.7 to 4.7. The manganese content varies between 45 and 60 per cent. It occurs in massive forms, frequently botryoidal or reniform and is formed normally at or near the earth's surface.

Pyrolusite-- MnO_2 (generally contains a little H_2O)
--varies in color from black to steel-grey, has a black streak,

2) Harder, E. C.: "Manganese Deposits of the United States";
U.S.G.S. Bull. 427, p.20 (1910)

a hardness of 2 to 2.5, and a specific gravity of 4.8. It readily soils the fingers. When pure, pyrolusite contains 63.2 per cent manganese, the highest metal content of the commoner manganese ores, but it is rarely found in the pure state. Pyrolusite is formed at or near the earth's surface under strongly oxidizing conditions, and generally occurs in association with psilomelane.

Braunite-- $3\text{Mn}_2\text{O}_3 \cdot \text{MnSiO}_3$ --is a brownish to greyish-black mineral with a streak of the same color, hardness of 6 to 6.5 and specific gravity of 4.8. The mineral is usually crystalline but also occurs massive. It usually contains about 62 per cent manganese with silica varying from a trace to 10 per cent.

Manganite-- $\text{Mn}_2\text{O}_3 \cdot \text{H}_2\text{O}$ --is a dark steel-grey to iron-black mineral with a reddish-brown streak, hardness of 4 and specific gravity of 4.2 to 4.4. Pure manganite contains 62.4 per cent manganese and 10 per cent water. Under oxidizing conditions it is replaced by pyrolusite.

Hausmannite-- Mn_3O_4 --is of primary origin, commonly occurring in veins associated with acid igneous rocks. It is brownish-black with a brown streak, hardness of 5 to 5.5 and specific gravity of 4.8. Hausmannite contains 72 per cent manganese, but is of relatively small importance as an ore.

Wad or bog manganese is a black to blue-black amorphous earthy mixture of manganese oxides and water with iron oxide and sometimes baryta, alumina and silica. It is

usually very soft and soils the fingers. The only difference between wad and bog manganese is that the former is not generally saturated with water, whereas the latter, as the name implies, is a wet bog deposit.

Rhodocrosite-- MnCO_3 --is a pink mineral which on exposure becomes black by oxidation. It has a hardness of 3.5 to 4.5 and specific gravity of 3.45 to 3.6. The pure mineral contains 47.56 per cent manganese.

Other manganiferous carbonates include manganocalcite $(\text{Ca}, \text{Mn})\text{CO}_3$, manganosiderite $(\text{Fe}, \text{Mn})\text{CO}_3$, and ankerite $(\text{Ca}, \text{Mg}, \text{Fe}, \text{Mn})\text{CO}_3$, but they are not so common as the other manganese minerals listed above.

Rhodonite-- MnSiO_3 --is a pink mineral generally occurring as gangue along with quartz and rhodocrosite in ore or pegmatite veins. It has a hardness of 5.5 to 6.5 and a specific gravity of 3.4 to 3.7. Like rhodocrosite, it becomes black on exposure. Pure rhodonite contains 41.9 per cent manganese but is not commercially valuable because of its high silica content.

Other minor sources of manganese are manganiferous silver ores and the manganiferous zinc residuum at Franklin Furnace, New Jersey. The former consist of varying amounts of silver and lead minerals with manganese and iron oxides. The latter is a product remaining after the zinc has been volatilized from franklinite concentrates. The residuum, commonly containing 14 to 15 per cent manganese and about 40 per cent iron, is used in the manufacture of spiegeleisen. Manganiferous iron ores also contain small amounts of manganese and are often im-

portant sources of that metal. They will be described in the section on ore grades.

Classification of Manganese Deposits and their Origin.

The average igneous rock of the earth's crust contains 0.124 per cent of MnO^3 . Manganese is also present as a trace in most other rocks, in organic substances, and in most waters. Springs and underground waters in general contain more manganese than surface waters. In certain spring waters the manganese content reaches a maximum of 117 parts per million; in river waters in the temperate zone it commonly ranges from 0.5 to 5 parts per million⁴. Mellor⁵, basing his calculations on data provided by J. Murray, states that 37,000,000 tons of manganese oxide, Mn_2O_3 , or nearly 26,000,000 tons of manganese are brought every year by rivers into the oceans. This bears out the generally accepted view that manganese disseminated throughout the igneous and sedimentary rocks is taken into solution by percolating meteoric waters. The manganese is later deposited in a more or less concentrated form which is sometimes sufficient to make a commercially valuable deposit.

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- 3) Clarke, F.W., and Washington, H.S.: "The Composition of the Earth's Crust"; U.S. Geol. Sur. Prof. Paper 127, p.16 (1924)
 - 4) Twenhofel, W.H., and others: "A Treatise on Sedimentation"; p. 563 (1932)
 - 5) Mellor, J.W.: "A Comprehensive Treatise on Inorganic and Theoretical Chemistry"; vol.12, p.152. (1932)

Hanson⁶ classifies the manganese deposits as follows, the classification being based on the nature of the concentration processes giving rise to the occurrences:

- 1) Sedimentary deposits.
 - (a) oxide type.
 - (b) carbonate type.
 - (c) bog type.
- 2) Replacement and residual deposits.
- 3) Vein deposits.

The sedimentary and replacement types of deposits are the result of solution of manganese from country rock, its transportation and finally its deposition upon encountering favorable conditions. Although there is general agreement now as to the chemistry involved in the process, there have been different views held at different times. When a scientific exploration party aboard the H. M. S. Challenger conducted a survey of the ocean bottom between the years 1873 and 1876, they found that manganese nodules were common in several areas over the ocean bed. This manganese is in the form of hydrated oxides. At that time there were four theories to explain the origin of the manganese in the nodules⁷:-

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- 6) Hanson, G.: "Manganese Deposits of Canada"; Geol. Sur. Can., Econ. Geol. Ser. no. 12, p. 10. (1932)
 - 7) Murray, J., and Renard, A. F.: "Challenger Report on Deep Sea Deposits"; p. 373. (1891)

1. The manganese of the nodules is chiefly derived from the decomposition of the more basic volcanic rocks and minerals with which the nodules are nearly always associated in deep-sea deposits. The manganese and iron of these rocks and minerals are at first transformed into carbonates, and subsequently into oxides, which, on depositing from solution in the watery ooze, take a concretionary form around various kinds of nuclei. (Murray). Renard states that while admitting a part of the manganese accumulated at the bottom of the ocean may have been derived from the decomposition of volcanic rocks, the greater part appears to have been derived from manganese in solution in the sea-water.

2. The oxides of manganese are formed under the reducing influence of organic matter on the sulphates of sea-water, sulphides being produced and subsequently oxidized. (Buchanan). Murray and Irvine showed experimentally that the nodules could not be formed in the manner proposed by Buchanan. They put powdered manganese nodules into sea-water along with decomposing mussel-flesh; in a few days the sulphates present in the sea-water had been reduced to sulphides, which first altered the manganese peroxide to protoxide. The protoxide, being soluble in the carbonic acid (the product of oxidation of the organic matter), remained as soluble manganese bicarbonate in the water, while the iron sesquioxide present in the nodules was precipitated as insoluble sulphide.

3. The manganese nodules result from the precipitation

of manganese contained in the waters of submarine springs at the bottom of the ocean. (Gümbel).

4. The manganese oxides in the nodules are formed from the compounds of manganese dissolved in sea-water in the form of bicarbonates, and transformed at the surface of the sea into oxides, which are precipitated in a permanent form on the ocean-bottom. (Boussingault, Dieulafait).

The first step in the cycle which almost all manganese goes through before forming commercial deposits is that of solution, a process coincidental with rock decay. According to Twenhofel⁸ the processes responsible for the greater portion of rock decay are solution, oxidation, hydration and carbonation. F. W. Clarke⁹ states that acidic waters found in volcanic regions and which have a strong solvent action on the surrounding rocks are relatively rare, and their geological importance as solvents is small compared with that of carbonated waters. He considers meteoric waters carrying free carbonic acid to be the most powerful agents in the solution of rocks. Endell¹⁰ proved that the acidity of swamp water is due mainly to carbonic acid resulting from the decay of veg-

8) Twenhofel, W. H., and others: op. cit., p. 15.

9) Clarke, F. W.: "Data of Geochemistry"; U. S. Geol. Sur. Bull. 770, p.210. (1924)

10) Endell -- quoted by W. S. Savage: "Solution, Transportation and Precipitation of Manganese"; Econ. Geol. 31, p.284 (1936)

etable matter under oxidizing conditions. Various manganese minerals in which the manganese has different valences are not equally soluble in circulating underground waters. D. F. Hewett¹¹ states that the minerals containing manganous oxide are more susceptible to solution than those which contain it in higher states of oxidation. Vincent¹² showed that the higher oxides of manganese are less soluble in carbonated waters than the small amounts of primary manganese distributed in igneous and sedimentary rocks. He also showed that the greater the concentration of CO₂ in solution, the greater is the solubility of the manganese oxides. He concluded that manganese is dissolved by means of carbonic acid and yields a bicarbonate analogous to calcium bicarbonate. The formula of this manganese compound would be Mn(HCO₃)₂ and it would exist only in solution. More recently, Savage,¹³ in a series of experiments on the solution of manganese, arrived at similar conclusions. He found that manganese carbonate and manganous oxides were soluble in carbonated waters, but that the higher oxides of manganese were soluble only to a very slight degree. Savage further proved that distilled water and oxygenated water were poor solvents of manganese.

11) Twenhofel, W. H., and others: op. cit., p.562.

12) Vincent, M. V.: "Circulation du manganèse dans les eaux naturelles"; Comptes Rendus 162, p.260 (1916)

13) Savage, W. S.: "Solution, Transportation and Precipitation of Manganese"; Econ. Geol. 31, p.285 (1936)

When manganese is extracted from manganese-bearing rocks it may be transported either in solution as a bicarbonate or in colloidal suspension. Opinion now favors the former view. Hewett¹⁴ states that in general, waters containing much manganese belong to the mixed carbonate type. He adds that it has been widely asserted that manganese is transported in solution as the bicarbonate. Hanson¹⁵ is of the opinion that whereas in groundwaters manganese is carried in solution, in streams where there is so much opportunity for oxidation the manganese may in large part be carried as oxide in suspension. He adds however, that, as iron is readily carried in solution in waters containing much organic matter, it may be that manganese is transported in a similar manner, since manganese and iron are related chemically. Dale¹⁶ believes that manganese is transported chiefly as the bicarbonate and to a less extent as suspended particles of oxide. Zappfe¹⁷ considers the manganese in the Brainerd water supply carried in solution as bicarbonate.

14) Twenhofel, W. H., and others: op. cit., p. 563.

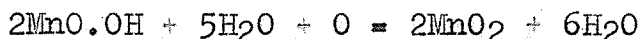
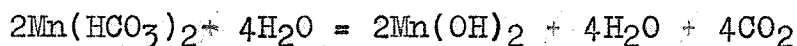
15) Hanson, G.: op. cit., p. 11.

16) Dale -- quoted by W. S. Savage: op. cit., p. 285.

17) Zappfe, Carl: "Catalysis"; Econ. Geol. 28, p. 756. (1933)

As long as the water is acidic the manganese will remain in solution as a bicarbonate. Many have recognized the fact that a slight degree of alkalinity is necessary before simple aeration can precipitate manganese from a bicarbonate solution. Savage¹⁸ performed an experiment in which O₂ and CO₂ were bubbled simultaneously through a manganese bicarbonate solution for five days, after which time it was found that none of the manganese had been precipitated. When the excess of CO₂ has been removed, the solution becomes slightly alkaline and manganous hydroxide, Mn(OH)₂, an unstable compound can form and remain in solution. However, the reaction is reversible and nothing results until the equilibrium is destroyed by the introduction of another factor such as oxygen into the reaction. Bradley¹⁹ showed that the oxidation of manganous hydroxide results in the formation of a stable though partly dehydrated manganese hydrate MnO.OH. The hydrate is further oxidized to form MnO₂.

Savage summarized the series of reactions as follows:²⁰



18) Savage, W. S.: op.cit., p. 286.

19) Bradley -- quoted by Carl Zappfe: "Deposition of Manganese";
Econ. Geol. 26, p. 821 (1931)

20) Savage, W. S.: op. cit., p. 288.

The MnO_2 , as soon as formed, acts as a catalyst, accelerating the process, and removing almost every trace of manganese from the solution. According to Zappfe²¹ the manganese bicarbonate in solution on contact with MnO_2 produces $Mn(OH)_2$, leaving the dioxide unchanged. As shown in the series of reactions above, the $Mn(OH)_2$ is eventually oxidized to MnO_2 .

Manganese can also be removed from a bicarbonate solution by reaction with calcium carbonate to give manganese carbonate.

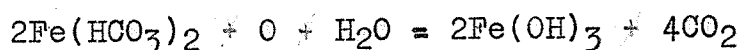


The precipitation of manganese may also be brought about organically. Several species of "iron bacteria" precipitate manganese as well as iron, and at least two species, *Crenothrix polyspora* and *Leptothrix ochracea* prefer inorganic manganese salts to iron salts to grow on.

Although manganese and iron are very similar chemically and almost invariably occur together in the same primary rocks from which both are leached, in passing through the cycle of solution, transportation and precipitation they are more or less effectively separated. It is a well established fact that iron goes into solution with greater difficulty and is precipitated

21) Zappfe, Carl: "Deposition of Manganese"; *Econ. Geol.* 26, p. 824 (1931)

out more rapidly than manganese. Fresenius²² noted that in the spring waters at Wiesbaden, manganese remained in solution much longer than iron. Iron hydrates are soluble in acids but oxidize readily upon aeration in neutral to weakly acid solutions, whereas atmospheric oxygen has no effect on manganese bicarbonate in neutral or weakly acid solutions. The reaction for iron is



The $\text{Fe}(\text{OH})_3$ is a stable compound and is rapidly precipitated. The $\text{Mn}(\text{OH})_2$ produced in a similar reaction involving $\text{Mn}(\text{HCO}_3)_2$ is not a stable compound and remains in solution.

The different conditions under which the manganese is transported and precipitated give rise to the different types of sedimentary and replacement deposits. As noted previously, Hanson divides the sedimentary manganese occurrences into three types--oxide, carbonate, and bog deposits. He describes the oxide type as follows:²³

"They are black sedimentary beds consisting mostly of manganese oxides and are interbedded with ordinary shales and sandstones. Individual beds of manganese are rarely thicker than 1 or 2 feet, but several thin beds each a few inches thick

22) Fresenius -- quoted by Savage: op. cit., p. 286.

23) Hanson, G.: op. cit., p. 12.

commonly occur in a single horizon. Beds of manganese ore, together with interbedded mangiferous sandstones and shales, which commonly contain nodules of manganese oxide, are in places 10 feet or more thick. The manganese minerals in the deposits are chiefly pyrolusite, psilomelane and manganite. The ores are typically concretionary and oolitic. The purest are commonly oolitic, and the impure varieties, associated with shale and other sedimentary rocks, are commonly concretionary. Barite occurs in most ores of this type, but phosphate, silica, and iron oxides are not so common as in manganese deposits of the carbonate type. The close association between the manganese oxide beds and clastic sediments suggests that they were laid down in shallow water such as lagoons or lakes".

The manganese oxides forming these sedimentary beds were put down while sedimentation was going on or at intervals when the sedimentary process was at a minimum. Streams may have carried the oxides in suspension, dropping them upon reaching a large body of still water. If these streams are relatively free of sediment, fairly pure mangiferous beds may be formed. The same applies to clear streams carrying manganese in solution. The manganese may be precipitated by bacteria or a change in chemical conditions upon reaching open water. Manganese dioxide once formed, will act as a catalyst in the precipitation of manganese in solution. Springs issuing into bodies of still water might deposit large amounts of manganese which would be distributed over the lake or sea-bottom by wave or stream action. An example of the sedimentary oxide type of deposit is the one at Tchiatouri, Russia, one of the largest manganese occurrences in the world.

The carbonate type deposits are stratified sediments interbedded commonly with shales and limestones. The carbonates are pink but on weathering oxidize to the black oxides. The manganese carbonate is ordinarily present in nodular and oolitic form, the manganiferous nodules often being found in manganiferous shales. A typical deposit may consist of many shaly beds which sometimes make a total thickness of about 20 feet; the beds contain both manganese and iron carbonate. Manganese carbonate beds often contain barite and usually considerably more phosphate and silica than the sedimentary oxide deposits. The manganiferous carbonates not only have more phosphate associated with them than the oxides, but sometimes distinct beds of these carbonates and phosphatic nodules occur in close proximity, locally thick enough to be mined. The manganese carbonate beds are also commonly associated with beds of chert and glauconite. A characteristic feature is the association of this group of materials with fine-grained sediments. Manganiferous carbonates are much more widespread in unweathered sediments than the oxides, and thin zones of these carbonates and carbonate concretions are fairly common in fine-grained marine sediments. In the Batesville district, Arkansas²⁴, the Cason shale of Upper Ordovician age attains a

24) Twenhofel, W. H., and others: op. cit., p. 572.

maximum thickness of 12 feet. It is largely made up of thin, rather persistent layers of shale, fine sandstone, phosphate and nodules of iron-manganese carbonate. These nodules resemble concretions but are regarded by Ulrich as fossil algae of the genus *Girvanella*. Stratified layers of relatively pure manganese carbonate or zones of iron-manganese carbonate concretions are the source for nearby bodies of manganese oxides in residual materials which occur persistently over large areas at definite stratigraphic horizons. Often the marine strata in which the beds of manganiferous carbonate occur are not very fossiliferous.

There are several hypotheses to explain the origin of this type of deposit. Beds of pure manganese carbonate such as those found in the Franciscan cherts of California were probably laid down as $MnCO_3$. The manganese may have been carried in solution as a bicarbonate and precipitated as a carbonate through escape of carbon-dioxide. Manganese bearing springs emerging below the surface of a large body of water may deposit manganese carbonate instead of oxide if the environment is reducing in nature. The manganese may also have been deposited as an oxide in sediments that contained organic matter which would create a reducing atmosphere for the oxide to be converted to carbonate. A good example of the carbonate type of manganese deposit occurs at Conception and Trinity Bays, Newfoundland, and was described by Dale²⁵.

25) Dale, N.C.: "The Cambrian Manganese Deposits of Conception and Trinity Bays, Newfoundland"; Amer.Phil.Soc.vol.LIV, pp..371-456. (1915)

Bog manganese deposits, although made up of manganese oxides, are separated from the sedimentary oxide type in the classification because of the difference in their mode of occurrence. Bog deposits are soft, wet oozes in which the manganese occurs chiefly as pyrolusite, but in which other oxides of manganese are also present. Iron oxides, silica, lime, magnesia and baryta are commonly associated with the manganese minerals. The deposits are formed at the surface by precipitation of manganese from manganiferous springs near their point of issue. Underground waters leach the manganese from manganiferous rocks or nodules, carry it in solution as the bicarbonate, and at or near the surface the manganese is precipitated by oxidation. The chemistry of the process has already been outlined.

Deposits of bog manganese are very common in eastern Canada, but on the western plains are likely to be small and scarce because of relatively recent glacial action which removed most loose surface material. A general lack of manganese in the sedimentary country rock is also responsible for the absence of bog deposits.

Replacement and residual deposits, although two distinct types, are classified together because they often grade into each other so that many deposits are a combination of both replacement and residual origin.

Although replacement deposits are common, very few are large or of much economic value. They contain psilomelane,

manganite, pyrolusite, wad, and other manganese oxides, as well as limonite and hematite. Most deposits of this type are very irregular and occur in easily replaced rocks such as limestone. The process of formation of these deposits is one of simple replacement of rock or mineral by manganese in solution which precipitates as the oxide. These oxides may also be deposited in cavities in the rock caused by solution. Solutions containing manganese bicarbonate will react with limestone to deposit manganese carbonate and take into solution calcium bicarbonate. As most replacement deposits are usually exposed at the surface, oxidation and weathering will cause psilomelane to change to manganite, and manganite to pyrolusite.

Truly residual manganese deposits are rare. In most instances the deposits are formed by the breaking down of complex minerals by weathering, manganese being taken into solution, carried down a short distance and precipitated by replacement of other minerals, or precipitated at the surface as oxides and hydroxides. The deposits formed in this manner are a combination of replacement and residual origin. Occurrences of this type produce much of the manganese ore in India. One of the largest deposits of this type is located at Hill 5 at Ramdongri in the Nagpur area in the central provinces of India. It consists of a body of impure manganese ore 2,500 feet long, 1,500 feet wide and 140 feet thick.

Vein-like deposits are formed by replacement, and fissure filling by circulating groundwaters produces veins of manganese oxides. Hydrothermal solutions give rise to veins

containing rhodocrosite or other manganiferous carbonates, which, although rarely of value as they are, may be enriched by solution and oxidation to commercially valuable veins of manganese oxide. At Butte, Montana, rhodocrosite occurs with rhodonite in veins which are oxidized near the surface to form high-grade manganese deposits. The rhodocrosite, which is also mined, is sintered to give a product unusually high in manganese.

Manganese Deposits of the World.²⁶

U. S. S. R.

The two important manganese ore producing districts in Russia are located at Chiaturi and Nikopol.

The Chiaturi deposits are on the southern slope of the central part of the Caucasus mountains near the town of Chiaturi in the Kvrila River valley. They are found in an area 19 miles long by 5 or 6 miles wide upon a highly dissected plateau. The manganiferous beds, which are horizontal and continuous, vary in thickness from 4 to 9 feet, the average being about 7 feet. The ore itself is 3 to 5 feet thick. The ore deposit, representing a shallow water formation, belongs to the Lower Eocene, and lies a little above the contact with

26) Harder, E. C.: op. cit.

Groves, A. W.: "Manganese"; Imp. Inst., Mineral Resources Dept. (1938)

the Upper Cretaceous limestone. Sandstone occurs both in the roof and the floor of the ore-body. The deposit has a distinctly stratified structure and is composed mainly of pyrolusite, though psilomelane and wad also occur. The ore occurs both as compact oolites and concretions cemented with silica and carbonate of lime, and as a soft oolitic material. There are also clay bands with fine-grained pyrolusite and earthy ore. In many places strata of sandstone or of loose, friable arenaceous or calcareous material are intercalated with the manganese ore, and vary in thickness from a fraction of an inch to a foot. Much of the ore is very soft, disintegrating to a fine powder during mining, cleaning and transportation. Concentrates of exceptional purity, prepared by washing for use in chemical industries, contain 80 to 90 per cent of manganese dioxide. The crude ore averages 40 per cent manganese, but the concentrated material obtained from it has a manganese content varying from 44 to 52 per cent. Of the 1937 manganese production in the U. S. S. R., 57 per cent came from the Chiaturi deposits.

The Nikopol deposits are situated along one side of the Dnieper river, about 100 miles from its entrance into the Gulf of Odessa. The field is divided into an eastern and a western section by a zone of crystalline rocks barren of ore. The western section covers an area about 12 miles long and 6 miles wide. In the eastern section the limits of five ore-bodies have been defined, all of similar type and each covering an area of a few square miles. The ore-bed occurs in

Oligocene strata, is horizontal, and varies in thickness from 3 to $11\frac{1}{2}$ feet, averaging $6\frac{1}{2}$ feet. It consists of a sandy clay with powdered manganese ore and contains oolites and nodules of pyrolusite and psilomelane. Wad, limonite and hematite are also present. The deposits are but a short distance above crystalline bed rock and are believed to have been derived from it through weathering processes. The greater part of the ore consists of pyrolusite averaging about 30 per cent manganese, but it can be concentrated to material containing 40 to 50 per cent manganese. In 1937, 33 per cent of the manganese production of the U.S.S.R. came from the Nikopol deposits.

There are many other manganese occurrences in the U. S. S. R. but they are all small compared to the Chiaturi and Nikopol deposits.

India.

Manganese deposits are found in the Madras and Bombay Presidencies, in Central India, in the Central Provinces, in Bengal, and in Lower Burma. All the occurrences however, can be classified into three main types. Two of these occur in rocks of Archean age, the Gondite series and the Kodurite series; the third is of comparatively recent date and consists of lateritic material derived from the older formations.

The Gondite series is composed mainly of manganeseiferous schists and gneisses. The rock known as gondite consists essentially of spessartite and quartz. With this series are associated the principal manganese occurrences of India, such as those

of the Central Provinces. The ore bodies occur as lenticular masses and bands intercalated in the other metamorphosed sediments of the Gondite series. The deposits have resulted from chemical concentration of the manganese, effected mainly by the action of groundwater. The ore-bodies are often of large size, at least two attaining a length of $1\frac{1}{2}$ and $1\frac{3}{4}$ miles respectively. In one instance an ore-band is exposed more or less continuously for nearly 6 miles. The ores do not usually exceed a thickness of 45 to 50 feet, and are often much thinner. The ores are hard and fine-grained consisting of mixtures of braunite and psilomelane of different degrees of coarseness. First-grade ore produced from this series has a manganese content varying from 50 to 54 per cent. High grade pyrolusite averaging 85 per cent MnO_2 and 0.45 per cent iron is worked in Keonjhar State.

The Kodurite series consists of plutonic intrusions in the very ancient gneissose and schistose rocks of the Khondalites. All members of the series are characterized by manganiferous minerals. The concentration of manganese is the result of alteration of the manganese silicates to compounds soluble in carbonated waters which eventually replace the rocks with manganese ore. The ore consists mainly of psilomelane, with minor amounts of pyrolusite and braunite. Manganese ore with at least 43 per cent manganese, and manganiferous iron ore with 35 to 43 per cent manganese and not less than 15 per cent iron are produced.

Lateritic manganese deposits are found in several parts of the country but are of less importance than those associated with the Gondite and Kodurite series. The lateritic ores when derived from rocks of the Dharwar series, contain psilomelane or pyrolusite or a mixture of both. The deposits are associated with iron ores such as limonite and earthy hematite into which they grade. The manganese content is usually low.

Gold Coast.

The manganese ores of the Gold Coast are found in the very ancient rocks of the Birrimian System, and in their mode of occurrence bear a strong resemblance to the manganese ores of India and Brazil. Among the Upper Birrimian volcanics is a well-defined horizon with a marked manganese content. Metamorphism converted these rocks into manganiferous phyllites and other metamorphic types containing spessartite, and in places, rhodonite. At Nsuta there are large deposits of black primary oxide ore. Apart from Nsuta, ores of commercial grade appear to be wholly confined to secondary reconstituted and detrital ore capping the hills, and there appears to be little or no primary black ore.

The Nsuta-Dagwin deposits are the only ones from which there is any large scale production. They have been traced almost continuously for about $2\frac{1}{2}$ miles along two parallel ridges. The rocks in which the ores occur are grey and black manganiferous phyllites bedded in the Upper Birrimian System of metamorphosed lavas and pyroclasts. The beds have been folded and are displaced by strong cross faulting. The ore-bodies are decidedly lenticular. Although the manganiferous horizon is continuous

over many miles along the strike, individual lenses of ore are small, except at Nsuta. All the ore-bodies at Nsuta are considered to persist along a definite horizon, their separation being due to folding and faulting.

The main ore-bodies at Nsuta form five prominent hills named A to E. A typical section through one of the hills shows a capping of detrital ore, averaging about 30 feet in thickness and containing about 40 per cent manganese. The detrital material rests on large lenticular ore-bodies containing about 50 to 55 per cent manganese, and on the surrounding country rocks. The upper parts of the ore-bodies consist chiefly of hard mammillary and stalactitic ore containing only a little quartz. This ore gradually changes in depth to a soft black ore containing thin seams of white kaolin and cut by numerous veins of white quartz showing little or no evidence of staining or veining by manganese oxides. Bishopp and Hughes maintain that the principal ore-bodies are largely due to differential enrichment of manganiferous phyllites by meteoric waters. N. R. Junner believes that the Nsuta ores represent pre-Cambrian deposits of high-grade manganese occurrences which, in general, have not been greatly modified by meteoric and ground waters in recent geologic time. The ore-bodies vary in size from 90,000 to 760,000 tons.

Union of South Africa.

The Postmasburg deposits in Cape Province, South Africa, are the most important source of manganese in the Union. They are about 120 miles west-north-west of Kimberley. The deposits in which both manganese and hematite ores are closely associated, occur in two symmetrically set belts linked at their ends, and separated by an area from which the ore-bodies have been denuded. The western belt, known as Gamagara ridge, is 40 miles long from north to south. The eastern belt consists of an arcuate chain of outliers, known as the Klipfontein Hills. The maximum width of the field is 9 miles.

The manganese ore in the eastern belt occurs as disconnected masses varying greatly in size and shape, and scattered irregularly through chert or other siliceous material which lies along the junction of the underlying dolomite and the overlying Blink Klip breccia. Masses of ore may occur in the lower part of the Blink Klip breccia itself. In the western belt the manganese ore occurs in two forms. At the southern end and the northern end conditions somewhat similar to those in the eastern belt prevail; in the central, and on portions of the northern part the ore appears as a bedded deposit associated with the basal conglomerates and shales of the Gamagara Series. The ore is not confined to a single horizon in this zone, and more than one ore-body may be present in the sequence. In places the ore deposits cut across the basal conglomerate and shales. In the central part of the western belt the ore is really of two types -- bedded and massive, the

latter usually being of higher grade.

Along the Gamagara Ridge the ore occurs in sheet-like bodies with a maximum width of 1,100 yards and in one instance appear almost continuously for a distance of about 27 miles. Along the Klipfontein Ridge the ore-bodies are irregular in shape rather than sheet-like.

The ore is hard and requires crushing. The high-grade varies in manganese content between 50 and 54 per cent.

Brazil.

Manganese ores are widely distributed in Brazil, but only those in the State of Minas Geraes have been exploited to any extent. Deposits in the States of Bahia and Matto Grosso have been worked on a much smaller scale.

The two manganese producing centres in the State of Minas Geraes are the Miguel-Burnier and the Lafayette (or Queluz) districts. The former was the first to be developed and in the early years was the principal producer, but later the Morro da Mina Mine made the Lafayette district the more important. Although the two districts are close geographically, they contain entirely different types of deposits.

Miguel-Burnier station is 310 miles north of Rio de Janeiro on the Central Brazil Railway. The ore-bodies occur as lenses or beds intercalated in a series of sedimentary strata showing a rapid succession of itabirite (quartzite containing abundant iron ore), schist and limestone. These belong to the upper part of the Itabira iron-formation and the lower part of the overlying Piracicaba schist, formations

probably of Algonkian age. The ores consist chiefly of a mixture of psilomelane and pyrolusite, averaging 50 per cent manganese, 1 per cent silica, and 0.03 to 0.05 per cent phosphorus. The great drawback of the district is the fact that the beds dip steeply and rarely exceed 6 feet in width, so that expensive underground mining is necessary for working individual deposits which are relatively small. There are two theories to explain the origin of the ores. Scott and Derby consider the ores to be residual deposits; Harder and Chamberlin believe them to be similar in origin to the associated rocks, that is, they are original sedimentary deposits of manganese oxides.

Lafayette is on the Central Brazil Railway about 20 miles south of Miguel-Burnier and 283 miles north of Rio de Janeiro. The Morro da Mina Mine which is the largest of its kind in Brazil is about 4 miles from Lafayette. The country rocks are gneisses, schists and amphibolites in the basement complex of Archean age, which underlies a large part of the State of Minas Geraes. The manganese deposits occur as elongated masses more or less lenticular in shape, which are considered to represent residual decomposition products of a rock originally made up of manganese carbonate and silicates. Though decomposition of the original manganese rock has extended to considerable depth, in places in the workings of the Morro da Mina portions of the unaltered rock are exposed. It is characterized by a predominance of the silicates,

spessartite, rhodonite and tephroite, and by much rhodocrosite, together with flakes of graphite. Singewald and Miller believe this rock to be the product of dynamo-metamorphism of manganese sediments deposited in the form of manganese carbonate with much silica and some alumina. The ore-bodies occur at the top and on the flanks of a hill as a series of more or less overlapping lenses. The ore consists mainly of psilomelane, with manganite and pyrolusite occurring as cavity linings and fillings.

The deposits in the Nazareth district, State of Bahia, and in the State of Matto Grosso have supplied only a very small percentage of Brazilian manganese ore and are not important.

Cuba.

Manganese has been found in many provinces in Cuba, but only in Oriente Province does it occur in large workable deposits. The only extensive occurrences are found north of Santiago de Cuba, and south of Bayamo and Baire, all in Oriente Province.

The manganese ores occur mainly near the surface, but in places extend to depths of 150 feet. They are found principally in sedimentary rocks of Upper Eocene age, metamorphosed in places, and in a former subaqueous tuff now partly replaced by manganese oxide, zeolites, calcite and other minerals. Associated with the ore are large amounts of dense amorphous jasper. The ore consists chiefly of mixtures

of some or all of the oxides, pyrolusite, psilomelane, manganite and wad. The manganese ores of Oriente are grouped into three general types according to their associations:

- 1) deposits in bedded rocks,
- 2) deposits in irregular masses of jasper,
- 3) deposits of nodules and fragments in clay.

The extent and quality of the deposits vary considerably. Most of the largest and richest ore-bodies are associated with jasper; those that have thoroughly replaced limestone are also rich, but small. The principal mines are the Ponupo and Quinto groups in the Santiago district, and the Manuel and Costa groups in the district south of Bayamo. The concentrated ore averages between 50 and 52 per cent manganese.

Production of Manganese Ores.

Most of the world's supply of manganese comes from five countries, Russia, India, the Gold Coast, Brazil and South Africa. In the last 25 years 80 per cent of the total manganese output has come from four major producers, and another 10 per cent from five intermediate producers, leaving less than 10 per cent to be distributed among more than thirty minor producers. Table I indicates the production of the larger producers and that of the United States since 1933. Other countries producing more than 10,000 metric tons in 1938 were as follows: French Morocco (86,597), Rumania (60,173), Phillipine Islands (49,359 exported), Italy (48,282), Unfederated Malay States (32,483), Hungary (22,221), Chile (19,967).

TABLE 1. World Production of Manganese Ore. (thousands of metric tons)²⁷

Year	Russia	India	Brazil	Gold Coast	Egypt	South Africa	Cuba	Czecho-Slovakia	United States	Others	Total
1933	1,021	222	25	269	-	21	91	17	19	141	1,826
1934	1,821	413	8	345	1	66	65	59	27	160	2,965
1935	2,385	652	42	437	87	95	35	71.	27	144	3,975
1936	3,002	826	156	418	135	258	48	93	33	209	5,178
1937	2,752	1,068	254	535	186	631	131	106	41	336	6,040
1938	2,272	983	222	329	153	552	124	*	26	447	5,108
1939	*	*	193	*	120	420	102	*	30	*	*

* Data not available.

²⁷) Roush, G. A.: op. cit., p. 43; revised and added to from Minerals Yearbook, 1940.

The figures on world production presented above do not really represent the true requirements for manganese ore, since there has been more or less stockpiling for emergency purposes since 1922. The outputs recorded therefore include not only current consumption, but also relatively large amounts for stocks. It has been estimated that 25 to 30 per cent of the manganese ore produced between 1922 and 1937 was stocked. In 1937 the world steel output was approximately double that of 1922, yet in the same period the manganese ore output had increased by five times. The estimated 1937 total of manganese ore produced was split between consumption and stocks in the proportions of 55 per cent and 45 per cent respectively. In 1939 approximately 70,000 long tons of imported ore containing 35 per cent or more manganese were added to the reserve stocks of the United States.

Table II indicates the distribution of manganese in the steel industry and the amounts of manganese ores and alloys imported and available in the United States.

Canada produced approximately 23,000 tons of high-grade ore between the years 1868 and 1894. Since that date production has been very small, most of the manganese ore being used for non-metallurgical purposes. Canada however, imports large quantities of manganese ore which is used principally in the manufacture of ferromanganese. A large part of this alloy produced here is exported, almost all going to the United States. Canadian manufacture of ferromanganese is restricted mainly to two centres, Welland and Port Colborne, Ontario.

Table II. Salient statistics of the manganese industry in the United States. (in long tons)²⁸

	1938	1939
Manganese ore:		
Total shipments containing 35 per cent or more Mn	25,321	29,307
Shipments of metallurgical ore	16,989	18,580
Shipments of battery ore	4,959	7,767
Imports for consumption	483,586	627,131
Stocks in bonded warehouses at end of year	842,048	903,561
Indicated consumption (35 per cent or more Mn)	509,930	656,438
Ferro-alloys:		
Production of ferromanganese	242,994	270,111
Imports of ferromanganese for consumption*	21,118	33,414
Production of spiegeleisen	11,311	91,491
Imports of spiegeleisen for consumption	17,248	38,264
Exports of spiegeleisen and ferromanganese	247	2,923
Stocks of ferromanganese in bonded warehouses	8,392	4,253

* Manganese content.

28) Minerals Yearbook, 1940, p.572.

TABLE III. Manganese Ore (35 per cent or more Mn) imported into the United States. (Long tons)²⁹

Country	Manganese ore for consumption			Manganese content of ore			General Imports of ore 1939
	1937	1938	1939	1937	1938	1939	
Brazil	77,987	29,698	42,713	35,505	13,307	19,499	103,526
Cuba	122,937	131,422	105,936	56,385	61,534	51,719	105,936
Gold Coast	254,547	126,857	242,924	130,147	63,890	122,769	155,123
India, Br.	70,380	25,480	89,545	36,523	13,121	45,556	108,984
Philippine Islands	---	4,002	6,966	---	1,600	3,483	
Union of South Africa	209	---	3,401	119	---	1,697	
U. S. S. R.	383,949	166,042	135,243	186,736	80,673	68,882	200,781
Others	1,190	85	403	1,019	43	206	24,140
	911,919	483,586	627,131	446,434	234,168	313,811	698,490

²⁹) Minerals Yearbook, 1940, p. 572.

TABLE IV. Canadian imports and exports of manganese and alloys (tons)³⁰

	1932	1933	1934	1935	1936	1937
IMPORTS						
Manganese ore:						
Union of South Africa	-	4,012	5,014	2,704	5,000	9,900
Gold Coast	-	22,258	21,404	28,343	50,545	56,895
United States	1,082	1,226	1,215	1,540	1,789	2,084
Other Countries	268	3,167	4	253	43	73
Total	1,350	30,663	27,637	32,840	57,377	68,952
EXPORTS						
Ferromanganese and other ferro-alloys, excluding ferrosilicon:						
United States	14,395	42,026	24,147	31,704	44,190	19,948
Other Countries	5	8	87	8	83	1,126
Total	14,400	42,034	24,234	31,712	44,273	21,074

30) Groves, A. W.: op. cit., p. 51.

Grades of Manganese Ores.

Manganese and iron almost always occur together and deposits vary in composition from iron ores practically free of manganese to manganese ores practically free of iron. The character and manganese content of the ore determines its use. Ore for use in the iron and steel industry should be uniform in composition, should contain a minimum of impurities deleterious to iron and steel, and should contain as small a proportion of fines as possible so as not to be objectionable for blast furnace use. Manganese ores are divided into four grades, based on the nature of the ore:

1. Chemical ores.-- This type of ore is used mostly in dry battery manufacture and for this purpose the most important quality of the manganese ore is its ability to liberate oxygen easily; therefore pyrolusite, which of all the manganese minerals has the highest content of available oxygen, is the most valuable. Although Roush states that chemical grade ores must contain 72 to 87 per cent manganese dioxide, the specifications of the Department of Mines and Resources at Ottawa call for an ore containing not less than 80 per cent and preferably 85 per cent manganese dioxide. The maximum for impurities is:- iron 1.5 per cent, alumina 1.0 per cent, silica 6.0 per cent, copper 0.02 per cent and all other metals less than 0.05 per cent, moisture 1.0 per cent.

2. Metallurgical ores.-- These are also known as ferro-grade ores. For use in the manufacture of ferromanganese

the ores should have a minimum of 40 per cent manganese, although normally, ores containing less than 42 per cent manganese are not considered to be true ferro-grade. The required manganese-iron ratio in the ore is about 8:1. During the World War of 1914-18 the standard for ferro-grade ores was reduced to 35 per cent manganese and a manganese-iron ratio of 5:1, but this was raised to the original level soon after the war. The 35 per cent basis, however, is still used in calculating reserves. The specifications as set forth by the Dominion Department of Mines and Resources call for a minimum of 48 per cent manganese and a maximum allowance of:- iron 7 per cent (the Mn-Fe ratio should be not less than 7:1, preferably 8:1), silica 8.0 per cent, phosphorus 0.15 per cent, alumina 6.0 per cent, zinc 1.0 per cent, and low in copper, lead and barium. The ore should be hard and in lumps of less than 4 inches and not more than 12 per cent fines through 20 mesh.

3. Ferruginous manganese ores (spiegel ores).-- These are ores with less than 35 per cent and more than 10 per cent manganese, and are used in the production of the standard 20 per cent grade of spiegeleisen. The iron content must not be more than 2.7 times the manganese content. During emergencies such as in war-time the standard may be reduced to 16 per cent spiegeleisen and the iron content may be as much as 3.7 times that of the manganese.

4. Manganiferous iron ores.-- Ores with 5 to 10

per cent manganese, and a high iron content, are classed as manganiferous iron ores and are used in the production of high-manganese pig iron. In practice producers segregate ores with as little as 2 per cent manganese and sell them separately.

Ores consisting mainly of iron and containing less than 5 per cent manganese are classed as iron ores.

Concentration of Manganese Ores.

Much ore is put on the market in the crude state or after only a little hand picking. Some requires crushing, screening and classifying before export. Ore containing clay or earthy matter has to be freed from such impurities by washing. Most of the Chiaturi ore is washed, and the ore produced from the Nikopol deposits goes through a concentrating plant where it is crushed, washed in log washers and jigs, and concentrated with jigs and tables or by flotation. In the United States beneficiation of domestic ore has been attempted repeatedly, in some instances with good results, but the amount of manganese ore suitable for dressing in competition with imported ore is decidedly limited. In the course of a series of investigations for finding means of concentrating low-grade material, a flotation method was developed for the treatment of both carbonate and oxide ores. Flotation of low-grade carbonate ores from the Butte district produced low phosphorus concentrates which, when sintered, contained

about 60 to 62 per cent manganese and about 7 per cent silica. The United States Bureau of Mines has been working on a smelting process for the production of ferromanganese from the low-grade Cuyuna ores. They have also done extensive work with low-grade ores in an attempt to develop an electrolytic process for the recovery of manganese, but up to date costs have been too high for the process to be of any commercial value.

In connection with the beneficiation of low-grade ores it is interesting to note the possibilities of an enormous deposit of nodular manganese near Chamberlain, South Dakota. Because the nodules and the shales they occur in are similar to nodules and shale formations found in Manitoba, the deposit is described below:³¹

Explorations during 1928 and 1929 in the vicinity of Chamberlain showed the presence of a horizontal bed of shale containing manganese-iron carbonate nodules. This shale bed extends for many miles along the valley of the Missouri river in south-central South Dakota. The shale containing the concretions is 38 feet thick, lies 130 feet above the base of the Pierre shale and 6 feet above a persistent sandstone layer, and will give an average yield per cubic yard of 164 pounds of nodules having a manganese content of about 25 pounds. The carbonate concretions are not uniformly distributed through

31) Twenhofel, W. H., and others: op. cit., p.572.

"Manganese-Iron Carbonate Near Chamberlain, South Dakota";
U.S. Geol. Sur., Memorandum for the Press. (1930)

the shale bed, but occur in two zones — an upper zone 25 feet thick showing abundant concretions, and a lower zone 13 feet thick with few concretions. The nodules commonly range from 2 to 3 inches in thickness and 3 to 8 inches in diameter, and form persistent layers in the shale. The color of the fresh nodules varies from pale grey to olive green, but under the influence of weathering the carbonates change to oxides and become black. The nodules often show nuclei of invertebrate marine fossils and fragments of bones. They contain 16 per cent manganese and 10 per cent iron. The deposit has been estimated to contain more than 100,000,000 tons of manganese. The concretions appear to have developed in the sediments of a shallow sea shortly after burial.

Uses of Manganese.

The consumption of manganese falls under two general heads, metallurgical and chemical, in the proportion of about 95 per cent and 5 per cent respectively of the total. In general, metallurgical uses require the conversion of the ore to a metal or alloy, but most of that in chemical use requires an ore high in MnO_2 , which is used in the oxide form.

Metallurgical uses.

Most of the manganese consumed in the metallurgical industry is used in the manufacture of ordinary steel; a small percentage is used in the production of special high-manganese steel alloys, in foundry work and in other types of alloys.

The chief duty of manganese in steel manufacture is to act as a deoxidizer and desulfurizer. It is usually added to the bath in the form of ferromanganese while the metal is being tapped from the furnace, and by combination with the residual oxygen and sulfur of the bath helps to produce a sound, clean metal free from blowholes and iron sulphide. The use of manganese gives rise to a more fluid slag than when either silicon or aluminum, or both, are used as deoxidizers. A small percentage of unoxidized manganese remains in the steel and helps to increase the elastic limit and tenacity of the finished product. The amount of manganese varies with the kind of steel being made and with the process being used, but over a long period of years the total has averaged about 14 pounds of manganese per ton of steel made.

The most important form in which manganese appears on the market is ferromanganese, an alloy containing between 78 and 82 per cent manganese, the remainder being chiefly iron and carbon. Smaller amounts of spiegeleisen are made, with a generally recognized standard of 18 to 22 per cent manganese, the remainder consisting of iron and carbon. The so-called metallic manganese is usually a high-grade ferromanganese running 90 per cent or better in manganese. Two other alloys of minor importance are silicomanganese with 55 to 70 per cent manganese and 18 to 25 per cent silicon, and silicospiegel which has the usual manganese content of

spiegeleisen, but in addition contains 4 to 12 per cent silicon, replacing part of the iron. High-manganese pig iron contains 4 to 10 per cent manganese.

Manganese steel, discovered by Sir Robert Hadfield in 1883, is an alloy of iron with about 12 per cent manganese and $\frac{1}{4}$ per cent carbon. It has very strong wearing qualities and is used in special track layouts, points and crossings on railways, wearing parts of rock crushers, and wherever mechanical conditions are severe.

Manganese is a constituent of many other alloys, but only those of manganese with copper and with aluminum have attained considerable commercial importance.

Chemical uses.

The value of manganese ore of chemical grade in industry is its ability to act as an oxidizing agent. For this purpose the ore must contain at least 80 per cent and preferably 85 per cent or more manganese dioxide. The principal use of chemical grade ore is in the manufacture of dry batteries of the Leclanche type where it acts as the depolarizer. The ore must contain as little iron as possible and be free of copper, nickel, cobalt and similar metals. It must also have a certain degree of porosity. Pyrolusite was formerly used in considerable amount for the preparation of chlorine, but electrolytic processes for the production of that substance have largely supplanted this use. Pyrolusite however, is still used in the manufacture of iodine

and to some extent bromine.

Manganese ore with a high percentage of MnO_2 is used in the glass industry. The raw materials used in glass-making invariably contain some iron, which, when converted to ferrous silicate during the manufacturing process, imparts a green color to the glass. Manganese dioxide in the melt removes this color. An excess of MnO_2 gives the glass an amethystine tint.

Manganese oxides and various manganese salts are added as driers to linseed and other vegetable oils to make them capable of absorbing oxygen from the air during the so-called drying of the oil. The compounds used for this purpose are manganese sesquioxide (Mn_2O_3), pyrolusite and various salts of manganese. Very pure pyrolusite is necessary to prepare some of the organic compounds used in the manufacture of oils, varnishes and paints.

Pyrolusite is used as a coloring agent in pottery, bricks and glazes. In a pottery glaze, mixtures of MnO_2 and iron oxides will produce black and various shades of brown. Pyrolusite is often used to make a speckled effect in pottery bodies. It is also used to produce certain colors in heavy clay wares. It will change a red burning clay into several shades of brown, will turn a buff clay to grey, and also produce speckled brick. In eastern Canada much bog manganese is consumed by the brick industry.

Spring and Bog Manganese Deposits.

Manganese deposits similar to those in the Riding Mountain area are common in the Maritime Provinces and the western United States.

Typical bog deposits occur on the west bank of the upper north branch of Canaan river, Westmorland County, New Brunswick³². The ground on which the bogs are located slopes gently toward the river bottom. The manganese bogs lie below the orifices of a series of mineral springs with which the manganese is genetically associated. The manganese deposits are fan shaped, with their narrow ends at the mouths of the springs and their thickest parts directly below the mouths. Laterally, and at the lowest parts, the manganese ore pinches to nothing. The deposits are between the hard bottom of the bog and the grass roots. In some of the bogs the only manganese dioxide that can be observed occurs in a somewhat hard compact layer immediately below the grass and tree roots. In other bogs, manganese dioxide occurs throughout the whole thickness of the bog. In places it is relatively pure, occurring by itself, whereas in others it is mixed with both hard and soft types of bog iron, and with peat.

A thermal spring manganese deposit in west central

32) Hanson, G.: op. cit., p.81.

Utah³³ possesses many features similar to a manganese occurrence in Riding Mountain National Park. The manganese deposits associated with the hot spring are lenticular in shape. In one pit the south wall is made up of brown clay at the base, then black vuggy manganese ore, and at the top a mixture of sand, clay, iron oxide and porous calcite. At the north side of the same pit the manganese ore has pinched out and the brown clay is overlain successively by red clay, clay with small amounts of black oxides of manganese and iron, and porous calcite. Several pits reveal a surface coating of calcite underlain by red and black nodular material. According to Callaghan and Thomas the deposition of manganese was a distinct episode in the history of the spring, and that shallow aprons of manganese oxides must have been laid down on what was then the surface. The ensuing history of the spring favored the deposition of CaCO_3 with small amounts of iron oxides.

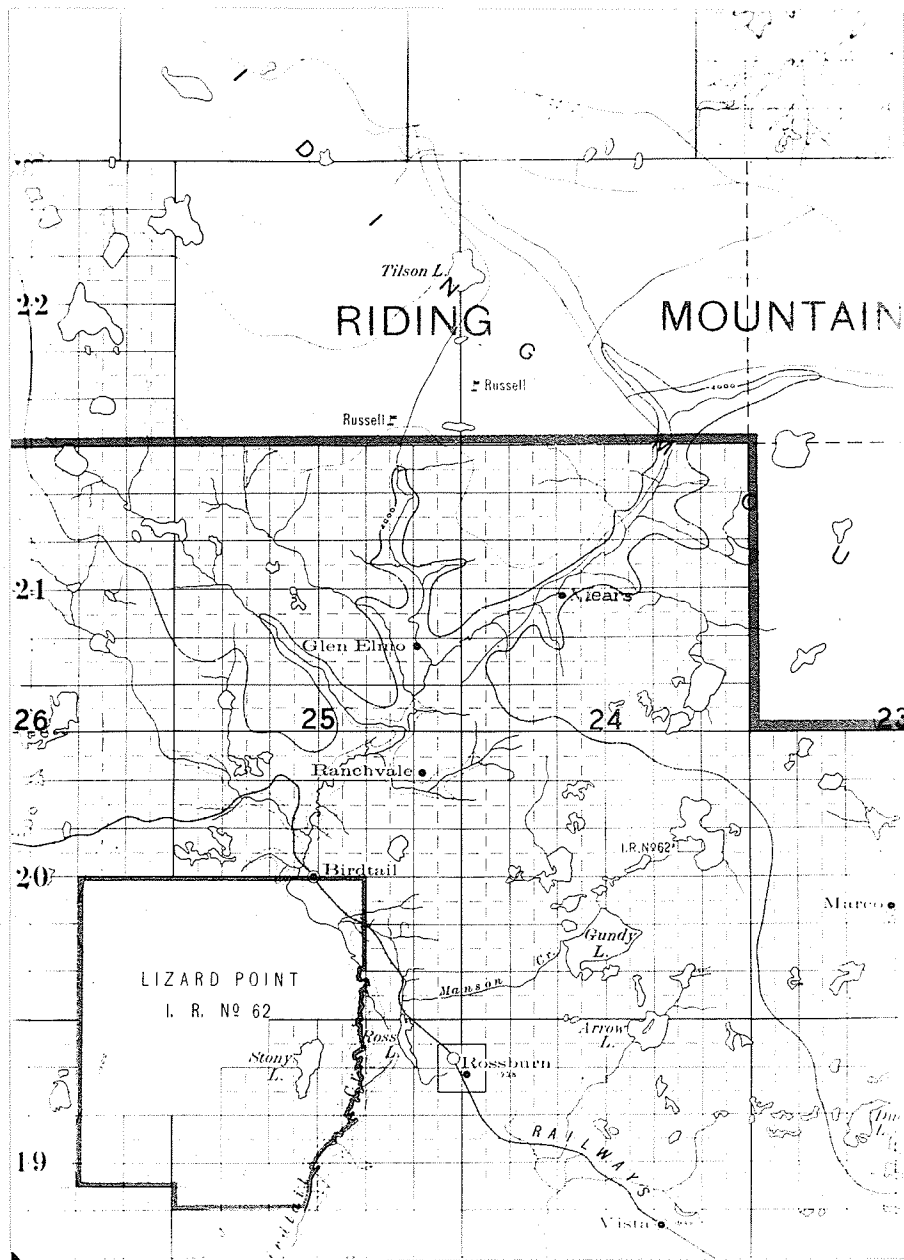
A manganese occurrence in southern Manitoba resembles portions of the deposit in Riding Mountain National Park. Up until recently it was the only known manganese deposit in Manitoba. Wallace describes it as follows:³⁴

33) Callaghan, Eugene, and Thomas, H. E.: "Manganese in a Thermal Spring in West Central Utah"; Econ. Geol. 34, pp. 905-20 (1939)

34) Wallace, R. C.: "The Mineral Resources of Manitoba"; p. 37 (1927)



"Four miles northwest of Roseisle, on the northeast quarter of sec. 36, tp. 6, range 8, W., an occurrence of manganese has been discovered recently. It has been apparently deposited by springs issuing from the Pembina hills in the form of hydrous oxides, probably manganite and psilomelane or wad. The manganese is found in the low swampy land at the base of the escarpment, partly overlain by 1 or 2 feet of soil and partly on the surface. Considerable proportions of limonite invariably accompany it. Insufficient work has been done to determine the economic possibilities of the deposit. An analysis of the best material showed:
Mn 26.96, Fe 13.11".



Diag. 1. Map of the area. Scale: 1 inch = 4 miles

Geography and Geology of the
Riding Mountain Area.

Manganese was first found in the Riding Mountain area in the spring of 1940 on the farm of John Maydaniuk, which comprises the north-west quarter of section 26, township 21, range 24 west of the principal meridian. Six other occurrences have since been found in the area which lies in the valley of Birdtail river between Mears and a point 7 miles to the north. Mears is the nearest post office to the deposits and the closest railway point is Rosssburn, seventeen miles south of Mears by road. The deposits can be easily reached by road in dry weather, but only with difficulty after heavy rains. Six of the occurrences lie a short distance to the east of Birdtail river, the seventh a distance of one and a half miles to the west.

The area lies on the south flank of Riding Mountain towards its west end. The mountain consists of a group of hills which rise to an elevation of over 2,200 feet above sea level. The approximate elevation at Mears is 2,000 feet. The hills are rolling, and cliffs are found only where the shales are dissected by streams.

Riding Mountain forms a part of the Cretaceous escarpment of Manitoba. The Cretaceous rocks lie disconformably above beds of Paleozoic age which underlie the plains to the east of the escarpment. An intermittent layer of till overlies the Cretaceous sediments.

The Cretaceous rocks of the Riding Mountain area have been subdivided by Kirk³⁵ as follows:

Pierre	Odanah beds — 300 feet
	Riding Mountain beds — 200 feet
Pierre or Niobrara?	Vermilion River beds — 250-300 feet
Niobrara or Benton?	Assiniboine beds — 70 feet
Benton	Keld beds — 60-65 feet
	Ashville beds — 170 feet
	Basal beds — 19-90 feet

In the Riding Mountain area the consolidated rocks are exposed in a few road cuts and in exploratory trenches. Exposures are also found in deep ravines to the immediate south of the area. These rocks are all shales of Odanah age. Kirk describes them as follows³⁶:

"The Odanah shale is a relatively hard, brittle rock....Analyses have shown it to be highly siliceous. When moist, the shale is of a dark greenish grey colour, but on drying turns to a light steel or slightly greenish grey and resembles parts of the underlying Riding Mountain beds. Unlike the latter, however, it does not disintegrate in water, as can be seen by its abundance as gravel in many of the streams of the Manitoba escarpment. In parts the rock is fissile, but more commonly it is rather compact and breaks into sharp-edged splinters and slabs with a tendency to sub-conchoidal fracture. In

35) Kirk, S. R.: "Cretaceous Stratigraphy of the Manitoba Escarpment"; Sum. Rept., 1929, Part B. Geol. Surv., Canada, p.114.

36) Kirk, S. R.: idem. p.126.

natural or artificial cuts it is capable of holding steep or vertical faces, and it is everywhere traversed by numerous joints whose surfaces show black or reddish brown staining by iron oxide. Ironstone nodules occur in bands in the shale....."

In the Riding Mountain area the ironstone nodules mentioned by Kirk were examined and found to be manganiferous.

Description of the Manganese Occurrences.

General

The manganese deposits are irregularly distributed along the base of the steeper slopes where they have evidently been deposited by springs issuing from the hills. The deposits extend to the outlets of the springs. In one instance no spring is in evidence but the former existence of one is indicated by the presence of travertine. Bogs have formed at or slightly below the springs and accordingly some of the deposits of manganese are intimately associated with the wet bog material. In such instances the deposits are restricted to areas within the bog adjacent to the springs.

A somewhat different type of deposit consists of manganese oxides intimately mixed with fractured shale where springs emerge near the bottom of low cliffs. Where the slope is gentler but still steep enough for good drainage, the deposits although relatively dry, contain much vegetation.

The better grade occurrences vary in areal extent from approximately 40 to 1,000 square feet and in maximum

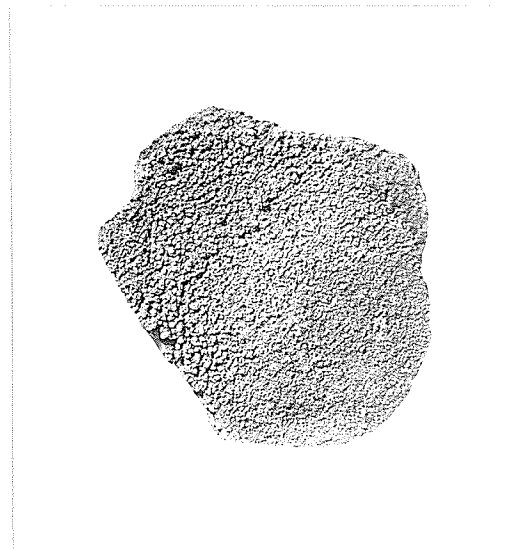
thickness from 8 to 42 inches. The deposits are more or less fan-shaped in plan, thin and lenticular in cross-section. Their attitude depends on the slope of the surface upon which they were laid down. Dried material passing through a $\frac{1}{4}$ inch screen contains from about 25 to 50 per cent manganese.

The occurrences are typical wad or bog manganese. Difficulty was encountered in preparing polished sections of the samples collected because of the loose, friable character of the material. A dry polishing method was found to be moderately successful and was used for polishing several sections. Between 1 and 2 grams of the powdered wad was pressed into a disc $\frac{3}{4}$ inch in diameter under a pressure of 5,000 pounds per square inch. No binder was used. A flat surface of the disc was then polished in a dry state on a lap covered with brown wrapping paper into which an abrasive had been rubbed. Although a perfect polished surface was not obtained, it was sufficient for conducting etch tests. All tested portions of the sections proved to be pyrolusite. No other manganese mineral was identified. The pyrolusite is believed to form the greater part of the deposits. An X-ray study of the material may have determined what minerals are present in the deposits, but the necessary apparatus was not available.

The manganese oxides are porous when dry and for the most part earthy and amorphous. In places horizontal bands $\frac{1}{2}$ to $\frac{3}{4}$ inch in thickness exhibit a finely columnar



Cross-section $\times 1\frac{1}{2}$



Top view $\times 1\frac{1}{2}$

Diag. 2. Banded manganese oxides

structure (diagram 2). In a few instances thicknesses of 4 or 5 inches of banded material are found.

The manganese oxides also occur in certain deposits as limonite-coated nodules 1/8 to 1 inch in size. In two of the occurrences large amounts of travertine and limonite are associated with the manganese. They both occur as irregular bands and lenses which often appear to be cutting the manganese deposits or interbedded with them.

The bog deposits are of recent age. Being surface deposits they must have been formed since glaciation, otherwise they would have been removed by the ice. Other evidences include the fact that they are undoubtedly associated with springs now issuing from the hills and with bogs which are still in the process of being formed. In one of the occurrences recently buried woody material was found at a depth of 3 feet below the surface of the manganese deposit, and in another instance part of a bison skull was discovered below a 2 foot thickness of manganese and clay.

Individual deposits.

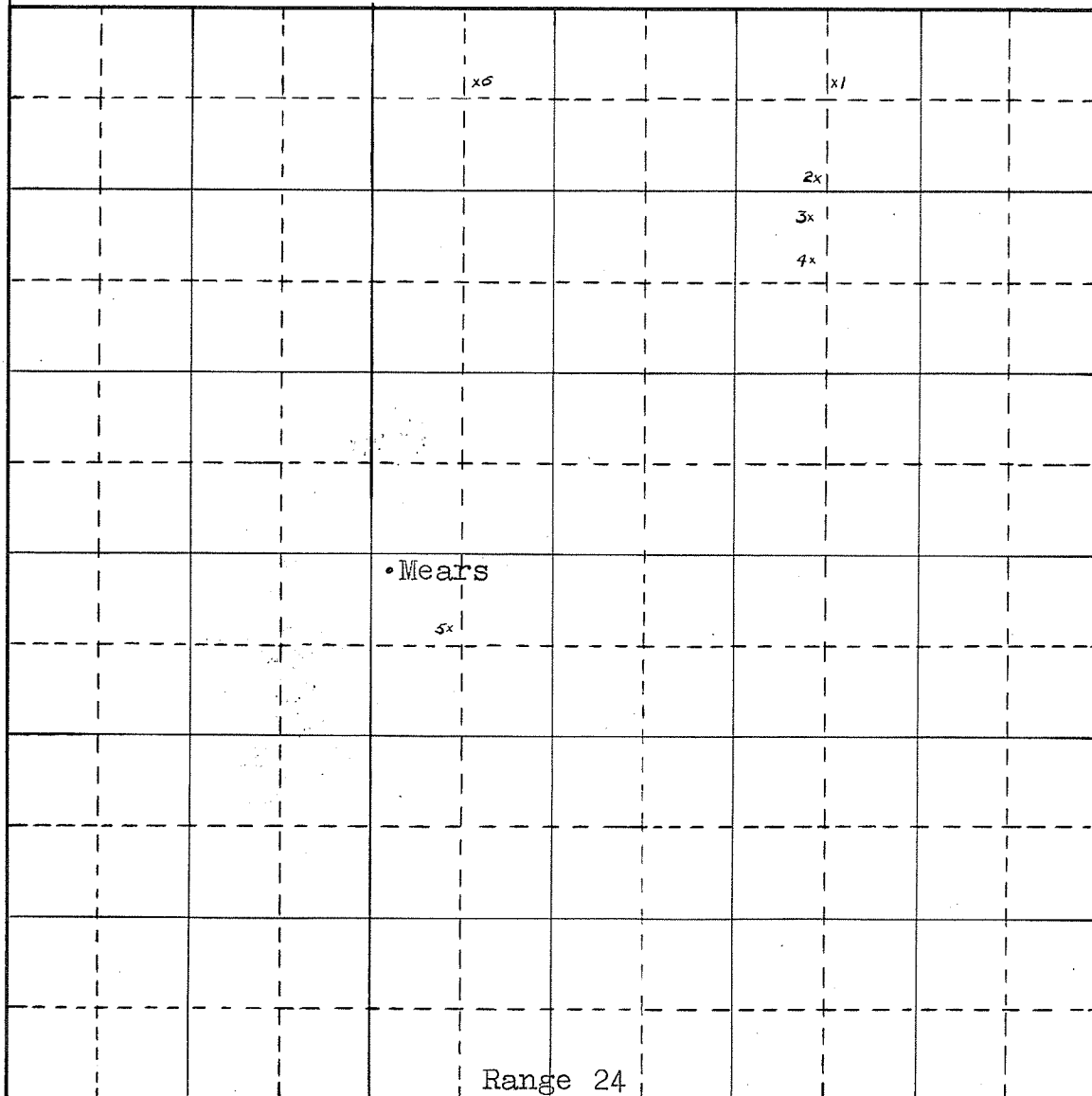
Following is a short description of the deposits examined:-- (all the analyses given, with two exceptions were made by the writer in the laboratory of the Mines Branch of the Manitoba Department of Mines and Natural Resources).

1. An occurrence of manganese is located on the north-east quarter of section 35, township 21, range 24 west of the principal meridian, on the farm of H. Komhere. A trench

x7

RIDING MOUNTAIN
NATIONAL PARK

Tp.
22



Diag. 3. Location of deposits. Scale: 1 inch = 1 miles

45 feet long trending west from the base of a hill where a spring emerges, exposes a seam of manganese varying from 6 to 16 inches in thickness. The manganese is in a relatively dry bog and most of the mineral is mixed with the vegetation. The overburden varies from 1 to 8 inches in depth. The bog extends for a distance of 15 to 20 feet north and south on either side of the trench and several shallow pits in the bog exposed manganese intimately mixed with vegetation to a depth of several inches below the surface. A sample taken from the middle 6 inches of a 12 inch seam was dried at 110°C and put through a 10 mesh screen. The screened material assayed 45.85 per cent manganese³⁷. Most of the sample passed the 10 mesh.

2. A manganese deposit of good grade was found on the south-west quarter of section 35, township 21, range 24 west of the principal meridian. This quarter forms a part of the same farm on which No. 1 deposit was found. The deposit is $\frac{1}{4}$ mile away from a road leading to Rossburn, which is 18 miles distant. The occurrence is on a gentle slope at the base of a steep hill, and several pits show it to be at least 55 feet long and at one point 20 feet wide. The deposit is lenticular in cross-section and varies in thickness from 6 inches near the edge to at least $3\frac{1}{2}$ feet near the middle.

37) Analysis by J. S. Richards, Provincial assayer.

The manganese throughout appears to be relatively free of clay, shale and other impurities except for some vegetation which at some points goes to a depth of 8 inches into the manganese. The manganese is exposed at or very close to the surface. A bulk sample assayed 50.32 per cent manganese for material dried at 110°C and passing a ¼ inch screen. A very small proportion of the sample remained on the screen. A representative portion of the sample was ignited for more than an hour over a Meeker burner and then analysed to give the following result:

SiO ₂	3.11	per cent	
Fe ₂ O ₃51	"	"
Al ₂ O ₃	2.58	"	"
Mn ₃ O ₄	88.88	"	"
CaO.....	2.88	"	"

The dried but unignited sample yielded 0.07 per cent phosphorus on analysis.

3. A small occurrence of manganese was partly exposed by a trench in the north half of the north-west quarter of section 26, township 21, range 24 west of the principal meridian, on the farm of John Maydaniuk. It is a typical bog deposit, the manganese probably being precipitated from the spring water flowing through the bog. The deposit covers an area of no more than 40 square feet and attains a maximum thickness of 8 inches, the upper portion of which contains much vegetation in the form of mossy material. An 8 inch

vertical channel sample dried at 110°C and passed through a 10 mesh screen assayed 38.22 per cent manganese³⁸. Only a small portion of the sample remained on the 10 mesh screen.

4. A second manganese occurrence is located on the same quarter section as the No. 3 deposit. Here the manganese is exposed in a series of shallow pits along the base of a hill from which a number of springs emerge. The manganese appears to occur in three lenses at least 10, 3 and 6 feet long, separated by 40 and 15 feet respectively of clay and shale free of manganese. One pit showed a 10 inch thickness of apparently good grade material, but in all other instances, shale and some clay was intimately mixed with the manganese minerals. Several small pits dug on a line parallel to, and 3 to 5 feet distant from the first series of pits, exposed no manganese except for a 2 inch seam through the boggy material in one pit. A composite of channel samples taken from three pits in the deposit assayed 34.16 per cent manganese for material passing a 10 mesh screen. Recalculated on a moisture-free basis, 39.91 per cent manganese is indicated. The material here contained much shale, a large part of which was removed by the screening. A sample picked from a 10 inch seam exposed in the most northerly pit was dried at 110°C and passed through a 10 mesh screen. The screened material gave the following analysis:

38) Analysis by J. S. Richards, Provincial assayer.

SiO ₂	11.72	per cent	
Fe ₂ O ₃ +Al ₂ O ₃	3.03	"	"
Mn.....	42.85	"	"
CaO.....	2.52	"	"
MgO.....	3.23	"	"
P.....	0.05	"	"

5. A small spring deposit occurs on the north-west quarter of section 16, township 21, range 24 west of the principal meridian, on the farm of W. Butler. The deposit is less than 10 feet wide, and about 12 feet long, with a thickness varying from 2 to 10 inches and averaging about 5 inches. There is a large proportion of shale mixed with the manganese minerals.

6. The only manganese occurrence not obviously associated with a flowing spring was found on the north-east quarter of section 33, township 21, range 24 west of the principal meridian; the farm of W. Maydaniuk. Here good grade manganese is found in a lenticular body which at one point attains a thickness of 18 inches and the edges of which grade into a mixture of limonite and travertine. A clay cap 2 to 3 feet thick contains thin irregular seams of manganese. Picked material assayed 37.95 per cent manganese which was recalculated to 44.08 per cent manganese on a moisture-free basis. Two channel samples through 10 and 12 inches of the lens were combined and assayed 35 per cent manganese.

7. A large occurrence of manganese is located in the Riding Mountain National Park at a distance of about $3\frac{1}{2}$ to 4 miles north of section 35, township 21, range 24 west of the principal meridian. This deposit is at least 300 feet long and in one place 70 feet wide. Much of the manganese is mixed with limonite and calcareous tufa, and near the surface contains organic matter in the form of plant and grass roots. There are, however, lenticular bodies of apparently high grade manganese varying from 2 to 15 inches in thickness and up to at least 10 feet in diameter. These lenses are found at different depths from the surface down to 2 feet below the surface. Much of the manganese occurs as limonite-covered nodules up to 1 inch in size.

A sample picked from a 15 inch lens and passed through a 10 mesh screen assayed 31.56 per cent manganese. After determining the moisture content the percentage of manganese was calculated to be 37.57 per cent in the dry sample. Another sample picked from a $1\frac{1}{2}$ foot seam of manganese, travertine and clay assayed 23.45 per cent manganese for material passing a 10 mesh screen. After deducting the moisture content the calculated manganese content becomes 24.45 per cent.

Method of Analysis.

The method used in the analysis of manganese is that described by Low in his "Technical Methods of Ore Analysis", and is given below in brief:

A 0.5 gram sample is treated in an 8 oz. flask with 10 c.c. strong hydrochloric acid. The flask is heated very gently at first until decomposition is complete. Finally about 5 c.c. strong sulphuric acid are added and the mixture is heated strongly, best over a free flame, almost to dryness. The mass is cooled and about 100 c.c. of water are added. The mixture is boiled a moment and allowed to stand, hot, with occasional shaking, until anhydrous ferric sulphate, etc., has dissolved (a minute or two). One or two grams of finely powdered zinc oxide in an emulsion with water are added and the flask is heated to boiling. It is then removed from the heat and more zinc oxide is added in small portions, while shaking, until all iron is precipitated and a moderate amount of white zinc oxide remains in the bottom of the flask. The solution is heated to boiling and then filtered through an 11 cm. filter having a small wad of wetted absorbent cotton in the apex. The precipitate is washed ten times with hot water, the filtrate being received in a 400 c.c. beaker. To the filtrate is added 3-4 grams of sodium acetate, and if the solution is not clear, a drop or two of acetic acid. The solution is heated almost to boiling and 40 c.c. of saturated bromine water are added; the solution and precipitate are then boiled for several minutes. If bromine vapors do not

appear above the liquid in the covered beaker, more bromine water is added. The contents of the beaker are filtered through an 11 cm. filter and the precipitate is washed ten times with hot water. Any MnO_2 adhering to the beaker is simply washed clean and left there. The washed precipitate, together with the filter paper, is placed back in the beaker. An excess of standard oxalic acid solution is run in from a burette; 50 c.c. dilute 1:10 sulphuric acid are added and the mixture heated nearly to boiling with gentle agitation. When the precipitate has entirely dissolved, the solution is diluted to 150-200 c.c. with hot water and titrated to a permanent faint pink tinge with a standard solution of potassium permanganate. The excess of oxalic acid not consumed by the MnO_2 is thus found. Subtracting this from the total amount of oxalic acid used, the remainder is the amount used in reducing the MnO_2 to MnO . This figure is multiplied by the weight of manganese equivalent to 1 c.c. of oxalic acid solution to obtain the amount of manganese in the sample.

Manganiferous Nodules

The presence of manganiferous "ironstone" nodules in the shale of the Riding Mountain area has been previously mentioned in this report. These nodules, varying in diameter from 2 to 6 inches are found scattered throughout the Odanah shale which is the bedrock formation of the area. The nodules are light grey in color and are very irregular in form although

many have a roughly flat ellipsoidal shape. They are composed of carbonates of iron, manganese, calcium and magnesium, along with alumina and silica. Following is an analysis of a typical concretion:

SiO ₂	7.98	Per cent	
Al ₂ O ₃	4.50	"	"
FeO.....	37.61	"	"
MnO.....	4.44	"	"
CaO.....	5.44	"	"
MgO.....	4.91	"	" (assumed by difference)
CO ₂	35.12	"	"

Most of the nodules have an outer brown to black oxidized shell averaging about 1/8 to 1/4 inch thick. This outer shell is the result of the alteration of the carbonates to oxides and hydroxides of the metals. In some instances the brown material grades into the grey portion of the nodule, but in others there is a sharp contact between the two. Some nodules found along the base of steep slopes and rock cuts are brown and black throughout, indicating that they have evidently been exposed to weathering for a long period of time.

A study of five thin sections from portions of two nodules showed the grey core of the concretion to be a fine-grained mass of material with a very high birefringence that suggested a carbonate. The dark shell of the nodule is opaque in thin section. A gradational zone between the dark and light portions of the concretions is reddish in color and is very dense, showing no granular structure. A spectrographic analysis



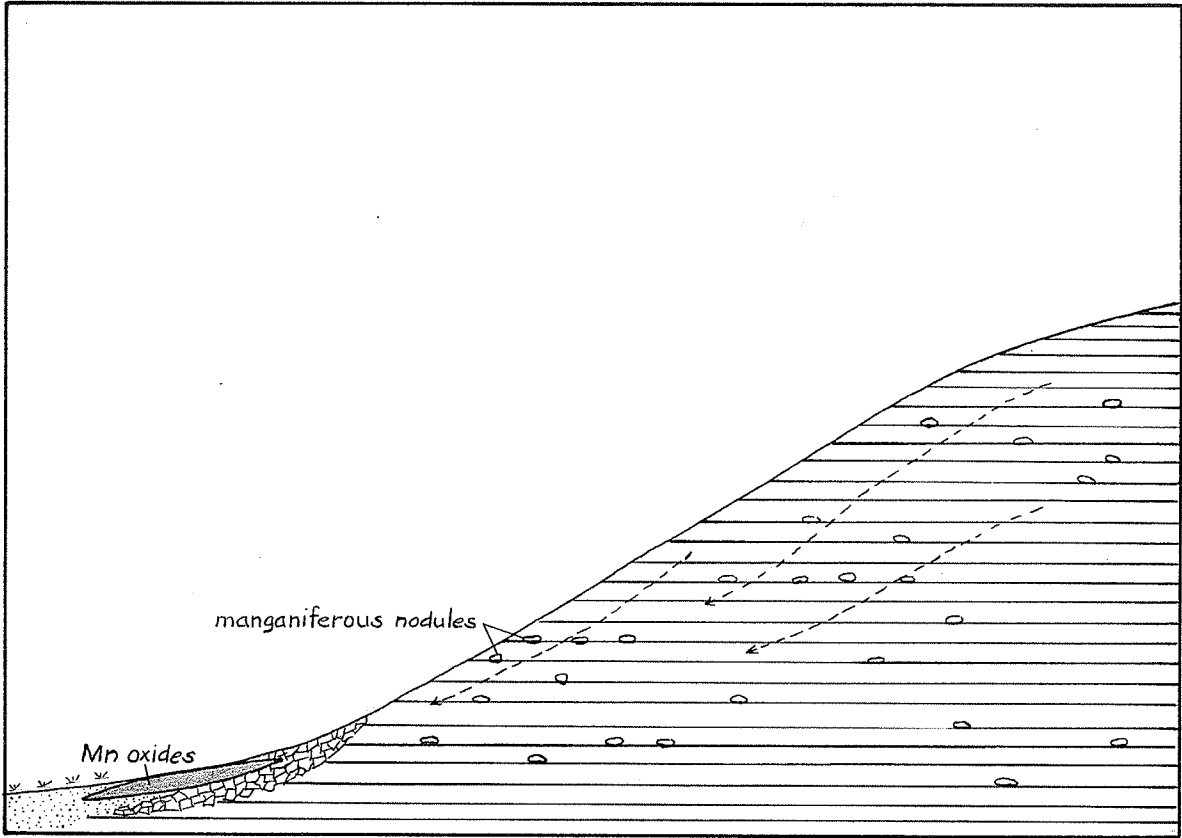
Diag. 4. Cross-section of a nodule xl

of grey and black material from two of the nodules did not show the presence of any element that had not previously been found by chemical analysis.

In the alteration from carbonates of the metals to oxides and hydroxides there is normally an increase in the relative percentage of manganese, as the molecular weights of the oxides are proportionately lighter than that of the carbonate. This increase is approximately 20 per cent by weight of manganese if pyrolusite or manganite is the result of the alteration. The same is true of the iron carbonate and the limonite to which it is altered.

In the Riding Mountain area the carbon dioxide content of the grey inner portion of the nodules varies from about 33 to 35 per cent, while that of the outer brown shell is less than 12 per cent, and commonly much less. This decrease of CO₂ content indicates that oxidation of the carbonates has taken place. In most instances the manganese content of the outer shell is not as high as would be expected if no manganese were removed. In one nodule the manganese content of the outer dark brown shell was less than that of the inner grey core; in two others there was an increase of 10 per cent and 3 per cent respectively.

Manganiferous iron carbonate nodules are not confined to the vicinity of the deposits as outlined above, but are found over a much larger area. In a rock cut 2 miles from Millwood on the road to Binscarth a band of iron-stained shale containing "ironstone" concretions is exposed. One of



Diag. 5. Origin of the deposits.

Water circulating through the shales leaches manganese from the carbonate nodules and deposits oxides of manganese at or near spring openings.

the concretions yielded 3.74 per cent manganese on analysis. Carbonate concretions were also taken from the Riding Mountain shale exposed on the west bank of the Assiniboine River 3 miles north of Millwood. The concretions occur in irregular bands through the shale and are not very numerous. Almost all the nodules have blue-black manganese oxides as a coating around them or occurring as a stain along the fractures. One of the nodules on analysis showed a manganese content of 3.79 per cent. A third concretion found in the Odanah shale exposed in a road cut on the east bank of Silver Creek $1\frac{1}{2}$ miles east of Binscarth has a comparatively high manganese content of 21.53 per cent.

Origin of the Deposits.

From these analyses the conclusion is reached that carbonated waters, circulating down through the shales, probably leached the manganese from the nodules and carried it in solution as manganese bicarbonate. The waters, reaching the surface at the spring openings, were exposed to the air and the resulting oxidizing action precipitated manganese oxides from solution. The chemistry of the process has been discussed above. The manganese bog deposits are obviously associated with springs. Although water was tested from one spring at which manganese occurs, no manganese was detected. It has been shown by Zappfe³⁹ that pyrolusite acts as a catalyst in promptly

39) Zappfe, Carl: "Deposition of Manganese"; Econ. Geol. 26, p. 824 (1931).

precipitating manganese from solution. The absence of soluble manganese compounds in the spring waters could then be explained by presuming that the manganese carried in solution by the underground waters would be immediately precipitated upon encountering previously formed manganese dioxide at the spring opening. The oxidized manganese would be distributed in suspension over the area of the deposit.

The Odanah shale contains very small traces of manganese in a relatively insoluble form and cannot be considered as a likely source of the manganese in the deposits.

Screening Tests.

The friable nature of the ore, together with the fact that the most obvious impurity consists of flat fragments of shale, suggests the possibility of effecting a concentration by selective grinding and screening. Preliminary tests were conducted along these lines. The procedure was as follows:

The material was dried at 110°C and passed through a $\frac{1}{4}$ inch screen to remove coarse shale fragments. The under-size was passed through a 10 mesh screen. The +10 mesh material was shaken for ten minutes in a quart sealer with rubber stoppers and screened through 10 mesh and 35 mesh.

The results in tabular form are as follows:

Size of material	Per cent of $-\frac{1}{4}$ inch material	Per cent of manganese
$-\frac{1}{4}$ inch	100	40.32
+10 mesh	34.7	35.55
-10 mesh	65.3	42.85
<hr/>		
After grinding +10 mesh material		
+10 mesh	5.31	17.34
-10,+35 mesh	20.65	35.11
-35 mesh	8.74	43.70

Possible Uses for the Manganese

The manganese deposits in the Riding Mountain area resemble those in the Maritime Provinces, where much of the manganese produced is used in the brick industry. As has already been noted, manganese dioxide is used in producing certain colors in heavy clay wares. It will change a red burning clay into several shades of brown, a buff clay to grey, and also produce a speckled brick. The ore used should be uniform in quality and in fineness to insure the securing of uniform results.

Finely ground manganese dioxide of 100 mesh is used for producing brown brick from a red burning brick. About 20 pounds per 1,000 brick may be considered as a proper amount. For speckled brown brick the above procedure is followed and in addition granulated manganese dioxide of the desired coarse-

ness is added; 40-60 mesh is desirable. Grey brick are produced in the same manner as brown brick except that a buff burning clay is used and a greater quantity of manganese is required. For producing grey or speckled face brick, the particle fineness of the manganese ore is very important. The number and size of the spots produced depends on the particle size ratio, while the background color is influenced by the percentage of fines. Firing conditions in the kiln must be watched to obtain the desired shade of speckled brick. To get the greatest possible effect from the manganese, it is necessary to have a reducing atmosphere in the kiln for a part of the firing, either just before the firing temperature is reached, or by soaking in a reducing atmosphere at the firing point. This causes the coarse manganese to fuse with the clay and produce large round spots⁴⁰.

The nature of the manganese occurrences of the area described in this report would indicate that the brick industry could provide one of the possible markets for the Riding Mountain manganese. High grade deposits of manganese dioxide relatively free of impurities would provide material for the battery industry.

40) Ceramic Data Book, Eighth Edition. (1935)

Conclusion

The known manganese deposits in the Riding Mountain area are limited in extent. Large scale production at present does not appear to be feasible, although the possibility of marketing a limited quantity of chemical grade material should be kept in mind. While results of tests using manganese from the Riding Mountain area in the manufacture of brick cannot yet be obtained, the material appears to be suitable for use in that industry.

Possibilities of finding other deposits are considered favorable where springs are found emerging from the hills in areas where Odanah shales and Riding Mountain shales containing manganiferous nodules make up the bedrock formations. Although no large occurrences may be expected, several small ones of high grade may be profitably worked.

Acknowledgements

The writer gratefully acknowledges the kindness of Mr. G. E. Cole, director of the Manitoba Mines Branch in permitting the use of material and information gathered while on survey for the Mines Branch, and for the use of the facilities of the Provincial Assay Laboratory.

Thanks are due to Dr. J. S. DeLury, Dr. G. M. Brownell and Mr. A. S. Dawson for suggestions concerning the problem and criticism of the manuscript.