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THE ORIGIN AND ECONOMIC POSSIBILITIES OF CANADIAN MANGANESE OCCURRENCES.

by

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THE ORIGIN AND ECONOMIC POSSIBILITIES OF CANADIAN MANGANESE OCCURRENCES

INTRODUCTION

Importance of Manganese.

Manganese ore is considered to be the most important of the strategic minerals. It is the one of which the greatest tonnage is required, and it has very low secondary return. When

Rousch, Strategic Minerals.

manganese has been used once in industry it can seldom be used again.

It has been estimated that in the accelerated production of this war, the output of steel by the United States might reach 60 to 70 million tons per year. To produce this 8 or 9 hundred thousand tons of ferro-grade ore would be needed.

Rousch, Strategic Minerals.

35,000 tons of chemical ore, 525,000 tons of spiegel ore, and 2,500,000 tons of manganiferous iron ore would also be required. Hence at the present time manganese assumes a place of considerable importance.

Purpose of Investigation.

The purpose of this investigation has been to examine the literature on manganese deposits of Canada and to find out what the mode of occurrence of these deposits suggests as to origin. By the study of all of the deposits certain relationships have been indicated by their geographical and geological distribution and their mineralogy. The deposits of Nova Scotia and New Brunswick have been the most fruitful in this respect.

The economic possibilities of the manganese occurrences have been investigated.

Acknowledgments.

The author wishes to express his appreciation for the excellent guidance and criticism given by Dr. J.E. Gill of McGill University. Thanks are due to the National Research Council and McGill University for the financial requirements of the investigation. Dr. W.J. Wright, Provincial Geologist of New Brunswick was very generous with information and suggestions concerning the New Brunswick deposits. Professor M.F. Bancroft, of Acadia University, was very helpful in connection with the Nova Scotia occurrences. Dr. J.C. Sproule, of Ottawa, gave some valuable suggestions.

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OCCURRENCE IN MANGANESE

Manganese Minerals.

Manganese occurs in three main forms in nature, as the oxide, as the carbonate and as the silicate. Five oxides form important ores: pyrolusite, psilomelane, braunite, manganite and wad.

Pyrolusite MnO_2, is a greyish-black to black mineral with crystalline or granular structure. It is orthorhombic, has a hardness of from 2-4, and a specific gravity of 4.7-4.8, and has a black streak. It is often pseudomorphous after manganite. It is opaque and has a metallic luster. It is usually associated with psilomelane, lining or filling cavities in it or in alternating layers with it in botryoidal masses. It may be distinguished from psilomelane by its crystallinity and lesser hardness, and from manganite by its black streak. When pure it contains 63.2% manganese. Pyrolusite is one of the commonest manganese minerals of lateritic origin.

Psilomelane contains 70 to 83% MnO_2, 3-8% MnO, 3-6% H_2O with varying amounts of BaO and K_2O. It is massive, botryoidal, reniform or stalactitic. It has a hardness of 5-6.5, a specific gravity of 3.7-4.7. Its luster is submetallic and dull. Its streak is brownish black and shines. Color is iron-black to steel grey. The mineral is opaque, is amorphous and has a

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G.A. Thiel, Manganese minerals, their identification and paragenesis: Econ. Geol. Vol. 19 p. 115.

G.A. Thiel, Op. Cit.

conchoidal fracture. Psilomelane is regarded as colloidal MnO_2 with various adsorbed impurities.

Wad is amorphous and reniform, earthy or compact. It is usually quite soft soiling the fingers. Less frequently it is hard up to a hardness of 6. It not uncommonly contains some iron oxides and silica, alumina and baryta. It contains 20 to 30 per cent manganese. Bog manganese is the same mineral soaked with water, and contains a large percentage of organic matter.

Manganite, $Mn_2O_3.H_2O$, is a dark steel-grey to iron black mineral. It has a reddish-brown streak, and may thus be distinguished from pyrolusite, which has a black streak. It crystallizes in the orthorhombic system, commonly in prismatic crystals vertically striated. It is brittle and has an uneven fracture, a hardness of 4 and a specific gravity of 4.2 to 4.4. It occurs as crystals in columnar or sometimes granular form. It alters to pyrolusite. It is often found in veins associated with acid igneous rocks. It contains 62.4% manganese when pure.

Braunite, $3Mn_2O_3.MnSiO_3$, is a brownish to greyish black mineral, has a hardness of 6 to 6.5, a specific gravity of from 4.75 to 4.82, and a submetallic luster. It crystallizes in the tetragonal system but may also occur in a massive form. It forms at ordinary temperatures near the surface and is oxidized to pyrolusite and manganite. In the pure state it contains 64.4% of manganese.

Rhodochrosite, $MnCO_3$, is a pink mineral with a hardness of from 3.5 to 4.5, and a specific gravity of 3.45 to 3.6. It is rhombohedral occurs in cleavable masses and massive or granular compact masses. Its luster is glassy. The molecule of rhodochrosite and siderite are completely miscible, and there is usually some iron carbonate in the mineral. Rhodochrosite occurs as a primary gangue mineral associated in veins with silver, copper and lead deposits.

Rhodonite, $MnSiO_3$, is a pink mineral with a white streak, a hardness of 5.5 to 6.5, and a specific gravity of 3.4 to 3.68. It is triclinic and commonly tabular or massive. It has two distinct cleavages and a conchoidal to uneven fracture, and is transparent to translucent. Rhodonite is frequently associated with rhodochrosite and forms by ascending thermal solutions of igneous origin. It is also formed during metamorphism.

Hausmannite, Mn_3O_4, is steel grey, has a chesnut brown streak and a submetallic luster. It is brittle, finely to coarsely granular but locally crystalline. It has a perfect basal cleavage and an uneven fracture. Its hardness is about 5.5. On thin edges it is translucent and it is weakly magnetic. The pure mineral contains 72% manganese.

G.A. Thiel, Manganese Minerals, their identification and paragenesis: Econ. Geol. Val. 19 p. 107-146.

General Character of Ore Deposits.

Commercial deposits of manganese nearly always consist of the various oxides. Some of these occur interbedded with limestone strata in beds up to eight feet thick as in the

Russian deposits. Others occur in irregular bodies either replacing limestones or as residual masses in clays and other weathered rocks. The Indian and Brazilian deposits are of this nature. Manganese oxides are common in bog deposits associated with iron minerals and peat. Still other deposits occur as veins.

Some deposits consist of manganese silicates and carbonates but little manganese is mined from such sources.

Previous Ideas as to Origin..

The manganese deposits of India have been thoroughly investigated by L.L. Fermor. Here the manganese is associated with metamorphic and igneous rocks containing a high percentage of manganese in the form of manganese silicates, the most abundand of which is spessartite, the manganese garnet. Fermor believes that the oxide deposits were derived from these rocks by the alteration of the manganese minerals to oxides. This necessitated the removal of silica and alumina. The removal of these substances, Fermor says, would be attended by a decrease in volume. There are few open spaces in the deposits. He says the reason for this is that manganese minerals were deposited in any space which tended to form. This manganese was transported in carbonated waters and precipitated as the oxide. He thinks that the CO_2 in the solution came from below where the metamorphism of limestone resulted in the release of that substance.

L.L. Fermor, Mem. Geol. Surv. Ind. 37, 1909.

He believes that the metamorphic rocks were once highly manganiferous sediments and that, in their metamorphism, the manganese entered such minerals as manganese garnet.

Fermor thinks that organic acids may have been important in the transportation of manganese. He also considers it possible that the manganese may be transported as the sulphate.

The deposits in Brazil are similar to those in India. They are associated with a schist containing much rhodochrosite, spessartite, rhodonite and manganese olivine.

Singewald and Miller, Manganese-ores of the Lafayette district, Minaes Geraes, Brazil; A.I.M.M.E., Trans. LVI (1916) p.7

Singewald and Miller examined these deposits and concluded that the oxide ores were formed by weathering of this highly manganiferous metamorphic rock. They were in complete agreement with Fermor in their theory of the origin of this type of deposit. The occurrence of $McCO_3$ made some of the details of their theory slightly different. They considered that in the Brazil deposits SiO_2 and CO_2 were removed in the alteration of the manganiferous rock. Manganese oxides were introduced and replaced these compounds. The introduced manganese was dissolved from $MnCO_3$, transported as the bicarbonate in carbonated waters and deposited as the oxide.

E. Kitson and N.R. Junner examined the deposits of the Gold Coast. These deposits are in argillaceous and

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E. Kitson and N.R. Junner, Trans. A.I.M.M.E. 75, 1927, p.372-396.

siliceous phyllites in which the minerals spessartite, rhodonite and braunite are plentiful. They consider that the origin of these deposits is the same as the Indian deposits.

The Russian deposits are very extensive, undoubtedly sedimentary deposits. Because of this the geologists have had no need to examine their origin very extensively. D.F. Hewett says that the ores contain oolites of manganese oxides and that these were mechanically transported even if only a short distance. These oolites were originally precipitated chemically. De la Sauce does not think that the oolites have an organic origin.

D.F. Hewett considers that bacteria may have been the cause of deposition. In his discussion of some of the ores of the United States, Hewett states that the manganese carbonate deposits are in some way related to unconformities, and he observes that beds of rhodochrosite are associated with chert, glauconite and calcium phosphate.

From analogy with the case of iron Hewett says "It appears that manganese in waters that carry organic matter exists in the state of the hydrosol stabilized by organic colloids". This was disproved by Savage, as will be explained later.

<u>Twenhofel's Treatise on Sedimentation. P. 562-581.</u>

<u>De la Sauce, Beitrage zur Kentnisse der Manganerzlagerstatte Tschiaturi in Kaukasus.; Abhandl. sur Prak. Geol. Halle.1926</u>.

At Batesville in Arkansas are deposits of manganese associated with shales and limestones and residual clays on these. Penrose believed that manganese derived from crystalline schists to the south was deposited largely in the St. Claire limestone. This was later weathered and the manganese was concentrated residually as nodules and irregular masses of oxides in clay.

Harder thinks that when the Izard and Polk Bayou Limestones (equivalent to the St. Claire of Penrose) were being deposited, residual deposits were forming on the St. Francis mountains to the north-east. Later this residual material, together with others, was deposited over the Polk Bayou limestone after a short period of erosion. Residual deposits in clay were derived from this material by weathering. Harder considered that residual processes on land surfaces were important in the concentration of manganese.

In the Appalachian region are numerous deposits of manganese oxides in residual clays derived from shales and limestone of Cambrian and Ordovician age. Harder is of the opinion that the manganese was derived from crystalline and metamorphic rocks of the Piedmont region, in which it occurred as silicates. After the sediments emerged from the

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R.A.F. Penrose, Annual Rept.1,Ark. Geol. Surv.vol.1 1890 p.586

E.C.Harder, Manganese deposits of the United States; Bull. U.S. Geol. Surv. p. 117

sea erosion took place. During this time manganese was taken into solution, carried downward and deposited in favorable localities, such as where underlying quartzite or faults impeded the solutions. "As erosion continued the ores were continually carried down, being often re-dissolved and deposited elsewhere, giving rise to veins and replacement deposits of pyrolusite in sandstone and sandy clay masses".

In general, geologists working on manganese deposits have not gone deeply into the chemical aspects of solution and deposition. The possibility of the precipitation of manganese from colloidal solution has often been mentioned but the author has not seen any attempt to describe such a process. Most of the chemical knowledge along these lines in regard to manganese has been the result of quite recent investigations.

Genetic Types Recognized.

Manganese deposits have been classified by Hanson as follows: (2) p. 10.

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

To this might be added a Complex Type which would include those deposits which have originated by a number of different processes. This group would include such deposits as those of India and Brazil, where sedimentary Metamorphic and weathering processes produced the deposits. Some of the deposits in British Columbia might fall into this group.

Since the Bog deposits are composed of oxides, it would be better to class them as a sub-class under the "Oxide Type".

CANADIAN DEPOSITS.

General Statement.

Most of the manganese deposits in Canada occur in the Maritime Provinces and British Columbia. Other insignificant deposits occur in Ontario and Quebec.

Between the years 1886 and 1890 the annual production of manganese amounted to from 1100 to 1600 tons. Before 1918 the entire production came from deposits in Nova Scotia and New Brunswick. Since 1918 some bog manganese has been produced in British Columbia.

A.W. Groves, Op. Cit. p. 50.

The Maritime deposits will be discussed first.

Deposits in Nova Scotia and New Brunswick.

Distribution and Production.

Over 150 manganese deposits and occurrences are known in the Maritime Provinces. These are distributed over all of Nova Scotia and the Southern half of New Brunswick. The deposits are most numerous and most important in the areas which drain into the Bay of Fundy. Most of the production has been from the south shore of Cobequid Bay in Hants County, Nova Scotia, and from a strip 16 miles wide in New Brunswick, extending along the north shore of the Bay of Fundy from Moncton to within 20 miles of Saint John. A deposit of importance occurs on the southern limit of the Bay of Fundy drainage system, near New Ross, in the northern corner of Lunenburg county.

The deposits occur in rocks of nearly all ages found in the Maritimes, but are most plentiful in the Windsor Limestone, of Lower Carboniferous age, and in recent unconsolidated rocks, especially where they are underlain by Carboniferous rocks. Most of the important deposits occur in the outcrop area of these rocks in the regions mentioned above.

In New Brunswick the largest deposits are: the Markhamville Mine, Kings County, from which more than 23,000 tons of ore have been mined, and deposits at Shepody Mountain, Jordan Mountain, Turtle Creek and Gowland Mountain, in Albert County. Several hundred tons of ore have been shipped from each of these. Other deposits occur in bogs and are of low grade, but are easily worked. The largest of these deposits is in Dawson Settlement, Albert County. About 4,000 tons of dry ore have been shipped and about twice this amount remains in the deposit. Other deposits containing several thousand tons of ore occur at North Renous in Northumberland County, and about five miles south-east of Canaan Station in Westmorland County. There is a low grade iron deposit, similar to the Lake Superior deposits, containing about 12% of manganese near Woodstock. This deposit is very extensive and it has only potential value pending the discovery of some economical method of treatment or concentration.

In Nova Scotia most of the production has been from the Tennycape mine on the south side of Cobequid Bay and from the New Ross deposit in the northern corner of Lunenburg County. About 4,000 tons of"chemical ore" was produced from the Tennycape Mine, and more than 1,200 tons from the New Ross deposit.

Several hundred tons of ore have been produced from each of the deposits at Cheverie, Hants County; Lochlomond, in Cape Breton County, Cape Breton Island; and in the vicinity of Manganese Mines in Colchester County. The largest bog deposits are on Boulardarie Island, Cape Breton Island. There are two deposits here, located near Island Point. The largest covers about 27 acres.

General Geological Setting.

Physiography of the Maritime Provinces.

The surface of the Maritimes is in general moderately undulating. Its highest parts preserve remnants of a Tertiary peneplain, which slopes gently south-east from an elevation of about 4,000 feet on the Gaspé Peninsula to a few feet above sea level on the south-east coast of Nova Scotia. The local relief rarely exceeds a few hundred feet, but in some highland regions, as the Cobequid Mountains in Nova Scotia and the Caledonia Mountains in New Brunswick, the local relief approaches 1,000 feet.

The Maritimes may be divided, physiographically, into upland areas and lowland areas. The upland areas are underlain by crystalline rocks and the lowlands by softer sediments. These latter are largely of Carboniferous age.

The drainage has been considerably disarranged by glaciation. Swamps and lakes are numerous, and the river systems in many places are very irregular. All but the most exposed hilltops are covered by a mantle of glacial till.

J.W. Goldthwaite, Physiography of Nova Scotia; Mem. 140, Can. Geol. Surv.

Geology.

The rocks which occur in Nova Scotia and New Brunswick are outlined in the following section:

Recent - gravels, sands, silts, salt marshes.
Glacial - till, kames, outwash plains, drumline.

-.-.-.-.-.-.-.-.-.-.-.-.

Triassic - basalt
red sandstone
-.-.-.-.-.-.-.-.-.-.-.-.-.
Carboniferous - *Pennsylvanian* sandstone shale, conglomerate, coal and some volcanics.
-.-.-.-.-.-.-.-.-.-.-.-.-.
Windsor series limestone, shale, gypsum.
....
Horton series sandstone, shale, conglomerate.

Devonian - slate, sandstone, shale, volcanics.

Silurian - limestone, slate, shale, sandstone, volcanics.

Ordovician - grit, volcanics, sandstone, limestone, schists.

Cambrian - shale, sandstone, conglomerate, slate.

Precambrian - slate, quartzite, limestone, volcanics.

Unconformities -.-.-.-.-.-.-.-.-.-.-.-.

Disconformities ....

Maps 39A and 259A Can. Geol. Surv.

M.Y. Williams, Geology of Arisaig, Antigonish Counties, Nova Scotia; Mem. 60 Can. Geol. Surv. p. 52.
W.A. Bell, Geology of the Horton-Windsor district; Mem. 155 Can. Geol. Surv. p. 21
F.J. Alcock, Geology of the Saint John district; Mem. 216 Can. Geol. Surv. p. 9
W.J. Wright, Geology of the Moncton map-area; Mem. 129 Can. Geol. Surv. p. 2

Intrusive rocks outcrop over large areas in the Maritimes. These are largely of an acid character. Devonian granite is the most widespread of the intrusives. Carboniferous gabbro occurs in Antigonish County, Nova Scotia, and small areas of intrusives of uncertain age outcrop in various parts of New Brunswick and Nova Scotia.

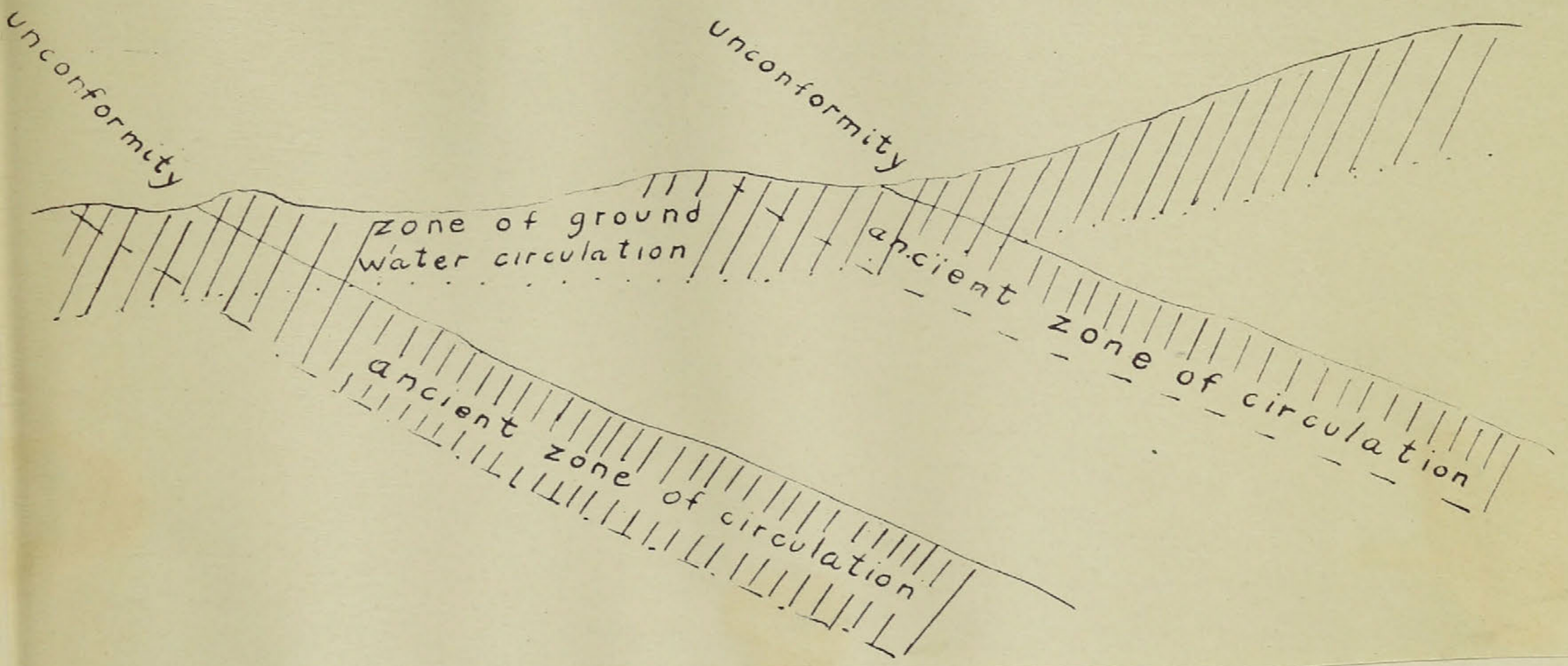
Most of the Maritimes is underlain directly by sediments of Carboniferous and Precambrian age, and Devonian intrusives. Of the remaining systems, the Triassic rocks outcrop over the largest area. The rest of the rocks do not underlie a very large percentage of the surface.

The important host rocks for the manganese are the Windsor Limestone and the Devonian granite. Some manganese deposits also occur in most of the other formations.

It has been found that the maritime deposits are closely associated with unconformities. The unconformity between the Horton and the Windsor is most important. Most of these deposits occur near the base of the Windsor. The unconformity at the top of the Windsor is also important because the Pennsylvanian derived its manganese from the land surface represented by that unconformity, and the bog deposits derived their manganese from the Pennsylvanian.

The Maritime deposits may be subdivided into those associated directly with unconformities and those associated with the present surface. The latter class may again be subdivided into preglacial and postglacial deposits. This last division is only practical in connection with the bog and the residual deposits.

The main deposits in the Maritimes are of three types; replacement, vein, and bog deposits. Since manganese is deposited by circulating ground waters in the zone of circulation, and since such a zone existed below each ancient erosion surface there is a zone in which manganese can occur immediately below all unconformities and also below the present erosion surface.



▨ Volume in which it is possible for manganese deposited by circulating ground water to occur.

The deposits may hence be divided into two classes;

1. Those deposited during the period of erosion represented by an unconformity.
2. Those deposited during the period of erosion which resulted in the present surface.

This subdivision of the deposits is justifiable because a different system of underground exploration would be adopted in each case. In the first type explorations in any one deposit would not be extended to the region above an unconformity. Also, since the most favorable place for the deposition of manganese in replacement and ground water vein deposits is in the zone of aeration above the water table, and since in Nova Scotia and New Brunswick the water table is rarely at a depth greater than 200 feet, most extensive prospecting would be carried on within about 200 feet of unconformity surfaces in the favorable formations.

In the case of the second type of deposits underground, exploration would be most extensive above the water table, or to a moderate depth below it if it had moved upward in recent times. As explained in the chapter on origin, there is reason to believe that manganese may be deposited below the ground water table by percolating waters. Nevertheless, it would seem advisable not to extend workings much below the water table, except to follow an ore body already discovered. One feature of the Maritime occurrences which detracts from the value of this subdivision is the fact that most of the deposits have such small ore bodies that deep mining would not be profitable. Mining in the zone of saturation is considerably more expensive than mining above the water table, because of the cost of water removal. Hence, explorations cannot be carried to very great depth, even though the deposits of type 1 would very probably be found at considerable depth. Another difficulty is that there are not enough data available to definitely classify the deposits on this basis.

Since most of the deposits are in the Windsor limestone, or closely associated with it, the Windsor Series will be described in considerable detail.

The Windsor Series.

The Windsor Series outcrops in many districts in the Maritimes, as shown on the accompanying maps. It consists of a thick series of marine limestone, gypsum, shale, and some sandstone. In the district near Windsor, from which it gets its name, the series is from 1,100 to 1,550 feet thick.

W.A. Bell, Horton-Windsor district, Nova Scotia; Mem. 155, Can. Geol. Surv. p. 21

Gypsum makes up 20% of the total volume of the series, red shale 55%, and calcareous beds 25%. The gypsum occurs in four or five horizons. The basal member of the series is usually but not always a limestone bed. Other limestone beds occur interstratified with shale and gypsum. In Antigonish County to the east much more sandstone occurs.

The Windsor limestones are predominantly of the calcium variety but magnesian and dolomitic limestones are not uncommon. The limestones are all fine-grained to dense in texture, and are colored blue, brown, red, and nearly black. Many of the limestones have a ripple-marked and sun-cracked surface, and contain bands of intraformational conglomerate and oolites at various horizons. These features suggest shallow water conditions. Bell states that the basal contacts of the Windsor Series record low-lying shores.

The gypsum deposits, the red shales and the fossils indicate that a hot climate prevailed in Windsor time and the Windsor seas were confined in numerous embayments. If such a hot climate existed on the pre-Windsor land surface, it would be conducive to the formation of residual deposits. Low-lying shores would tend to cause their preservation. They would not be greatly disturbed by the advancing Windsor sea, and would be preserved on the pre-Windsor unconformity. Under slightly more rigorous conditions this manganese would be deposited in the basal beds of the Windsor Series.

M.F. Gouge, Limestones in Canada, part 2; Mines Branch Publication No. 742. p. 16.

W.A. Bell, Op. Cit. p. 55

Sedimentary Deposits.

Bog Deposits.

A number of bog deposits occur in Nova Scotia and New Brunswick. The most important of these are at Dawson Settlement, Albert County; North Renous, Northumberland County, and at Canaan in Westmorland County, New Brunswick. In Nova Scotia the only important deposit is on Boularderie Island, Cape Breton.

These deposits are of low grade, but are easily mined and occur at the surface.

Their origin presents no great difficulties. (2) p.15. Carbonated ground water dissolves manganese from rocks containing a high percentage of that element. It is transported as the bicarbonate. These waters come to the surface and form springs. The CO_2 escapes; the solutions are oxygenated and the manganese is precipitated as a hydrated oxide. Bacteria may have some effect in precipitating the manganese. Their action is to absorb CO_2, thereby aiding in precipitation.

Carl Zappfe Op. Cit. p. 799

The iron is precipitated sooner than the manganese, and so is found in greater quantity near the mouth of the springs.

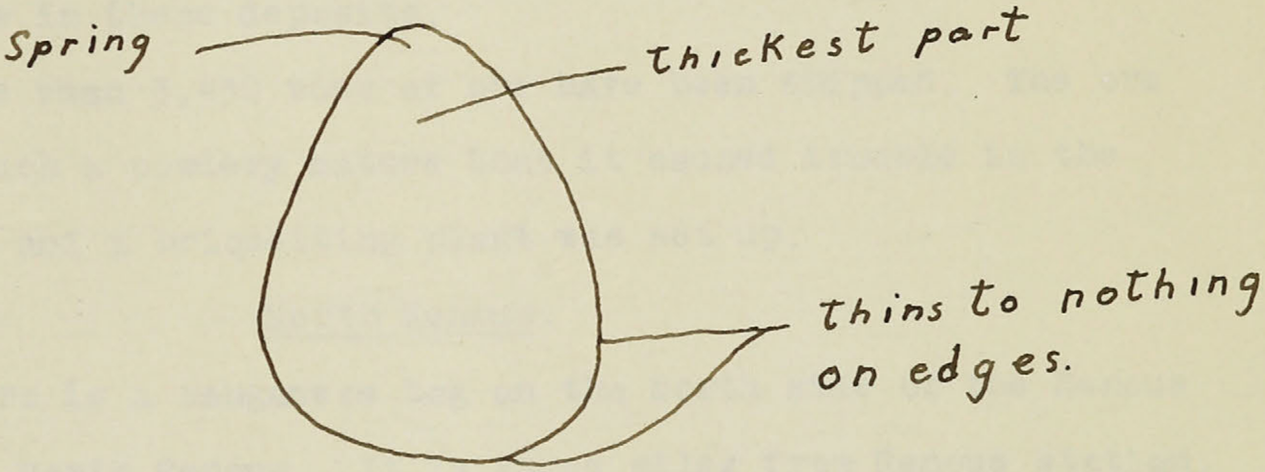
The deposit at Dawson Settlement may be taken as typical.

Dawson Settlement.

There are three bog manganese deposits half a mile south of Dawson and 5½ miles north-west of Hillsbro. The deposits are less than 1½ miles from the Canadian National Railway at

Salisbury. A spur line was once built into the deposits, and now only the embankment is left.

The bogs are on a gentle slope on the south side of Hopper Creek, and are underlain by Carboniferous rocks. They are mostly below the mouth of a series of mineral springs from which the manganese is still being deposited. The upper limits of the bogs are 50 to 100 feet up the slope from the present mouths of the springs. The deposits are fan-shaped and, analogous to laccoliths, have made room for themselves between the hard bottom and the grass roots.



The bogs are up to 15 feet thick.

The material of the bogs is a soggy mixture of MnO_2 and limonite. At some places the manganese minerals and the limonite are mixed and at others they are in separate bands. Much peat is commonly associated with the ore. The ore is readily obtained by shovelling.

Uglow [(5) p. 84] has estimated the tonnage in two of the bogs to be 42,690 tons of wet ore over an area of 9.6 acres.

The following information was obtained by Uglow:

Crude wet ore				Dry ore				Ignited ore		
Tons	%Mn	%Fe	%H_2O 110°	Tons	%Mn	%Fe	Loss ign.	Tons	%Mn	%Fe
22,370	6.98	6.74	65.68	7,671	20.33	19.65	29.19	5436	28.71	27.75
20,320	6.96	2.80	73.20	5,446	29.98	10.44	37.42	3408	41.51	16.68
42,690				13,123				8844		
	6.97	4.77	69.44		25.15	15.05	33.3		35.16	22.22

Analytic data presented by Uglow indicates that the proportion of manganese to iron increases with distance from the source. As is commonly the case, iron is deposited before manganese in these deposits.

More than 3,430 tons of ore have been shipped. The ore was of such a powdery nature that it caused trouble in the furnaces and a briquetting plant was set up.

North Renous.

There is a manganese bog on the North side of the Renous River at North Renous. It is three miles from Renous station. The main highway is 500 yards away.

Three deposits occur in this district. These were examined by borings with a 2-inch hand auger. The size of these deposits as calculated by W.J. Wright is as follows:

(1) 30 by 60 by 3 feet
(2) 60 by 80 by 2.5 feet
(3) 70 by 140 by 6 feet.

Canaan River.

The bogs are on the upper north branch of the Canaan

W.J. Wright, Bog manganese on the E. Singleton farm North Renous, Northumberland County, manuscript report.

river about 4½ miles from Canaan Station over an old bush road.

This district is underlain by Pennsylvanian rocks. The bogs are located on gentle slopes just below the orifices of springs. The ground slopes to the river with grades of between 3 and 12.5 feet in 100 feet. The bogs are similar to those at Dawson Settlement. The best ore is in a compact layer just below the grass roots. A representative sample of this layer yielded the following results:

(2) p. 82

Mn	10%
Fe	0.08
H_2O (110°).....	76.22
Loss on ignition	7.86

This is equivalent to 62.81% of manganese and 0.5% iron in the ignited ore. The lower part of the bog consists largely of peat, and its manganese content is inconsiderable. The total tonnages from the five bogs are as follows:

			%Mn	%Fe
Wet ore	20,289	tons ...	5.01	1.31
Dry ore	4,904	" ...	20.71	5.40
Ignited ore ..	2,506	" ...	40.45	10.49

The manganese content increases with distance from the source. Hanson states "The explanation is that iron in solution oxidizes to limonite more readily than manganese in solution oxidizes to manganese dioxides". (2) p. 83.

Boulardarie Island.

Two deposits of bog manganese occur on the south-east shore of Boulardarie Island, Cape Breton Island. In one deposit the ore lies on sandstone. It locally penetrates the rock and apparently replaces it along joints. Limonite is common and in places layers of limonite alternate with layers of bog manganese. The material is semi-consolidated and is said to contain much iron and silica. It is as much as 5 feet thick and covers an area of 5 or more acres. It has not been appreciably mined and no work has been done on it since 1917.

The other deposit lies on a layer of fine white sand. It ranges in thickness from 1-7 feet and extends over an area of 27 acres. (21) p. 29. A map of the deposit by J.E. Gill indicates an area of 7½ acres. The mineralogy is similar.

The wad of these two deposits is friable and fine grained, and would likely have to be briquetted before it could be used in the manufacture of ferro-alloys.

Channel samples were taken from the thickest part of the main deposit. When the ore was ignited to remove organic matter and water, analyses of it gave the following results:

	Mn	Fe	Si	P
No. 2	17.7%	45.1%		
No. 3	30.3%	23.7%	2.66%	0.12%

The original material directly from the bog lost a total of 35% on ignition; 11% of the original material was water.

J.E. Gill concluded that there were 90,000 tons of probable ore in these two deposits.

J.E. Gill, Report on certain manganese deposits on Cape Breton Island, N.S.; Manuscript Report.

Woodstock.

A manganiferous iron formation similar to that of the Cuyuna district in Minnesota occurs in the vicinity of Woodstock. Good exposures of the ore are located (1) In a group extending from near Campbell's corner through Moody hill and Iron Ore hill to Jacksontown; (2) at Ashland; (3) Glassville; (4) on the Glassville-Bristol road where it crosses the west branch of Black brook; and (5) on the Shiktahawk river about half a mile below the bridge on the West Glassville Road (12)p.18.

The deposits occur as a layer 1-16 feet thick, interbedded with red and green, greatly folded, Silurian slate. This ore body is believed to extend in a North-easterly direction from Campbell's corner to Glassville. The distribution of the outcrops is explainable by the hypothesis that they are in one bed repeated by close folding. (12) p. 19.

The material of the bed is a manganiferous hematite with small quantities of carbonate and varying amounts of fine quartz grains. This deposit was sampled in 1939 and the samples were analyzed by J.T. Donald and Co., Montreal. The location of the samples and the width sampled is indicated on the accompanying sketches taken from a map by W.J. Wright and S.C. Perry. The results of the analyses are as follows:

J. T. DONALD & Co., LIMITED

1181 Guy Street, Montreal.

December 30, 1939.

ASSAY CERTIFICATE.

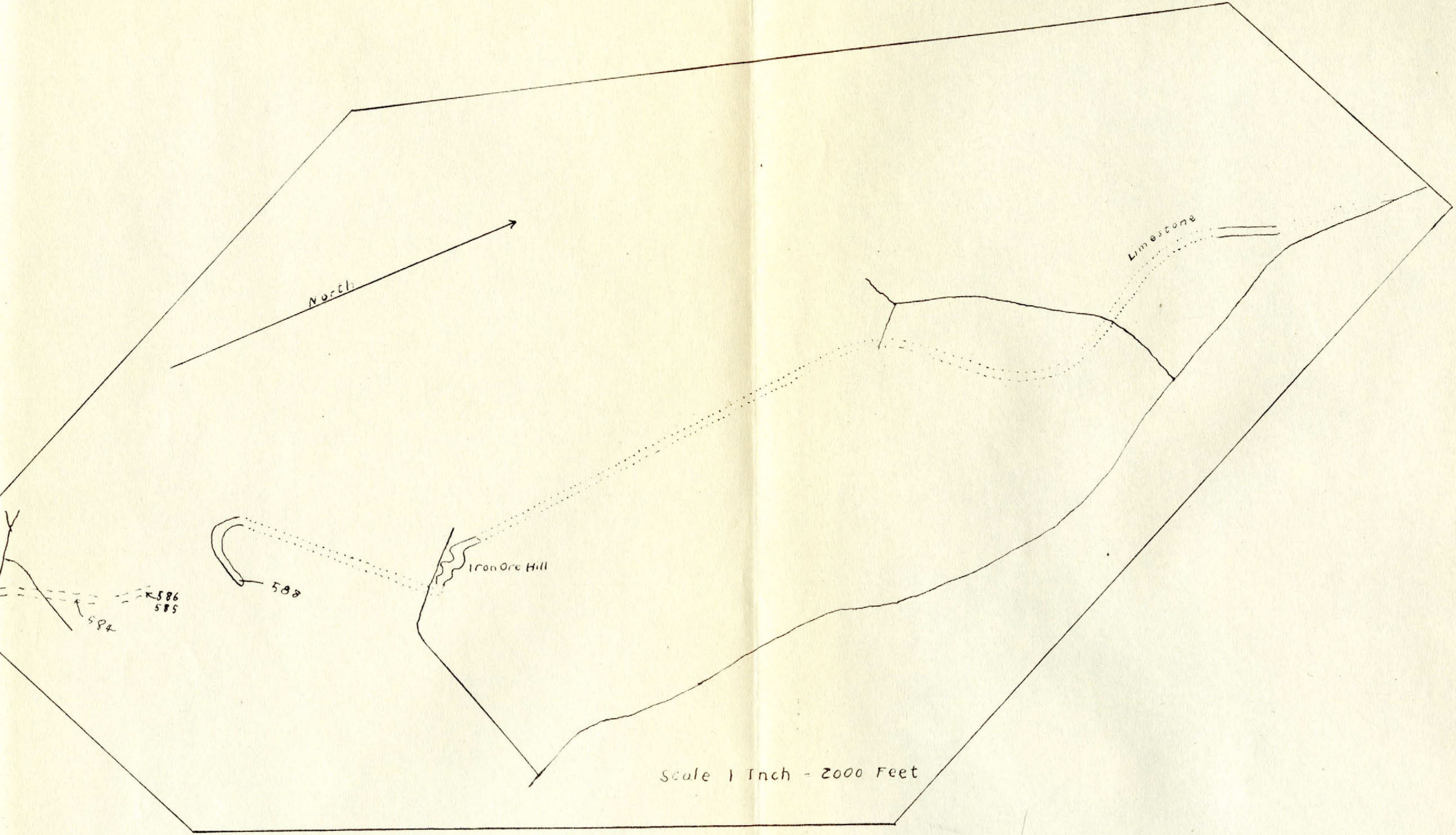
Laboratory No. B-5096-5112

17 Samples of Ore Date Received - Dec. 18, 1939.

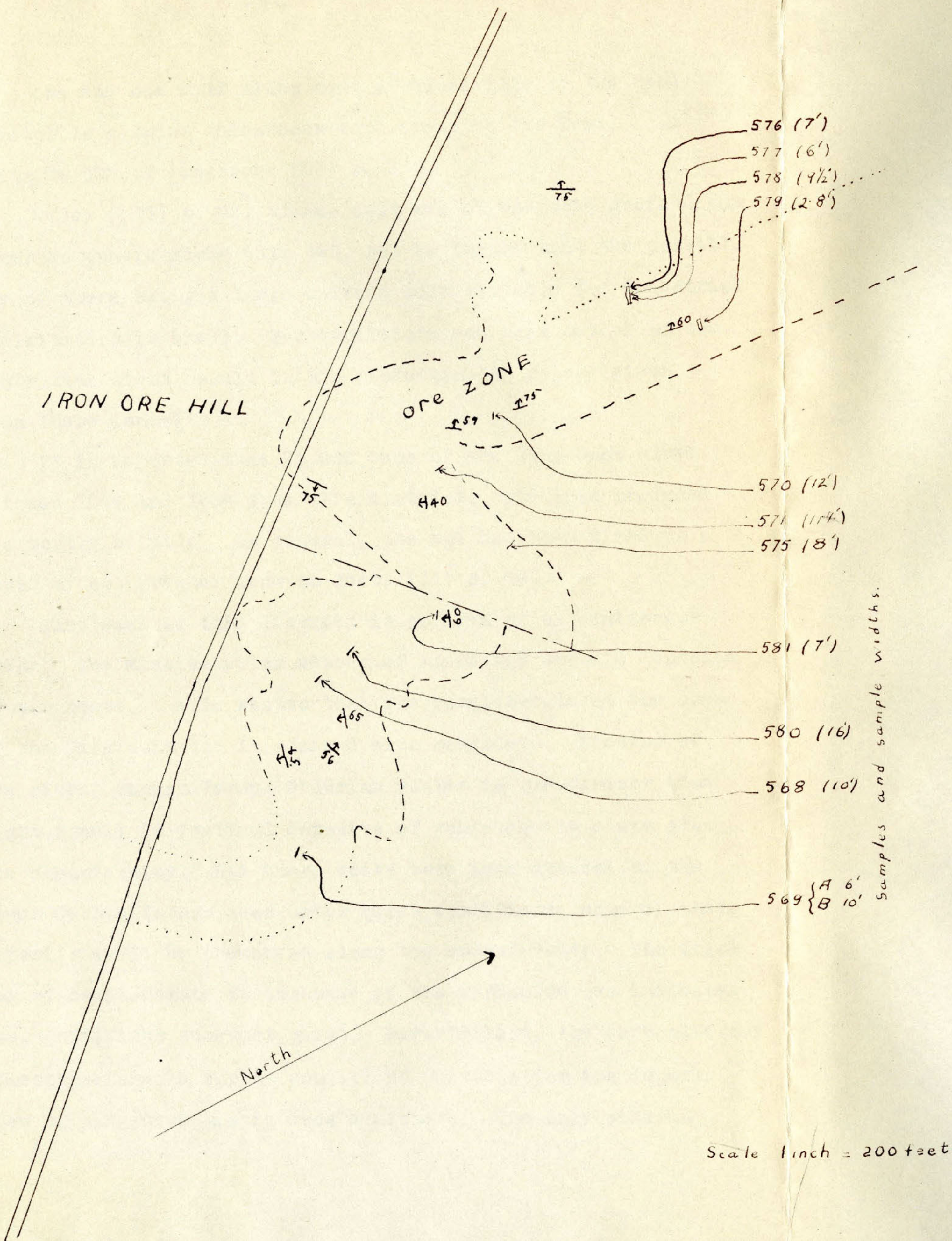
Received from DEPARTMENT OF LANDS & MINES
Fredericton, N.B.

MARKS	IRON	MANGANESE	SULPHUR	PHOSPHORUS	INSOLUBLE	GOLD (oz. per ton)
568A	33.73%	13.38%	--	--	--	--
568B	20.91	18.53	trace	1.28%	--	--
569	15.05	14.10	0.25%	0.56	--	--
570	30.00	9.30	0.02	1.02	--	--
571	27.47	10.80	0.03	0.89	--	--
573	11.31	7.50	0.02	0.21	--	--
574	20.60	11.40	0.01	0.63	--	--
576	--	13.50	0.13	0.66	--	none detected
579-1 & 2	25.48	14.69	0.09	0.96	21.76%	--
579A	--	--	--	--	--	none detected
580	27.57	11.78	0.42	1.09	--	--
581	24.95	10.28	0.13	0.86	--	--
582	26.97	17.10	0.06	0.86	--	--
583	31.51	12.15	0.02	1.08	14.48	--
584	26.97	14.85	0.02	1.09	--	--
585	24.85	11.10	0.05	0.87	--	--
586	26.06	11.25	0.03	0.88	--	--
587	23.63	14.25	0.04	1.25	--	--
538	22.02	12.08	0.03	0.87	--	--

(Sgd.) J. T. DONALD & COMPANY LIMITED



Copied from a map by the Department
of Lands and Mines Fredericton


576 (7')
577 (6')
578 (4½')
579 (2·8')
75
60
IRON ORE HILL
Ore ZONE
75
59
75
40
570 (12')
571 (11¼')
575 (8')
60
581 (7')
65
580 (16')
5
56
568 (10')
569 {A 6' B 10'
Samples and sample widths.
North
Scale 1 inch = 200 feet

One and one half miles west of Glassville on the road to Bristol is a thick calcareous band crossing the road. It contains 20% of manganese (11) p. 102.

Caley [(11) p. 98] states that ore of economic grade might occur somewhere along this bed, but he thinks that the possibility of there being a large uniform body suitable for industrial exploitation is small. War conditions and some method of concentration might result in the production of spiegeleisen from these deposits.

It is reported that 70,000 tons of ore have been mined between 1848 and 1884 from this district. The iron produced was mostly brittle. In general, the bed has been mined to a depth of not greater than 20 feet. (11) p. 98.

Just east of this district is an area of carboniferous rocks. The Mississippian member of these may contain deposits of manganese. Ells states that the conglomerate at the base of the Mississippian is stained with manganese. Erosion of the richly manganiferous Silurian slates in pre-Windsor time might result in residual deposits of manganese in clays along the unconformity. Had these rocks been transgressed by the Lower Carboniferous seas under quiet conditions, some of these deposits would be preserved along the unconformity. The thick bed of conglomerate at the base of the carboniferous indicates that conditions were not quiet. Nevertheless, the carboniferous limestones should supply conditions suitable for the deposition of manganese as it does elsewhere. The only other requirement is that the drainage be from the Silurian to the Carboniferous rocks. The direction of flow of the Saint John river is in this direction.

Replacement Deposits.

The replacement deposits are the most important in the Maritimes. From them most of the ore has been mined. They generally occur in the lower portions of the Windsor Limestone. This formation outcrops in many areas from Lunenburg County to the tip of Cape Breton Island in Nova Scotia and throughout much of the south-eastern part of New Brunswick.

The ore may also replace other rocks, as quartzite. The Sturgis Mine on the south shore of Cobequid Bay is an example of such an occurrence. Here pyrolusite and limonite replace quartzite along joints (2) p. 29.

The replacement deposits have a variety of forms in irregular distribution. The ore may occur as stringers, pockets, and irregular bodies, as at the Tennycape mine. The pockets and bodies range in size from a fraction of an inch to bodies containing over a hundred tons. One body at the Markhamville Mine in New Brunswick yielded 3,000 tons, and more than a thousand tons was won from a pocket in the Tennycape Mine. In other places the replacement seems to have followed some definite layer of the limestone and resulted in bodies of tabular and lenticular shape. Such bodies occur at Manganese Mines in Nova Scotia and at Turtle Creek in New Brunswick. At Turtle Creek such a body has a width of 3 or 4 feet; at other places they are only a few inches wide.

The ore minerals are pyrolusite, manganite and psilomelane, and, less abundantly, hausmannite and braunite. The manganite and pyrolusite commonly occur in intergrown acicular crystals, and in vuggy masses. In these the pyrolusite crystals extend into the vugs. Ore of this type may be finely porous. Manganite and hausmannite sometimes occur together in dense massive ore. Such ore is found at Lochlomond. In places this ore is conspicuously altered to pyrolusite. Psilomelane occurs in globular, botryoidal masses, which may be hollow or have a concentric structure. The Turtle Creek ore consists predominantly of psilomelane which has this characteristic concentric structure, in which layers of psilomelane are separated by thin layers of soft brown pyrolusite. (2) p. 79. Braunite occurs at the Markhamville Mine in finely crystalline nodular or vein-like bodies or in more irregular replacement masses. Some of these masses have a colloform structure, and in various bands puramidal crystals of braunite have a random orientation.

The most common mineral in the gangue is barite which is present in nearly all the deposits. Calcite, selenite and limonite commonly occur. Hematite is of less wide-spread occurrence.

Replacement Deposits of New Brunswick:

Turtle Creek.

Manganese occurs near the junction of Berryton brook and the west fork of Turtle Creek. The deposit is 15 miles south-southwest of Moncton. Turtle Creek, $5\frac{1}{2}$ miles north of the deposit, on a Canadian National branch line, is the nearest shipping point. Good gravel roads connect the deposit to Turtle Creek and to Moncton.

The rocks are Carboniferous sediments dipping north-west at angles of about ten degrees. The lowest beds are the Hillsborough Conglomerate. Upon these lies Windsor limestone, unconformably overlain by Pennsylvanian sandstone and conglomerate. The ore replaces the upper beds of Windsor limestone, which have a nearly horizontal attitude. The ore body is lenticular, 3-4 feet thick, and is conformable with the bedding. It is known to be at least 200 feet long. The ore consists of psilomelane and some pyrolusite. It is porous and nodular. Clay, limonite and barite occur as gangue. An average analysis of the ore from samples taken at 5 foot intervals along the main tunnel is as follows:

Mn	48.57
Si	5.4
Fe	5.13
P	0.068
Cu	0.66

<u>Genesis</u>:

There are three possible sources of the manganese in this deposit. These are (1) the Pennsylvanian; (2) the Windsor Series; (3) Concentrations along the unconformity between the Windsor and Pennsylvanian. All of these probably supplied some manganese.

The fact that bog deposits occur the manganese of which undoubtedly came from the Pennsylvanian, (North Renous; see map) indicates that it could supply that element to the deposit.

The Windsor is also highly manganiferous. Since both these groups of rocks outcrop extensively in the region of the deposits, the possibility of their being a source of some of the manganese must be considered.

The association of this deposit with the unconformity must be explained as well as its location below it. This is most easily done by postulating that most of the manganese came from concentrations along the unconformity. This leads to two possible explanations of the relation of the ore body to the unconformity. The first is: Residual deposits formed on the Windsor limestone in the post-Windsor erosion period. At the same time manganese was carried down from these deposits in solution and replaced the Windsor limestone. Later, the Pennsylvanian was laid over the region. The original residual deposits were probably largely removed. In this case other deposits should occur at other places just below the unconformity and these would not be limited by depth below the present erosion surface, but would only be found within a moderate distance below the unconformity.

The other possibility is that the residual deposits on the post-Windsor erosion surface were in some measure preserved along the unconformity. Then in some post-Pennsylvanian period of erosion, ground waters dissolved the manganese from these residual deposits and deposited it in the nearest precipitating environment. This environment was found in the highest Windsor limestone bed. In this case the deposits would be limited to the zone of ground water circulation below the present erosion surface.

In 1939 eight drill holes were drilled through the Pennsylvanian and for a considerable distance into the Windsor limestone. These holes struck the Windsor down dip from the exposed ore body. This drilling was undertaken because the location of the deposits below the unconformity suggested the first hypothesis, and it was desired to prove whether or not the ore was continuous down dip. No ore was struck in any of these holes. Although this does not necessarily disprove the hypothesis that this deposit formed in pre-Pennsylvanian time, yet it proves that the present ore bodies are not continuous down the dip, and this fact suggests that the manganese was restricted to the zone of circulation near the present surface, and that, hence, they probably formed in post-Pennsylvanian time.

Seven carloads of ore have been shipped from this deposit, but the present known reserves are negligible.

Jordan Mountain (2) p. 84.

This deposit is located on the south slope of Jordan Mountain, 8 miles north of Sussex. A dirt road connects it to Sussex on the Saint John - Moncton railway.

The rocks of the district are Lower Carboniferous conglomerate and reddish brown shale, underlain by Precambrian felsites and gneisses.

The ore body, as seen by Bailey (4) in 1898, was a lenticular mass 6 feet thick and 65 feet long conformable with the bedding of the Carboniferous conglomerate, which dips south-east

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W.J. Wright, Provincial Geologist, N.B. Personal Communication.

at 70°. Small stringers of oxides penetrate the surrounding rocks for 20 or 30 feet. In places angular fragments of conglomerate were cemented by the ore into a sort of breccia.

The ore is fine grained massive pyrolusite with some crystalline manganite and hausmannite, and perhaps a little psilomelane. Barite occurs as a gangue mineral. Where manganese oxides occur as cement in breccia the rock minerals have been partly replaced by the oxides. Two samples of breccia ore analyzed by the Mines Branch have the following constituents:

Mn	52.28	57.37
SiO_2	9.7	0.23
Fe	1.18	
P	0.014	0.015
S		0.61

Genesis.

The theory of origin suggested by the mode of occurrence of this deposit is as follows: This deposit is located near the contact with underlying Precambrian felsite. During the latter part of the long period of erosion prior to the flooding of the land by Lower Carboniferous seas, conditions would have been favorable for the formation of bog and residual deposits of manganese on the ancient land surface. This manganese was deposited mechanically with the conglomerate as the sea advanced over the land. It was later dissolved and re-deposited by circulating ground waters, or added to by manganese brought in from elsewhere by these waters. The dominance of pyrolusite is explained by this hypothesis. The occurrence of barite in the ore and the replacement of the rock minerals by the oxides indicates that chemical action, such as takes place in ground waters, was active at some stage of deposition. The catalytic action of the mechanically deposited manganese would have a strong effect in precipitating more manganese from ground water solutions. There can be little doubt that both syngenetic and epigenetic manganese occurred in the conglomerate, but the quantitative ratio of the two types is debatable.

About 400 tons of ore have been shipped from this deposit.

Markhamville Mine.

This mine is 10 miles south of Sussex near the head of Hammond river.

The ore is in Lower Carboniferous limestone between two ridges of Precambrian volcanic rocks. It occurs in lenticular bodies interstratified with limestone. In some places these widen into pockets which do not conform with the bedding. The first ore removed was from pockets in superficial beds of clay mixed with gravel and containing boulders of limestone. These deposits were about 12 feet deep. This clay is a residual deposit formed by the weathering of the limestone. The decomposition is most rapid along the ore bodies. Caves have been formed in the limestone. On the floors of these masses of ore are found.

The minerals of the ore are: pyrolusite, manganite, hausmannite and braunite. Limonite and hematite occur alone.

Carl Zappfe, Deposition of manganese; Econ. Geol. Vol. 26 p.819

Limonite is also associated with the manganese ores either mixed with it or as thin films between manganese ore and limestone.

Genesis.

This deposit probably originated by precipitation as the oxide, which replaced the limestone. The manganese was carried by ground water. The source of the manganese was the concentrations along the unconformity at the base of the Windsor series and all other manganiferous rocks which outcrop in the drainage basin of the deposit. These are Precambrian igneous rocks and Mississippian sediments.

The origin of this deposit is the same as that for all the other maritime occurrences in basal Windsor limestone, and is explained more fully elsewhere.

The total production from this mine between 1868 and 1894 was over 23,000 tons. No ore has since been mined, and all the workings were caved and inaccessible. Two types of ore were shipped: "Chemical ore" was sent to Boston and the "furnace ore" was shipped to England. The high grade ores were crushed, washed and screened, and shipped in petroleum barrels. The tenor of the ore was as follows: (9)

MnO_2	98.7	97.25	96.62
Fe	0.75	0.59	0.55
SiO_2 & BaO	0.55	0.95	0.85

W .J. Wright is of the opinion that this mine has been worked out

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Personal Communication

Gwillim also stated that this mine has been worked out (5) p.61 Denis says that the work was stopped after careful prospecting, which included diamond drilling to a depth of 100 feet. (8)

Replacement Deposits of Nova Scotia.

The main replacement deposits of Nova Scotia occur in three districts: (1) South shore of Cobequid Bay, in Hants County; (2) about 6-7 miles in a westerly direction from Truro, in the vicinity of " Manganese Mines"; (3) near Lochlomond, Cape Breton.

The Hants County occurrences are on the south flank of the Walton anticline. This anticline underlies a strip of country several miles wide extending along the south shore of Cobequid Bay. Its axis is roughly parallel to the shore, and the rocks on its south flank (in the vicinity of the deposits) dip from 40° to 60° to the south. The rocks in most of the anticline are of the Horton series, which are Lower Carboniferous, and consist of sandstones, shales, arkose and conglomerate. This series is from 1,600 feet to 4,000 feet thick.

Rocks of the Windsor Series, also of Lower Carboniferous age, overlie the Horton Series on the south flank of the anticline. The contact is a disconformity. The Windsor Series consists of interbedded limestone, shale and gypsum. The manganese deposits occur in the basal limestone member. Bell

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W.A. Bell, Horton-Windsor district, Nova Scotia; Mem. 155, Can. Geol. Surv. p. 21.

states that the "Basal contacts of the Windsor so far as is known record low lying shores".

W.A. Bell, Op. Cit. p.

In places the lower part of the limestone is brecciated and cemented with calcite. It contains bands of intraformational conglomerate, five inches or more in thickness. These are commonly replaced by manganese. (27) The important deposits of this district are at Tennycape and Cheverie.

The manganese deposits in the vicinity of "Manganese Mines" are in sandstones and shales, probably of lower Mississippian age. These are overlain by patches of Windsor limestone and red Triassic sandstone. Only one deposit is known to occur in the small areas of Windsor limestone in the district, but the possibility of the occurrence of others is worth considering. The host rocks of the manganese dip at angles of 50° to 70° in various directions. These are intruded by acid igneous rocks, two small stocks of which outcrop only a few miles from the deposits.

Hugh Fletcher, Geological Surveys and explorations in the Counties of Pictou and Colchester, Nova Scotia; Ann. Rept. Vol. V pt. II pt. P. Can. Geol. Surv.

Tennycape Mine.

The Tennycape Mine is 1½ miles south-west of the town of Tennycape, Hants County. (1) p. 41. One and a half miles of secondary road connect it with the main road a half mile west of Tennycape.

A bed of limy shale 8 feet thick overlies sandstone and is overlain by brown or grey dolomitic Windsor limestone. This limestone is said to be 250 feet thick and is overlain by gypsum. (3) p. 521. The rocks strike easterly and dip 40° south. M.F. Bancroft states that the ore-bearing limestone contains bands of intraformational conglomerate and that these were favorable to replacement by pyrolusite and gave rise to sheet-like ore bodies.

M.F. Bancroft. Manganese occurrences about Minas Basin; Ann. Rept. on Mines 1937, pt. 2

The ore occurs as stringers, nests and pockets in the brecciated limestone. The stringers were from 0 to 10 inches thick. Near the calcareous shale many of the stringers widen and join to form pockets. (1) p. 43. The nests and pockets were of all sizes. From one mass 1,000 tons of ore were mined. The commercial ore was restricted to the bottom 40 feet of the limestone and is known to occur for 800 feet along the strike. Veinlets of ore occur in the calcareous shale, and in some places are so closely spaced that this veined rock is of commercial grade. Considerable quantities of ore were mined from residual clay just north of the limestone outcrops.

The ore consisted of exceptionally pure pyrolusite with varying amounts of psilomelane and manganite. Gangue minerals were: limonite, calcite, selenite and barite.

Penrose believed that the brecciation of the limestone was caused by the increase in volume resulting from the formation of gypsum from anhydrite in the overlying beds. (23)

The mine produced about 4,000 tons of ore, which was used in the chemical industry. (1) p. 44. The mine had not been worked below the 160 feet level. Smitheringale states that under favorable conditions the dumps and foot-wall shale might be worked, but the total amount of manganese from these sources would be small. (13) M.F. Bancroft states thet "Below the 60 foot level west of the main shaft there must still be good chances of finding more ore bodies". (27)

Cheverie.

This mine is at the mouth of Cheverie Creek on the south shore of the Basin of Mines, in Hants County. The deposits are a hundred yards or so from the main post road.

The Lower Windsor rocks in the vicinity of the mine dip gently north-east, and are as follows: (27)

M.F. Goudge, Limestones of Canada; Mines Branch publication No. 742 part II p. 75

-Gypsum and anhydrite 55 feet
-Limestone, platy, reddish, bituminous, nodules of manganese 5 feet.
-Limestone, reddish, brecciated, high calcium, unfossiliferous 13 feet.
-Quartzite and grey to reddish sandy limestone conglomerate 22 feet
---Disconformity---
-Horton Series.

Manganite and pyrosulite occur in joints in the 13 foot limestone bed. It also occurs as a cement and small masses in the limestone breccia or conglomerate. The small masses are as much as 6 inches in diamteer (1) p. 5. The veins are from an eighth of an inch to 3 or 4 inches wide. Below the water table the ore is said to be more plentiful (3) pp.522 & 523 . The ore is associated with calcite.

The following has been taken from analyses by E. Gilpin. (4) pp. 10 and 11.

Peroxide of manganese	90.15	
Manganese oxides		86.81
Iron peroxide	2.55	) 2.05
Baryta	1.22	)
Insoluble	2.80	1.14
Phosphorus		0.45
Available oxygen		47.73

About 200 to 300 tons of ore have been shipped.

Genesis of the Hants County Deposits.

The theory of origin which seems most probable for these deposits is as follows: At the end of Horton time there was a long period of erosion, the land was worn down to a very low lying region with very little relief. The climate was warm and transportation of materials from the land was largely by chemical processes. A thick mantle of residual material, largely clay, collected on the surface. The ground waters of that time were probably alkaline or neutral. In these clays, manganese oxides accumulated. On the advance of the Windsor seas a part of these deposits was incorporated in the basal Windsor beds and a part may have been preserved in places on the unconformity. In some post-Windsor erosion period, carbonated ground waters dissolved the manganese from the unconformity and from the outcropping manganese-bearing carboniferous rocks in the district. Some of the manganese was probably also carried as the bicarbonate.

Other limestone beds occur in the Windsor Series but only the basal bed contains manganese. The precipitation of the manganese was hence controlled by some conditions in addition to those in limestone beds in general. In other words, conditions in the basal limestone member were different from conditions in stratigraphically higher members. The basal bed differs from the others structurally in its nearness to the underlying unconformity. An investigation comparing the chemical and mineralogical composition of the basal beds with the others might yield important information concerning the origin of these deposits. In the absence of this direct information we may examine the possibilities, considering the sequence of events which lead to deposition. The basal limestone member derived its material more directly from the pre-Windsor erosion surface and hence contained more of the materials which were to be found on that surface. These materials were of a residual nature and very likely contained considerable manganese dioxide. This would cause a higher manganese content in the basal member than in the others.

The manganese-bearing water deposited its manganese in the nearest locality conducive to precipitation. This nearest locality was the basal Windsor limestone. It had many characteristics favorable to the precipitation of manganese.

1. Its high original manganese content had a catalytic action on the precipitation of manganese. (Manganese permutit is used to precipitate manganese in water supply systems)

Carl Zappfe, Deposition of manganese; Econ. Geol. vol. 26 p. 811.

2. Its content of magnesium carbonate may have been an important factor in precipitation.

G.A. Thiel, Precipitation of manganese from meteoric waters; Amer. Jour. Sci. (5) 7. Art. XXXIV p. 457

3. The ease with which limestone is replaced and the tendency for openings to occur in it is important.
4. M.F. Bancroft states that "The presence of intraformational conglomerate in limestone strata is a common mark". He considers that during an interval of erosion, represented by the intraformational conglomerate, resorption of the limestone occurred, which process tended to concentrate the manganese which was less soluble. (27) p. 17.

   It is not likely that enough resorption of limestone would take place to cause any considerable concentration of manganese in the intraformational conglomerate. The most probable explanation of the association of the manganese with these conglomerate bands is that they supplied open spaces through which ground water could circulate and deposit manganese.
5. The presence of barite as a gangue mineral indicates that it was present in solution probably at the time of deposition of the manganese. It probably had a large effect in coagulating the manganese colloids, as described in the chapter on origin. Specimens of the Tennycape ore in the

Redpath Museum at McGill indicate that barite crystallized before the pyrolusite and after <u>most</u> of the manganite. Needles of pyrolusite terminate against crystal faces of barite, but many prismatic crystals of manganite penetrate those faces; others do not, indicating an overlapping crystallization of barite and manganite. The manganese was probably precipitated as psilomelane. This altered to manganite and the contained barium crystallized as barite. The manganite and psilomelane both altered to pyrolusite, which is now the dominant mineral.

<u>Manganese Mines</u> (1) pp. 35 & 36.

These workings are located about 6½ miles east of Truro, near Manganese Mines post office.

Earltown sheet, No. 58, Geol. Surv. Can.

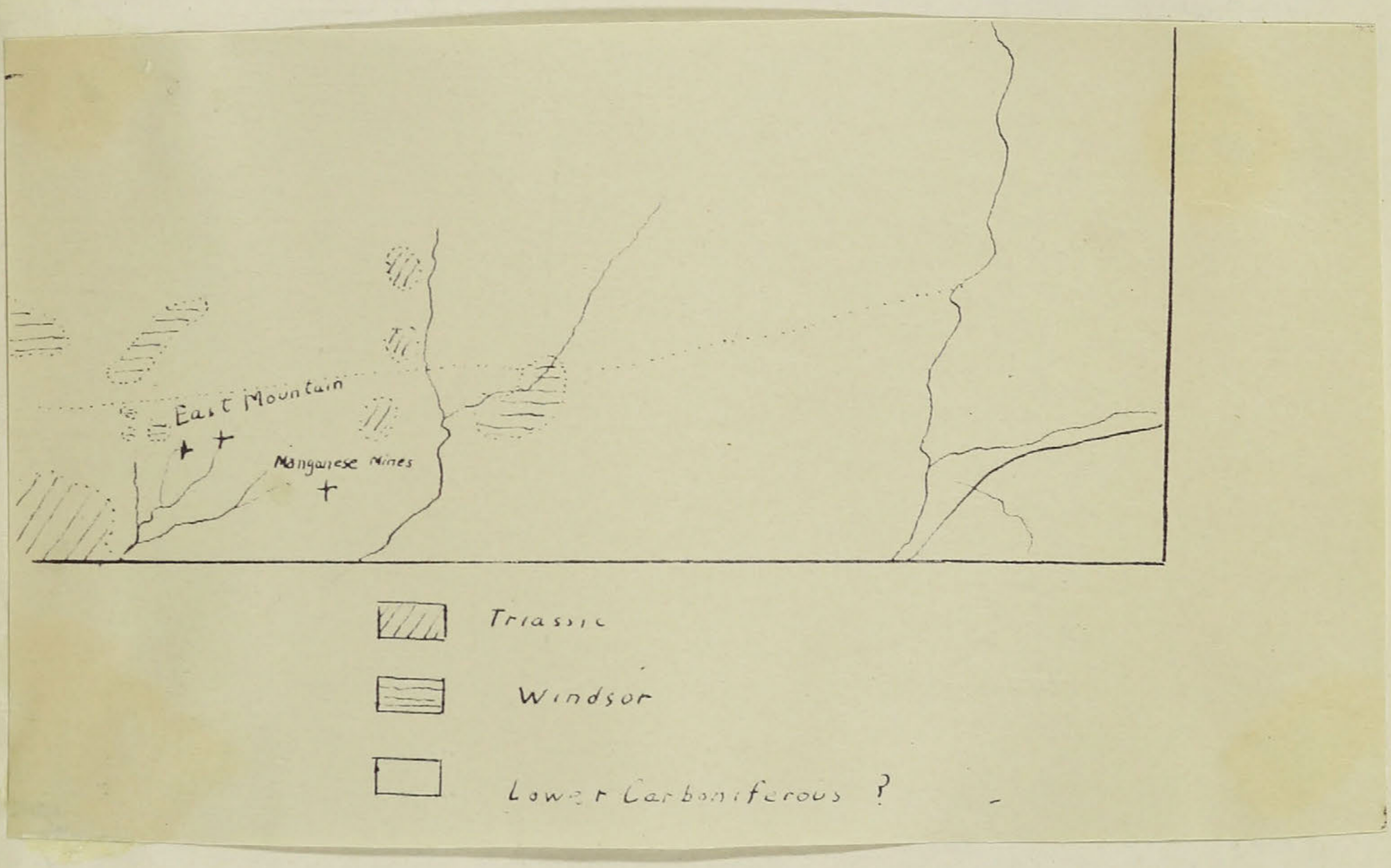
The rocks of this locality consist of red Lower Carboniferous sandstone and argillite dipping steeply.

Pyrolusite occurs in narrow seams along joints and bedding planes, and as the matrix in a sandstone breccia. The ore bodies were associated with one band of flinty rock and were as much as one foot thick. Mangamite and calcite also occur in the ore.

H.Fletcher, Annual Report vol. V, pt. 2 p.184 P (1890-91)
Can. Geol. Surv.

In 1938 when the author was at the property, the main working, which consisted of an open pit about 50 feet long 40 feet wide and 30 feet deep, had been dewatered. A short tunnel had been driven from the bottom of the pit. A number of narrow seams about one inch thick were exposed in this tunnel. The deposits were considered to be in a fault zone on which other deposits farther west are apparently located.

Genesis. Small patches of Windsor rocks unconformably overlie the rocks containing this deposit. These patches are located near the deposit and in various directions from it.

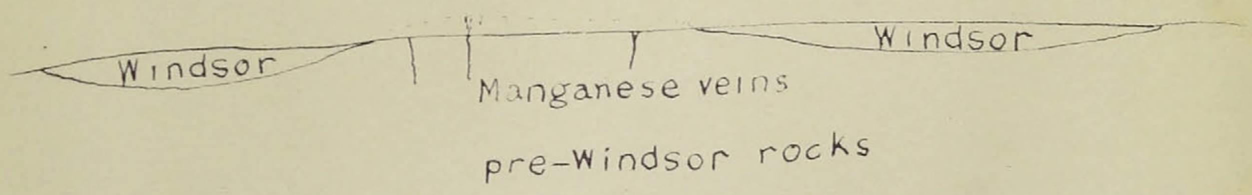


There can be little doubt that the Windsor overlaid this area at some time in the past. This deposit at that time would be just below the unconformity. This situation could have been obtained by two possibilities: (1) Deposition in a pre-Windsor period of erosion; (2) Deposition in the present period of erosion.

In the first case, the manganese would be deposited during the formation of residual deposits on the pre-Windsor surface. Manganese would be carried down from these deposits by descending waters and deposited in the veins and open spaces in the sandstone.

In the second case, percolating waters would dissolve manganese from residual deposits along the unconformity, transport it in colloidal solution and deposit it in the veins and spaces in the sandstone.

The distribution of the deposits would be the same in either case, in this particular locality; that is, they would be restricted to a comparatively shallow zone below the present surface. The reason for this is that if the unconformity were restored it would be above the present surface rather than below it. The pre-Windsor and the present zones of circulation nearly coincide here. It is hence impossible to determine from the distribution of the manganese which of the above two theories is the correct one. (see diagram)



The cause of the deposition is obscure. No mention of barite is made in the literature on these deposits.

334 tons of ore are reported to have been shipped. This was crushed and concentrated before shipment.

East Mountain Mine (21) p. 33-35

This deposit is about six miles east of Truro beside a gulley which empties into Clifford Brook. It is a quarter of a mile north of the corner along the road to East Mountain. (Earl-town sheet No. 58).

Buff Colored limestones grading up into red calcareous shale and underlain by a thin bedded reddish to grey sandstone are the rocks at the deposit.

The ore is pyrolusite in nodules in a down-faulted block of Windsor limestone at its contact with underlying sandstone. The nodules were from the size of a pea up to four inches in diameter. Two samples taken from six barrels of the ore sent to Ottawa were analyzed and the results averaged. These are as follows: (6) p. 89.

Mn	47.94%
Fe	0.90
SiO_2	15.77
P	0.027
S	0.017
H_2O.......	5.81

A sample collected by W.V. Smitheringale from ore stored at the workings yielded 57.89%.

In 1938 six to ten men were employed for eight months on this deposit. A slope was sunk to a depth of 60 feet by Messrs. Munroe and McLellan of Truro. A 4-foot face of ore

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Ann. Rept. on Mines, Nova Scotia, 1938.

was seen in the bottom of this shaft by Dr. J.C. Sproule of the Geological Survey. (Personal Communication). A number of diamond drill holes were drilled on this property in 1939, with negative results.

Ann. Rept. on Mines, Nova Scotia for 1939.

Genesis of the Ores.

The ore in this deposit originated similarly to that in Hants County. It differs from it in that the underlying rocks are more highly metamorphosed than the Horton Series is in Hants County. Besides, the Windsor is preserved here only because a block of it has been faulted down into the underlying rocks.

Loch Lomond (21) p. 30.

Manganese deposits occur on the adjoining farms of Messrs. Morrison and McCuish about three miles from the Enon post office, Cape Breton Island.

The rocks at the Morrison Mine are Windsor and Horton conglomerate, shale, and limestones, overlying a pink granite.

The ore of the Morrison Mine "occurs as irregular bodies in red shale, as veinlets, nodular masses, and irregular replacements in limestone, as a cement and as a coating of pebbles in the conglomerate and as small irregular replacements in the underlying gramite. In the limestone the replacements tend to follow the bedding planes and retain to some extent the original structure of the limestone. Most of the ore found in the rocks occurs in red shale". Manganese occurs in minor quantities in the conglomerate and underlying granite. The thickness of the ore body was measurable in inches rather than feet. The ore is pyrolusite, which commonly occurs in groups of radiating acicular crystals in dense massive nodules. The gangue minerals are, calcite, barite, and selenite. Specimens of the ore analyzed 91.84% MnO_2 (58.2% Mn), Fe_2O_3 0.12%

<u>McCuish Mine</u>.

Rocks of Windsor and Horton age dip gently north-west and consist of:

1. grey to buff crystalline limestone
2. hard conglomerate
3. red shale 1-10 feet thick
4. brown crystalline limestone.

Most of the ore occurs in the red shale as layers and lenses lying roughly parallel to the bedding planes of the shale. These layers had a maximum thickness of 18 inches, and were connected by cross-stringers of ore. Manganese nodules occur in the soil and creek bed and probably weathered out of the shale. Manganese occurs as irregular replacement in the limestone under the red shale also as a cement and as a coating of pebbles in the conglomerate.

The ore minerals are: pyrolusite, manganite, hausmannite ($MnMn_2O4$). The ore is massive or finely porous and is made up of interlocking acicular crystals. The porous ore consists mostly of pyrolusite containing scattered remnants of other manganese minerals. (21) p. 31. Manganite and hausmannite are more plentiful in the massive ore, but alteration to pyrolusite is conspicuous. "Vugs in the porous ore contain delicate incrustations of barite. Some of the massive ore was formed as a replacement of limestone. In thin section this replacement is seen to begin as a slight yellowish smudge on calcite; the smudge gradually becomes intensified and manganite blebs appear within and eventually completely replace the calcite. In the final replacement of the calcite, manganite and hausmannite appear in crystalline form. Oxidation resulted in porous ore consisting mostly of pyrolusite". (21) p. 31. Gwillim said the ore was of chemical grade. (26) p. 63.

Genesis. These deposits originated in a manner similar to the Hants county deposits. This is indicated by the similarity of relationships. They differ, however, from the Hants county deposits in that the rocks containing them are underlain by granite instead of sediments, and also the dominant minerals are manganite and hausmannite instead of manganite and pyrolusite. The ultimate source of the manganese was, probably, the underlying granite. It may be that this is the cause of the occurrence of manganese as hausmannite. The manganese in the granite would be in the reduced state and possibly more difficult to oxidize than the manganese in the sediments below the Hants county deposits. Hence a less oxidized form of manganese was developed and thus we get the mineral hausmannite.

It is probable that the massive ore of this deposit was transported as the bicarbonate in carbonated waters. This view is more in line with the occurrence of hausmannite, and the derivation of the manganese from the granite. The initial deposition was probably from a colloidal solution under the precipitating influence of the barium ion. This solution derived its manganese from concentrations along the unconformity where the manganese occurred as the dioxide. These two statements are based on: 1. the association of the ore with the unconformity. The deposits are above the unconformity, not below it. This suggests that they were either deposited during the present erosion cycle, or were deposited (in part at least) by sedimentation with the containing rocks. 2. The occurrence of barite in the massive ore is made in the literature. This should be investigated. 3. The fact that this ore is porous suggests that it formed by the alteration of a less dense mineral. Since the porous ore is largely pyrolusite (G. 4.7-4-8), the author is convinced that it formed by the alteration of psilomelane. (G.3.7-4-7). In this mineral the barium occurred as BaO which changed to $BaSO_4$ when the psilomelane altered to pyrolusite. According to this theory the location of the deposit was controlled by the colloidal process. The catalytic action of the manganese deposited by this process was a major factor in the precipitation of the manganese from the bicarbonate solution. A search should be made for psilomelane remnants in the porous ore, and to find out if this mineral is earlier than the massive ore.

Residual Deposits.

The weathering of replacement deposits in limestone results in residual deposits of manganese in clay. The clay is usually reddish and less commonly greyish. The most abundant mineral in these deposits is pyrolusite, but manganite is common as residual fragments in the pyrolusite, into which it alters under surface conditions. Nodules of psilomelane are common.

These deposits may form by weathering of deposits of commercial value as at Markhamville and Tennycape, or they may form by weathering of leaner material. Such a deposit occurs at Shepody Mountain, Albert County, New Brunswick.

The surface of the maritimes has been greatly affected by glaciation. The manganese deposits of the bog and the residual types on the preglacial surface must have been damaged or completely destroyed by this process. No preglacial bog deposits are known to occur in the Maritimes. These have probably all been scattered by the glacier. There is considerable evidence suggesting that glacial erosion in New Brunswick and Nova Scotia was not severe. At the Markhamville Mine residual clays containing manganese occur. These have not been removed by glacial scour. The Markhamville Mine is at an elevation of 650 feet (5) p. 60 on the north-west bank of the Hammond River, which flows south-west. Just north and north-west of the mine are hills from 900 to 1,000 feet high. The direction of movement of the ice, as indicated by glacial

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Map No. 1. N.E. to accompany Ann. Rept. vol. IV 1888-89, part N. Geol. Surv. Can.

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striae, was South 20° East.

In this valley, transverse to the direction of ice movement, there would be very little glacial scour, and for this reason the residual clays were not removed. Such deposits are rare in the Maritime Provinces, but there are some minor occurrences in Hants County. In view of the fact that a large number of manganese deposits in residual clays occur in the United States south of the glaciated region, it seems probable that a considerable number existed in Canada.

Shepody Mountain.

This deposit is located about three miles from Hopewell Hill, Albert County, on the west side of Shepody Mountain.

Chlorite schists are overlain by a thinly laminated limestone which, in turn, is overlain by a thin bed of reddish clay, and then conglomerate. These sediments dip at 45° into the hill.

The ore occurs as nodules in the red to greyish sticky clay between limestone and conglomerate, and also as veinlets and replacement in limestone. "The clay occurs in circular or elliptical pockets thinning on the edges to narrow seams which connected with other clay pockets. The nodular masses are as much as eight inches in diameter and have a vesicular and drusy interior. They consist of pyrolusite and manganite. The manganite is largely altered to pyrolusite. (2) pp. 71-72.

M.F. Bancroft, Manganese occurrences about Minas Basin; Ann. Rept. on Mines 1937, pt. 2.

Smitheringale suggests that the clay and manganese ore were derived from the underlying limestone by weathering in Lower Carboniferous time. It was later covered by gravels which hardened into conglomerate. This is an excellent example of a deposit along an unconformity. Manganese ore may hence be expected anywhere between the limestone and conglomerate.

About 500 tons of ore have been shipped.

Vein Deposits in the Maritimes.

Occurrences of manganese minerals in veins are quite common but few are of great economic value. Such veins occur with replacement deposits as at Tennycape and at Manganese Mines.

The veins form along faults or in joints. The width of the veins is from a few inches to five feet.

The minerals of the ore are: pyrolusite, manganite, and psilomelane. Pyrolusite is more common near the surface, but in the deeper parts manganite and psilomelane predominate.

The gangue consists of calcite, iron oxides, barite, barium carbonate, and fragments of the country rock.

The vein deposits are more independent of the type of rock in which they form than are the replacement deposits. The host rocks must of course be capable of being fractured.

New Ross.

The best example of such deposits in the Maritimes occurs at New Ross. Here the deposits occur as lenticular veins in

Devonian biotite granite. In the vicinity of the deposits the granite is jointed in three directions: vertically, striking north-east and north-west, and horizontally. The veins are in fault zones 25 to 100 feet wide (21) p. 55.

The ore is separated from the granite by a zone of soft altered granite, mixed with calcite and iron and manganese oxides. In this zone the feldspars of the granite are altered to kaolin. The granite wall rock is only slightly weathered in the deepest workings. (21) p. 55.

Pyrolusite is more plentiful near the surface and grades into manganite and psilomelane at depth. The outcrop of the vein consists almost entirely of goethite and limonite. The gangue minerals are: barite, granite minerals, iron oxides, and calcite containing 0.5% to 3% of manganese. The ore contains locally as much as 5% of barium carbonate. (21) p. 55. Some pyrolusite is pseudomorphous after a carbonate. "In some places below the ore zone calcite and oxides of iron and manganese occur; in others, below the ore, there is only porous granite". (21) p. 56.

Commercial ore disappeared at a depth of 180 feet to 215 feet.

F.C. Fearing, Manganese deposits of Lunenburg County, Nova Scotia; Eng. and Min. Jour. Press vol. 115, 1923, p. 13.

Genesis.

H.E. Kramm considers that the granite was the source of the manganese. He states that the biotite of the granite, when tested chemically for manganese gave a strong reaction and is the mineral which contains the manganese in the granite. He says that biotite is easily broken down by weathering and gives rise to blackish brown stains. This, together with the fact that the veins occur in the granite, suggests to Kramm that the source of the manganese was the granite. He thinks that manganese was deposited as psilomelane from the surface waters.

F.C. Fearing (2) believes that the manganese was deposited as a carbonate from percolating surface waters which derived their manganese content from Carboniferous rocks, which he assumes to have overlain the area.

In order to disprove the theory that the manganese was dissolved from the granite by hypogene solutions and then redeposited where it is now found, Fearing took a number of samples of wall rock and examined them microscopically and chemically. One set was taken near the vein deposit and another was taken from several hundred feet away. From this examination he makes the following generalizations:

1. "The biotite is the only mineral present in the granite which contains manganese.

2. The biotite remains fresh long after the other constituents have altered. In the few instances where the biotite has been attacked, no manganese minerals whatever were formed.

3. In the vicinity of the fissures the granite shows no signs of alteration.

H.E. Kramm, On the occurrence of manganese at New Ross in Nova Scotia; Can. Min. Inst. vol. 15 p. 210-217.

4. Sulphide occurs in minor amounts in the granite.

5. At the surface the manganese content of the granite, although highly variable, averaged 0.22% as compared with 0.13% in the average granite, but at depth its manganese content was normal and the biotite still lustrous, even though directly in the path of whatever mineralizers had traversed the fissures. The granite shows no sign of any impoverishment of its manganese content". (20) p. 14.

From these five generalizations Fearing concludes that "The source of the manganese cannot be found in the granite". (20) p. 15. Objections to the derivation of this conclusion from the above five generalizations are:

1. One would not expect impoverishment of the granite near the zone of deposition, where Fearing's samples were taken, because there would be no solution of manganese in waters already so concentrated in that element that it was separating out to form an ore deposit. If hypogene solutions dissolved the manganese from the granite, this process would have to take place at so great a distance from the place of deposition that a marked difference in physical chemical conditions could exist.

2. The manganese may have been derived from the granite by surface waters outside of the zone in which conditions were favorable for deposition. Kramm states "That biotite is the least stable of the minerals constituting the granite can readily be observed in the hand specimen. It loses its luster and crumbles. Blackish-brown stains

colour the surrounding orthoclase and quartz" This is contradictory to Fearing's statement. Experiments by W.S. Savage lead him to conclude that "Manganese in primary distribution in rocks (includes igneous rocks...A.W.N.) is taken into solution chiefly by the action of carbonated waters".

Fearing's objections to a source in the Precambrian gold-bearing series are: In Devonian time erosion must have been exceedingly intense to have removed the rocks overlying the granite before Horton time. "It seems unlikely that such deposits could have accumulated in the face of the erosion just described, and least of all in the region of the present deposits, where this erosion was probably severe. The source of the manganese should therefore be sought in still younger rocks".

Granting that it was impossible for manganese deposits to accumulate in Devonian time, we are still not forced to seek a source in younger rocks, but must consider also the possibility of concentration at some later date. In the southern part of Nova Scotia the Horton Series is absent. (Map 39A. Can. Geol. Surv.) so that the Windsor Series directly overlies the granite and the Precambrian. There is a possibility that this was the case in the vicinity of

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H.E. Kramm Op. Cit. p. 216.

W.S. Savage, Solution, transportation and precipitation of manganese; Econ. Geol. Vol. 31, p. 278.

the New Ross deposit prior to the removal of the Windsor Series in that part. In that case there would probably be time during the Horton period for erosion to have slowed down enough so that a manganese deposit could accumulate. This view is upheld by the fact that the Windsor rocks indicate low-lying shores.

Another possibility is that the manganese came from Precambrian rocks in post-Carboniferous time. There is a roof pendant of Precambrian rocks 4 miles south-east of the deposits. At an earlier date the borders of this mass would be closer still to the deposit. During some post-Carboniferous period of erosion ground water could dissolve manganese from these rocks and transport it to the locality of the deposit.

Fearing concludes that Carboniferous rocks which once overlaid the locality were the source of the manganese. He thinks that while these rocks "were undergoing erosion and weathering, surface waters dissolved out their contained manganese, subsequently sank to the underlying surface of the granite, and then followed the drainage system of the latter .... Precipitation then took place at these favored points along the fissures". He thinks the metals were deposited as the carbonate and that these were later oxidized to oxides.

J.A. Reid thinks that the most obvious explanation of the origin of these deposits is that they resulted from

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W.A. Bell. Op. Cit. p. 55.

oxidation, in situ, of manganiferous calcite veins of hypogene origin.

A.O. Hayes also favors this view, but he does not commit himself as to the origin of the manganiferous calcite. The occurrence of pseudomorphs of pyrolusite after calcite is as easily explained by replacement of calcite by manganese from surface solutions as by weathering of a manganiferous calcite to give pyrolusite.

Evidence against the origin of this deposit by weathering of manganiferous calcite of hypogene origin is the lack of hydrothermal alteration of the wall rock and the scarcity of calcite below the ore bodies in the fractures. In some places calcite is absent below the ore bodies. This is not evidence against the formation of the deposits from manganiferous calcite of surficial origin, because we would expect the calcite to disappear at the bottom of the zone of ground water circulation in that case. This latter theory is improbable. The calcite would have to be deposited below the zone of weathering, because in the zone of weathering, according to the theory, manganiferous calcite is not in equilibrium with its surroundings; otherwise, it would not alter to manganese ore. The percentage of manganese in the calcite is from 0.5 to 3% (20) p. 13. The ore averages about 60% of manganese; hence a volume of manganiferous calcite at least 20 times the volume of the ore deposit would be required to produce the ore. This volume would have to be formed along the fracture between the bottom of the zone of weathering and the lower limit of the zone of ground water circulation. This appears to be quite improbable.

In the light of the present knowledge about this deposit, as described in the literature on the subject, the following explanation of the genesis seems most plausible:

The manganese was deposited as hydrated oxides from ground waters. The waters obtained their manganese from all those rocks through which they travelled prior to passing through the fissures now containing the manganese. More manganese would be obtained from one formation than from others. The amount of manganese derived from each rock formation would depend on:
1. ease of solution of the manganese from the minerals, i.e. the state in which the manganese occurs in the rocks;
2. volume of formation in the drainage basin of the deposits;
3. manganese content of the rocks; 4. time water was in contact with the rocks; 5. extent of fracturing of the rocks;
6. chemical make-up of the waters while passing through the rocks (e.g. CO_2 content). These things are very difficult to evaluate.

Three formations may be seriously considered as being a possible source of the manganese: the granite, the Precambrian roof pendants, and the Windsor. In evaluating which of these three formations was the most important source, one must know when the ore was deposited. We are concerned with those rocks which predominated in the drainage basin during the period of deposition. A number of things suggest that deposition took place while the Tertiary peneplain existed, preferably just after uplift while considerable flat areas existed in the vicinity of the deposit, but the water table had fallen to about 200 feet below the peneplain surface. Before uplift the underground circulation would be very sluggish and the water table near the surface. This condition would not be favorable for the deposition of manganese in veins.

The workings at New Ross are divided into an "upper mine" and a "Lower mine". The outcrop of the upper mine is 60 feet higher than that of the lower mine. In the lower mine the minerals psilomelane and manganite predominate, even in the ore near the surface. In the upper mine pyrolusite occurs to a depth of 70 feet and then grades into manganite and psilomelane. Also the bottoms of the ore bodies are at about the same elevation in both mines. This looks as though the pyrolusite zone of the lower mine has been eroded away. At least 60 feet of granite would have been eroded since deposition. There is, however, the possibility that the lower mine may have been protected from oxidation by a peat bog.

The elevation at the upper mine is 650 feet. (21) p. 54. This is just about the elevation of the peneplain as projected to this district. These things are suggestive of deposition after peneplanation.

Because of their location, greater than 12 miles from the deposits, and at a lower elevation, the Windsor rocks might be considered an unlikely source of much of the manganese. The direction of the present drainage is from the deposits to the Windsor rocks. This must have been so for quite a long time, especially since the Windsor rocks, because of their softness, have a tendency to be worn down to lower levels.

It is possible, however, that the manganese was deposited while a thin layer of Windsor limestone overlaid the locality of the deposits. It is not likely that the manganese came from residual deposits along the unconformity between the Windsor and the granite, because granite rarely yields residual deposits of manganese on weathering. Bog deposits could form however. The source of the manganese could be from these bog deposits or from the limestone itself. If the source of the manganese were bog deposits on the granite surface there is no need to bring the Windsor limestone into the hypothesis at all.

Two other possibilities are:

First:- During the formation of the peneplain manganese became concentrated at the surface in bog deposits rather than residual deposits. After uplift and some erosion, these manganese oxides were dissolved and transported as a colloidal solution to the locality of the deposits. Here, under the precipitating influence of the barium ion the manganese was precipitated as psilomelane. The barium may have been derived from the granite. The deposit may have been a locality where two different solutions met; the one containing barium, the other manganese. At the same time manganese was being dissolved directly from the granite in carbonated waters and transported to the deposit as the bicarbonate. It was there precipitated, under the influence of the oxides already present, to form the mineral manganite. These two minerals were later oxidized near the surface to pyrolusite.

(2) The other possibility is that the manganese was dissolved from the granite in carbonated waters. It was transported in the zone of oxidation, and oxidized. It then formed a colloidal solution from which it was precipitated by the barium ion to form psilomelane in the deposit.

The association of nearly all of the maritime deposits with the base of the Windsor suggests very strongly that this deposit is no exception. Further investigation may lead to conclusive results.

Gowland Mountain

A deposit of manganese occurs four miles east of Elgin on the north slope of Gowland mountain. Elgin, on the Canadian National Railway, is the nearest shipping center.

The deposit is a vein in a fine grained, altered rock which is associated with granite and greenstone, probably of Precambrian age. Carboniferous sediments overlie these rocks a few hundred feet to the north. Ten trenches prove the existence of the vein for 225 feet along the strike. The ore body is nearly vertical. The walls are slickensided vertically and the gangue is chiefly angular fragments of wall rock.

Wright (1) divides the mineralized zone into three types: (1) Grade A. almost pure manganese minerals; (2) Grade B. manganese minerals with numerous fragments of wall rock; and (3) manganiferous breccia, consisting chiefly of angular rock fragments cemented with manganese minerals. These types grade into one another. The ore consists of manganese oxides. The original mineral was probably psilomelane. (2) p. 78. This has altered to crystals of braunite with some manganite and pyrolusite. Analyses of ore collected by Hayes (3) in 1917 gave the following results:

Mn	50.67	24.69
Fe	0.30	3.0
SiO_2	15.0	

Concentration tests were made on the lower grade material by the Mines Branch, Ottawa, in 1918. As a result of these tests Hayes concludes that, "In practise, on an ore of this class to obtain a concentrate of grade 50% manganese, a recovery of 50% of the manganese values could be expected. To obtain a concentrate of 40% manganese a recovery of 60% could be expected" . (3)

The whole vein varies in width up to six feet and averages about 3½ feet. The grade A ore has a maximum width of 4 feet 4 inches, and averages three feet. Calculations by W.J. Wright (1) indicate that the vein would yield 75 tons of grade A ore per foot of depth. He thinks it not improbable that the ore would extend to a depth of about 200 feet.

Wright states that "The mineralogy and texture of the vein indicate that the manganese minerals were concentrated by descending atmospheric waters". (1) p. 287.

This deposit is very similar to that at New Ross and hence must have a similar origin. However, it differs from the New Ross deposit in several details. It contains the mineral braunite, $3Mn_2O_3.MnSiO_3$. It is at an elevation of less than 1,000 feet. (2) p.77. Hence it is more than 100 feet below the peneplain surface. It is in Precambrian igneous rocks and Carboniferous sediments outcrop a few hundred feet to the north.

The source of the manganese was both the Precambrian and the Carboniferous rocks. After uplift more erosion took place both before and after deposition than at New Ross. The result of this was that more of the pyrolusite zone was eroded away. (This assumes that erosion proceeded faster than alteration to pyrolusite.) Also the ground waters obtained their manganese from fresher less weathered igneous rock. Mechanical erosion was faster with the result that manganese was deposited in a more reduced condition forming the mineral braunite.

Two processes were active in the formation of this deposit. In the first, manganese dioxides were dissolved from the Windsor to form a colloidal solution. It was transported to the deposit and precipitated as psilomelane. In the second, manganese was dissolved by carbonated waters from the igneous rock and precipitated as braunite by the catalytic action of the already precipitated manganese oxides. This is substantiated by the fact that braunite is of later origin than psilomelane. Other investigators explained this relation by saying the psilomelane altered to braunite. (2) p. 78. The predominance of psilomelane in the ore suggests that the colloidal process was the most active of the two; and hence, the overlying Carboniferous rocks supplied most of the manganese.

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British Columbia Deposits.

A number of deposits occur in British Columbia, but they are not of great economic importance. In the case of an emergency a few tons may be derived from the known deposits.

Three deposits are worthy of consideration. The most important is in the vicinity of Cowichan Lake, Vancouver Island. From it most of the manganese ore produced in British Columbia has been mined. Bog deposits, known as the Manganese Group, are located about 7 miles from Kaslo in south-western B.C.

Residual and Replacement Deposits.

Cowichan Lake.

There are several deposits near the north-east side of Cowichan Lake.

The rocks in this vicinity are the Vancouver volcanics, and the Sicker series, which consists of metamorphosed, sedimentary and volcanic rocks. These are all of Jurassic or Triassic age. Stocks of granodiorite intrude these in several places. The manganese deposits are in a bed of cherty quartzite of the Sicker series.

Two of the Cowichan lake deposits are of importance, the Hill 60 group and the Black Prince group.

At the Hill 60 group the ore body was 20 feet wide at the surface, 40 feet long and 30 feet deep. The bottom of the ore body was wedge shaped, and the ends interfingered with the quartzite, which strikes N70°W and dips steeply south.

The ore was a mixture of compact oxides. It contained from 40 to 48% of manganese, and about 22% of silica. Rhodonite is plentiful in the leaner parts of the ore body and in the quartzite. Not enough is known about this deposit to indicate how it originated.

The concentration of the manganese has been attributed to removal of waste by solution and to replacement processes. The present ore body is thought to be the result of weathering of the rhodonite.

G. Hanson, Manganese deposits of Canada; Econ. Geol. Ser. No.12 Geol. Surv. Can. p. 118.

About 1,000 tons of ore have been removed from it.

Contact Claims.

This deposit is on the south-western slope of Kaslo Creek, 14½ miles by rail from Kaslo.

A limestone member of the Slocan series is intruded by a small porphyritic igneous body. This limestone has been replaced by a manganiferous siderite, which has been oxidized near the surface. Galena, sphalerite, and pyrite are associated with the ore.

The thickness of the body averages 20 feet and is known for 200 feet along the strike.

The ore contains from 8 to 12% of manganese and from 43 to 62% of iron.

The mineralogy and geology of this deposit suggests that it is of hydrothermal origin.

Sedimentary Deposits (Bog Type).

Manganese Group.

These deposits are on the eastern slops of Kaslo Creek valley, 7 miles from Kaslo.

The rocks underlying this locality are black argillites dipping about 65° south-west. These rocks are underlain in the east by greenstones, which are underlain in turn by Milford sediments. A thick mantle of glacial till and alluvium overlie these rocks. The deposits are of the bog type on river terraces.

One of the bogs covers an area of 5½ acres, another 2½ acres. The bogs have a thickness of from nothing to 3 feet.

The material in the deposit is of variable grade. The lowest grade material contains about 10% of manganese. That of highest grade contains 50% (G. Hanson, Op. Cit. p. 110) These deposits were sampled by drilling auger holes, irregularly spaced, all over the deposits. It was calculated that about 2,270 tons of 30% ore and several hundred tons of 50% ore occurred in one deposit.

C.E. Cairnes, Econ. Geol. Ser. No. 12, Can. Geol. Surv. p. 109.

About 700 or 800 tons are still left in another deposit from which most of the production has come.

About 1,000 tons of ore have been removed from this deposit. This ore contained between 45 and 50% of manganese.

The manganese was dissolved by ground water from the underlying rocks of the region and precipitated where this water issued at the surface as springs.

CHEMICAL ASPECTS OF THE CONCENTRATION OF MANGANESE.

The percentage of manganese in the earth's crust is, according to F.W. Clarke, 0.084.

F.W. Clarke; Data of Geochemistry; Bull. 770. U.S. Geol.Surv.
The amount of manganese in igneous rocks is from 0.05 to 0.15.
Twenhofel; Principles of Stratigraphy.

The percentage is higher in basic than in acidic rocks. These rocks are the ultimate source of all manganese deposits.

To be of commercial value a manganese deposit must contain 30 to 40% of manganese depending on the size of the deposit, its location and many other economic factors upon which the cost of production depends. In order to obtain such concentration of manganese from an average of 0.084% manganese must be transported and segregated, or concentrated by residual processes. The mode of occurrence of manganese minerals indicate that this concentration occurs by two types of processes: igneous and aqueous.

The minerals rhodochrosite and rhodonite occur in veins and are the result of concentration from hydrothermal solutions emanating from igneous bodies. These solutions form by processes of differentiation in the magma and then proceed upward along fractures. As they get farther from the magma their physical environment changes, the temperature falls and the pressure decreases. The manganese minerals may no longer be in equilibrium with these solutions and they separate out largely as the carbonate and silicate, forming deposits of these two minerals. Such a deposit occurs at Blue Hill, Maine, where rhodonite forms a vein 15 feet wide. These minerals may subsequently be oxidized to oxides by the processes of weathering, resulting in a deposit rich enough to be worked profitably. Considerable manganese has been mined from the oxidized parts of such veins near Philipsburg and Butte, in Montana.

Manganese may be transported by water either mechanically or in solution. Mechanically deposited manganese is not of great importance. Such a deposit occurs at Memel in Albert County, New Brunswick. (G. Hanson, Op. Cit. p.70) Here nodules of manganese occur in a conglomerate bed. The nodules are hard and consist largely of psilomelane. These may be regarded as placer deposits.

Manganese is not commonly concentrated in placer deposits. The reason for this is that the manganese minerals found at the surface are quite soft and disintegrate readily. The harder minerals, such as psilomelane, alter to softer oxides at the surface. If mechanical erosion is faster than chemical weathering, some unaltered psilomelane may accumulate in placer deposits.

Concentration of Manganese in Rocks by Ground Water.

The deposition of manganese from ground water is a chemical process and the chemical properties of manganese is the dominant controlling factor. The history of the rocks and the mode of occurrence of the minerals indicate what conditions existed at the time of deposition. We may then determine what chemical processes involving manganese may take place under these conditions, and which will result in the mineral associations found in the deposits. In the investigation of the origin of these deposits, we are fortunate that natural conditions are easily duplicated in experiments. Many of these have been carried out and are described in the various chemical journals. Unfortunately, few of them have been carried out by geologists and the investigators have not realized that their results are of great value to the geological science.

In igneous rocks manganese is largely in the form of silicates. Manganese can take the place of iron in many of its compounds. Hence, it is quite common as a constituent of the ferro-magnesian minerals, such as biotite, olivine, garnets, pyroxenes, amphiboles, and also a large number of other minerals.

E.C. Harder, Manganese deposits of the United States; Bull. 427. U.S. Geol. Surv. p. 20 to 23.

Manganese has three common valences, namely, 2, 4 and 7. In natural compounds it exhibits the valences 2 and 4 most commonly. The manganic compounds have a valence of 4, and in this report is called the "oxidized" state. The manganous compounds have a valence of 2 and are said to be in the "reduced" state. In igneous rocks manganese occurs in the reduced state. But in sedimentary rocks it may occur in the reduced state as the carbonate, or it may occur in the oxidized form.

W.S. Savage (1) conducted a series of experiments to determine the solvent action of pure water, oxygenated water, carbonated water, and solutions from decaying organic matter, on the manganese in certain rocks known to contain it in small amounts. A syenite and a diabase were the rocks used in the experiment. The syenite contained 0.062% of MnO and the diabase 0.136%. Coarsely and finely ground samples of each rock were used to determine if the degree of disintegration had any effect on the rate of solution. These samples were placed in the various solutions in Winchester jars and allowed to remain in contact with the solutions.

As a result of these experiments Savage concludes (1) p.285.

1. "Manganese in <u>primary</u> distribution in rocks is taken into solution chiefly by the action of percolating carbonated waters.

2. Carbonated waters will take manganese carbonate and manganous oxides into solution but the higher oxides are soluble only to a very slight degree.

3. Peat solution is the next most effective solvent, largely on account of free carbonic acid resulting from the decay of organic matter. The organic acids may play a small part as solvents of manganese.

4. Oxygenated water had the least solvent action of any of the solutions used in the experiments.

5. The degree of disintegration has a direct bearing on the quantity of manganese taken into solution by circulating waters.

6. The role of water containing free sulphuric or hydrochloric acid in the solution of manganese is small in comparison with the widespread solvent action of meteoric waters containing free carbonic acid".

It is quite probable that the manganese dissolved in the above manner is transported as the bicarbonate. (3) p.756. W.S. Savage says that the waters must be acid, (1) p. 290., and that this acidity is due to carbonic acid. Experiments by him show that manganese is not precipitated in acid water by oxygenation, but it is in alkaline water. Experiments by Savage in which he oxygenated alkaline carbonated water containing manganese and peat solution indicate that the transportation of manganese is independent of organic matter.(1) p.288. Organic acids must have little effect in the transportation of manganese, otherwise it would not be precipitated in peat bogs.

The problem of the deposition of manganese has been quite well investigated beaause it must be removed from water supply systems. If the manganese has not been removed it may be precipitated in the water mains, and will plug them up.

Such an investigation has been carried on at Brainerd, Minnesota, and described by Carl Zapffe. (2) p.799. He had a manganese removal unit designed and installed. This has been very successful in removing the manganese. Zapffe is of the opinion that the conditions in this unit are the same as conditions of deposition in nature. (3) p. 767. The main principle used in demanganizing the water at Brainerd is that MnO_2 catalyzes the precipitation of manganese from solution in natural waters. It was found that when slightly alkaline water (natural) was shaken with a precipitate of Mn and Fe oxides the iron and manganese were precipitated quickly and completely as oxides. In the Brainerd demanganization unit the alkalinity of the water rarely exceeded 7.5 A slight degree of alkalinity is essential. The alkalinity need not be high. In this unit the water is sprayed to bring it in intimate contact with oxygen, and to remove CO_2. The role of the oxygen is to oxidize the manganese from a valence of 2 to a valence of 4. The equations which best describe this reaction are given by Savage. (1) p. 288.

$$2Mn(HCO_3)_2 + 4H_2O = 2Mn(OH)_2 + 4H_2O + 4CO_2$$

$$2Mn(OH)_2 + 4H_2O + O = 2MnO.OH + 5H_2O$$

$$2MnO.OH + 5H_2O + O = 2MnO_2 + 6H_2O$$

It is well known that the "iron bacteria" are active in precipitating iron. Two of these species, Crenothrix polyspora and Leptothrix ochracea, increase in size on inorganic manganese salts, and prefer them to iron salts. (1) p. 290. Bacteria have frequently been used to remove manganese from water supply systems. They are however more difficult to control in demanganization plants and may themselves become so abundant as to create a nuisance. Savage thinks that their action in the precipitation of manganese is to absorb CO_2 and to increase the alkinity, thereby tending to cause precipitation.

In nature we find manganese not only in the form of the dioxides, but also as the carbonate.

N.C. Dale, The Cambrian manganese deposits of Conception and Trinity Bays, Newfoundland; Amer.Phil.Soc., vol.14 pp.371-456

The explanation of the occurrence of $MnCO_3$ is suggested by Zappfe in the following equations: (3) p. 757.

(a) $FeO + CO_2 = FeCO_3 + 5.0$ calories

(b) $MnO + CO_2 = MnCO_3 + 6.8$ "

(c) $2FeO + O = Fe_2O_3 + 26.6$ "

(d) $2MnO + 2O = 2MnO_2 + 21.4$ "

It is a well known principle in chemistry that when there is the possibility of several reactions taking place, that one proceeds which is accompanied by the greatest evolution of heat. Zappfe says that when a limited amount of oxygen is present together with carbon dioxide, the iron in solution will combine with the oxygen before the manganese, because reaction (c), above, will proceed before reaction (d). The CO_2 in the solution will combine with the manganese in preference to iron to form $MnCO_3$. This same principle explains the earlier deposition of iron in bog deposits of manganese.

The solubility of rhodochrosite in a saturated carbonic acid solution is about 40 p.p.m. (5) p.468. Since the concentration of manganese in natural waters is much lower than this, the deposition of $MnCO_3$ from these waters must be explained by some other means than insolubility under existing conditions in these solutions. Savage showed by experiment (1) p. 291 that manganese is precipitated as $MnCO_3$ from a solution of manganese bicarbonate by powdered limestone.

G.A. Thiel conducted some experiments on the precipitation of manganese from various solutions by means of different rocks, including limestone, $MgCO_3$ and clays. He found that $MgCO_3$ had the greatest effect in precipitating manganese from carbonated solutions. A survey of the literature of manganese deposits in United States indicates that manganese deposits are quite commonly associated with dolomite or dolomitic limestone. The deposit at Tennycape, Nova Scotia, is in a dolomitic limestone.

<u>Summary</u>: Manganese is dissolved from rocks in which it occurs in the reduced state by carbonated waters. These waters are acid by virtue of the carbonic acid they contain. The element is transported as the bicarbonate. Factors in precipitation are: the catalytic effect of MnO_2, Oxygenation, Alkalinity, Thread Bacteria, $CaCO_3$ or $MgCO_3$, Escape of CO_2.

The above process probably will not explain transportation of manganic compounds, because to be transported as the bicarbonate the manganese would first have to be reduced to a valence of 2. Reducing conditions are rare in the zone of

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G.Hanson, Op. Cit. p. 42.

ground water circulation, but they do exist in peat bogs. An investigation to determine if manganic compounds can be reduced in peat bogs would be instructive.

The following theory is offered to explain the transportation of manganese from a source in which it occurs as dioxides to a deposit in which it is found in the same mineralogical forms. The hydrated manganese dioxides alter to pyrolusite. This powdery mineral is taken up by ground waters. The MnO_2 may first be in suspension and later the particles become more finely divided, and are also hydrated. This results in a colloidal solution of hydrated manganese dioxide. The manganese is transported in this form and is deposited by means of the precipitating influence of the Barium ion, and possibly other electrolytes. Psilomelane is formed in this way.

Considerable experimentation has been done by chemists on colloidal manganese dioxide. B. Ghosh states that "Hydrated manganese oxides carry a negative charge in contact with water". It is this negative charge that keeps apart the colloidal particles of manganese oxide. The particles repel each other and hence have no tendency to coagulate. If, however, an electrolyte is added to the colloidal solution the positively charged cations are adsorbed on the surface of the particles. The positive charge of the cation neutralizes the negative charge of the particles, which may then come together and the colloid

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B. Ghosh, Parallelism between the effect of neutral salts on the electric charge of hydrated manganese oxides and the concentration of the hydrogen ion liberated: Jour.Chem.Soc. 1926 p.2605-14.

coagulates. The adsorbed ions of the electrolyte are found in the resulting precipitate, intimately mixed with it.

B. Ghosh states, as a result of his experiments, that "The capacity of the cations to decrease the negative charge of the surface is in the order: Ba, Sr, Mg, K, Na, Li." Vitalius and Baladin and others (listed in the bibliography) have shown by experiment that the barium ion is strongly adsorbed on hydrated manganese dioxide. N.G. Chatterji and N.R. Dhar state: "Our experiments show clearly that coagulating power and adsorption go hand in hand". These experiments and others show without doubt that the barium ion has a strong tendency to precipitate hydrated manganese oxides from colloidal solution.

B. Ghosh (Op. Cit. p. 2605) says that in the precipitation of manganese oxides from colloidal solution "A solid of variable composition, *depending on conditions of preparation*, is produced which can be represented as $xMnO_2.yMnO.\ zH_2O$.

The mineral psilomelane has all those characteristics which definitely indicate that it is formed from a colloidal solution. These are: 1. it is not crystalline; 2. it has a botryoidal concentric structure; 3. it has an abundance of impurities. This feature is very characteristic of colloidal precipitates. The impurities in psilomelane are ions which

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B. Ghosh, Op. Cit.

Vitalius and Baladin, Zeitschrift Anorg. Allgem. Chem. 149, pp. 159-166, 1925.

Colloid Zeitschrift 33, pp. 18-29 (1923) have been found by experiment to have a strong tendency to coagulate MnO_2. Its composition is well described by the formula given by Ghosh for these precipitates, i.e. $xMnO_2 . yMnO . zH_2O$.

Analyses of psilomelane from various localities are as follows:

E.S. Dana, Descriptive Mineralogy, sixth edition, p.257

MnO_2	MnO	O	BaO	CaO	MgO	Na_2O	K_2O	Li_2O	H_2O	Al_2O_3
	75.74	14.66		0.26	0.08	0.84	3.38	0.48	3.76	2.53
	67.87	13.66	0.20	0.10	0.20	0.39	0.38	0.21	6.42	6.32
	74.79	15.06	0.61	1.18	0.52	0.18	2.59	----	3.06	1.16
	69.76	13.93	6.50	0.52	0.66	0.76	2.17	----	3.90	0.87
	67.29	12.19	6.43	1.33	0.21	0.69	1.89	tr.	3.10	1.10
69.2	8.5	---	16.8	0.4	0.2	0.1		----	4.8	
71.6	8.2	---	8.5	1.1	0.7	--	1.0		8.9	
83.6	8.2	---	1.0	0.2	0.2	1.4	---	----	5.4	

Minor amounts of iron, copper, cobalt, lead and silica are also present. It is seen from the above analyses that much barium and potassium are contained in the mineral. There can be little doubt that these were the electrolytes which caused the precipitation of the manganese. In psilomelane the barium apparently occurs in intimate association with the MnO_2. That is to say, in such a finely divided state that most of the barium can not be detected as a separate mineral under the microscope.

Psilomelane alters to manganite. This process is not colloidal, and the formation of crystals results. The contained barium is naturally also affected, and it crystallizes in the form of barite, which is almost invariably associated with manganite and pyrolusite. Sometimes it forms barium carbonate but this mineral is much less common in manganese deposits. It is also probable that some deposits may be formed by a combination of the above two processes. Manganese would be taken into solution in carbonated waters from manganous compounds. It would then be transported through the zone of oxidation in acid solution. The manganese in solution would become oxidized to hydrated oxides and would remain in solution as a colloid. When this colloid came into contact with some electrolyte it would be precipitated as psilomelane.

Of the two processes outlined above, it is probable that the colloidal process was the dominant one in the Maritime deposits in Windsor limestone. The large amounts of psilomelane and the invariable association of barite suggests this.

THE ORIGIN OF CANADIAN MANGANESE DEPOSITS.

Nova Scotia and New Brunswick Deposits.

Summary of Geological Relations:- Manganese deposits occur in rocks of nearly all ages. The occurrence of a few small bog deposits overlying the Precambrian sediments and one or two analyses indicate that the Precambrian contains considerable manganese. This may either have been introduced or deposited with the sediments. A vein deposit at Gowland Mountain, N.B., in Precambrian felsite has probably been introduced from near-by Windsor rocks.

In Ordovician slate, manganese is found in veins near Bathurst, New Brunswick.

In the Silurian a sedimentary concentration of manganese occurs near Woodstock.

In Devonian granite veins of manganese occur near New Ross. These have been introduced into the granite by ground waters. These waters may have derived their manganese either from the granite or from the Windsor which overlies the granite twelve miles away. In the Cobequid Mountains, Nova Scotia, igneous rocks, probably of Devonian age, have introduced manganese as the mineral ankerite in fissures in sediments.

In the Horton Series a number of vein deposits occur just below the unconformity at its top. These may have derived their manganese from residual deposits on the unconformity or from the Windsor Series which overlies the Horton.

In the Windsor Series replacement deposits occur in the basal limestone just above the unconformity. These deposits are always in the basal bed.

At Shepody Mountain, New Brunswick, a residual deposit occurs along an unconformity. The deposit is underlain by Lower Carboniferous limestone and is overlain by a conglomerate which may be of Lower Carboniferous age. At Memel, in the same district, pebbles of ore occur in a conglomerate of similar appearance to that at Shepody Mountain. The ore was incorporated in the conglomerate in the same manner as the pebbles. This conglomerate lies on an unconformity.

In the upper part of the Windsor, manganese replaces Windsor limestone along layers just below the unconformity. The Windsor is overlain by Pennsylvanian rocks.

In the Pennsylvanian there must be a high concentration of manganese because large bog deposits occur in regions underlain by these rocks. Some of them occur in places where the only possible source of the manganese is the underlying Pennsylvanian.

Sources and Redistributions of Manganese.

The Devonian granite and Precambrian igneous rocks are the only rocks which need to be seriously considered as possible sources of manganese in the Maritimes.

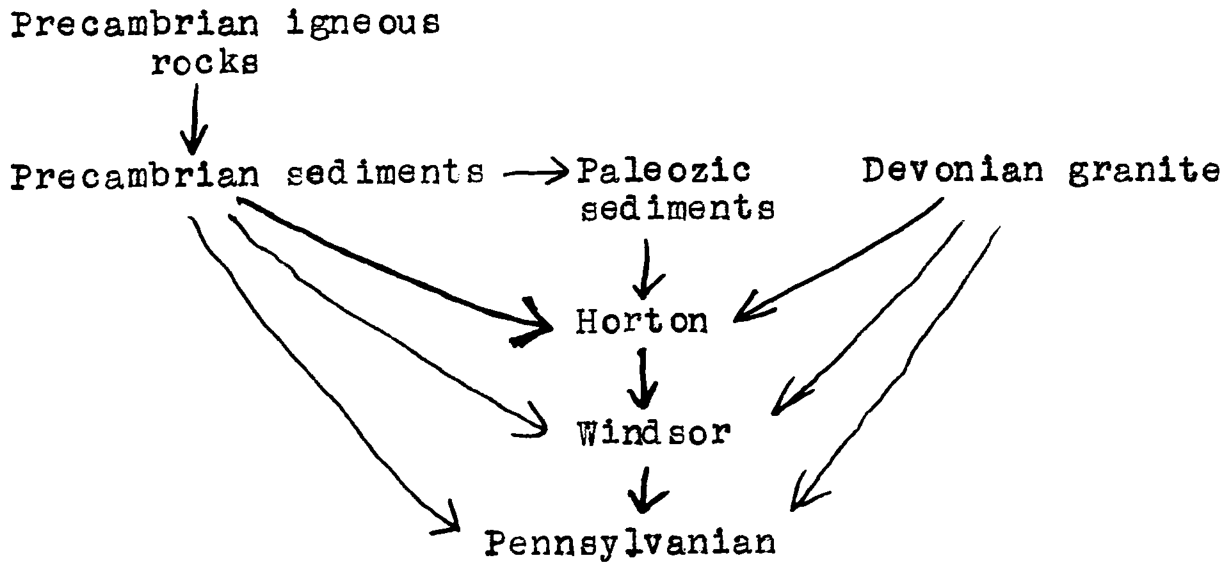
Nova Scotia: The first igneous rocks were of Precambrian age and older than the Meguma Series. Both volcanics and intrusives probably occurred. These rocks were either directly or indirectly the source of the sediments of the Meguma Series and of any disseminated sedimentary manganese which they contain. Analyses of the Meguma Series, quoted by W.J. Wright, indicate a high manganese content.

W.J. Wright, Data on the method of granitic intrusion in Nova Scotia; Trans. Roy. Soc. Can. sec. IV. 1931, p. 323

The part played by the pre-Carboniferous Paleozoic sediments in the development of the manganese deposits is unknown. The present areal extent of these rocks is small, but they may at one time have been widespread and later removed by erosion, or they may have been deposited only in local basins. The fact that coarse grained Devonian granite is now found cutting Devonian sediments, suggests that, at these places, during crystallization, the granite was overlain by such a thickness of sediments (which must have been Devonian), that a coarsely crystalline granite formed. These early Paleozoic rocks were nearly all removed by Carboniferous time. They may have provided a large part of the material of the Horton Series. If so, their only effect, as far as the manganese is concerned, was to provide temporary storage of manganese, which was later transferred to the Horton Series.

The gold bearing series and the Devonian granite also supplied much of the material of which the Horton Series is composed. The Devonian granite brought to the surface a fresh supply of manganese and contributed some of it to the Horton Series.

By the end of Horton time, according to Bell, the land surface was reduced to a low-lying peneplain. Because chemical transportation and because manganese oxides are not readily transported chemically, residual concentrations of manganese became abundant upon the surface underlain by Horton rocks. Much of this manganese was transferred to the Windsor Series by sedimentation. Another erosion period occurred at the end of Windsor time. Some residual manganese probably formed on this surface, most of which was later transferred to thá Pennsylvanian. The Windsor and the Pennsylvanian could also obtain some manganese directly from the pre-Carboniferous rocks. The following diagram illustrates these ideas:

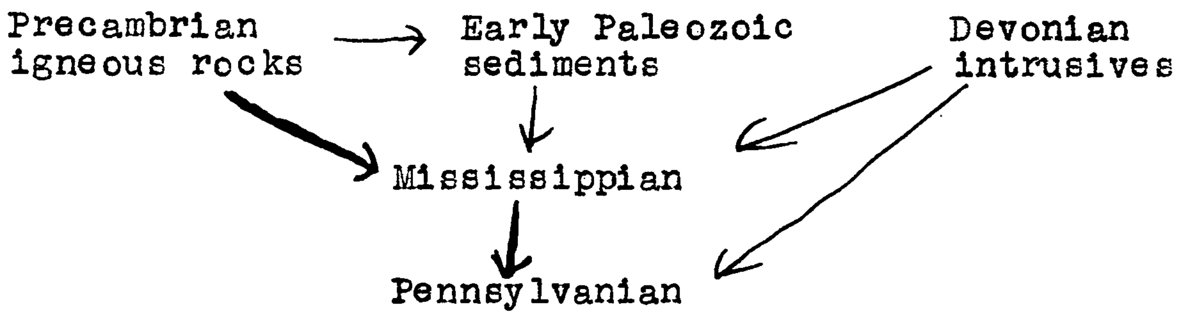


The arrows indicate transference of manganese.

The deposits obtained their manganese from these rocks in the manner described under each deposit.

New Brunswick. In New Brunswick the Maguma series and the Horton series are absent, and Precambrian volcanics occur.

Precambrian igneous rocks brought the first manganese to the surface. From these rocks the Lower Carboniferous obtained most of its manganese, with possibly some additions from Devonian intrusives and early Paleozoic sediments. The Pennsylvanian obtained most of its manganese from residual deposits on the Mississippian. The following diagram illustrates the situation.



Causes of Concentration.

In the Maritimes the most important factor in bringing about the concentration of manganese was the pre-Windsor erosion period and the conditions existing on that surface.

The occurrence of salt and gypsum in the lower parts of the Windsor indicates that a warm climate prevailed. The thinness of elastic beds at the base of the Windsor is evidence that the pre-Windsor land surface was one of low relief. Bell's observations agree with this.

W.A.Bell, Mem. 155, Can. Geol. Surv. p. 55.

A warm climate tends to speed up chemical weathering processes and a low-lying land is not conducive to mechanical transportation. These conditions would be favorable to the accumulation of residual manganese deposits. The manganese minerals would be oxidized near such a surface where, being very insoluble, they are not readily transported in solution; but they could be transported mechanically, especially after conversion to pyrolusite, which breaks down easily into fine particles.

When the Windsor seas transgressed the low-lying Horton land surface much of the residual manganese was probably incorporated in the Windsor sediments. In general this transgression was not very vigorous, as is indicated by the small amount of clastic sediments at the base of the Windsor.

Because of the inactive nature of the advancing Windsor sea some of the residual deposits may have been preserved along the unconformity. If the above is a correct view of conditions during the deposition of the Windsor Series the basal beds should be richer in manganese than those higher in the series, because the residual deposits from which the manganese was obtained would have soon been all removed or covered up. Analyses made by E. Gilpin suggest that this is the case. Four analyses of basal limestone from Springville, (Pictou Co.), Tennycape, and Salmon River have the following

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E. Gilpin, Manganese ores of Nova Scotia; Trans. Roy. Soc. Can. vol. ii. (1884) p. 9

manganese content:

Springville... 1.38 and 1.83% $MnCO_3$
Tennycape ... 4.58% MnO_2
Salmon River..14.586% $MnCO_3$

Another analysis by the Durham College of Science of a limestone above the first gypsum bed gave only 0.55% MnO_2.

Other analyses should be made at various localities in a series from the bottom of the Windsor to the top to prove that this relationship was constant. It might also be done petrographically.

The Pennsylvanian sediments were later laid down on the Windsor Series after another period of erosion.

After uplift the present erosion surface was developed. This cut across the dipping pre-Windsor unconformity. As erosion progressed it would be a simple matter for the solutions to dissolve manganese from the residual deposits along the unconformity and from the Windsor rocks and to deposit it in the limestone where conditions were favorable to deposition.

The characteristics of the limestone which made it favorable to deposition were: 1. The proximity of the basal bed to the source of much of the manganese; i.e. the upper part of the Horton, deposits along the unconformity, and the primary disseminations in the lower part of the Windsor.

2. Fractures, solution cavities and bands of intraformational conglomerate formed channels and openings in which the solutions could migrate. 3. The chemical composition of the

limestone, such as its content of manganese, $MgCO_3$ and $CaCO_3$ which have a chemical effect in precipitating manganese. It also contained various electrolytes which would precipitate manganese colloids. It probably contained barium which was effective in precipitating much manganese and is commonly found in association with the manganese oxides.

The two features which caused the deposition in the basal bed rather than others are: it was nearer to the unconformity with its residual deposits, and it had a higher original content of manganese.

An erosion period took place at the end of Windsor time. This also probably caused the concentration of much manganese in residual deposits. Since there are thick beds of conglomerate at the base of the Pennsylvanian, we may say that the transgression of the Pennsylvanian seas was considerably more active than that of the Windsor. Hence, residual deposits would have a smaller tendency to be preserved along this unconformity. Most of this material would be incorporated in the Pennsylvanian, giving it the high manganese content now observed. In this case also the higher manganese content should be found near the base of the Pennsylvanian. The Dawson Settlement bogs are underlain by the lower formations of the Pennsylvanian.

Although the manganese content of the Pennsylvanian is high, deposits of manganese in it are not common. The logical explanation of this, in view of the fact that we get bog deposits derived from the Pennsylvanian, is that conditions in these rocks were not suitable for deposition. In the Maritimes, soils derived from the Pennsylvanian are not farmed because of their acid character, whereas soils above the Windsor are farmed. The Pennsylvanian rocks themselves would, hence, tend to have an acid character. Zappfe and others found that manganese was not precipitated in an acid environment. So we have deposits in the Windsor not necessarily because of a more abundant source of manganese than in the Pennsylvanian but because conditions were more favorable to deposition.

At each unconformity and on the present surface the following deposits are possible:

1. Residual deposits in clays on the unconformity surface.
2. Bog deposits on the unconformity.
3. Vein deposits below the unconformity in the zone of ground water circulation of that time.
4. Replacement deposits below the unconformity.
5. Sedimentary deposits and disseminations above the unconformity.

Where two surfaces of erosion come near each other in space, it is necessary to determine to which of the surfaces the deposit is most closely related. This involves the time of deposition. When the time of deposition is known, the unconformity to which it is most closely related is also known, and vice versa.

British Columbia Deposits.

The bog ores of British Columbia have an origin similar to those of the Maritimes, that is, manganese was dissolved from underlying rocks by carbonated waters and was deposited where these waters issued at the surface as springs.

Considerably more work is required to be done on the Cowichan Lake and Contact Claims deposits before their origin can be worked out with certainty. However their relationships have some similarity to the deposits in India and Brazil. The oxides were derived from silicates and carbonates by weathering. The silicates and carbonates may have been introduced hydrothermally or they may be the result of metamorphism on the original manganese in the sediments.

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SUMMARY OF ECONOMIC POSSIBILITIES.

The deposits at the base of the Windsor are of most economic importance. Further exploration in the basal beds will probably expose replacement deposits similar in size, distribution and grade to those already mined. The largest mine in the Maritimes, the Markhamville, yielded 23,000 tons of high grade ore. Most of the others produced only a few hundred tons. It can be seen that such deposits can not be the basis of any very large industry, but a number of small operations may develop.

It is possible that large residual deposits may exist on the unconformity at the base of the Windsor. It would be advisable to prospect thoroughly along this unconformity, especially in those places where a quiet overlap of the Windsor sea is indicated, and also in the vicinity of the Shepody Mountain deposit.

The base of the Lower Carboniferous east of Woodstock should be well inspected. The rich supply of manganese in the Silurian in that district might give rise to deposits in the Carboniferous rocks.

It is also possible that sedimentary deposits may occur in the basal limestone of the Windsor. The deposits in Russia are associated with a marine limestone bed just above an unconformity.

The sedimentary deposits near Woodstock will probably not be of economic value unless some method of concentration is devised, or the price of spiegeleisen goes up considerably, due to emergency conditions.

The possibility of working the bog deposits is more hopeful. These ores may be mined with a smaller increase in price. They are much more easily mined than the Woodstock deposit would be. However, the bog ores would have to be briquetted before use because of their powdery nature when dried and ignited.

In 1939 the dump at Tennycape was investigated by diamond drilling. Considerable manganese may be obtained from this source by using some method of concentration.

APPENDIX.

Uses of Manganese.

Alloys:

1. Ferromanganese
2. Spiegeleisen
3. Manganese steels and low alloy steels
4. Cupro-manganese
5. Manganese bronze and brass
6. Manganese German silver
7. Manganese-aluminium alloys
8. Alloys with magnesium and antimony.

Other uses:

Batteries,
Chemicals,
Driers,
Fertilizer,
Ceramics,
Glass-making,
Pigments,
Miscellaneous.

About 95 per cent of the manganese ore mined is used in the metallurgical industry. The rest is used in the chemical and related industries.

Most of the manganese used for metallurgical purposes is consumed in the manufacture of carbon steel. The remainder is used in foundry work and high-manganese steels, and to a minor degree in non-ferrous alloys.

In the manufacture of steel, manganese is added in two forms; as ferro-manganese and as spiegeleisen.

A.W. Groves, "Manganese" Imperial Institute Mineral Resources Department.

Ferro-manganese contains 50 to 80% of iron together with from 5 to 7% of carbon. Spiegeleisen contains from 10-35% manganese, from 60 to 85% iron, and 4 - 5% carbon. These alloys are used in the manufacture of steel for the following purposes:

1. They reduce iron oxide which is detrimental to the steel.
2. They add manganese which alloys with the iron and imparts to the finished steel certain desirable physical properties.
3. They hinder the formation of blow holes.
4. They counteract the effect of phosphorus and sulphur, which is to cause brittle and weak steel.
5. They make the iron slag, fluid, and easy to run off.
6. They add carbon to the steel.

No satisfactory substitute for manganese has ever been found. No other element available in large quantities can do the work of manganese in the production of steel with as great economy and efficiency.

Silico-manganese and silico-spiegel are manganese-iron-silica alloys which are used in the manufacture of low carbon steels. High-manganese pig-iron containing from 4 to 10% of manganese is derived from manganiferous iron ores and may also be used as a source of manganese in steel manufacture. Of these alloys ferr-manganese is the most widely used because its high manganese content results in a better control of the manganese-iron ratio in the furnaces.

It also has the advantage of containing more manganese per unit weight than spiegeleisen, thereby making the cost of transportation per unit of manganese less.

During the manufacture of ferro-manganese 15 to 25 per cent of manganese is lost and in the production of spiegeleisen and high-manganese pig-iron about 30 per cent is lost. Between 1911 and 1930 an average of 14.2 pounds of metallic manganese was consumed per ton of steel produced.

The committee consider 14.3 pounds as a good figure for future calculations. Their reasons for this inferred increase are:

1. The modern tendency is to add the ferro-manganese to the furnace instead of to the ladle. This entails a greater loss of manganese.
2. The required manganese content of steel is increasing.
3. The production of manganese steel is increasing.

Manganese steel contains about 86% iron, 12% manganese, and 1¼% carbon. It is very tough and resistant to abrasion. For this reason it is used in such parts as bucket lips of excavators and dredges, sprockets and clutches, wire line sheaves for oil wells, in crossings and points on railways,

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A.W. Groves, Manganese; Imperial Institute, Mineral Resources Department.

Manganese for National Defense; Contribution 48; Amer. Inst. Min. & Metall. Committee on Industrial Preparedness.

and in stamp mill plates.

A.W. Groves, Op. Cit.

It has been recently discovered that manganese may be substituted for some of the nickel in stainless steel alloys. M.J.R. Morris says that increasing attention is being paid to the role of manganese in these steels. Manganese maintains the workability as elements as columbium and titanium are added. An alloy containing 5-10% manganese, 17-19% chromium, and some copper and nickel is not easily oxidized,

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M.J.R. Morris, Iron and Steel; Mining and Metallurgy, January, 1940 p. 55.

resists corrosion and is easily worked.

Mining Journal, 1933, 180. Special supplement February 11,p.14
Chromium-manganese steels; Metallurgist, Feb. 1937, pp.11-13

Steels containing from 0.6-1.6% manganese have greater tensile strength than ordinary steel and are used as structural steels and in other places where greater strength is desired. M.J.R. Morris states that these high tensile low alloy steels will be more widely used in the future.

Average analyses given by Morris for these steels are as follows:

	C	Mn	P	Si	Cu	Ni	Mo	Cr
A....	0.10	0.65	0.015	0.010	1.10	1.20	0.10	
B...	0.14	1.05	0.020	0.015	1.05	---	0.25	
C...	0.08	0.40	0.12	0.70	0.40	---	---	0.95
D...	0.10	0.75	0.10	0.30	0.60	0.50	---	0.60
E...	0.12	0.60	0.015	0.15	1.00	1.75		
F...	0.14	0.65	0.02	0.85	0.22	---	---	0.60
G...	0.09	0.53	0.095	0.04	1.10	0.60		

Morris, Op. Cit.

All these steels are furnished to minimum specifications of 50,000 pounds per square inch yield point, and 70,000 pounds per square inch tensile strength.

Manganese-molybdenum steel is used as a structural steel when a better grade of steel is required. Manganese-silicon steel is used for springs.

Alloys of manganese with copper and aluminium are the most important of the non-ferrous manganese alloys.

Copper-manganese alloys containing from 4 to 5% of manganese are used extensively for ships' propellers and turbine blades. Those containing 8-12% of manganese and 4% of nickel are known as manganin and are used in standard resistances because the electrical resistance of manganin changes very little with changing temperature. Cupro-manganese is used in the manufacture of manganese bronze, manganese brass, and manganese German silver.

Manganese bronze contains from 0.05 to 3.5% of manganese, with copper, tin, zinc, lead, and iron. Silicon, nickel, and aluminium may also be present. This alloy is very tough and strong when forged, and is used for screws, nails, bolts and nuts, pins, and pump rods. Its remarkable resistance to corrosion renders it well suited for ships' propellers and parts of mining machinery. Manganese bronze is used in electrical and automotive work because of its non-magnetic nature.

Morris Op. Cit.p. 55.

A.W. Groves, Op. Cit. p.17

Everdur is an alloy containing 94.3% copper, 4.5% silicon, and 1.2% manganese. It is inert to reaction with chemical reagents and industrial waters. It is used for hot water storage tanks, pressure vessels, fans and ducts for acid vapors, brewery equipment, and pickling crates.

Dry Batteries.

Much manganise dioxide is used as a depolarizer in Leclanché dry cells. Ores should have a high content of available oxygen and be free from copper, nickel, cobalt, arsenic and iron. The ore must be porous and contain more than 85% MnO_2.

Chemical Uses.

Manganese dioxide is a good oxidizing agent, and for this reason is used extensively in the chemical industries. The manganese ore must contain at least 84% MnO_2.

Manganese sulphate is prepared from pyrolusite and serves as a starting point in the manufacture of carbonates, phosphate, and driers. It has been found that manganese sulphate may be used as a fertilizer, (3) p. 451, and its use as such is increasing.

"Chemical ore" was formerly used to a large extent in the production of chlorine. The manganese chloride produced in this reaction is used in making black flashed brick and manganese driers. (3) p. 451.

Manganese ore is used in the production of hydroquinone and potassium permanganate. Hydroquinone is used as a photographic developer and to a minor degree as an antiseptic. Potassium permanganate has a wide range of uses, among which are: disinfectant, deodorant, wood preservation, dyes, bleaching textiles, medicine, and the manufacture of organic chemicals. (4) p. 371.

Driers. Manganese dioxide and other manganese salts are used as driers in varnish and printing ink.

Glass. Manganese colors glass giving it an amethystine tint. It also destroys the yellowish green color due to iron, but in this it has largely been replaced by selenium. Black glass for table tops, stemware, store fronts, and wall panels is colored with manganese.

Ceramics.

Manganese is useful in enamels for bathtubs, tea kettles, and refrigerators. Grey and black bricks are colored with manganese ore, either by "flashing" or by mixing it with the brick clay. Manganese is very useful as a coloring agent in the manufacture of pottery and tile. The chocolate brown glaze on high tension line porcelain insulators is often made with manganese, chromium and iron oxides. Greys and blacks are frequently produced with manganese.

Pigments.

Manganese carbonate is used as a white pigment, manganous oxide for green, manganese metaphosphate for violet, and pyrolusite for black. (1) p. 22. Umbers contain up to 14% of higher oxides of manganese. In Germany a printing ink with crude manganese dioxide as a base has been introduced in the newspaper industry. It has the advantage that it is easily bleached with sulphur dioxide.

Manganese is used in a composition for coating welding rods. Its compounds are used in dying cotton and calico-printing. Others are used as flotation agents, fluxes, medicines, in the match industry, and in preparations for impregnating leather.

The manganese minerals, rhodochrosite and rhodonite are used for ornamental purposes.

It may be seen that manganese is an essential element of our economic system. It finds application in many and varied industries. Curtailment of the supply of manganese would derange many industrial enterprises and cause much difficulty, especially in the steel industry.

Bibliography of Uses of Manganese.

(1) A.W.Groves, Manganese; Imperial Institute Mineral Resources Department, pp. 14-23.

(2) E.C.Harder, Manganese deposits of the United States; Bull. 457 U.S. Geol. Surv. pp.243-268

(3) G.H.Chambers, Manganese, Chapter XXV; Industrial Minerals and Rocks, pp. 450-454.

(4) Condensed Chemical Dictionary, Chemical Engineering Catalog Company.

COMMERCIAL CLASSIFICATION OF THE ORES.

The ores of manganese fall into four important classes:

Rousch, Strategic Minerals.

1. Chemical grade, contains 72 to 87% manganese dioxide.

2. Ferro-grade ore contains more than 40% of manganese and has a ratio of manganese to iron of greater than 8 to 1. During the last war the minimum manganese content of ferro-manganese fell from 80% to 70%. This made possible the use of ore with 35% manganese. The ores are penalized if they contain more than 8% of silica, 0.25% phosphorus, or more than 10% alumina.

3. Spiegel ores must contain more than 10% of manganese. The iron content of the ore must not be more than 2.7 times that of manganese, but during the last war spiegeleisen with as

A.W.Groves, Manganese; Imperial Institutes, p.10.

little as 16% of manganese was accepted so that the iron content of the ores could be as much as 3.7 times the manganese content.

4. Manganiferous iron ore contains from 5 to 10% of manganese, but some ores containing as little as 2% manganese are sold separately. These ores are used to manufacture a manganiferous pig-iron.

Rousch, Strategic Minerals.

Sulphur in the ores is not so objectionable as is phosphorus, because it usually passes into the slag.

A.W.Groves, Manganese p.10

Other ores used for their manganese content are the manganiferous zinc ores, such as occur at Franklin Furnace, New Jersey, and the manganiferous silver ores. The manganiferous silver ores occur in the oxidized portions of many of the silver deposits in the United States.

E.C. Harder, Manganese deposits of the United States, Bull.427.

U.S. Geol. Surv. p. 25.

MAP OF
NOVA SCOTIA
SHOWING
MANGANESE RESOURCES

MAP OF

NEW BRUNSWICK

SHOWING

MANGANESE RESOURCES