

# MAINE GEOLOGICAL SURVEY

JOSEPH M. TREFETHEN, State Geologist

## BULLETIN 4

Manganese Deposits of Aroostook County, Maine

By

Ralph L. Miller



Prepared in cooperation with the Geological Survey of the  
United States Department of the Interior

State Geologist and Maine Development Commission

April 1, 1947

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## ABSTRACT

Manganiferous and iron-bearing shale deposits have been known in Aroostook County, Maine, for more than 100 years, but they have never been worked for either iron or manganese. They were first seriously prospected in 1941 by the State of Maine. Geologic field work done at the same time by W. S. White of the Federal Geological Survey formed the basis for a report describing the regional geology and general economic geology of central Aroostook County. In 1942 the Manganese Ore Co., a subsidiary of the M. A. Hanna Co., began systematic prospecting of the larger deposits in Aroostook County. The present report, based on field work done in 1943 and 1944, includes the results of all prospecting to the end of 1944. It contains descriptions of all the known deposits, and more complete information on the grade and tonnage of ore at the deposits than was available in 1941.

The known manganese deposits of Aroostook County are in three districts—a northern, a central, and a southern. All but two of the deposits in the northern district lie along a belt of Silurian slate 20 miles long from north to south and about 3 miles wide. All of them are sedimentary lenses interbedded with slate and calcareous shale. The manganese ores are partly in hematitic shale, and partly in siliceous, chloritic limestone. The manganese in the primary, unoxidized ore is combined partly as oxide-silicate and partly as carbonate. The minerals braunite and bementite have been positively identified. These may be altered to black manganese oxide in the oxidized zone, which extends not more than 20 feet from the surface. The primary manganese ore contains from 5 to 20 per cent metallic manganese and from 7 to 34 per cent iron. Oxidation of the primary ore increases the manganese percentage by from 0.5 to 5 points, so that some of the oxidized ore contains as much as 25 per cent manganese and 36 per cent iron. The over-all average manganese content of "ore" in individual deposits ranges from 5 to 13 per cent, and the percentage of iron in each deposit is about twice as high.

Most of the twenty deposits in the northern district are small and economically unimportant. The Gelot Hill deposit is large but of low grade; the Dudley deposit is large and of somewhat higher grade. The Silver, Smith, and Higgins deposits, at which little prospecting has been done, may also be of fair to good size, and may be comparable in grade to the Dudley deposit.

Only three deposits are known in the central district. These lie in wooded country, ten miles from the nearest road or railroad. The Upper Maple Mountain deposit appears to contain a large tonnage of manganese ore, comparable in grade to that of the better of the prospected deposits. The other deposits in the central district are smaller but may be of slightly higher grade.

The southern district, which lies just west of the international border, is about 15 miles long from north to south and 8 miles wide. The manganiferous zones are interbedded with Ordovician (?) and Silurian slates, which have been strongly folded and much faulted. The deposits therefore lack the uniformity and continuity of those in the northern and central districts. The ore is similar in lithology and mineralogy to that in the northern district, except that magnetite displaces hematite as the most prominent iron mineral. Most of the deposits are strongly magnetic and may be accurately traced with a dip needle.

All of the deposits of the southern district are small or of low grade, or both, except the Littleton Ridge prospect. Limited prospecting of this deposit reveals a fairly large amount of ore containing more than 9 per cent manganese. Thorough exploration may show that the deposit is large, although it is probably not comparable in size to the Dudley and Upper Maple Mountain deposits of the northern and central districts.

The reasonably assured reserves of metallic manganese in Aroostook County amount to 1,300,000 tons, and an additional reserve of 800,000 tons seems probable on the basis of present knowledge. Further prospecting will enlarge these figures somewhat. The average manganese content of the ore is about 9 per cent. The bulk of the tonnage is concentrated in six deposits, the other 30 being probably of little or no economic importance. The amount of manganese in the largest deposit to a depth of 200 feet nearly equals the amount of manganese consumed in the United States in the year 1939.

Utilization of the Aroostook County manganese deposits depends on several contingencies. Most important of these is the development of a metallurgical process by which the manganese may be extracted efficiently and economically, in a form in which it is usable in the metallurgical industry.

## INTRODUCTION

### Location

The known manganese deposits of Aroostook County, Maine, are localized in three districts. The northern district (fig. 1) is west and northwest of Presque Isle and the central district west of Monticello. The southern district lies north, southeast and south of Houlton.

### Topography and Culture

Eastern Aroostook County is largely a region of gently rolling hills, which rise only a few hundred feet above the stream valleys. Most of the hills are elongate in a general north-south direction as the result of scouring by the southward-moving ice sheet. Out-

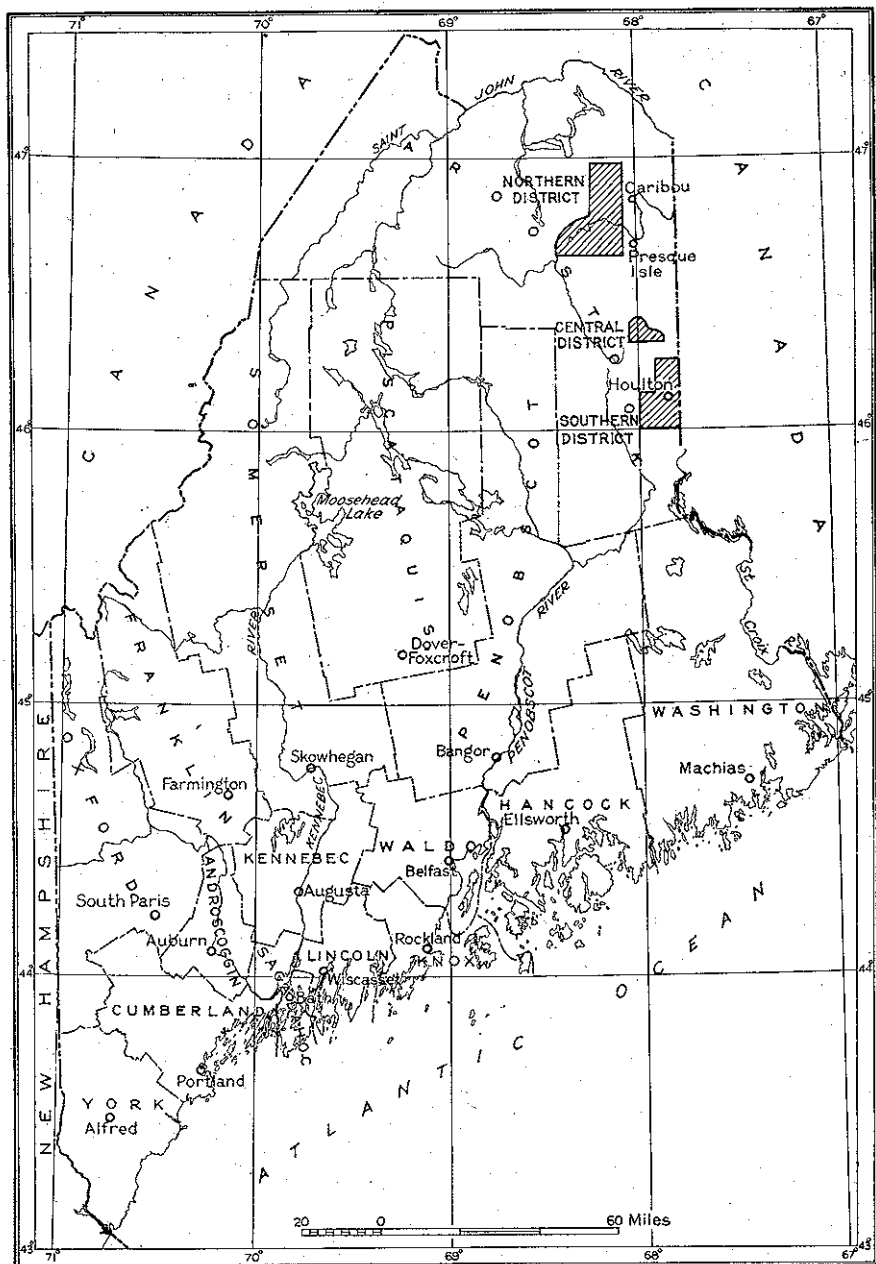


Figure 1: Index map of Maine, showing locations of the northern, central and southern manganese districts of Aroostook County.

crops are common on the slopes of the hills, but most are small and inconspicuous. In the potato fields plowing may expose the bedrock in a few places one season, but may cover the outcrops with a thin mantle of soil another year. The valley bottoms are broad, flat and swampy. They are almost everywhere covered with a dense growth of timber and underbrush. On most valley bottoms there are no outcrops, but in a few places small rounded knobs of bedrock rise above the mantle of glacial till and alluvium. The mantle of glacial drift, which covers the entire region, is normally from 1 to 10 feet thick on the hills but is much thicker in the valleys.

In the southern manganese district three excellently preserved eskers are prominent features of the topography. They form part of a subglacial drainage system, in which the streams were converging in a general southeast direction. Two of the eskers unite just north of Houlton and the esker near Linneus unites with the Houlton esker 15 miles south of Houlton. The eskers form the principal sand and gravel resource of the region and have been quarried in many places. They have been described and mapped in Leavitt and Perkins'<sup>1</sup> report on the glacial geology of Maine.

Prominent knobs and ridges rise above the general level in several places in eastern Aroostook County. These are composed of more resistant rock than the Ordovician and Silurian shales, slates and limestones that underlie most of the region. Mars Hill, a prominent ridge south of Presque Isle, is capped by Devonian conglomerate. Most of the high knobs, such as Pyle Mountain and Haystack Mountain west of Mapleton (plate 2), and the mountains that lie south of the northern manganese district, are composed of intrusive igneous rocks. The photograph (plate 1A) shows a typical landscape in the manganese-bearing part of eastern Aroostook County. It was taken from the top of Haystack Mountain looking eastward toward Presque Isle. The Dudley manganese deposit is almost centrally located in the photograph just beyond the conspicuous elongate white field.

A long narrow belt of eastern Aroostook County is cultivated, except for the swampy valley bottoms and occasional small wood lots. To the west of this agricultural belt, almost unbroken forest extends into the mountainous region of central Maine. The northern and southern manganese districts of this report lie in the cultivated part of Aroostook, but the central manganese district is in the forest about 10 miles west of the agricultural belt. The Bangor and Aroostook Railroad and a network of paved and gravel roads give ready access to all parts of the agricultural belt, but the forested region is traversed by only a few improved roads.

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<sup>1</sup>Leavitt, A. W. and Perkins, E. H., A survey of the road materials and glacial geology of Maine: Maine Technology Experiment Station, Bull. 30, 1935.



## History

Manganiferous iron ore was first discovered in Aroostook County in 1837 by C. T. Jackson<sup>1</sup>, who briefly described what is probably the Haines prospect of this report.

Subsequent reports<sup>2</sup> published by the State of Maine give additional information upon the Haines prospect and mention another, which is probably the Dudley prospect. Williams and Gregory<sup>3</sup> have given the most complete account of the geology of Aroostook County, but their report contains only a very generalized geologic map and only brief mention of the manganese deposits. In 1941, White and Cloud<sup>4</sup> of the Federal Geological Survey examined the geology of the regions in which the manganiferous deposits occur. At the same time, Paul Eckstorm prospected many of the manganese deposits for the State of Maine. The history, occurrence, and exploration of the manganese deposits of Aroostook County have been summarized by the State Geologist of Maine.<sup>5</sup> His report includes a table of manganiferous localities, and indicates the grade of the manganiferous rock for those prospects, which were sampled by Eckstorm. Many of Eckstorm's data are included in White's<sup>6</sup> final report. The present report is supplemental to White's, being largely based on more detailed studies of the manganese deposits and on recent prospecting. Most of the information on the stratigraphy of the area is taken from White's report.

Many of the manganese prospects of the northern district were discovered by Olof Nylander, and many of those in the southern district by Harry Thwaites.

The Manganese Ore Co., a subsidiary of the M. A. Hanna Co. of Cleveland, began systematic prospecting of the more promising deposits in 1942. At the end of 1944, two deposits had been diamond drilled and ten others explored with one or more trenches.

## Production

Despite the fact that the manganese-iron deposits of Aroostook County have been known for more than a hundred years, no attempt has ever been made to mine them. Similar deposits near Woodstock, New Brunswick, 15 miles east of Houlton, were worked extensively for iron during the last century.

<sup>1</sup>Jackson, C. T., Second Annual Report of the Geology of the Public Lands belonging to the State of Maine and Massachusetts, pp. 34-38, 1838.

<sup>2</sup>Jackson, C. T., Second Report on the Geology of the State of Maine, pp. 127-128, 1837.

<sup>3</sup>Hitchcock, C. H., General Report upon the Geology of Maine: Preliminary Report upon the Natural History and Geology of the State of Maine, p. 308, 1861.

<sup>4</sup>Hitchcock, C. H., Second Annual Report upon the Geology of Maine, p. 413, 1862.

<sup>5</sup>Williams, H. S., and Gregory, H. E., Contributions to the Geology of Maine: U. S. Geol. Survey Bull. 165, pp. 1-212, 1900.

<sup>6</sup>White, W. S., and Cloud, P. E., Manganese deposits of Eastern Aroostook County, Maine: U. S. Geol. Survey Strategic Minerals Investigations, Preliminary Map, 1942.

<sup>7</sup>Trefethen, J. M., Report of the State Geologist of Maine, 1942-43, pp. 25-33.

<sup>8</sup>White, W. S., Occurrence of manganese in Eastern Aroostook County, Maine: U. S. Geol. Survey Bull. 940-E, pp. 125-161, 1943.

## Field Work

In the summer of 1943 the writer undertook, as a cooperative project of the State of Maine and the U. S. Geological Survey, a more complete examination of the manganese deposits than had been made up to that time. Three months were devoted to field studies of the deposits, including a small amount of regional geologic mapping in the northern part of the northern manganese district, and reconnaissance regional studies in the southern district. All known occurrences of manganese in the agricultural sections of Aroostook County were studied, but reported showings of possible manganiferous rocks in the backwoods were not visited except in the central manganese district. An additional three weeks were spent in the field in 1944, revisiting the Dudley and Maple Mountain deposits, and studying the records of the prospecting in 1944 at these two localities.

## Acknowledgments

Most of the information on grade and tonnage of ore given in this report is based on prospecting records of the Manganese Ore Co. For permission to use these records, and for numerous other courtesies, the writer is greatly indebted to Messrs. A. E. Walker, Clarence Harrer, and Frank Spencer. Many days were spent in the field with Mr. Harrer, examining manganese prospects. Mr. Walter White of the Federal Geological Survey showed the writer over the district at the start of the field season, and made all his field data available. Mr. Harry Thwaites of Houlton and Mr. Dan Brewer of Littleton acted as guides. Minerals were identified by Mr. Charles Milton, and X-ray analyses were made by Mr. J. M. Axelrod in the Federal Geological Survey laboratories.

Information on Ordovician faunas of Aroostook County was supplied by Mr. Preston Cloud of the Federal Geological Survey. The project was under the supervision of Mr. T. A. Hendricks, of the Federal Geological Survey, and Mr. Joseph Trefethen, State Geologist of Maine. The report has been read and criticized by Hendricks and by D. F. Hewett and Frank Calkins of the Federal Survey.

# GENERAL GEOLOGY

## Northern District

### *Sedimentary Rocks*

The area of the northern manganese district is shown in plate 2. This area, together with the adjacent area to the east and southeast was mapped geologically by White and Cloud<sup>1</sup> in 1941. The geologic boundaries shown on plate 2 are taken from their map. The stratigraphic section for the region as interpreted by them is given below.

#### Sequence and character of the rocks in the northern manganese district

Age	Formation	Lithology	Apparent thickness (feet)
Upper Devonian	Mapleton sandstone	Upper 500 feet are red and greenish sandstone, the remainder red conglomerate and sandstone.	1,800-2,500
	Marked angular unconformity		
Lower Devonian	Chapman sandstone	Greenish sandstone, Becraft or Oriskany fauna.	Over 700
	Volcanics . . . . .	Calcareous tuffs and breccias, New Scotland fauna.	2,000
Middle Silurian	Slight unconformity		
	Shale and slate <sup>2</sup> . . . . .	Upper member blue and gray calcareous shale with limestone lenses; lower member greenish argillite with thin calcareous layers.	5,000 <sup>+</sup>
	Aroostook limestone . . . . .	Upper member gray, nubbly argillaceous limestone; middle member ribbon limestone; lower member slate, partly calcareous.	18,000 <sup>+</sup>
	Sandstone <sup>3</sup> . . . . .	Sandstone and conglomerate with a little slate and calcareous argillite.	5,000 <sup>+</sup>
Middle Ordovician	Marked angular unconformity		
	Undifferentiated gray-blue calcareous siltstone, greenish argillite, black shale, and chert. Three fossil zones recognized.		Unknown

<sup>1</sup>White, W. S. and Cloud, P. E., Jr., Manganese deposits of eastern Aroostook County, Maine: U. S. Geological Survey, Strategic Minerals Investigations, Preliminary map, 1942.

<sup>2</sup>Ashland shale and Ashland limestone of Williams and Gregory (Williams, H. S., and Gregory, H. E., Contributions to the geology of Maine: U. S. Geol. Survey Bull. 165, 1900).

<sup>3</sup>Sheridan sandstone of Williams and Gregory (Williams, H. S., and Gregory, H. E., op. cit.).

This stratigraphic column is based on reconnaissance geologic mapping. White<sup>1</sup> notes that it is to be considered provisional, and especially that the "apparent thicknesses" of the formations may be in excess of the true thicknesses due to unrecognized folding and faulting. White also notes that the units mapped as upper and lower members of the Aroostook limestone may be equivalent beds, and not in fact separated by the ribbon limestone member. The field evidence is equivocal, and more detailed regional and paleontologic studies will be necessary before the stratigraphic sequence of Silurian formations for northern Aroostook can be considered established.

Brief descriptions and discussion of the formations, based in part on White and Cloud's published work and in part on the writer's field observations, follow.

## ORDOVICIAN FORMATIONS

### *Middle Ordovician rocks*

The Middle Ordovician rocks crop out in a north-south belt south of the Aroostook River and just west of the Silurian slate belt (plate 2). White and Cloud believed them to be in fault contact with the Silurian slates because of the absence of the "Sheridan" sandstone between the two. Twenhofel<sup>2</sup> has suggested that the "Sheridan" sandstone overlies the "Ashland" formation, but the regional relations shown by White and Cloud's mapping would seem to preclude this interpretation.

The Middle Ordovician rocks consist of dark colored shales, slates, and siltstones, which in places contain some schist beds. Typical Ordovician shales are exposed in a quarry just south of the Mapleton-to-Ashland road, 0.6 mile east of the sharp corner at the foot of Pyle Mountain. Here Olof Nylander collected a graptolite faunule in 1934, which was examined by Rudolf Ruedemann and Charles Decker, and dated as Normanskill. The list of identified forms as supplied to the writer by Mr. Nylander is given below.

1. *Dicranograptus nicholsoni* Hopkinson.
2. *Dicranograptus nicholsoni* var. *geniculatus* Ruedemann and Decker.
3. *Dicranograptus ramosus* Hall; a piece of sandstone in the top layer containing several well preserved branches.
4. *Orthograptus calcaratus* var. *acutus* Lapworth—abundant.
5. *Climacograptus parvus* Hall—rare.
6. *Climacograptus antiquus* Lapworth var. *polytheca* Ruedemann—abundant in the middle layers.
7. *Climacograptus eximius* Ruedemann—rare.

<sup>1</sup>White, W. S., op. cit. p. 128.

<sup>2</sup>Twenhofel, W. H., The Silurian of Aroostook County, northern Maine: *Journal of Paleontology*, vol. 15, pp. 166-174, 1941.

8. *Diplograptus incisus* Lapworth.
9. *Lasiograptus whitfieldi* Hall.
10. The brachiopod, *Leptobolus walcotti* Ruedemann.

Faunules have also been collected by Cloud from numerous localities in the belt of Ordovician rocks west of Presque Isle. These faunules have not yet been described, but Cloud<sup>1</sup> reports that several are of probable Trenton age, other faunules are of Normanskill age and there is apparently one Deepkill faunule.

Due to complex structure and scattered outcrops, the thickness of the exposed Ordovician rocks is not known.

## SILURIAN FORMATIONS

### *Sandstone formation*

A thick sandstone and conglomerate formation is present in the western part of the northern manganese district. It was described by Williams and Gregory<sup>2</sup> and named the Sheridan sandstone, but the name Sheridan had previously been applied to a pre-Cambrian formation in Yellowstone Park so that it is not available for use in Maine. Williams believed that the "Sheridan" sandstone overlay the Aroostook limestone, but recent mapping and stratigraphic studies by White and Cloud<sup>3</sup> seem to indicate that the "Sheridan" is the basal formation of the Silurian in Aroostook. The writer's observations of the "Sheridan" west of New Sweden and near Frenchville favor the view that the "Sheridan sandstone" underlies slates, which in turn underlie the typical Aroostook limestone.

The "Sheridan" consists mainly of medium- to fine-grained sandstone and quartzite locally containing conglomeratic beds. Along the Aroostook River Gregory described conglomeratic boulders 20 feet or more in diameter. Slate is interbedded with the sandstone and conglomerate in places and locally beds of tuff and volcanic conglomerate are also included. The "Sheridan" sandstones and conglomerates are in places fossiliferous. Williams<sup>4</sup> lists several fossiliferous localities and the writer also found fossils in well-exposed "Sheridan" conglomeratic beds on the Westmoreland-New Sweden township line, due west of the town of Sweden. The faunule, as yet undescribed, consisted of horn corals, brachiopods, gastropods, and crinoid stems.

White and Cloud give the apparent thickness of the "Sheridan" sandstone as  $5,000 \pm$  feet. They recognize, however, that structures not revealed by their reconnaissance mapping may cause the apparent thickness of the formation to be considerably different from the true thickness.

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<sup>1</sup>Cloud, P. E., personal communication.

<sup>2</sup>Williams, H. S., and Gregory, H. E., Contributions to the geology of Maine: U. S. Geol. Survey Bull. 165, pp. 21, 45, 47-49, 51, 1900.

<sup>3</sup>White, W. S., and Cloud, P. E. Jr., op. cit.

<sup>4</sup>Williams, H. S. and Gregory, H. E., op. cit. pp. 47-49.

### *Aroostook limestone*

The Aroostook limestone is the most widespread formation in the northern manganese district. White and Cloud have divided the formation into three lithologic members, a lower slate member, a middle ribbon limestone member, and an upper argillaceous limestone member. The lower slate member of the Aroostook limestone is composed of gray and green shale, slate, and phyllite, calcareous shale and shaly limestone. Locally the member contains beds of red shale, and in the upper part thin beds of limestone are intercalated. Due to folding, faulting and metamorphism the sequence of lithologies is extremely difficult to decipher and no good sections of the member were seen by the writer. The shales and calcareous shales are locally manganiferous and most of the manganese prospects of the northern district lie within the belt of this member extending from New Sweden township southwestward to Castle Hill township.

The ribbon limestone member is very distinctive and has the lithology commonly associated with the Aroostook formation. It consists of a large but unknown thickness of platy beds of fine-grained gray limestone separated by thin shale partings. The member is excellently exposed along the Aroostook River at the dam in Caribou and also at and near the bridge at Washburn (pl. 1A).

Plate 1B is a photograph of typical folded ribbon limestone just above water level on the south bank of the Aroostook River three-fourths of a mile west of the Washburn bridge. The limestone bands are from 1 to 4 inches thick, of a dense, very fine-grained, dark gray limestone which weathers nearly white. The partings between bands are less than an inch thick, and consist of dark shaly limestone which weathers in relief giving a ribbed appearance to the outcrop. Gash veins of white crystalline calcite are prominent near the right edge of the photograph.

The upper member of the Aroostook limestone has almost no exposures in the manganiferous region studied by the writer. The broad belt of this member mapped by White and Cloud in western Mapleton township is in a flat drift-covered area with almost no outcrops. In the Presque Isle area where the member is better exposed White and Cloud describe it briefly as consisting of nubbly, argillaceous limestone.

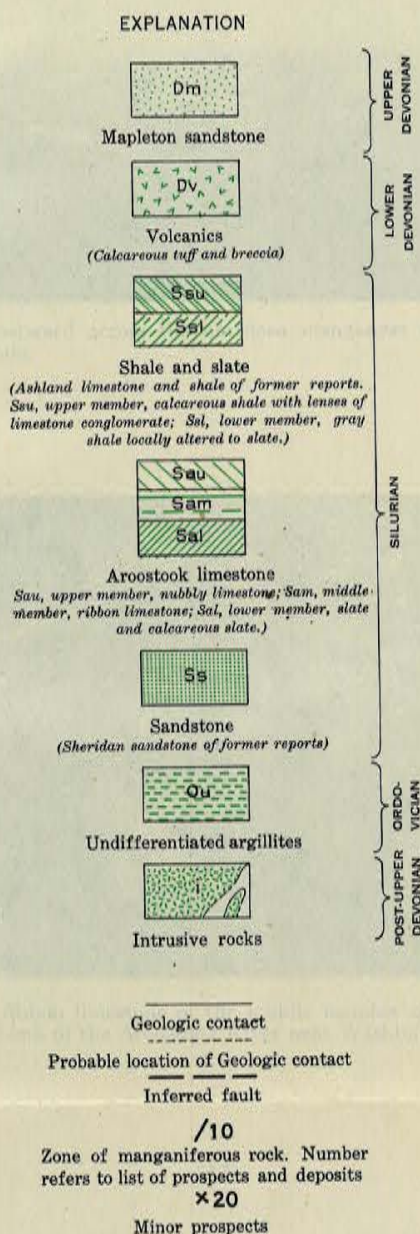
The apparent thickness of 18,000  $\pm$  feet for the Aroostook limestone shown in White's stratigraphic table seems excessive. The structure of the region is so complex, however, that there seems at present no practicable way to determine the true thickness of the formation.

### *Calcareous shale formation*

The youngest Silurian formation of the region according to White and Cloud is a thick sequence of calcareous shale and argillite locally containing thin limestone bands, and lenses of limestone conglomerate. This is the Ashland shale and limestone of Williams and Gregory<sup>1</sup>, named from the town of Ashland on the Aroostook River. The name "Ashland" for these rocks is not in good standing and the

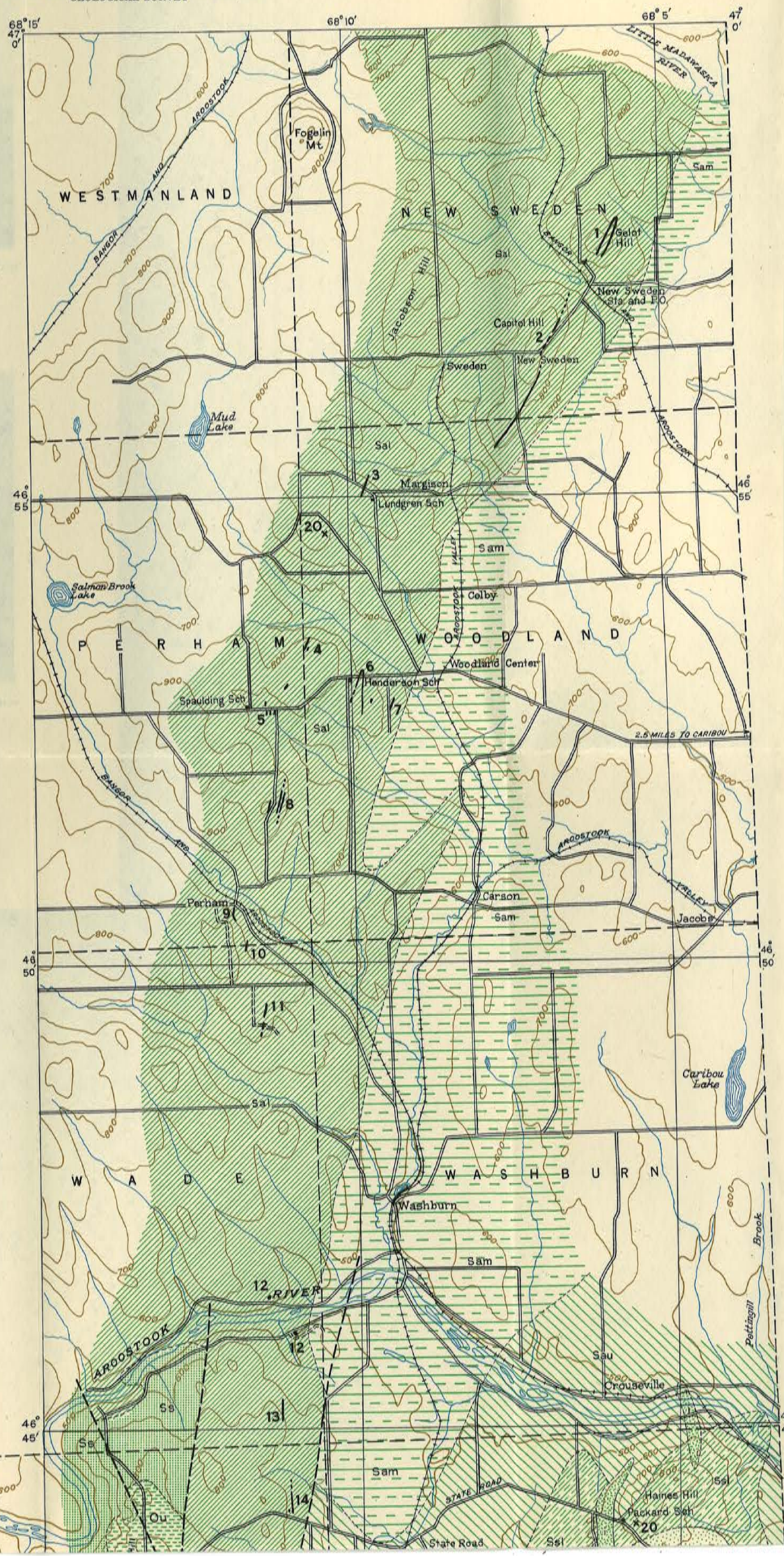
<sup>1</sup>Williams, H. S., and Gregory, H. E., op. cit. pp. 49-54.





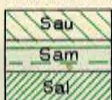
Areas of manganiferous rock numbered  
on map and referred to in text

1. Gelot Hill deposit
2. Capitol Hill deposit
3. Lundgren School prospect
4. Grant prospect
5. Spaulding School prospect
6. Henderson School prospect
7. Anderson prospect
8. Fox-McIntyre prospect
9. Perham Church prospect
10. Bugbee-Braddon prospect
11. Silver prospect
12. Aroostook River prospects
13. Haines prospect
14. Castle Hill Grange Hall prospect
15. Richardson prospect
16. Smith deposit
17. Dudley deposit
18. Higgins deposit
19. Frenchville prospect
20. Other prospects





Shale and slate  
(Ashland limestone and shale of former reports.  
Sau, upper member, calcareous shale with lenses of  
limestone conglomerate; Sal, lower member, gray  
shale locally altered to slate.)



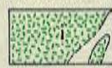
Aroostook limestone  
Sau, upper member, nubby limestone; Sam, middle  
member, ribbon limestone; Sal, lower member, slate  
and calcareous slate.)



Sandstone  
(Sheridan sandstone of former reports)



Undifferentiated argillites



Intrusive rocks

Geologic contact

Probable location of Geologic contact

Inferred fault

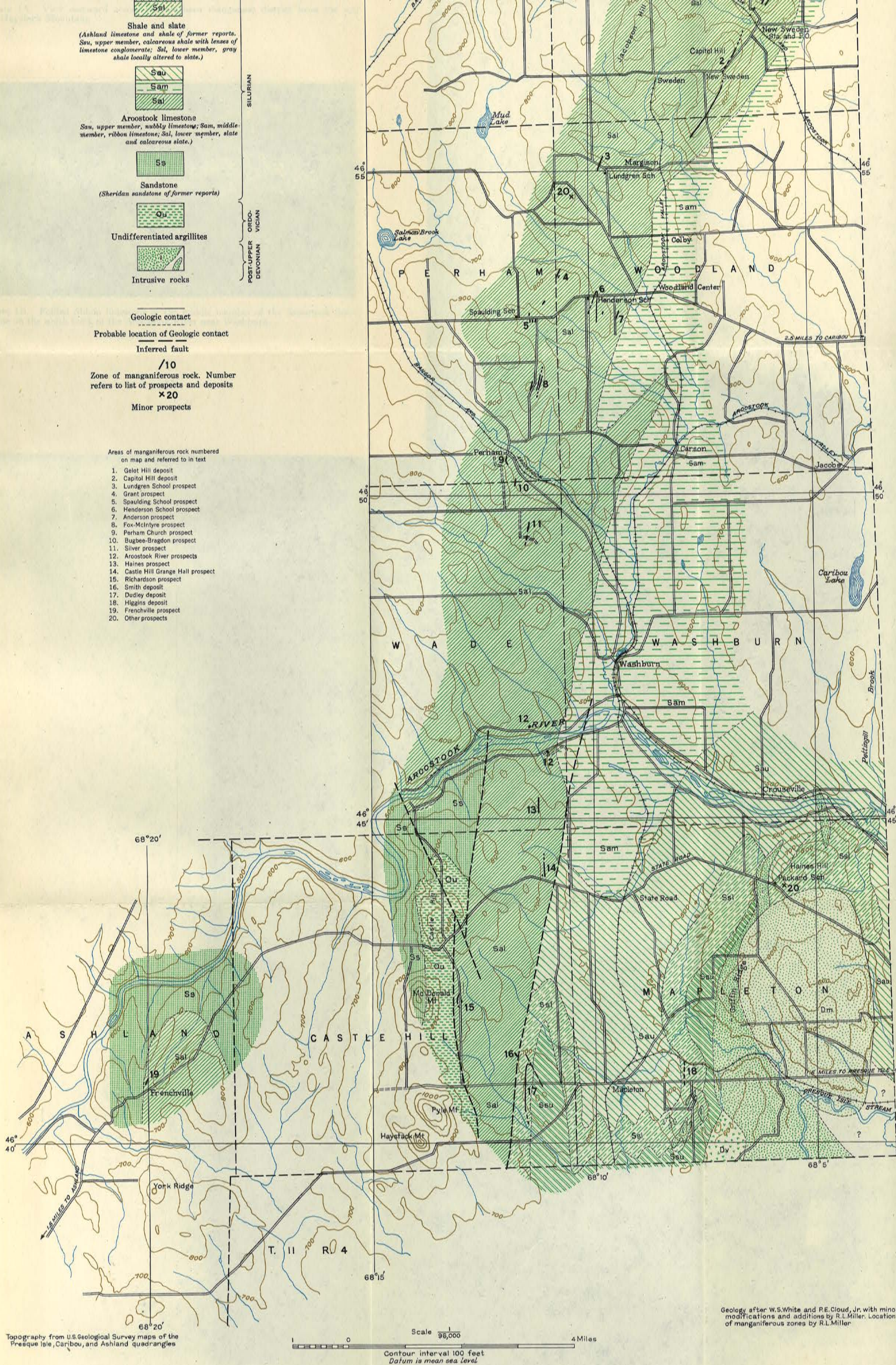
/10

Zone of manganiferous rock. Number  
refers to list of prospects and deposits  
x20

Minor prospects

Areas of manganiferous rock numbered  
on map and referred to in text

1. Gelot Hill deposit
2. Capitol Hill deposit
3. Lundgren School prospect
4. Grant prospect
5. Spaulding School prospect
6. Henderson School prospect
7. Anderson prospect
8. Fox-McIntyre prospect
9. Perham Church prospect
10. Bugbee-Braddon prospect
11. Silver prospect
12. Aroostook River prospects
13. Haines prospect
14. Castle Hill Grange Hall prospect
15. Richardson prospect
16. Smith deposit
17. Dudley deposit
18. Higgins deposit
19. Frenchville prospect
20. Other prospects



## RECONNAISSANCE GEOLOGIC MAP OF THE NORTHERN MANGANESE DISTRICT, SHOWING LOCATIONS OF MANGANESE DEPOSITS





Plate 1A. View eastward across the northern manganese district from the top of Haystack Mountain.



Plate 1B. Folded ribbon limestone of the middle member of the Aroostook limestone on the south bank of the Aroostook River near Washburn.

sequence needs additional careful stratigraphic and paleontologic study before a new name is applied to it.

White and Cloud recognize two lithologic members, a lower argillite containing thin calcareous layers and an upper blue and gray calcareous shale with limestone lenses. The lower member includes the Dudley manganese deposit and is exposed in numerous places in the vicinity of the ore body (plate 2). It consists of gray and greenish gray shaly limestone and shale containing lenses of red shale. The manganese- and iron-rich beds are lenticular and are interbedded with the shale and limestone.

The upper member is dominantly blue and gray calcareous shale but locally contains lenses of limestone and limestone conglomerate. The most prominent of the limestone conglomerate lenses lies about 300 feet east of the Dudley ore body. Plate 3A shows the appearance of the coarsest phases of the limestone conglomerate on the Dudley farm. Many of the cobbles are fossiliferous, and Williams<sup>1</sup> identified the following faunule from this locality.

Faunule from the limestone  
conglomerate zone on the Dudley farm

*Atrypa marginalis*  
*Strophomena rhomboidalis*  
*Conchidium nysius*  
*Stropheodonta varistriata*  
*Eatonia medialis* var.  
*Sowerbyella transversalis*  
*Eospirifer radiatus* (= *S. nympha* Billings)  
*Hyatella congesta*  
*Nucleospira pisiformis*  
*Pentamerus oblongus*  
*Lichas boltoni*  
*Dalmanites limulurus*  
*Paleocyclus rotuloides*  
Undetermined brachiopods

Twenhofel<sup>2</sup> has analyzed this and other faunas from the "Ashland" limestone and dates the "Ashland" as "very high Clinton or low Niagara", presumably meaning by this an upper Clinton or Rochester age. The shale beds of the upper member of the "Ashland" limestone also contain *Monograptus clintonensis* in numerous places.

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<sup>1</sup>Williams, H. S. and Gregory, H. E., op. cit. pp. 53-54.

<sup>2</sup>Twenhofel, W. H., The Silurian of Aroostook County, northern Maine: Jour. Paleontology, vol. 15, pp. 166-174, 1941.



Plate 3A. Intraformational limestone conglomerate of the upper member of the "Ashland limestone" near the Dudley deposit.



Plate 3B. Typical manganiferous shale in a prospect pit at the Dudley deposit.

## DEVONIAN FORMATIONS

Devonian formations in northern Aroostook lie east and south of the manganese district. They have not been examined by the writer. Devonian faunas from the region have been described by Williams<sup>1</sup> and the Devonian formations east of the manganese district have been mapped by White and Cloud<sup>2</sup>.

White and Cloud recognized two formations of Lower Devonian age, the lower of which consists of calcareous tuff and breccia carrying a New Scotland fauna, and the upper of which is the Chapman sandstone of Becraft or Oriskany age. The Lower Devonian beds are overlain unconformably by the Mapleton sandstone of Upper Devonian age, which consists of green sandstone, red sandstone, and conglomerate.

### *Intrusive Igneous Rocks*

Intrusive igneous rocks are common in the northern manganese district, and consist of dikes and sills of small size, and larger, stock-like bodies. Gregory<sup>3</sup> has described the petrology of the igneous rocks of northern Aroostook County and states that the igneous bodies are granite, rhyolite, trachyte, quartz trachyte, andesite, diabase, and teschenite, and that they are intrusive into Ordovician and Middle Silurian formations and are at least post-Middle Silurian. White believes them to be post-Upper Devonian. Igneous rocks are not present in the vicinity of most of the manganese deposits, and there is no evidence that the formation of the deposits has been the result of igneous activity. Rather, the deposits are believed to be contemporaneous with the formation of the enclosing sediments and have been unaffected by the later igneous activity. Intrusive igneous rocks are shown at several places on the regional geologic map (plate 2) and also on the large scale map of the Higgins deposit (plate 17).

The larger igneous bodies form prominent hills or knobs. One of the most striking of these is Haystack Mountain from which the regional photograph shown in plate 1A was taken. The small dikes and sills, which are present near the manganiferous region have little topographic expression, having been planed off by the glacier together with the sediments that enclose them.

### *Structure*

The rocks of the northern district are folded and faulted on a large scale, but in most places they are not intricately contorted. Competent beds may be traced, where outcrops are adequate, for

<sup>1</sup>Williams, H. S. and Gregory, H. E., op. cit.  
Williams, H. S. assisted by Breger, C. L., The fauna of the Chapman sandstone of Maine: U. S. Geol. Survey P. P. 89, 1916.

<sup>2</sup>White, W. S. and Cloud, P. E., op. cit.

White, W. S., op. cit.

<sup>3</sup>Williams, H. S. and Gregory, H. E., op. cit.

hundreds or thousands of feet without observing important deflections. The less competent rocks, especially the slate and the ribbon limestone of the Aroostook formation, locally have a multiplicity of folds and faults. An excellent example of complex structure in the ribbon limestone is shown in the photograph (plate 1B). Fortunately the iron- and manganese-bearing slates are more competent than the barren slates, and the structures in the manganese deposits of the northern district are relatively simple.

The larger folds are normally upright, their axial planes standing almost vertical and the dips on their limbs being approximately equal. Most are nearly isoclinal, but some of them, especially in the southern part of the district, are not closely compressed. Most of the folds strike north-northeast to east and plunge at angles less than  $45^{\circ}$ . In the contorted areas the axial planes of the small folds may strike in any direction, and the folds may plunge at any angle.

Large faults have been mapped by White in the northern district largely on the basis of stratigraphic discrepancies, although few, if any, of the fault contacts could be seen or even very precisely located. No reasonable interpretation of the stratigraphy can be worked out without postulating large-scale faults, but the number and location of the faults mapped depends upon how the stratigraphy is interpreted.

The small faults of the district dip steeply, and most of them stand nearly vertical. Most are parallel to the regional trend of the formations, but small cross-faults are present in some places. The attitude of the small faults, combined with the steep dips and lack of regional overturning of beds, make it probable that the large faults likewise are high-angle strike faults. No evidence of major overthrust faults has been seen anywhere in the district.

Many faults that have not been recognized are unquestionably present in the area. Their obscurity is largely due to scarcity of outcrops, but partly to the fact that rocks of similar lithology have been brought in contact with each other, thus concealing the faulted relationship. For example, test-pitting at the Dudley deposit proved that the ore body is cut off at the north end by a major fault (plate 16), which had previously been unrecognized, and which is still accurately located only in the immediate vicinity of the test pits and drill holes.

Fracture cleavage is strongly developed in the more argillaceous formations, where it commonly obscures or obliterates the bedding. In the northern part of the district, it trends about N.  $40^{\circ}$  E. over large areas, whereas the beds normally strike from N.  $0^{\circ}$  E. to N.  $30^{\circ}$  E. The manganiferous slates, on the other hand, are less susceptible to the development of fracture cleavage than the less dense, barren slates, and bedding is dominant over cleavage in most of the manganese deposits. Joints are common in all the rocks of the district, but no systematic joint studies were made and no regional trends were noted. Ripple marks occur in a few places.

The most persistent structural problem in the area is that of determining which were originally the tops of steeply dipping beds. The usual criteria are commonly wanting. In a few places sedimentary structures, fracture cleavage or fossils gave a satisfactory solution, but at most localities the problem remained unsolved.

### Central District

The central district was prospected briefly by Eckstorm<sup>1</sup> in 1941. It was visited by Mr. Clarence Harrer and the writer in 1943, and by Mr. A. E. Walker and the writer in 1944.

Two groups of manganese prospects lie in heavily wooded country about 7 miles airline and 10 miles by trail from Harvey, which is on the nearest passable road (fig. 2). The Hovey Mountain prospects are in Township 9, Range 3, and the Maple Mountain prospects in Township D, Range 2. Eckstorm, who did not have the help of topographic maps in making locations, describes what are evidently the same prospects as lying in Township C, Range 2, and White<sup>2</sup> cites Eckstorm briefly.

Almost nothing is known of the general geology of the central district. Outcrops are rare and difficult to locate, but the few that were seen apparently indicate that Spruce Mountain, Hovey Mountain, and Maple Mountain consist mainly of slates that resemble the Silurian slates of the northern and southern districts. The lowlands east of Spruce Mountain appear to be chiefly underlain by limestone. These rocks apparently belong to the same Silurian limestone and slate series that has been described in the northern district. No igneous rocks were seen in the central district.

### Southern District

#### *Sedimentary rocks*

The stratigraphy of the southern district is known only in a general way. Broad lithologic units have been recognized and their approximate limits mapped, but no detailed areal or stratigraphic studies have been made.

Plate 4 is thus intended only as a reconnaissance guide to the geology. It shows approximate geologic boundaries which will undoubtedly require adjustment when detailed geologic studies are made. The Ordovician slates have been included with the adjoining Silurian slates, for the only sure means of distinguishing the two in strongly folded areas is by finding fossils in them. Cloud<sup>3</sup> reports

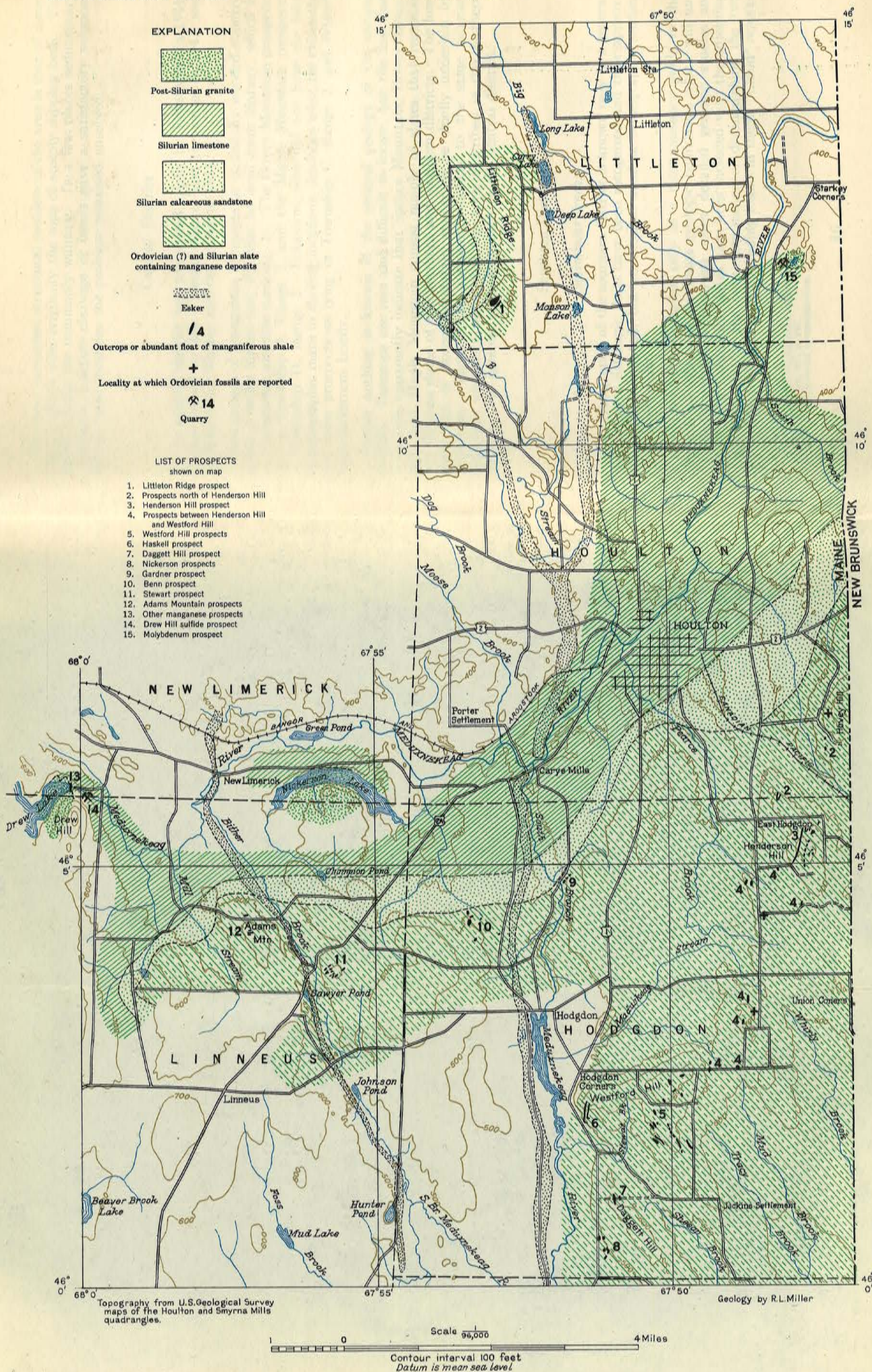
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<sup>1</sup>Eckstrom, Paul, Unpublished report.

<sup>2</sup>White, W. S., op. cit., p. 161.

<sup>3</sup>Cloud, P. E., personal communication.





RECONNAISSANCE GEOLOGIC MAP OF THE SOUTHERN MANGANESE DISTRICT,  
SHOWING LOCATIONS OF MANGANESE DEPOSITS



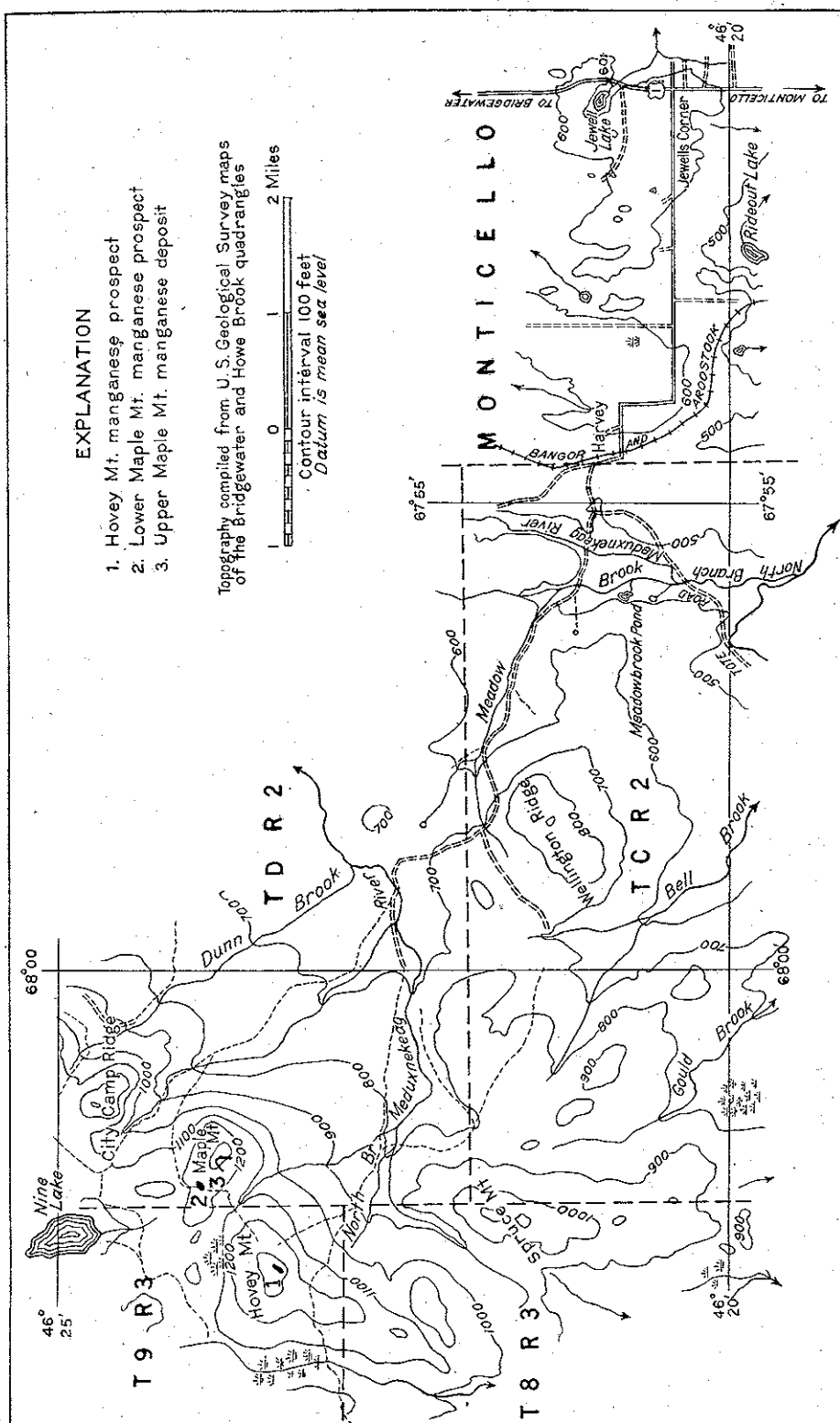


Figure 2: Topographic map showing location of manganese deposits of the central district.



Ordovician graptolites at three localities which have been marked on plate 4.

How the formations on Littleton Ridge are related to those in the southern part of the district is unknown. They are represented on plate 4 as belonging to those stratigraphic units in the southern part of the district which they most resemble lithologically, but this correlation remains to be established.

**Table of stratigraphic formations of the southern district**

Description	Estimated thickness (feet)	Age
Granitic stocks at Drew Hill and Nickerson Lake, and acidic dike rocks.	—	Post-Silurian
Thin-bedded siliceous limestone. Underlies northern and northwestern parts of district, except Littleton Ridge.	2,000+	Silurian
Buff, even-bedded calcareous sandstone and siliceous limestone. Forms belt $\frac{1}{4}$ to 1 mile wide across central part of district.	1,000+	Silurian
Gray slate, locally containing interbedded sandstone. Lenses of manganiferous shale at several horizons. See plate 4.	3,000+	Silurian
Gray slate, containing Ordovician graptolites. May contain interbedded manganiferous shale.	1,000+	Ordovician

### *Structure*

The geologic structure is much more complex in the southern district than in the northern district. In most of Aroostook County the general strike of the formations has a strong north-northeasterly trend, but in the southern district it varies widely. Throughout some large areas in Linneus and New Limerick Townships the strike of the beds is nearly east-west, and on part of Westford Hill it is northwest-southeast.

The argillaceous formations which contain the manganese deposits are almost everywhere strongly folded, and faults are abundant. White's<sup>1</sup> detailed geologic map of Westford Hill shows the complexity of the structure in a small area. Although the rocks have been greatly compressed, the beds are not overturned in many places, and the axial planes of most of the folds are nearly upright. Many of the folds, however, plunge at steep angles, and a few of them plunge almost vertically. The faults do not exhibit a regional trend but strike at various angles. All those that were seen were high-angle faults, and no evidence of overthrust faulting was found.

Fracture cleavage is developed in the argillaceous formations, but traces of bedding are visible in most large outcrops. The manganiferous shales are less susceptible to the development of cleavage than are the barren shales, and the most prominent lineation in almost all of the manganese deposits is bedding.

<sup>1</sup>White, W. S., Occurrence of manganese in Eastern Aroostook County, Maine: U. S. Geol. Survey Bull. 940-E, plate 28.

## ECONOMIC GEOLOGY

### Location of manganese deposits

#### *Northern District*

Nearly all of the manganese deposits in the northern district lie along a belt of slates, which is 22 miles long and half a mile to  $3\frac{1}{2}$  miles wide (plate 2). The belt trends nearly north in the southern part of the district but swings to N.  $17^{\circ}$  E. in the northern part. The deposits in the slate belt are variously located within the belt, some centrally and some marginally, but they all trend in the same general direction as the belt itself. Two prospects in the southern part of the district are in smaller areas of slate, one (the Higgins prospect) to the east, and the other (the Frenchville prospect) to the west of the main belt. Manganiferous rocks are also reported but unproved at the Packard School prospect.

The area in which these deposits lie is nearly all under cultivation. The woodlands north, south, and west of the region shown in plate 2 are practically unknown geologically. A few reports of black rocks or of "coal" from scattered localities mainly to the west of the district suggest that there may be additional manganese deposits in the unexplored woodland areas.

Topographically the deposits lie on the uplands and especially on the higher of the hills and ridges that are underlain by sedimentary rock. This is partly because the slates enclosing the manganese deposits, being more resistant than most of the other sedimentary formations, form hills and ridges parallel to the strike, and partly because the bottom lands are largely covered with swamp and timber, which effectively hide any manganese deposits that might be present.

The entire district has been strongly glaciated. The mantle of till is deep in the bottom lands, but it is rarely more than six feet thick on the uplands. In most places the relatively resistant manganiferous slates are within three feet of the surface, and they are normally indicated by outcrops or by float on all except the gentlest slopes.

#### *Central District*

The known manganese deposits of the central district lie on Hovey Mountain and Maple Mountain, two adjoining mountains that rise about 700 feet above the lowlands to the east (figure 2). At present the deposits are quite inaccessible, but a new logging road was being built in 1944, that was to pass about a mile north of Maple Mountain.

Both mountains are completely timbered, but the deposits are readily located, for the principal manganiferous exposures are on the crests of the two mountains.

### *Southern District*

With one exception, the manganese deposits of the southern district lie within a belt of shales that covers most of the southern part of the district (plate 4). The one deposit that lies outside the shale belt described above is on Littleton Ridge, in the northwestern part of the district. The shale belt crosses into New Brunswick, and appears to include the iron deposits northwest of Woodstock, N. B., which is 10 miles northeast of Houlton. On its north and northwest sides, the shale belt is in contact with siliceous limestone which stratigraphically overlies it. On the south, the manganiferous shale and slate belt disappears beneath a nearly continuous mantle of glacial drift and outwash. Most of the deposits lie on the higher hills of the region, and many of them are at or near the crests of hills.

### Form of manganese deposits

The manganese deposits are of sedimentary origin and are everywhere conformable with the enclosing slates and limestones. Most of the deposits are steeply tilted tabular masses, from one foot to 150 feet in thickness and traceable along the strike for a few hundred or a few thousand feet. The Gelot Hill-Capital Hill manganiferous zone in New Sweden Township (plate 2) is, however, traceable for  $3\frac{1}{4}$  miles.

Most of the deposits are homoclinal, dipping more or less uniformly throughout. Each probably lies on the limb of a large fold, the opposite limb of which either is not exposed or contains no ore zone. The Gelot Hill deposit, however, is a nearly isoclinal syncline (plate 10), and the Henderson School deposit a more open syncline.

The deposits of the southern district are more intricately deformed than those of the northern district and many minor folds and faults were visible in the prospect trenches.

The two deposits that have been diamond drilled have proved to be continuous downward to the greatest depths prospected, which was 640 feet in one drill hole on the Dudley deposit. The thicker and longer deposits may be expected to continue downward below minable depth for open cut operations unless interfered with by structural complications. The usual practice of estimating the extension in depth of a tilted sedimentary deposit as one half the length is probably inadmissible here. Areas of specialized deposition in seas along the Appalachian geosyncline were probably not even roughly circular, but elongate parallel to the shoreline and to the topographic features of the sea floor. These in turn approximately paralleled the trend of previous Appalachian orogeny, and of Appalachian orogenies yet to come. Hence lenticular sedimentary deposits in active geosynclinal regions such as this probably have much greater extent along the regional structural trend than across it. If a tabular deposit later becomes tilted, a factor of  $\frac{1}{3}$  to  $\frac{1}{4}$  the length of the deposit for its probable extension in depth would probably be nearer

the truth than  $\frac{1}{2}$ . But, even though a factor of  $\frac{1}{4}$  be used in the case of the Aroostook manganese deposits, the depth of ore, as thus estimated, in all the thicker and longer homoclinal deposits of the northern district is probably greater than the depth to which it would be practicable to mine.

## Mineralogy and Lithology of the ores

### *Northern District*

The unoxidized ores of the northern district are of two distinct types. A few of the deposits contain ore of both types, but most of them exemplify only one or the other. The most abundant type is a deep-red hematitic shale containing from 5 to 20 per cent manganese. The ore as a rule is strongly laminated. In general, though by no means always, the laminae are most abundant and most distinct in the high-grade ore. Some laminae are from one millimeter to several millimeters thick, but many zones are made up of wavy laminae much less than a millimeter in thickness. Some laminae are prominent because they are dark red to black in color, but in most of the rock all the laminae are red and merely differ slightly in tone. Thin beds and cross-cutting veins of pink carbonate are prominent in some of the ores, especially at the Dudley deposit, and blebs and lenses of carbonate, with their long axes aligned along the bedding, are also scattered through the ore. The hematitic shale is interbedded with green, slightly calcareous slate and with red slate. The interbedding of manganiferous shale with low grade or barren shale is shown in the detailed stratigraphic section of the Dudley deposit (plate 15).

The ore rich in manganese and iron cannot always be distinguished from low-grade ore by its appearance. Ore that is rich in one or both of these oxides is of high specific gravity, but the only reliable test for the manganese content of the ore is chemical analysis. The "ore" in the Richardson prospect, for example, is heavy and appears to be rich in manganese. It proves on analysis, however, to contain much iron but little manganese. Typical ore of the hematitic type occurs in the Dudley, Higgins, and Gelot Hill prospects. Plate 3B shows the typical appearance of the best grade of ore in a prospect pit at the Dudley deposit. Steeply dipping shaly manganiferous beds are exposed at the left and right of the photo, and the shaly rubble in the central part of the pit shows the extreme fissility of the weathered rock.

A polished surface of strongly laminated hematitic type ore from the Smith prospect is illustrated in plate 5A. The light colored bands and lenses are of pink carbonate. The darker bands are of calcareous shale, which contains visible blebs of red hematite in the lowest layer of the specimen. Braunite and bementite are scattered through both light and dark bands, but are too finely divided for individual crystals to be visible. Black manganese oxide, formed as the result of weathering, has encroached on the upper and right edges of the specimen and a prominent patch of black manganese oxide transgresses the banding near the right edge



Plate 5A. Polished surface of laminated manganese ore from the Smith prospect. Numbered scale divisions are in centimeters. x 1.



Plate 5B. Ledge of even bedded and crinkled laminated ore at the Maple Mountain deposit.

of the specimen. A small area just above the 1 centimeter mark on the scale has been treated with acid. It effervesced freely, and the resulting bleached area shows small hematite blebs as light colored patches.

The second type of ore in the northern district is a gray to greenish-gray, finely crystalline rock that is basically a siliceous limestone. Much of this ore, also, is faintly laminated, but the laminae appear as shadowy gray bands that are much less distinct than the bands in the hematitic type of ore. The lamination is an original bedding structure. Where it is absent, the ore is massive and homogeneous and the bedding frequently not discernible. Zones of the siliceous limestone type of ore lie between strata of green shale, or slate, or of red slate, but as a rule barren shale is not intimately interbedded with the ore as it may be with the hematitic type.

The Aroostook manganese ores are mineralogically complex. The manganese-bearing minerals are so finely disseminated that it is almost impossible to recognize them with the naked eye, and not easy to identify them even in the laboratory. Microscopic and x-ray studies have established, however, that the most abundant manganese mineral in both types of ore is braunite  $[3(\text{Mn},\text{Fe})_2\text{O}_3 \cdot \text{MnSiO}_3]$  and that a pink form of bementite  $[5\text{H}_2\text{O} \cdot 8\text{MnO} \cdot 7\text{SiO}_2]$  is also common. Manganiferous carbonate is visible in some of the ore, and is especially abundant in specimens from the Dudley deposit. The pinkest carbonate, which is also richest in manganese, approaches mangandolomite in composition. Manganiferous carbonate is probably also disseminated through much of the rock in which individual carbonate crystals are submicroscopic.

In the hematitic type of ore the iron is mostly contained in hematite but partly in limonite; this ore also contains collophanite  $[\text{Ca}_3(\text{PO}_4)_2 \cdot \text{H}_2\text{O}]$ , which probably accounts for its generally high phosphorus content. In the siliceous limestone type, the iron is largely in chlorite, a hydrous magnesium-iron-aluminum silicate of variable composition. In such ore, blebs and veins of pink manganiferous carbonate or mangandolomite are almost lacking, but gray to white carbonate finely disseminated throughout the rock is probably somewhat manganiferous. At and near the surface the manganese ores are oxidized, and all of the primary manganese minerals are there altered, wholly or in part, to black manganese oxide whose exact mineralogical nature is undetermined.

The specific gravity of the manganese ores varies with the content of the iron and manganese. Determinations on 19 specimens of ore from the Dudley deposit ranged between 2.72 and 3.89 and averaged 3.18, which corresponds to a volume of 11.3 cubic feet for a long ton of ore. Four specific gravity determinations on Gelot Hill and Higgins ore ranged from 3.1 to 3.6. A figure of 11 cubic feet per long ton of ore has been used throughout this report in calculating tonnages.

### *Central District*

The ore from the Maple Mountain and Hovey Mountain prospects of the central district differs somewhat in appearance from the ore types of the northern district. It contains less carbonate and appears to run higher in silica, though this has not been checked by chemical analysis. The ore is predominantly a deep hematitic-red or reddish-black color. Most of it is finely laminated with lighter pinkish and darker reddish-black bands standing out most prominently. Some of the more shaly layers are strongly crinkled but most specimens show straight even laminae. The ore is extremely fine-grained and dense.

Manganese minerals are so finely disseminated in the ore as not to be separately visible. They are presumed to be predominantly braunite and bementite, for the central district ores appear to be geologically and genetically similar to the ores of the northern district. The principal difference visible in the field is an apparent decrease in the amount of carbonate and increase in the amount of hematite.

The photograph (plate 5B) shows an outcrop of ore at Maple Mountain, in which the dark even-bedded layers in the lower part of the photo are typical of most of the ore. The upper crinkled layers contain light pinkish bands which emphasize the lamination of the ore. The height of the ledge is about a foot.

The surface exposures of ore are in places coated with black manganese oxide films, but the black color is not as uniform or as pervasive as it is in the oxidized ores of the northern district. Apparently the central district ores are somewhat less susceptible to weathering.

The ores of the central district are interbedded with red and green slate. The thicker zones of manganiferous rock may be almost free of slate interbeds except along their margins but thinner zones are apt to have slate interbeds throughout.

### *Southern District*

The ores of the southern district are similar to those of the northern district. The hematitic-shale type of ore, however, is less abundant. The rocks of the southern district have undergone more intensive regional metamorphism with the result that some of the hematite originally present in the manganiferous shale has been altered to magnetite. The metamorphosed ore is laminated, and is dark gray, greenish gray, or black rather than reddish. The manganese minerals in the ores of the southern district have not been positively identified, but according to Milton<sup>1</sup>, who made thin section studies of several specimens of southern ores, the ore resembles that in many of the Dudley specimens from the northern district except that it contains abundant magnetite. Magnetite crystals are strewn out along

<sup>1</sup>Milton, Charles, personal communication.

definite bands in the ore. Most of the crystals are too minute to be separately visible to the unaided eye, but occasional beds contain scattered octahedrons up to 3 millimeters in diameter. All the magnetite and hematite bearing ore of the southern district is so magnetic that covered ore zones may readily be detected with a dip needle. In many places this type of ore is interbedded with a green chloritic shale or slate in which there is little manganese, yet enough to produce a black stain in the oxidized rock at the surface. This manganese-stained chloritic shale makes up a large part of what are loosely called ore zones at most of the southern deposits, but it is of too low grade to be economically important.

In addition to this magnetitic and hematitic shale ore, the southern district contains ore that resembles the siliceous limestone ore of the northern district. This consists of a light gray, finely crystalline, massive-bedded rock that might be called either siliceous limestone or calcareous quartzite. It is extremely tough and dense, and is non-magnetic. Although this rock contains a higher percentage of manganese than the average magnetite-bearing ore of the southern district, very little manganese stain is visible on its weathered surface, and it probably is little enriched, if at all, by oxidation. Ore of this type is present at several deposits but is abundant only at the Littleton Ridge prospect.

#### Chemistry of the ores

Approximately complete chemical analyses of manganese ore have been run only on ore from drill hole number 2 at the Dudley deposit. Analyses representing 145 feet of high-grade ore, in core and sludge, from this hole give an average composition as follows:

Manganese.....	12.81
Iron.....	20.8
Silica.....	26.3
Alumina.....	8.3
Calcium oxide.....	1.27
Magnesium oxide.....	1.33 (?)
Sulphur.....	0.52
Phosphorus.....	0.676

These figures are probably representative for most of the high-grade ore at this deposit. The ores from other deposits in the northern district are generally lower in manganese and iron and higher in silica and alumina; some of them are also more calcareous. Phosphorus is consistently high wherever it has been determined; a few samples contain over one per cent. The phosphorus appears to be associated with the iron, for samples from Dudley drill hole 2 that are high in iron but low in manganese are high in phosphorus, whereas samples high in manganese but with an average amount of iron have an average amount of phosphorus.

Many determinations have been made of the manganese and iron content of ore and adjacent country rock from all the deposits

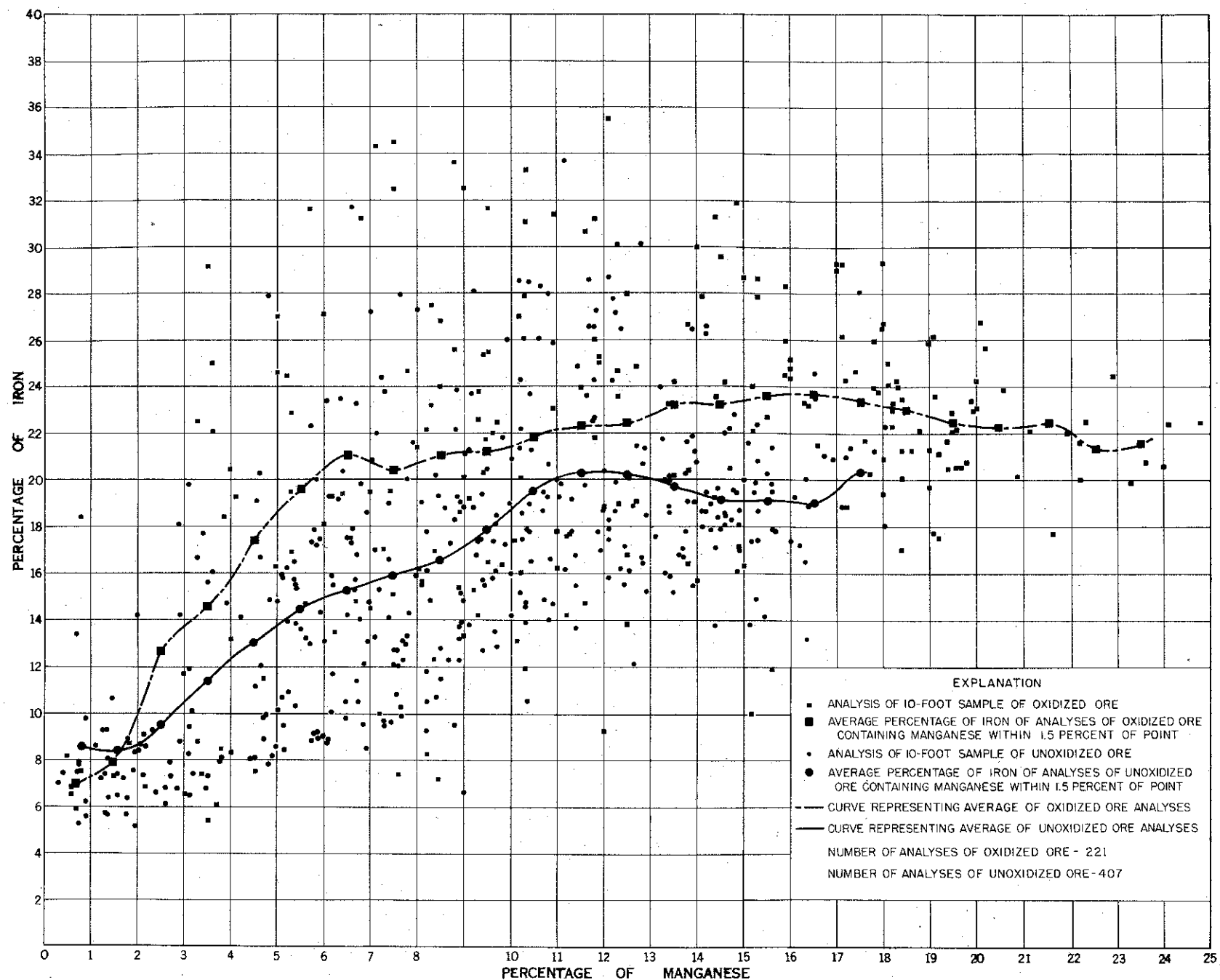


prospected by the Manganese Ore Co. Plate 6 shows as small circles 407 analyses of samples taken below the zone of oxidation at the Dudley deposit. These are plotted with percentages of manganese as ordinates and percentages of iron as abscissae. A curve, shown by the solid line, connects points representing the average percentage of iron in the ore for each 1 per cent increase in manganese. All analyses, whose manganese content is within  $1\frac{1}{2}$  per cent of the plotted point, are included in each average. The curve is thus based on a sliding or overlapping series of averages, and insignificant irregularities in the curve are thereby reduced. In "ore" containing between 3 and 11 per cent manganese, the curve rises sharply at the rate of more than 1 per cent of iron for every 1 per cent increase in manganese. Above 11 per cent, however, percentage of manganese increases with no corresponding increase in percentage of iron.

The points representing the analyses are not scattered at random over the graph. A nearly straight line may be drawn along the lower edge of the area containing almost all of the plotted points. Only a few analyses, representing samples in which the ratio of manganese to iron is unusually high, fall below this line. In the upper part of the graph, on the other hand, no similar cut-off line exists, and the analyses are more widely scattered. It is noteworthy, however, that the samples containing the highest percentages of manganese have only moderate amounts of iron, and those containing highest percentages of iron have moderate or small amounts of manganese.

A curve has been drawn in the same manner based on all the available analyses of unoxidized ore at the Higgins prospect (see plate 7, dashed line). This is the only other manganese deposit, besides the Dudley, which has been diamond drilled, and for which the composition of the unweathered ore is therefore established. In plate 7, the curve representing unoxidized Dudley ore has been redrawn (solid line) to serve as a basis of comparison. Comparison of the two curves shows that the Higgins ore has a lower ratio of iron to manganese than the Dudley ore, and also that none of the Higgins ore is as high-grade as is the best of the Dudley ore. The curve for Higgins ore more nearly approximates a straight line, but flattening of the curve is noticeable to the right of the 8 per cent manganese line. Apparently the tendency for manganese deposition to continue into the higher percentages without corresponding increase in iron content was also in effect at the Higgins deposit, but it became operative at a lower level of manganese concentration.

The other seven curves on plate 7 are based on analyses of oxidized ore from each of the deposits that have been extensively prospected by trenching. These include the Dudley and Higgins deposits, which were also diamond drilled. The effect of weathering on the grade of the ores, and on the iron-manganese ratio, is discussed in the succeeding section, but it should be noted here that the curves for oxidized ore show the same flattening tendency as do the curves for unoxidized ore previously discussed. This is most pronounced for Littleton Ridge ore.



GRAPH SHOWING PERCENTAGES OF MANGANESE AND IRON IN OXIDIZED  
AND UNOXIDIZED ORES OF THE DUDLEY DEPOSIT

The Maple Mountain prospect, which is the only deposit of the central district for which numerous analyses are available, shows a higher ratio of iron to manganese than any other deposit. For low and intermediate percentages of manganese the ore averages about 4 per cent more iron, but the percentage of iron falls off somewhat in ore which contains the highest percentages of manganese.

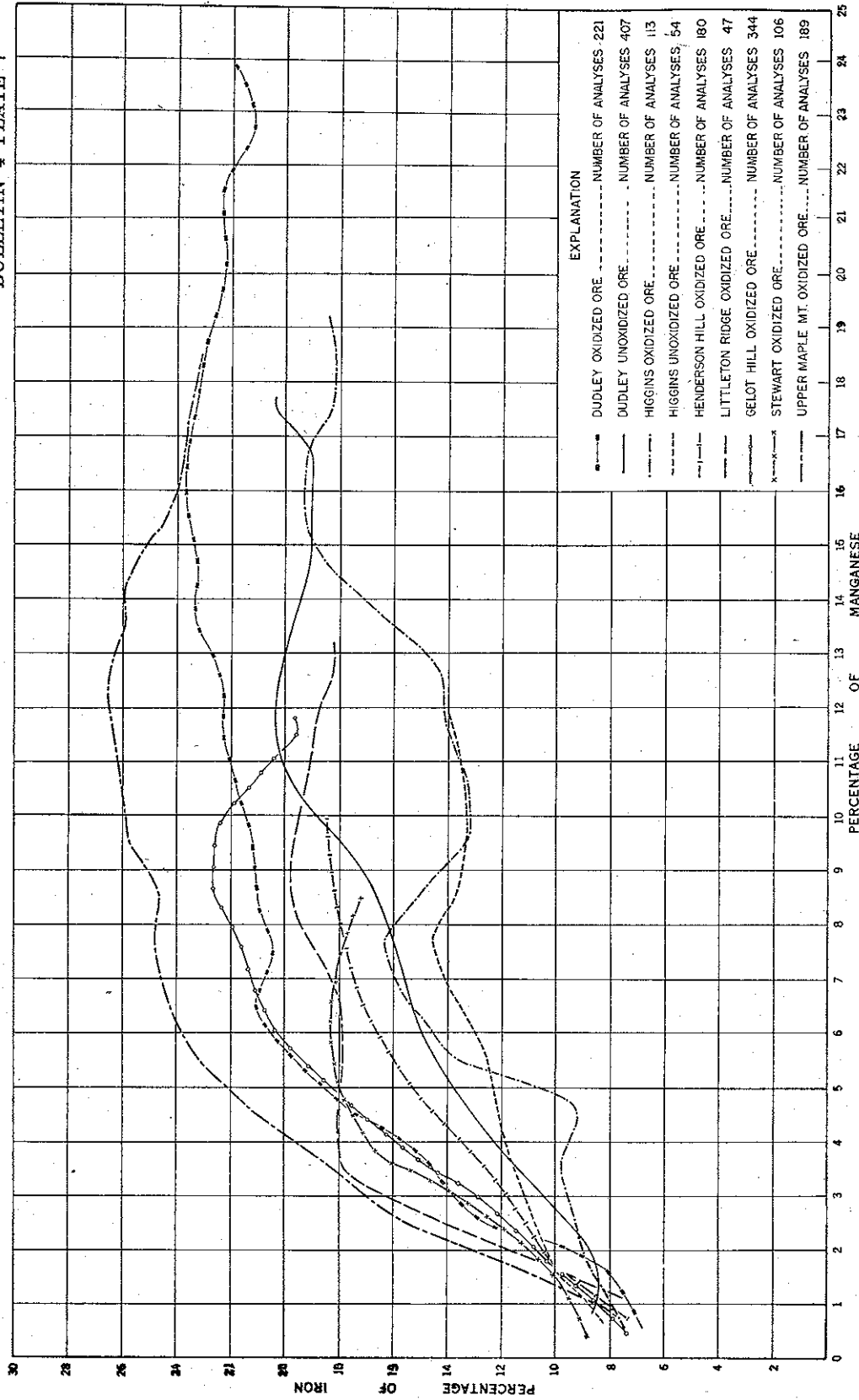
The iron-manganese ratio in ores of the southern district is almost identical with that in the ores of the northern district. Curves based on analyses of ores from the Littleton Ridge, Henderson Hill, and Stewart prospects are very close together, even though the curve for the Littleton Ridge prospect represents ore of the siliceous limestone type, while those for Henderson Hill and Stewart prospects represent ore of the magnetite-bearing shale type. All three curves lie between the highest and lowest curves representing ores from the northern district.

The curves for the manganese ores graphed in plate 7 may be used to predict the percentage of iron that will be obtained from manganese ore of a given grade.

#### Oxidation and surface enrichment of ores

In the unweathered manganiferous rock, the manganese appears to be largely in the form of silicate minerals, though partly in the form of carbonate and oxide. Under oxidizing conditions above the water table, the carbonates are leached, leaving a less dense rock which may be quite earthy. The manganese minerals are altered to black manganese oxide, the exact composition of which is unknown. Oxide coats all the bedding planes, joints, and cleavage surfaces in the fissile ores, and it also works inward from cracks, so that most specimens appear almost entirely black. Plate 8A shows a polished surface of an ore specimen, in which black manganese oxide has encroached on the surrounding rock along numerous minute bedding planes. However, sectioning or breaking of a solid piece of ore usually reveals a relatively unaltered core containing primary ore minerals. Iron minerals in the ore are altered to limonite. Manganese and iron oxide stains are abundant and prominent in the ore of the hematitic shale type, but they are much less so in the siliceous limestone type of ore. The latter is denser and more compact, and without open bedding planes and joints, so that oxidizing waters have less opportunity to pervade them. The hematitic shale ore oxidizes rapidly; that taken from deep test shafts on the Dudley property darkened noticeably in less than a year's exposure at the surface.

The depth to which leaching of soluble components of the rock and oxidation of the manganese progresses, is variable from deposit to deposit and from place to place within deposits, depending on the amount of jointing of the bedrock, the spacing and attitude of bedding planes, the position of the water table and other factors. At the Dudley deposit, the manganiferous shale is thin bedded and



GRAPH SHOWING AVERAGE PERCENTAGES OF MANGANESE AND IRON IN OXIDIZED AND UNOXIDIZED ORES FROM SEVEN MANGANESE DEPOSITS

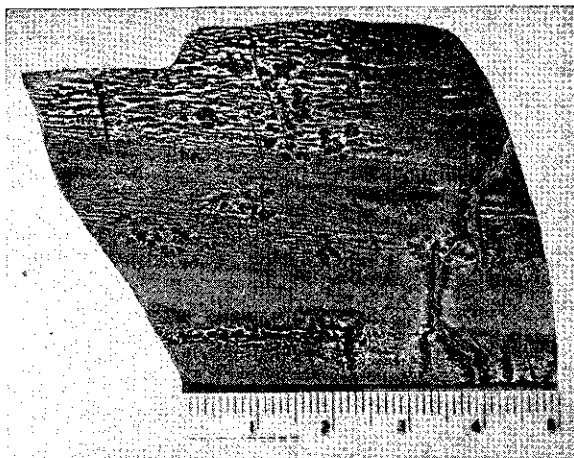


Plate 8A. Polished surface of specimen from the Higgins prospect, showing black manganese oxide coating and replacing manganiferous shale along numerous minute bedding planes. xl.



Plate 8B. Core of syncline at Gelot Hill deposit.

the beds are steeply dipping. In July 1943 the water levels in three shafts stood at 16.5, 19.5 and 22.5 feet below the surface. In nine diamond drill holes, which started and continued in the ore zone, core recovery was very poor to a depth averaging 14 feet and poor to a depth averaging 20 feet. The rock was heavily coated and partly replaced with manganese oxide to an average depth of 14 feet, and showed some secondary manganese oxide staining to an average depth of 18 feet. It appears from these data that leaching and secondary enrichment of the Dudley ore body is confined to a shallow zone above the water table, and is not an appreciable factor in determining the grade of the ore below a depth of about 20 feet.

Most of the oxide of manganese and also of iron is probably formed by alteration of the primary minerals in place, but a certain amount of migration of manganese and iron in solution is evidenced by the fact that zones of high-grade ore are always somewhat wider at the surface than they are 30 or 40 feet below the surface. This widening is usually something less than 10 feet on either side for the thickest ore zones, and may be only a few inches for thin ore zones. This fact must be kept in mind, however, in trying to estimate tonnages of unoxidized ore at depth from surface prospecting alone. Estimates made on the basis of measured width of the ore zones at the surface are sure to be too large.

In an attempt to determine quantitatively the variation in percentage of manganese with depth at the Dudley deposit, trench and drill core analyses from different depths for ore above 10 per cent grade were plotted as a graph. The results are shown in figure 3, in which depth below the surface forms the abscissa and percentage of manganese the ordinate. The circles indicate average percentage of manganese for ore at varying depths and the numbers alongside indicate the number of analyses on which the average was based. The average of analyses of 127 trench samples is about 2 per cent higher than the average of drill core samples for any of the depths plotted, showing clearly that surface ore is appreciably enriched. The number of drill cores available for study was not adequate to overcome the accidental variations in composition of the ore, due to penetration of different parts of the ore zones by the drill holes. There is thus no consistent trend in the analyses of samples below the surface, and the curve based on a sliding average of the plotted points probably has little significance. The poor core recovery to depths of 20 feet also makes all analyses based on core and sludge near the surface suspect because the proper combination of core and sludge analyses for irregularly weathered rock is almost impossible to evaluate.

Three 50-foot shafts were also sunk in the main ore zone of the Dudley orebody, and very large samples were taken at 5-foot intervals. The analyses representing the average percentages of manganese in the rock of the three shafts for each 5-foot interval from 0 to 50 feet have also been plotted on the graph. The points are widely scattered and show no consistent trend, and the curve based on a



sliding average shows no variation in composition that can be attributed to the effects of weathering. Apparently the variations due to penetrations of beds of different original composition, and the variations due to method of sampling and analysis entirely obscure any change in composition due to depth beneath the surface.

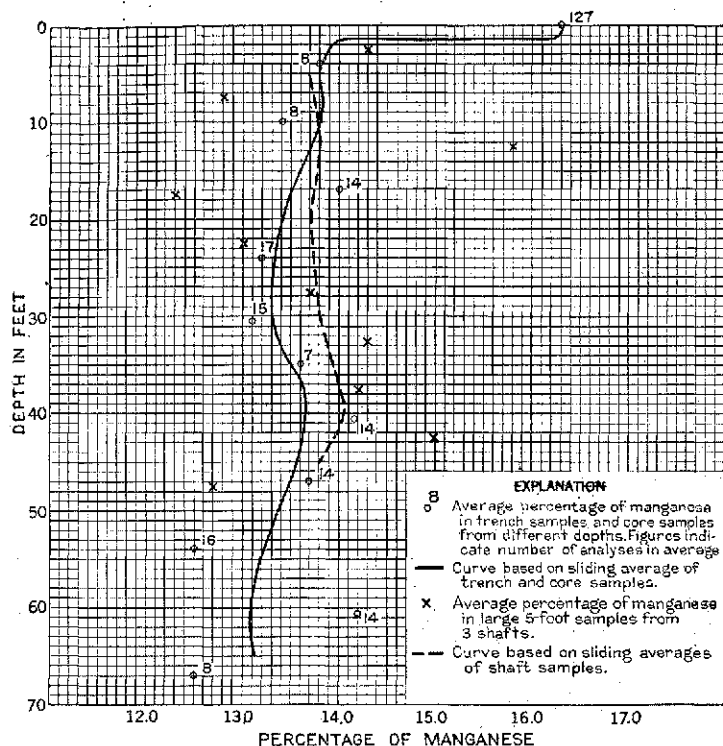


Figure 3: Graph showing variation in percentage of manganese with depth at the Dudley deposit.

The available chemical evidence at the Dudley deposit thus indicates that the best grade of ore at or within a few feet of the surface is from 2 to 3 per cent higher in manganese than ore at depth, and visual evidence indicates that some enrichment is affected down to a depth of about 20 feet.

In each of fifteen cross sections of the Dudley orebody comparison of the grade of surface and near-surface ore was made with the grade of ore in unweathered drill core across the same beds at depths between 20 and 100 feet. In these the average manganese content of ore at the surface exceeded that of ore 20 to 100 feet below the surface by 1.75 per cent where the percentage of manganese at depth was above 10 per cent, and by 2.81 per cent where the percentage of manganese at depth was between 5 and 10 per cent. Between

surface ore in these same sections and ore from depths between 100 and 200 feet, the difference was 1.73 per cent for ore containing over 10 per cent manganese and 2.87 per cent for ore containing 5 to 10 per cent. There is thus no enrichment whatever of ore at depths of 20 to 100 feet as compared with ore at depths of 100 to 200 feet.

At the Dudley deposit the relatively greater enrichment of the lower grade ores as compared with those of higher grade is believed to be due to migration in solution of some manganese and iron from high-grade zones into adjacent low-grade zones. In deposits that consist entirely of low-grade ore, the oxidized zone would probably be less enriched than is the low-grade ore at the Dudley deposit.

Oxidation has enriched the ores in iron more than in manganese. In the case of the Dudley deposit this fact is apparent by comparison of the curves showing the manganese-iron ratio for oxidized and unoxidized ores (plate 6). If the ores were enriched in iron and manganese in exact proportion to the percentage of these elements in the unoxidized ore, the two curves would fall on top of each other, but with the curve for oxidized ore extending farther to the right. Instead of that, the curve based on analyses of oxidized ores is everywhere above the one for unoxidized ores, the interval varying from 2 to 6 per cent. The true percentage of enrichment in iron for different grades of ore cannot be read directly from these curves, but will be somewhat greater than the vertical interval between the curves in that part of the graph where both curves are rising.

In the case of the Higgins deposit, the curve representing the manganese-iron ratio in the oxidized ore is very irregular, oscillating above and below the curve for unoxidized ore (plate 7). The Higgins deposit is anomalous, however, in many respects, and the behavior of the Dudley ores on oxidizing is probably more truly representative of the Aroostook manganese ores as a whole.

No figures relating to amount or depth of enrichment as reliable as those for the Dudley ore are available for any other deposit of the northern district. Ore below the water table at the other deposits would likewise, no doubt, be leaner than that exposed in surface trenches, but small differences in chemical or mineral composition or in permeability between the ores of different deposits might cause great differences in the amount of surface enrichment. Because no data are available at the other deposits a reduction of 1 per cent in grade has been assumed for ore below a depth of 20 feet in calculating reserves of manganese.

As no drilling has been done at any prospect in the central or southern districts, no quantitative estimate can be made of the extent to which the types of ores in these districts have been enriched near the surface by oxidation. There is less manganese stain, however, on most of the near-surface ores of these districts than on hematitic shales of the northern district, and there is practically no manganese stain on the siliceous limestone type of ore at Littleton Ridge. Presumably, therefore, surface enrichment has been less than in

northern district ores, and the Littleton Ridge ore is probably practically unaffected in its manganese content by weathering.

The depth to the water table, and hence the approximate depth of the oxidized ore zone, varies with location and geologic conditions, but the range of depths is probably not great. For example, the depth to water in the eleven wells of the northern district, listed in Water Supply Paper 102<sup>1</sup>, ranges between 8 and 30 feet, and averages 18 feet. In all but one of the 24 wells listed for Aroostook County, the depth to water level is between 6 and 40 feet, and it averages 24 feet. Lean unoxidized ore will probably be encountered, therefore, at some depth between 6 and 40 feet in almost all deposits, though oxidation may locally extend to depths exceeding 40 feet in a few deposits on unusually steep or high hills, such as Gelot Hill. An oxidized zone 20 feet thick has been assumed throughout this report in estimating tonnages of ore.

### Origin of the manganese deposits

Although comprehensive petrographic and chemical studies of the manganese ores of Aroostook County have not been made, it is clear from the field relations previously described that the manganese deposits are of sedimentary origin. The manganese and iron are believed to have been deposited in seas or lagoons, in which silt was also settling from suspension. Varying amounts of calcium carbonate were also precipitating simultaneously with the manganese and iron. In some places little silt reached the zone of manganese precipitation, so that the principal constituents of the ores besides the manganese and iron compounds were calcium carbonate and silica.

At the manganiferous iron deposit at Woodstock, New Brunswick, which is only a few miles east of Houlton, and is quite similar to the Aroostook deposits, Caley<sup>2</sup> has postulated that the metals were derived from volcanic extrusions. He notes the presence of volcanic rocks within 10 miles of the deposit. Trefethen<sup>3</sup> also has suggested that volcanic emanations contributed iron and manganese to the sea water giving rise to the deposits in a manner similar to the formation of the Lake Superior iron deposits. Lavas are not associated with the Aroostook deposits, however, nor are they known in the slate-limestone series in which the deposits lie. Several thin beds of volcanic ash are interbedded in the ores of the Dudley deposit, however, and thick lavas and ash beds are known in Silurian rocks in New Brunswick and also in southeastern Maine. Vulcanism seems, therefore, to have been going on during the time the manganese

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<sup>1</sup>Fuller, M. L., Contributions to the hydrology of Eastern United States: U. S. Geol. Survey Water Supply Paper 102, pp. 29-30, 1903.

<sup>2</sup>Caley, J. F., Geology of the Woodstock area, Carleton and York Counties, New Brunswick: Canada Dept. of Mines, Mem. 198, pp. 1-21, 1936.

<sup>3</sup>Trefethen, J. M., Report of the State Geologist of Maine, 1942-43, pp. 28-29.

deposits were forming, though not in the immediate vicinity of the deposits. The writer inclines to the view that the manganese was derived by subaerial weathering and erosion of abundant volcanic rocks lying an unknown distance to the east. Exhalations from submarine volcanoes may also have added their mineral content to the sea water, but there is no evidence that this took place anywhere in the vicinity of the ore bodies.

Great thicknesses of igneous rocks must have been weathered and eroded to account for the manganese in the ore deposits, and also for the abnormally high manganese in the enclosing slates. Normal granites contain less than 0.1 per cent, and basalt and gabbro less than 0.3 per cent manganese oxide. The concentration of manganese in extensive bodies of water in sufficient concentration to permit deposition of manganese from solution would therefore require the addition of small quantities of manganese in solution over long periods of time, and probably also require restricted circulation of the water in the sea or lagoon. Bacteria having the power to precipitate manganese, such as those described by Zapfe<sup>1</sup>, may have assisted deposition. Once under way, the process was undoubtedly assisted by the catalytic effect of the already precipitated manganese compounds upon the manganese remaining in solution. Laminations in most of the high-grade manganese ores suggest a rhythmic type of deposition.

The seas or lagoons, in which the manganese deposits formed, could not have been deep, for ripple marks are visible in the ores in a few places, notably in a test pit in the middle of the Dudley ore body. The enclosing silts are fine-grained and calcareous, which indicates quiet water deposition. Near the ore zones at some of the deposits, red shale or slate is common, suggesting a change to oxidizing conditions as a common accompaniment of manganese deposition. This seems not to have been a necessary condition for manganese precipitation, however, for red shale or slate is sparingly present or totally absent at other deposits.

Besides the deposition of manganese and iron in restricted areas in concentrations sufficient to form possible ore bodies, there was deposition of these metals in amounts above the normal over much more extensive areas. All analyses of the seemingly barren slate, which forms the country rock enclosing the deposits, show manganese varying in amount from 1 to 3 per cent and iron from 5 to 15 per cent.

Little information is available on the chemical form in which the manganese was transported in solution or the form in which it was deposited. Among the minerals identified in the ore, the manganese silicates braunite and bementite are most important. Some of the bementite forms veins and replacements transgressing the original bedding structure of the ore, and indicating a secondary origin for part at least of the bementite in the ore. Most, if not all, of the

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<sup>1</sup>Zapfe, Carl, Deposition of manganese; *Econ. Geol.*, vol. 26, pp. 799-833, 1931.

braunite, however, appears to be primary. Primary braunite is also known from the Black Diablo manganese mine in Pershing County, Nevada, where it is associated with sedimentary chert.<sup>1</sup>

The abundance of lenticular manganese deposits in the narrow belts of steeply dipping, mid-Silurian slates in eastern Aroostook County indicates that the conditions necessary for manganese deposition were developed in numerous places on the sea floor or in numerous embayments or lagoons. Conditions necessary for ore formation were also recurrent in the same region, as shown by the presence of ore bodies at different stratigraphic horizons.

Since the formation of the ore bodies, regional metamorphism is responsible for most of the changes that have affected them. This includes folding and faulting, the development in some places of slaty cleavage in the ores and enclosing rocks, recrystallization of the carbonate minerals and some silicification of the rock. Some migration and redeposition of manganese has also taken place, forming veins and replacements of manganiferous carbonate and bementite, but the total effect of this alteration is believed to have been of minor importance. In very recent geologic time, a weathered and enriched manganese oxide zone has developed at the surface, as the result of oxidation and hydration of the manganese minerals and leaching of the more soluble components of the ore and enclosing rock. Glaciation has effectively removed most, if not all, of the supergene ore zones developed before the last ice advance, and the relatively thin mantle of enriched ore now present at the deposits has developed in post-glacial time.

Among manganese deposits in the United States, the Aroostook ore bodies are unique. Braunite-bementite deposits are known from the western states, but they are usually associated with volcanic rocks or with chert, or both. In structure of the ore bodies and lithology of the ores, the low-grade "carbonate-slate" manganese ores of the Cuyuna Range in Minnesota rather closely resemble the Aroostook deposits. In the primary Cuyuna ores, however, the manganese is in carbonate form. Almost all of the other manganese deposits in the eastern part of the country lie in the central and southern Appalachian states, and are secondary deposits of manganese oxide minerals. The origin of the Aroostook ores is thus dissimilar from others described in this country.

Superficially at least the Aroostook manganese ores resemble the Clinton iron ores quite closely, although a number of differences exist. Among these are the absence of significant percentages of manganese in Clinton ores anywhere from New York to Alabama, the much greater areal extent of the iron ore beds, and the presence of abundant fossils in some of the Clinton ore. On the other hand, the Aroostook ores are of mid-Silurian, and possibly of Clinton age, and they bear the same general relations to their enclosing rocks

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<sup>1</sup>Crittenden, Max D., Jr.: personal communication.

as do the Clinton ores. Manganese may be present in the deposits which formed in Aroostook County in mid-Silurian time, but absent farther south, because abundant manganese-rich volcanic rocks were being extruded nearby in New Brunswick, whereas farther south only manganese-poor pre-Cambrian rocks or pre-Silurian Paleozoic sediments were being eroded to supply their mineral content to the Clinton seas. Whether the Aroostook manganese ores are the northern equivalents of the Clinton iron ores of the Appalachians is far from certain, but it seems likely that the genesis of the Aroostook ores as outlined above is quite similar to that of the Clinton ores.

### Reserves of Manganese

The reserves of manganese ore in Aroostook County are divided into three categories according to the degree of accuracy with which the size and grade of the ore bodies are known. Measured ore is ore for which tonnage of manganese has been computed from detailed prospecting and sampling, with a probable error of not more than 20 per cent. Indicated ore is ore for which tonnage of manganese has been calculated with a fairly large probable error from some specific measurements, supplemented by projection of the ore bodies for a reasonable distance on the basis of geologic evidence. Inferred ore is ore for which few or no measurements of size and grade have been made, but whose presence is deduced from geologic evidence; the quantity of inferred ore can only be roughly estimated.

In calculating the reserves of manganese a deposit is not considered minable by surface methods to a depth in excess of twice its width; the tonnage of manganese at a deposit 20 feet wide, for example, is calculated to a depth of only 40 feet. Where prospecting or geologic evidence indicate continuity downward, deposits more than 50 feet but less than 100 feet wide are calculated to a depth of 100 feet, and deposits more than 100 feet wide to a depth of 200 feet. Although the Dudley deposit is known to extend deeper than 200 feet and others probably do also, no calculations of ore below this level have been made, on the supposition that the expense of mining this deep ore by surface methods would be prohibitive, and that the grade of the ore would not warrant the expense of underground mining.

A 5 per cent cut-off is used in the calculations for all deposits except the Dudley and Maple Mountain deposits. No rock below 5 per cent grade has been included except where thin zones of low-grade material are interbedded with ore sufficiently high in manganese to bring the average above the cut-off grade. The weighted average of the higher- and lower-grade material is then applied to the combined width in calculating tonnage. This method was adopted in the belief that separation of low-grade zones a few feet thick from higher-grade ore by selective mining would not be feasible in working deposits of this type.

A cut-off grade of 9 per cent was used at the Maple Mountain deposit because this gave the largest tonnage of relatively high-grade ore. At the Dudley deposit the manganese tonnage has been



calculated on the basis of both a 5 per cent and a 10 per cent cut-off. With the 5 per cent cut-off the tonnage is appreciably larger than with a 10 per cent cut-off, but the average grade of the ore is about 2 per cent lower. Estimates for ore above 10 per cent grade were not made at other deposits, either because the tonnage of such ore would have been negligible in quantity or because detailed sampling had not been done to indicate the relative quantities of higher-grade and lower-grade ore.

Tonnage estimates for each of the prospects described in this report are shown in table 1. For convenience of comparison, the tonnages have been calculated in terms of the amount of metallic manganese. The average manganese content of the ores at each deposit is also given.

Measured tonnage can be calculated for only five of the prospects. For three of these the calculation includes ore to a depth of only 20 feet, because, although the size and grade of the deposit at the surface are well known, there are no data on the grade of ore below the zone of oxidation.

Indicated ore is calculated for 14 deposits. Figures for indicated tonnage of manganese include the measured tonnage where that has been determined. For many of the deposits, indicated ore is calculated only to a 20-foot depth, also because the size and grade of those deposits below the zone of oxidation is uncertain.

Inferred ore has been calculated for all but four of the prospects. At these four, geologic evidence indicates the presence of some ore above 5 per cent grade, but the data are too scanty to warrant any surmise as to the probable amount. None of the four show any signs of being commercially important. Manganese in the estimates of inferred ore includes that in the indicated ore. For deposits whose grade, width, or continuity downward is uncertain, the estimates are for depths of 20 feet only; and for better known deposits that do not seem to be economically minable to a depth of 100 feet the estimates are for a depth approximately twice the width. Tonnage is calculated to a 200-foot depth for the ore zones more than 100 feet wide that are known or thought to be continuous downward. Where there is doubt of such continuity, no tonnage is given for depths greater than 100 feet.

Table 1 shows that most of the manganese bodies in Aroostook County are small and that all are of low grade. The deposit having the greatest amount of higher-grade ore is the Dudley, but the Maple Mountain and Hovey Mountain prospects may also be large and of relatively high grade. The Littleton Ridge, Silver, and Smith prospects have not been thoroughly explored, and additional information concerning them might warrant a large increase in the estimates of inferred ore. The Gelot Hill deposit is large but of very low grade.

The data in table 1 have been used for making graphs that show the tonnages of manganese for different cut-offs (plate 9). Each

Table 1.—Table showing reserves of manganese in measured, indicated, and inferred ore at each of the described deposits in Aroostook County.

Name of prospect	Long tons of Mn in measured ore			Long tons of Mn in indicated ore			Long tons of Mn in inferred ore		
	To	100 feet	Grade	To	200 feet	Grade	To	100 feet	Grade
	100 feet	Grade	200 feet	Grade	200 feet	Grade	200 feet	Grade	200 feet
Gelat Hill.....	38,900*	6.7%	38,900*	6.7%	266,370	5.7%	232,000	6.0%	431,400
Capitol Hill.....	4,600*	8.8%	4,600*	8.8%	52,700†	8.0%	133,200†	8.0%	133,200†
Lundgren School.							1,600*	6.0%	1,600*
Grant.....							?		?
Spaulding School.							0		0
Henderson School.							600*	7.0%	600*
Anderson.....							0		0
Fox & McIntyre.							4,100*	9.0%	4,100*
Perham Church.							7,300†	8.0%	7,300†
Bugbee-Bragdon.							0		0
Silver.....							34,000	10.0%	34,000†
Aroostook River.							?		?
Haines.....							8,600†	10.0%	8,600†
Castle Hill Grange Hall.							14,800†	6.5%	14,800†
Richardson.....							0		0
Smith.....							3,800	8.0	3,800
Dudley:									
5% cut-off.	477,000	10.7%	904,000	10.4%	492,000	10.4%	492,000	10.7%	919,000
10% cut-off.	326,000	12.8%	603,000	12.6%	332,000	12.8%	332,000	12.8%	609,000
Higgins.....	6,900*	10.5%	6,900*	10.5%	10,700†	10.5%	10,700†	10.5%	10,700†
Frenchville.							500*	12.0%	500*
Others of northern district.							?		?
Hovey Mountain.							9,000†	9.0%	9,000†
Lower Maple Mountain.							38,000	12.0%	69,000
Upper Maple Mountain.							160,000	10.0%	?
Littleton Ridge.							63,000†	9.3%	63,000†
North of Henderson Hill.							0		0
Henderson Hill.	21,000*	7.0%	21,000*	7.0%	50,200†	6.5%	68,000†	6.5%	68,000†
Between Henderson & Westford Hills.							0		0
Westford Hill.							0		0
Haskell.....							4,900†	9.0%	4,900†
Daggett Hill.							3,200†	7.0%	3,200†
Nickerson.....							0		0
Gardner.....							1,600*	9.0%	1,600*
Benn.....							0		0
Stewart.....							?		?
Adams Mountain.							29,200†	6.5%	29,200†
Others of southern district.							200*	8.3%	200*
							0		0

\*Ore calculated to depth of 20 feet only.

†Ore calculated to depth less than indicated at top of column.

deposit is treated as a unit, and its tonnage and grade to the greatest depth calculated in table 1 are used. In the case of the Dudley deposit, the tonnage and grade with a 5 per cent cut-off is used for the part of the graph below the 10 per cent level, and the tonnage and grade with 10 per cent cut-off for the curves above that level. The curve that reaches only halfway across the diagram represents indicated ore, and the longer curve represents inferred ore. Of each pair of connected points, that one on the curve represents the tonnage of manganese in all deposits containing ore above the grade indicated, while the corresponding point vertically above it represents the average grade of the ore above the cut-off value. Cut-off values are taken for 1 per cent intervals from 5 per cent to 12 per cent. Ore above 13 per cent grade is present at several deposits, but in such small amount as to be unimportant.

The curves representing inferred ore are more significant than those representing indicated ore, for they give a more complete picture of the total amount of manganese. The shape of the curves is dominated by the large deposits. The Gelot Hill deposit accounts for the great extension of the curve representing inferred ore between the 5 and 6 per cent cut-offs. The similar long extension between the 9 and 10 per cent cut-offs is due to the Upper Maple Mountain prospect, and the long flat stretch for both curves at the left of the diagram is due almost wholly to the influence of the Dudley deposit. Collectively, the few large deposits thus have far more importance than the many smaller deposits.

### Economic Considerations

Possible future development of Aroostook manganese ores depends upon a variety of factors, not all of which are readily evaluated. Among the most important of the problems involved is the metallurgical treatment of the ores. The manganese in the primary ore and in some of the oxidized ore is largely in the form of complex oxide-silicate minerals, such as braunite and bementite, and manganese thus combined is not available for use in the metallurgical industry. The treatment of ores of the Aroostook type to convert the manganese into usable form has been and is being studied by the Manganese Ore Co. and the Bureau of Mines. Eventual utilization of the ores depends more than anything else on development of a process that will give reasonably high recovery and at the same time be inexpensive. Progress in this direction has been made, but the problem cannot yet be said to be solved.

Recovery of the iron, which is somewhat more than twice as abundant as manganese, would give a valuable by-product. Three of the methods of treatment that have been considered are leaching of the manganese with sulphurous acid, matte smelting and electrolytic separation. If the first-named method were used a local source for sulphur would be highly desirable. The Drew Lake sulphide prospect, west of Houlton (plate 4, No. 14) appears wholly inadequate in size to meet the need, but a large pyrrhotite deposit at the Katahdin

ganese deposits in Aroostook County are of low grade. Solution of metallurgical problems incident to handling low-grade ores on a quantity basis has, however, been one of the crowning achievements of the American mining industry, and that fact gives promise for eventual utilization of the Aroostook ores. The proximity of these deposits to large eastern consumers of manganese is in their favor.

At the Dudley deposit alone, the amount of measured manganese to a depth of 200 feet very nearly equals the total consumption of manganese in concentrates above 10 per cent in grade in the United States for the year 1939. This and other large deposits in Aroostook County thus constitute an important strategic reserve of a vital metal.

## [Descriptions of deposits

### *Northern District*

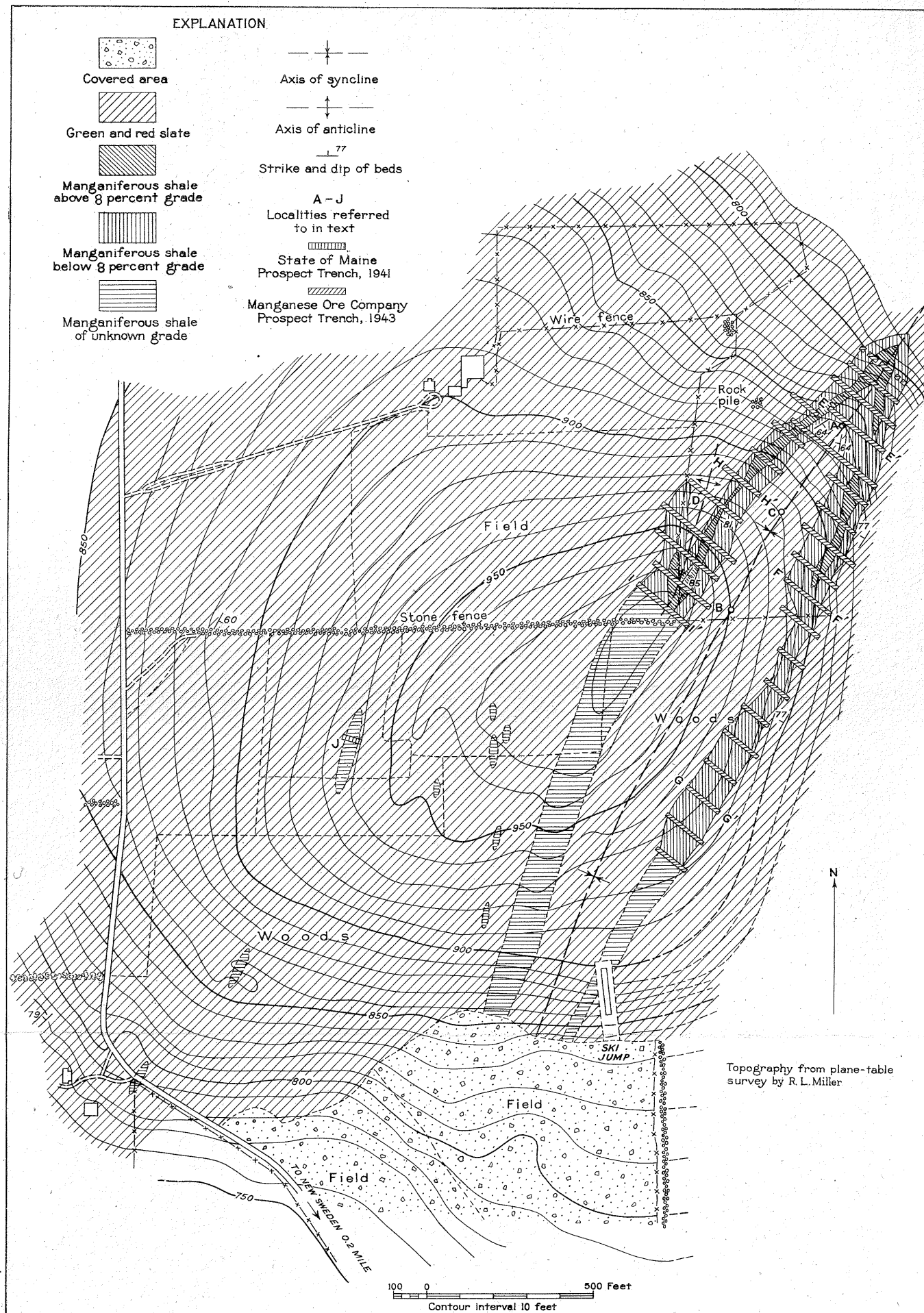
#### *Gelot Hill deposit*

Manganiferous rock has been found on the crest and slopes of Gelot Hill, a prominent knob in the southeastern part of New Sweden Township (pl. 2, No. 1).

The deposit has been prospected on the farms of Lawrence Hemberg and Aaron Anderson, which are on the north, east, and southeast slopes of the hill, and it also underlies the fields and woodlands of A. P. Pierson, on its southwest slopes (plate 10).

Gelot Hill is chiefly composed of gray and green chloritic slates, which in places contain thin interbeds of red slate. The bedding strikes about N. 25° E. and dips steeply; the cleavage strikes N. 40° E. and stands nearly vertical. Although the slates are locally manganiferous at many places on Gelot Hill, only two zones of potential "ore" have been recognized. The larger crosses the crest of the hill from north-northeast to south-southwest, and the smaller is on the west slope of the hill. The larger deposit was prospected in the summer of 1943 by the M. A. Hanna Co., which dug 26 trenches. A single trench was dug across the smaller one by the State of Maine in the summer of 1941.

The larger deposit is, in the form of a plunging syncline, the axis of which is well exposed at the point marked A in plate 2. The photograph (plate 8b) shows the core of the syncline at this point. The axial plane of the fold dips 84° NW., and the fold plunges 32° SW. The ore body diverges along the two limbs of the syncline for a distance of about 800 feet south-southwest of point A, but beyond this the two limbs are parallel. A minor synclinal fold causes a local thickening and deflection of the west limb of the major syncline at point D. The ore is traceable along both limbs of the syncline from the nose of the fold, on the north side of the hill, to the vicinity of the ski-slide at the edge of the woods on the south side of the hill. Farther to the southwest, a heavy glacial cover mantles the bedrock.



PLANETABLE MAP OF THE GELOT HILL DEPOSIT

By projecting dips downward from the two limbs of the syncline, the top of the ore zone in the trough of the syncline is calculated to be 260 feet above sea level, or 690 feet below the surface, at point B (plate 10), and 600 feet above sea level, or 320 feet below the surface, at point C.

The ore in the synclinal ore body at Gelot Hill is of low grade. Only a few of the many 10-foot samples taken from trenches contained more than 10 per cent manganese, and the average content of all ore above 5 per cent grade is 6.69 per cent manganese and 19.9 per cent iron. This average includes analyses of several 10-foot zones below 5 per cent grade, which, however, will have to be quarried with the higher-grade ore if the ore body is worked. The ratio of manganese to iron for different grades of ore is shown in plate 7.<sup>1</sup>

With a cut-off value of 5 per cent, the ore zone is 190 feet thick in trench EE' at the nose of the fold, 130 feet in trench FF', 110 feet in trench GG', 90 feet in trench HH', and 170 feet in trench II'.

The smaller ore body (plate 10, J) on Gelot Hill, though trenched by the State of Maine in 1941, was unexposed in the summer of 1943 except for a small showing of float. This ore body appears to be a separate lenticular deposit stratigraphically underlying the synclinal deposit on the crest of the hill. Eckstorm<sup>1</sup> found that a sample across a zone 42 feet wide contained 12.2 per cent manganese and 26.2 per cent iron. The zone is traceable only about 100 feet longitudinally by means of its float, but it probably continues farther beneath the glacial cover. Comparison of other analyses made by the State of Maine and the Hanna Co. suggests that if both deposits had been prospected by the same parties the assays of the ore in this zone would show only 2 or 3 per cent more manganese than that on the crest of the hill, rather than 5 per cent.

The assured tonnage of manganese at Gelot Hill consists of ore extending down to a depth of 20 feet and of the grade indicated by analyses of samples from the trenches. This ore contains 37,300 tons of metallic manganese in the part of the ore body that has been trenched. The ore body almost certainly continues, on both limbs of the fold, to depths below 200 feet except near the nose of the syncline, but the depth of oxidation, and the falling off in grade of the ore below the oxidized zone, must be estimated. Assuming 6 per cent as the average manganese content for ore down to 100 feet below the surface, the amount of manganese to that depth is 158,900 tons. Assuming 5.7 per cent as the average manganese content for ore down to a depth of 200 feet—since the enriching effect of the oxidized zone at the surface diminishes with increase in the proportion of the unoxidized ore included in the estimate—the amount of manganese is 293,000 tons. These estimates can hardly be more than 40 per cent in error, and it is believed that they are probably

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<sup>1</sup>Eckstorm, Paul: unpublished report.

correct within 20 per cent. The main possibility of error lies in the assumptions made as to the grade of the subsurface ore.

Additional ore probably could be obtained from both limbs of the synclinal ore body at least as far as the edge of the covered area (see plate 10), and also from the smaller ore body previously described. Assuming an average width of 80 feet for the synclinal ore body and the same grade of ore as in the known part of the deposit, the amount of metallic manganese obtainable from these additional sources to a depth of 20 feet is estimated at 20,000 tons, to a 100-foot depth at 87,000 tons, and to a 200-foot depth at 164,000 tons. Although the tonnage of manganese in Gelot Hill is large because of the size of the ore body, it is highly doubtful whether ore that averages only 7 per cent manganese in the oxidized zone, and that may fall to 6 per cent or 5 per cent in the unoxidized zone, can be profitably worked.

#### *Capitol Hill deposit*

On the southeast slope of Capitol Hill, a prominent ridge in southern New Sweden and northern Woodland Townships (plate 2, No. 2), an ore zone is continuously traceable for two miles. This ore zone may be continuous with one of the limbs of the Gelot Hill synclinal ore body, with which it is nearly in line, but it may be separated from that ore body or may even lie at a different stratigraphic horizon.

Capitol Hill consists chiefly of gray and green slates, which are interbedded with red slate, especially near the manganese ore body. The main ore zone is composed of black-stained hematitic and manganeseiferous shale that strikes about N. 30° E. and dips 80° NW. The structure seems to be a simple homocline in the northern part of the ore zone, but a deflection a quarter mile south of the highway that crosses the south end of Capitol Hill, probably indicates either a small fold or a cross fault. At the south end of the deposit the ore zone is warped into undulatory folds.

This ore body has been systematically prospected only on the farm of George Ostlund, 0.7 mile southwest of New Sweden post office. Four trenches spaced 100 feet apart along the strike gave highly variable results. Analyses of 10-foot samples from the northernmost trench indicated 50 feet of ore that contained over 5 per cent manganese; 10 feet out of this 50 contained more than 10 per cent. The next trench to the south revealed 60 feet of ore containing more than 10 per cent manganese, and an additional 20 feet containing between 5 and 10 per cent. Measurements in the two remaining trenches were similarly erratic. The ratio of iron to manganese is here unusually low. The writer did not see the trenches when they were open, but from studies elsewhere along the belt it seems likely that the changes in grade between trenches are due to lensing and to the varying degrees of surface enrichment by oxidation, rather than to folding of the ore beds or to their duplication by faulting.



Closely spaced outcrops or float mark the course of the ore zone from the Ostlund farm south-southwest across the highway—where the ore body appears much narrower and of leaner grade—and thence along the east side of the hill southeast of New Sweden. Here the thickness of the ore zone is between 24 and 80 feet, probably much nearer the smaller figure. One specimen of the richest oxidized ore visible here analyzed 13.66 per cent manganese, 12.1 per cent iron, and 0.414 per cent phosphorus. The ore zone is only 10 feet thick where it crosses State Highway 161, on the New Sweden-Woodland Township line, but in its southernmost exposure it is again more than 25 feet thick and appears to be of good grade.

The trenches dug on the Ostlund farm indicate an ore body that, on the surface, averages 70 feet in thickness and contains 8.8 per cent manganese and 16.2 per cent iron. Ore of this width and nearly this grade for a longitudinal distance of 400 feet and to a depth of 20 feet is reasonably assured, and this ore would contain 4,640 tons of metallic manganese. The ore zone probably continues downward to considerable depths, but possible changes in grade make it unwise to count on any minable ore below the depth of 50 feet. For the same surface area but to a depth of 50 feet, the ore body would contain 52,700 tons of manganese. The tonnages cited above might be increased manyfold by addition of ore contained in other parts of the Capitol Hill belt. The known deposit may reasonably be assumed to extend at least 300 feet on either side of the trenched area, and some ore of comparable grade is exposed at the southwest end of the Capitol Hill ore zone. Elsewhere along the belt geologic knowledge is scanty, but in a few places the ore zone may be seen to be both thinner and lower grade.

#### *Lundgren School prospect*

Manganese-bearing rock crops out in the road 0.2 mile northwest of Lundgren School, in front of the house of Oscar Peterson, in the northwestern part of Woodland Township (plate 2, No. 3). The ore zone is traceable S. 30° W. to the crest of the hill 500 feet from the road, and is continuous in the opposite direction for 1,000 feet to the edge of a swampy lowland, where outcrops and float fail.

The manganese-bearing rock consists of gray siliceous and slaty limestone stained with manganese and iron, interbedded with barren slaty limestone and calcareous slate. The beds are crinkled and folded but dip steeply and strike uniformly N. 30° E. The distinction between country rock and rock that carries appreciable quantities of manganese and iron is not sharp, and none of the ore appears to be of high grade. From southeast to northwest along the road, six zones of possible ore were noted in a distance of 300 feet. These were, in that order, 7, 4, 5, 30, 31 and 11 feet thick.

No prospecting has been done at this deposit, but three grab samples were analyzed with the results given below. The first sample represented the best-appearing ore in the road, the second was a com-

posite of all six ore zones in the road, and the third a composite of ore exposed northeast of the road.

	Mn (per cent)	Fe (per cent)	P (per cent)
Grab Sample 1	6.46	19.4	0.479
Grab Sample 2	4.11	28.9	....
Grab Sample 3	8.60	20.4	....

These data, taken together, indicate the presence of at least one ore zone which may reasonably be assumed to be 30 feet wide and at least 500 feet long, and to contain ore of 6 per cent grade to the depth of 20 feet. An ore zone with these measurements would contain 1,600 tons of metallic manganese.

#### *Grant prospect*

On the west edge of Woodland Township, 0.7 mile northwest of Henderson School (plate 2, No. 4), is the Walter Grant prospect, consisting of small outcrops and float of siliceous and slaty limestone stained with manganese and iron. These represent several manganese zones, one of which seems from its float to approximate 30 feet in thickness. The manganese belt extends N. 14° E. across a corner of cultivated land, then disappears into woods lying west and north of the fields. The total length of the belt is at least 1,500 feet, but there is no assurance that any one of the manganese zones contained in the belt is that long. No analyses of the ore have been made.

#### *Spaulding School prospects*

Spaulding School lends its name to a prospect (plate 2, No. 5) that actually is 1,500 feet east of the school, astride an east-west road in the extreme eastern part of Perham Township. The prospect consists of several outcrops south of the road, in a swampy pasture, owned by C. McKay, and one north of the road, in woods owned by J. McBriarty. Three belts of manganese-stained slaty and siliceous limestone are exposed, but they may all represent a single zone repeated by folding. The westernmost belt in the pasture is probably continuous with the outcrop in the woods north of the road, and if so the longitudinal extent of this zone is at least 800 feet. In the pasture this zone is more than 7 feet and less than 20 feet thick, and the other two zones are about 12 feet thick. No analyses of the Spaulding School ore are available.

Another small outcrop of ore lies 2,000 feet to the north-northeast, almost on a line between the Spaulding School prospect and the Grant prospect. A grab sample from this outcrop, which was lithologically very similar to the Spaulding School ore, analyzed:

Manganese.....	6.62	%
Iron.....	14.4	%
Phosphorus.....	0.285	%

No workable ore seems to be present at either of these prospects.

### *Henderson School prospect*

Some 800 feet east of Henderson School, in western Woodland Township, there is a prospect on land owned by L. R. Griffin (plate 2, No. 6). Here, between walls of gray calcareous slate, is a stratum of gray slaty limestone, indistinctly laminated in gray, red, and black, and stained and coated with black manganese oxide on outer surfaces. These rocks have been folded into a syncline plunging south-southwest. The nose of the fold is 350 feet north of the east-west road. Its western limb, which dips  $70^{\circ}$  S., was traced south-southwest for 2,500 feet, where it crosses the north-south road and disappears in timbered swampland. The eastern limb, which dips  $63^{\circ}$  W., was traced for 3,000 feet almost due south. The best ore exposed is in the east limb, on the hill slope 500 feet south of the road. Here the ore zone is apparently about 26 feet thick, but it seems thinner and of lower grade in most other places. There has been no systematic prospecting of this deposit. A composite grab sample from all outcrops of the ore zone analyzed as follows:

Manganese.....	6.94%
Iron.....	16.0 %

### *Anderson prospect*

A small showing of ore, mostly in the form of float, lies 100 yards north of the house of A. Anderson, which is 0.65 mile southeast of Henderson School, in western Woodland Township (plate 2, No. 7). The ore consists of red and black hematitic shale interbedded with red and green slates. At the time of the writer's visit the ore zone could not be traced because of crops growing in the fields, but White<sup>1</sup> indicates that it is continuous for at least 1,500 feet, in a north-northeast direction. Although the thickness of the zone is not known, the distribution of float indicates that it is relatively thin. A grab sample of the ore analyzed:

Manganese.....	5.45%
Iron.....	19.6 %

### *Fox and McIntyre prospects*

The Freeman Fox prospect is 100 yards east of a north-south road in the southeastern part of Perham Township (plate 2, No. 8). It contains two zones, about 50 feet apart, consisting of greenish-gray, crinkled, siliceous and slaty limestone, stained with manganese oxide, lying between strata of a fissile calcareous shale. Both are exposed in a small farm lane running east down the hillside. Bedding is largely obscured by cleavage, but where visible it shows crinkling; its average dip is  $45^{\circ}$  SE. No trenching has been done here, but on the basis of outcrops the western zone appears to be not more than 30 feet thick and the eastern zone not more than 26 feet thick. Manganiferous rocks were traced for a longitudinal distance of 1,600 feet, but neither zone singly extends that far, the western zone ex-

<sup>1</sup> White, W. S., op. cit.

tending farther to the north-northeast and the eastern zone farther to the south-southwest. A composite grab sample from the two zones assayed:

Manganese .....	9.14%
Iron .....	15.5 %

These observations indicate that ore of about 9 per cent grade might be mined on the Fox farm for a combined width for the two zones of 50 feet and a length of 500 feet, and to a depth of at least 20 feet. This amount of ore would contain 4,100 tons of metallic manganese.

A similar manganiferous zone lies 700 feet west of the Fox prospect, and west of the road, on land owned by Charles McIntyre. This zone is at least 12 feet thick and was traced 700 feet longitudinally. It dips 77° SE. No analyses of rock from this locality have been made.

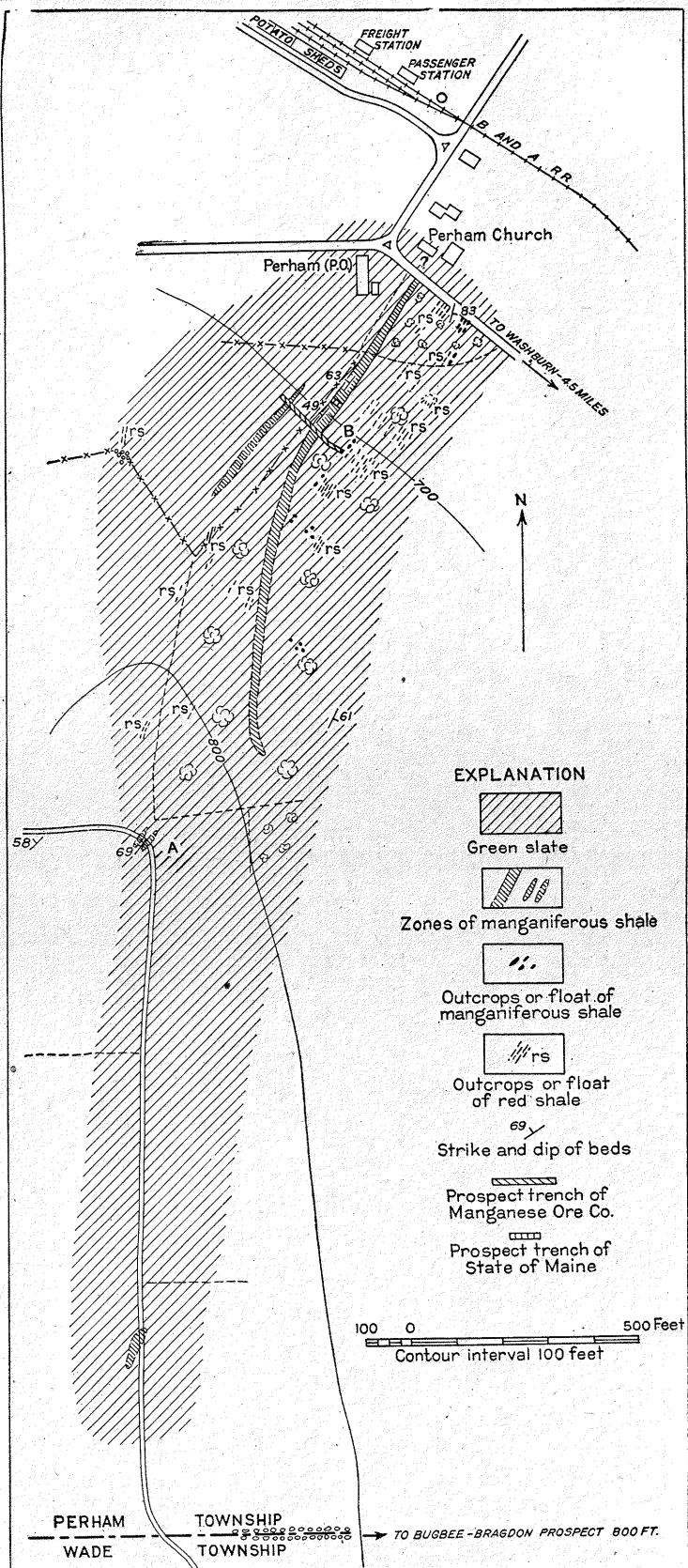
#### *Perham Church prospect*

In the village of Perham, on land owned by F. Sperry, is the Perham Church prospect, so called from its being exposed just across the highway from Perham Church (pl. 2, No. 9). The country rock in the vicinity consists of green and red slate, calcareous slate, and shaly limestone, which everywhere strikes north-northeastward but the dips vary in steepness and direction (plate 11). Manganese oxide stains the slates, especially the red slates, at a number of places, but the manganese and iron content of the rock is negligible at most of these showings.

From an outcrop directly across the road from the church, the main ore zone is traceable continuously for 1,100 feet south-southwestward and southward up the hill. One trench across this zone was dug by the State of Maine in 1941. Another trench, dug by the Manganese Ore Co. in 1943, crossed this zone and also a smaller zone to the west. An 18-foot sample from the State of Maine trench analyzed 11.0 per cent manganese and 17.3 per cent iron. The Manganese Ore Co. trench crossed 40 feet of beds that contained more than 5 per cent manganese, but only 10 feet out of this 40 assayed better than 10 per cent. As a whole the 40-foot zone averaged 8.40 per cent manganese and 13.6 per cent iron.

The beds dip about 60° W., but are warped and crinkled. Some duplication and thickening of beds by folding may have occurred in this ore zone, but the writer believes it is minor and that the zone is approximately 35 feet thick at this spot.

The ore consists of dense, heavy, gray and greenish-gray siliceous limestone. Unweathered pieces show parallel dark- and light-gray laminae, with a few red bands 2 to 5 millimeters thick. This ore zone seems to taper northward from the Manganese Ore Co. trench, but its behavior southward is not known, for it was traced in that direction almost entirely by following float.



# PACE AND COMPASS MAP OF THE PERHAM CHURCH PROSPECT

The Manganese Ore Co. trench was extended westward across a second ore zone. Bedrock was not struck between the two ore zones in a trench that was 6 feet deep over most of the distance. The western ore zone consists of 25 feet of beds dipping  $31^{\circ}$  SE., which analyzed 10.02 per cent manganese and 16.4 per cent iron. This zone is traceable 300 feet longitudinally. It probably represents a reappearance of the main ore zone in a small anticline.

Manganese- and iron-stained beds are also exposed in the farm road at point A, plate 11. A grab sample taken here analyzed 8.28 per cent manganese and 16.8 per cent iron. No other trace of this zone was found in either direction along the strike. Another grab sample from the main ore zone at point B, plate 11, analyzed 11.66 per cent manganese and 18.7 per cent iron. Here, as elsewhere, grab sample analyses usually give somewhat higher results than systematic sampling. Nevertheless the Perham Church deposit probably has an area of at least 20,000 square feet of ore at the surface assaying between 8 and 10 per cent manganese. This may be considered reasonably assured to a depth of 20 feet, and it probably extends to a depth of at least 50 feet, but with a decrease in the percentage of manganese below the level of oxidation.

#### *Bugbee-Bragdon prospect*

The Bugbee-Bragdon prospect is astride the Perham-Wade Township line (plate 2, No. 10). It lies in woods on a hillside about 1,100 feet west of the Washburn-Perham highway and an equal distance east of a north-south farm road. The land in Perham Township is owned by W. H. Bragdon, that in Wade Township by W. Bugbee. The deposit has not been prospected. It consists of manganese-stained gray and green shaly limestone containing a few red laminae. The manganese-bearing beds form a zone approximately 40 feet wide and traceable for 600 feet in a direction N.  $10^{\circ}$  E. The township line crosses the deposit about centrally. The grade of the ore is indicated only by one grab sample, which assayed:

Manganese.....	5.6%
Iron.....	18.7%

If this sample is representative, the deposit is probably too lean to warrant consideration as a possible manganese reserve.

#### *Silver prospect*

In the northeast corner of Wade Township, 0.6 mile from the east border and 0.8 mile from the north border, is a deposit that, though known only from a few incomplete exposures, may be the best one lying north of the Aroostook River (plate 2, No. 11). The deposit is best exposed on the C. L. Silver farm, but it is traceable S.  $19^{\circ}$  W. onto the E. Halford farm, and thence across a farm road onto the B. Tompkins farm.

The ore is a manganese-stained gray siliceous limestone dipping  $71^{\circ}$  SE. On the Silver farm, where ledges of ore form a small scarp,

the ore zone appears to be about 75 feet wide, but it contains at least one lens of barren calcareous slate of unknown thickness at this point. No other place was found where the width of the zone could be measured or estimated. Scattered outcrops indicate that the zone continues for at least 2,400 feet to the south-southwest. It may continue across the flat farmland to the north-northeast, although no exposures or float were found there. A grab sample taken from outcrops on the Silver farm assayed:

Manganese . . . . .	11.28%
Iron . . . . .	15.6 %

The known facts regarding this prospect are so scanty that any estimates relating to its ore are subject to great error. However, the only figures available indicate an ore body nearly 75 feet wide, probably more than 500 feet long, averaging about 10 per cent manganese beneath the weathered zone. Although no subsurface data are available, the structure at the surface indicates that the deposit should be continuous downward. The ore body might be minable to a depth of 100 feet, but with some decrease in dimensions and grade below the oxidized zone.

#### *Aroostook River prospects*

Many prospectors have examined the immediate vicinity of the Aroostook River in Wade Township, because Jackson<sup>1</sup> more than a century ago reported a bed of iron ore 450 feet long and 36 feet wide, containing 76.8 per cent iron oxide and 8.20 per cent manganese oxide. Jackson's description of the locality was rather vague, and persistent search over many years has failed to relocate the deposit. This deposit, the writer believes, is the Haines prospect, to be described presently, which lies more than a mile from the river. The remarkably high iron content reported by Jackson was presumably based on a sample that was not representative.

Only two showings of manganese-bearing rocks close to the river appear to have been found. On the north bank, a few feet of beds showing minor manganese and iron stain are exposed in the road (plate 2, No. 12). On the south bank, manganese-stained hematitic shales crop out in the angle between the river road and a private road. At this latter place the ore appears to be of good grade, and the width of the ore zone is apparently several tens of feet but cannot exceed 65 feet. No other outcrops nor any float of ore were found in either direction along the strike. Whether this apparent lack of continuity is due to faults, or merely to a heavy cover of glacial drift and alluvium concealing the ore zone, is unknown. The ore exposed north of the river has but a small area of exposure and is of low grade. The zone exposed south of the river is richer, and may not be restricted to the small area in which it outcrops.

<sup>1</sup>Jackson, C. T., Second Annual Report of the geology of the public lands belonging to the States of Maine and Massachusetts, pp. 34-35, 1837.



### *Haines prospect*

What is believed to be the Aroostook River deposit of Jackson<sup>1</sup> lies on east-facing slopes near the crest of a ridge 1.1 miles south of the Aroostook River and 0.5 mile west of the highway that follows the eastern border of Wade Township (plate 2, No. 13). The middle and southern parts of the deposit are on the farm of A. S. Haines, but its northern part extends onto the land of W. Baker.

The country rock consists of green and gray slate. The ore is a calcareous hematitic shale abundantly stained with black manganese oxide. The manganese-stained zone is about 20 feet thick. It was traced N. 4° E. for 1,400 feet, and it dips 84° SE. Two analyses of grab samples from the deposit have been made. The first is a composite from several different places along the ore belt, and the second is from the central part of the deposit.

Sample	Mn (per cent)	Fe (per cent)	P (per cent)
1	12.60	17.2	....
2	6.24	20.7	0.899

Although the Haines ore zone might be regarded as too narrow to be worth considering, the relatively high grade of sample 1 above makes the prospect somewhat inviting. Assuming a width of 20 feet, a workable depth of twice the width, an average manganese content of 10 per cent, and a length of 500 feet, the tonnage of manganese would be 3,600. If the entire 1,400 feet maintained the same width and 10 per cent grade, the deposit would contain about 10,000 tons of manganese, but the assumptions underlying the last estimate are perhaps over-optimistic.

### *Castle Hill Grange Hall prospect*

In the northeastern part of Castle Hill Township, 400 feet north of the state road and an equal distance north-northwest of the Grange Hall, is what is known as the Castle Hill Grange Hall prospect (plate 2, No. 14). It is on land owned by Raymond Chandler. A trench was dug across the deposit by the State of Maine in 1941 (figure 4) and a somewhat longer trench by the Manganese Ore Co. in 1943.

Between strata of folded green slate containing interbedded zones of red slate, there is here a zone of hematitic and chloritic shale stained with black manganese oxide. A zone 30 feet wide uncovered in the State of Maine trench analyzed 9.2 per cent manganese and 17.6 per cent iron. In the Manganese Ore Co.'s trench, 35 feet to the south, 10-foot samples were taken across a total width of 95 feet. A zone 20 feet wide averaged 9.53 per cent manganese and 18.4 per cent iron, and even when 30 feet of adjacent leaner beds was included the content was 7.47 per cent manganese and 17.8 per cent iron.

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<sup>1</sup>Jackson, C. T., op. cit.

If all rock above 5 per cent grade is reckoned as ore, a total width of 70 feet of ore would be obtained, averaging 6.94 per cent manganese and 16.9 per cent iron.

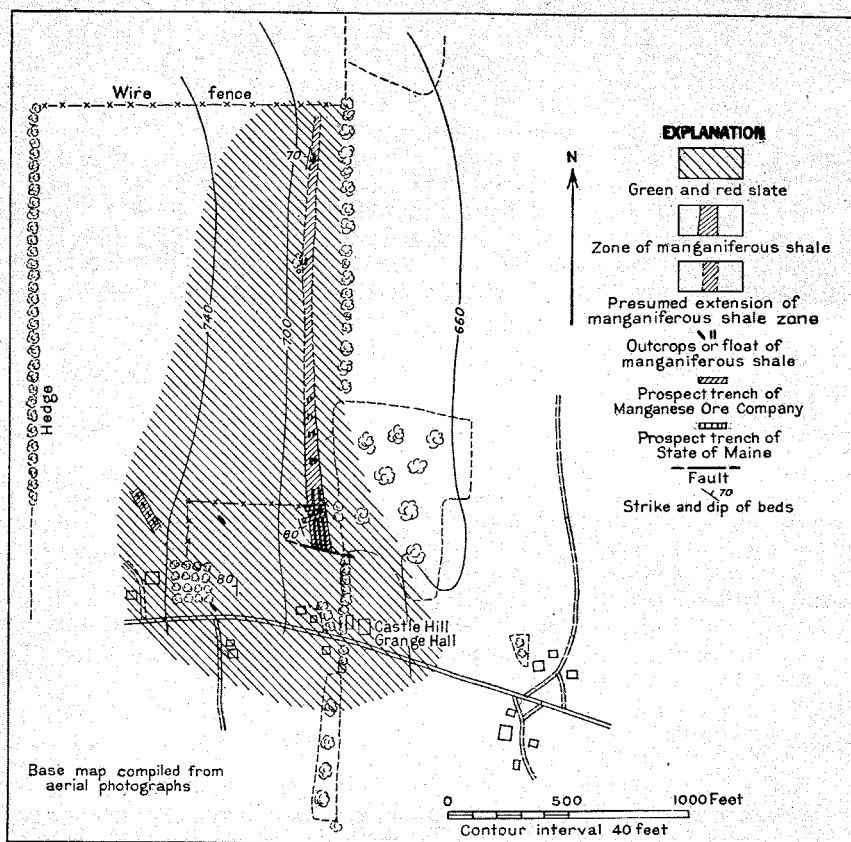


Figure 4: Geologic map of Castle Hill Grange Hall prospect.

About 150 feet south of the Manganese Ore Co.'s trench, the ore zone is cut off abruptly by a fault. Float from the ore zone is abundant in cultivated fields for about 400 feet north of the trench, and both float and small outcrops of ore appear along the strike 1,000 feet and 1,500 feet north of the trench. The zone is probably continuous between these exposures, but it apparently is thinning toward the north. The ore zone seems unlikely to maintain the width and grade that it has in the trenches for a length of more than 500 feet, but it pretty certainly does so for as much as 200 feet. Its depth is at least 20 feet and it may extend downward 100 feet or more.

### *Richardson prospect*

An ore zone in the central part of Castle Hill Township, due east of McDonald Mountain and 150 feet west of Turner Road, is exposed in a swale just west of the barn and orchard on the James Richardson farm (plate 2, No. 15 and plate 12). At this place a 75-foot trench was dug by the Manganese Ore Co. Although the rock is fairly heavy and has the outward appearance of good hematitic manganese ore, no single 10-foot sample from the trench contained over 5 per cent manganese. Twenty feet of beds averaged 24.0 per cent iron, but the manganese content was 3.55 per cent. The probable extension of this hematitic shale zone is shown in plate 12.

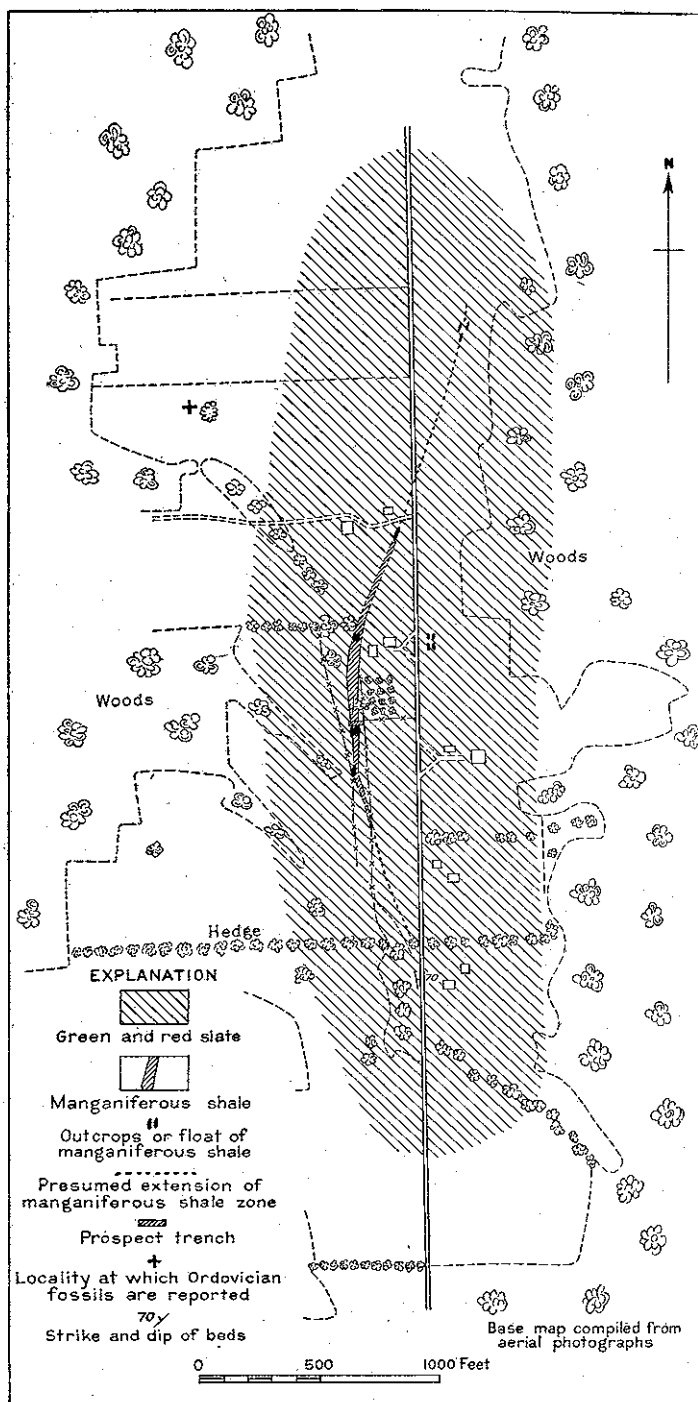
There is a small showing of manganese-stained hematitic shale directly across the highway from the Richardson house. It has not been trenched or sampled. The unexpectedly low grade of the Richardson rock removes the prospect from the list of potential producers of manganese.

### *Smith deposit*

Only 1,300 feet northwest of the north end of the Dudley deposit, 1.7 miles west-northwest of Mapleton (plate 2, No. 16), and 0.5 mile north of the highway running due west from Mapleton, a deposit is exposed on the farm of H. E. Smith. Despite their proximity, the Smith and Dudley prospects do not seem to be at the same horizon, for the enclosing rocks at the two localities are distinctly different.

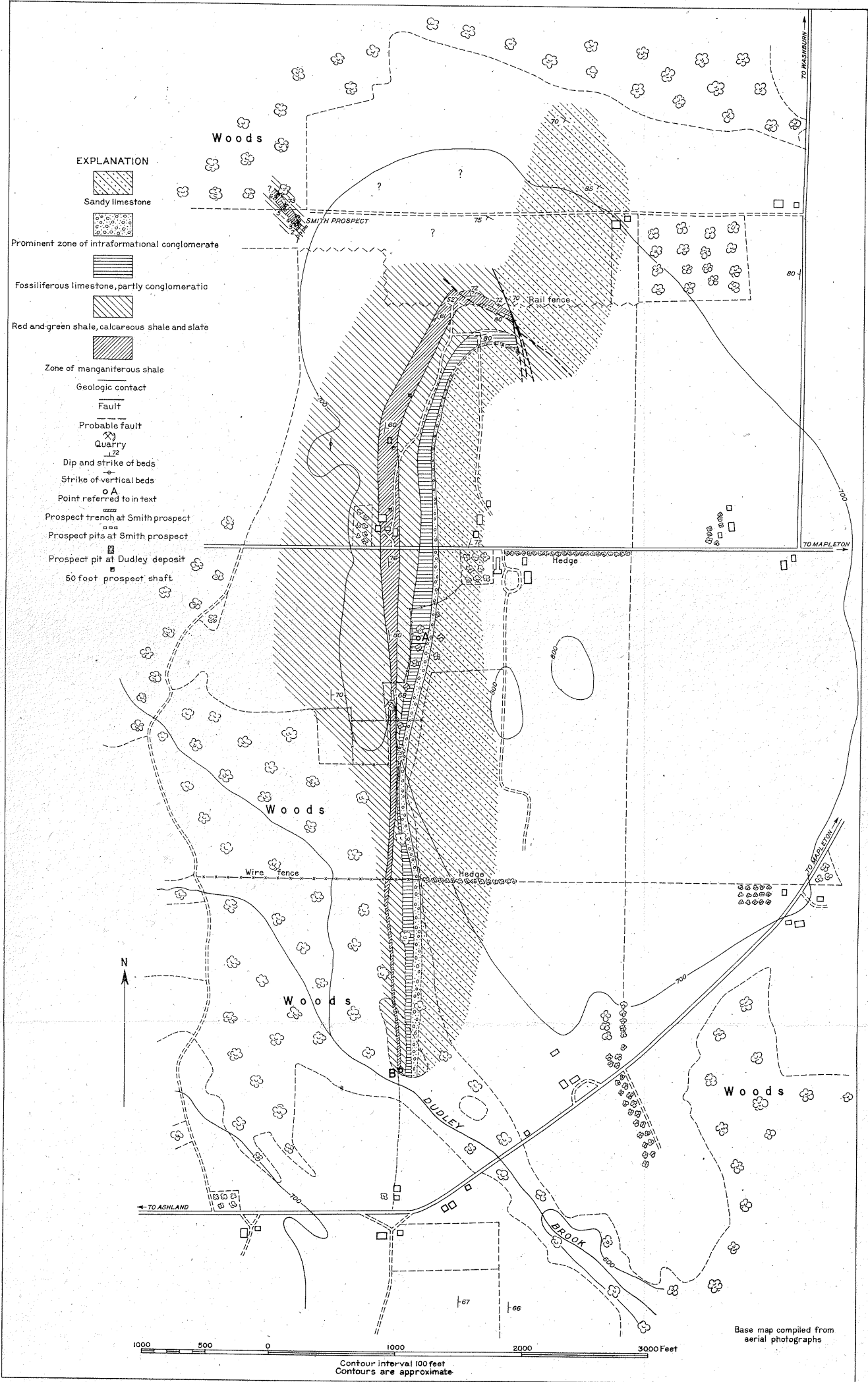
The Smith prospect is on low flat ground, covered with an unusually great thickness of glacial till. Bedrock does not crop out anywhere in the vicinity, and in parts of the prospect trenches it was more than 6 feet below the surface. Six trenches were dug across the deposit by the Manganese Ore Co. in 1943. In trenches 1 and 2 (plate 13), which were discontinuous and bottomed in till at some places, the only bedrock encountered was shaly limestone. In trench 3, some 25 feet of manganese-stained hematitic shale was uncovered. The ore zone of manganese-stained hematitic rock is 55 feet wide in trench 4, more than 35 feet wide in trench 5, and more than 25 feet wide in trench 6. The ore beds strike N. 28° W. and dip 73° to 90° NE. The rapid thinning and disappearance of the ore to the southwest suggests that the deposit is in the form of a plunging isoclinal fold, but the exposures in the trenches when they were visited were not adequate to determine whether this fold was an anticline plunging southeast or a syncline plunging northwest. The ore zone undoubtedly continues northwest of trench 6, but neither outcrops nor float could be found by which to trace its course.

A few samples of ore from the trenches analyzed over 10 per cent manganese, but in most of the ore the manganese content is between 7 per cent and 10 per cent. The average for all 10-foot samples above 5 per cent grade is 9.4 per cent manganese and 23.5 per cent iron. This is the highest ratio of iron to manganese found in any deposit having an appreciable manganese content.



GEOLOGIC MAP OF RICHARDSON PROSPECT





GEOLOGIC MAP OF THE DUDLEY AND SMITH DEPOSITS

Calculation of reserves of ore at this deposit is hazardous, because of inadequate prospecting, lack of surface indications, and uncertainty as to the structure of the deposit. A body of 9 per cent manganese ore, averaging 35 feet in width for a length of 300 feet and a depth of 20 feet, may safely be assumed as a minimum estimate. Ore of slightly lower grade may reasonably be inferred for a depth of 50 feet.

### *Dudley deposit*

Of all the manganese deposits in the northern district, the largest and best known, and apparently also the richest, is the Dudley deposit, which is in Castle Hill Township, on the west slope of a large hill 1.5 miles west of Mapleton (plate 2, No. 17). The northern tip of the deposit is on the land of E. Smith, and the remainder of its northern half on the farm of Milton Dudley. South of the highway the ore zone crosses the farm of Forest Dudley, and it is finally lost in swampy lowlands on the farm of A. A. Tarr. The photograph (plate 14A) shows the appearance of the orebody on the farm of Milton Dudley. The ore zone extends from the foreground to the center background of the photograph. Prospect shafts are visible in the left foreground and in the center background.

A partial geologic map of the area is shown in plate 13. The oldest rocks are gray shaly limestone and green and gray slates, which crop out at many places in the western third of the area. White has mapped, on stratigraphic evidence, a fault separating the calcareous shales and limestones on the west side of the belt from the relatively non-calcareous slates which enclose the ore body, but as the writer found no field evidence for this fault, he has omitted it from plate 13. Red shale is interbedded with the green shale and slate in the upper part of this series, and the manganese ore body is within 200 feet of the top of the series. Limestone overlies the shale, the contact between the two being gradational because of intertonguing. Much of this limestone was brecciated before it became completely solidified, and was cemented with a matrix of limy mud. A particularly prominent zone of the intraformational conglomerate (plate 3A) thus formed is mapped as a separate unit. It probably does not represent a stratigraphic horizon, however, for its distance above the base of the limestone series is variable. Both the intraformational conglomerates and the even-bedded limestones are highly fossiliferous in places, especially in the vicinity of point A in plate 13. These beds are overlain by thin-bedded sandy limestone. A detailed stratigraphic section across the ore body and enclosing rocks is shown in plate 15. The section is based on study and chemical analyses of diamond drill cores. The lithology of the ore beds and of the associated rock are given alongside the section.

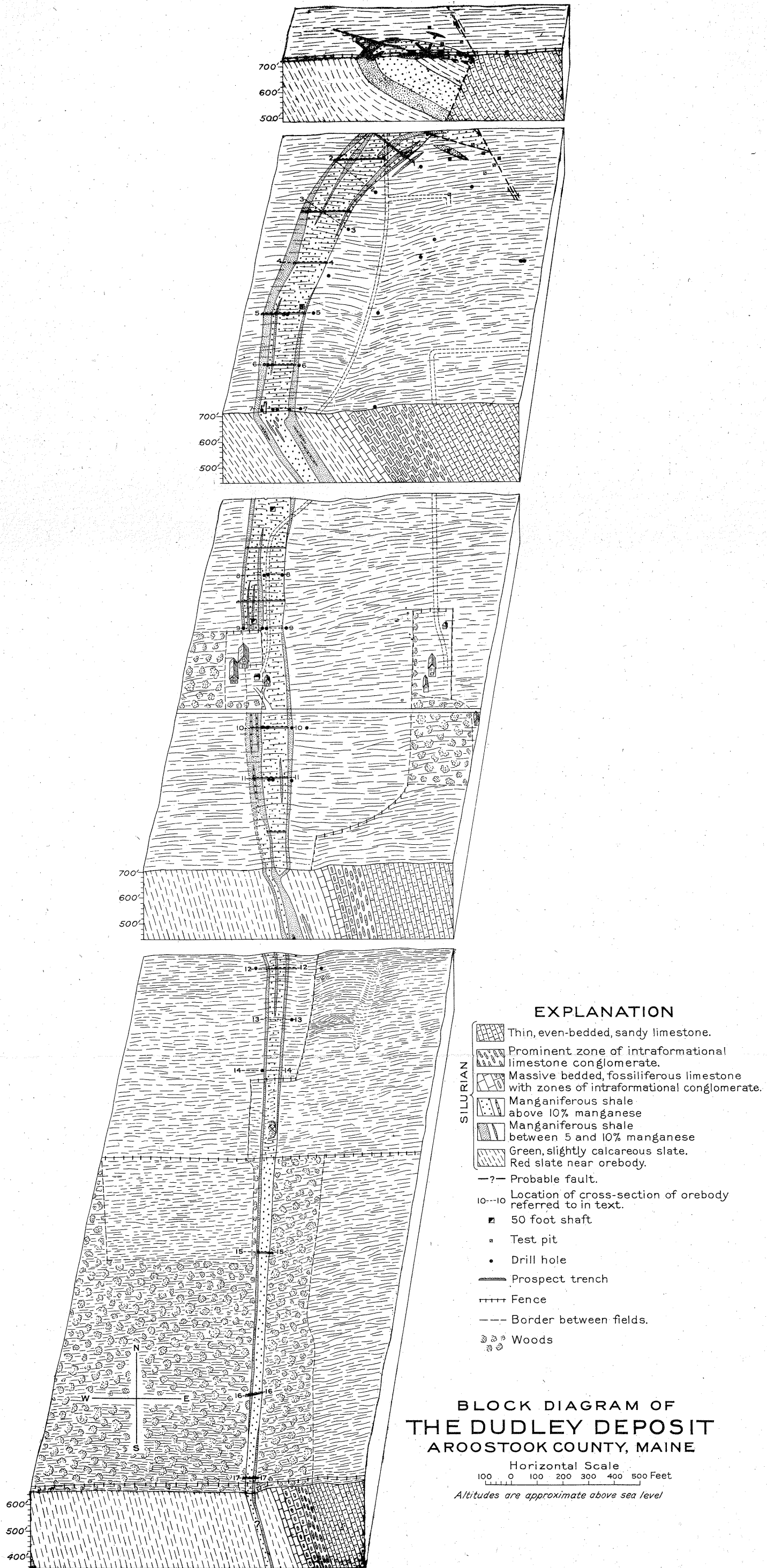
A major fault cuts off the ore body at the north end, but the trace of this fault is extremely obscure at the surface. Its location and



Plate 14A. View looking northward along the outcrop of the Dudley ore body on the farm of Milton Dudley.



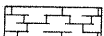
Plate 14B. Prospect trench across Stewart prospect. Resistant ledges in foreground and background of trench are of fair-grade ore, but deep parts of trench contain low-grade ore.



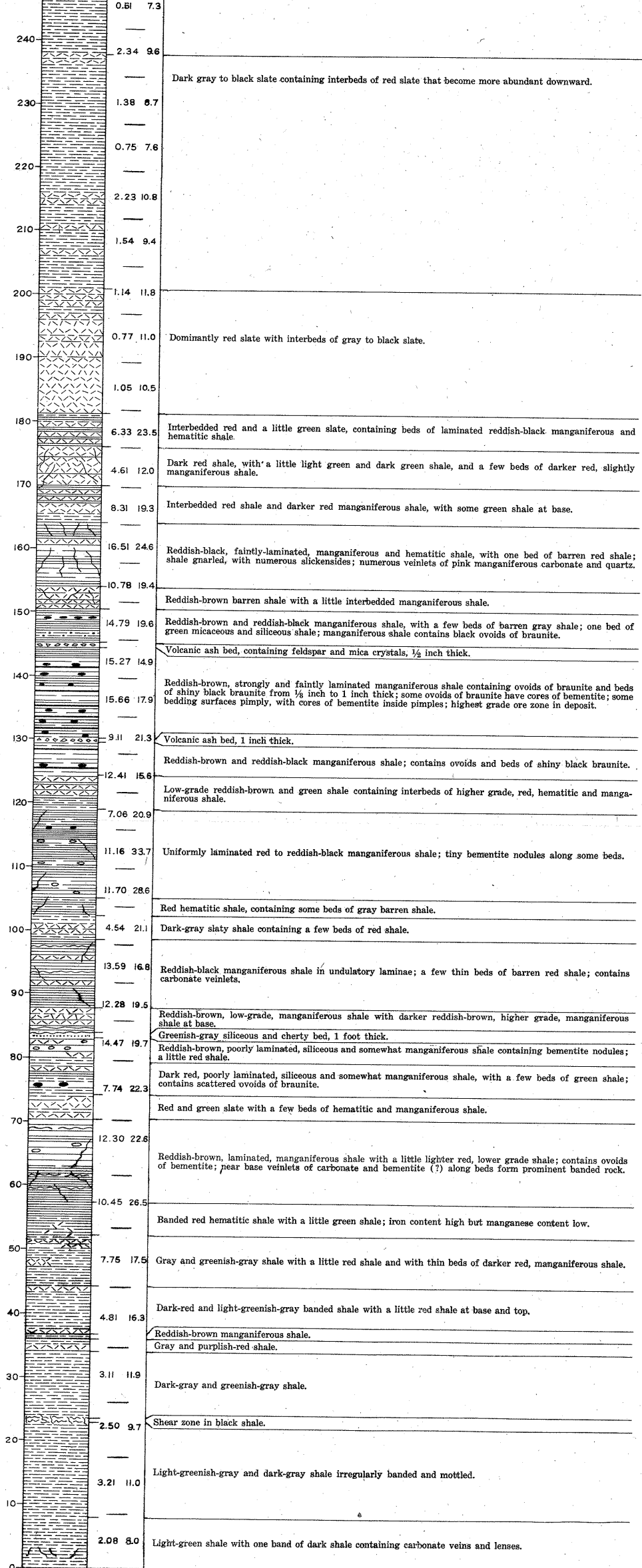
**STRATIGRAPHIC SECTION OF THE DUDLEY DEPOSIT**  
Based on study of cores from drillholes  
Chemical analyses by the Manganese Ore Co.

Feet	Lithology	% Mn	% Fe	Lithologic Description
290		0.79	?	Banded dark and medium-gray impure limestone.
				Volcanic ash bed, 4 inches thick.
280		0.26	?	Interbedded impure limestone and gray shale.
		1.62	?	
270		1.05	6.6	Dark gray slate and calcareous slate, not banded.
260		?	?	
		0.69	7.6	
250		0.61	7.3	
240		2.34	9.6	
				Dark gray to black slate containing interbeds of red slate that become more abundant downward.
230		1.38	6.7	
		0.75	7.6	
220		2.23	10.8	
210		1.54	9.4	
200		1.14	11.8	
		0.77	11.0	Dominantly red slate with interbeds of gray to black slate.
190		1.05	10.5	
180		6.33	23.5	Interbedded red and a little green slate, containing beds of laminated reddish-black manganiferous and hematitic shale.
		4.61	12.0	Dark red shale, with a little light green and dark green shale, and a few beds of darker red, slightly manganiferous shale.
170		6.31	19.3	Interbedded red shale and darker red manganiferous shale, with some green shale at base.
160		16.51	24.6	Reddish-black, faintly-laminated, manganiferous and hematitic shale, with one bed of barren red shale; shale gnarled, with numerous slickensides; numerous veinlets of pink manganiferous carbonate and quartz.
		10.78	19.4	Reddish-brown barren shale with a little interbedded manganiferous shale.
150		14.79	19.6	Reddish-brown and reddish-black manganiferous shale, with a few beds of barren gray shale; one bed of green micaceous and siliceous shale; manganiferous shale contains black ovoids of braunite.
		15.27	14.9	Volcanic ash bed, containing feldspar and mica crystals, 1/2 inch thick.
140		15.66	17.9	Reddish-brown, strongly and faintly laminated manganiferous shale containing ovoids of braunite and beds of shiny black braunite from 1/2 inch to 1 inch thick; some ovoids of braunite have cores of bementite; some bedding surfaces pimply, with cores of bementite inside pimples; highest grade ore zone in deposit.
130		9.11	21.3	Volcanic ash bed, 1 inch thick.
		12.41	15.6	Reddish-brown and reddish-black manganiferous shale; contains ovoids and beds of shiny black braunite.
120		7.06	20.9	Low-grade reddish-brown and green shale containing interbeds of higher grade, red, hematitic and manganiferous shale.
		11.16	33.7	Uniformly laminated red to reddish-black manganiferous shale; tiny bementite nodules along some beds.
110		11.70	28.6	Red hematitic shale, containing some beds of gray barren shale.
100		4.54	21.1	Dark-gray slaty shale containing a few beds of red shale.
		13.59	16.8	Reddish-black manganiferous shale in undulatory laminae; a few thin beds of barren red shale; contains carbonate veinlets.
90		12.28	19.5	Reddish-brown, low-grade, manganiferous shale with darker reddish-brown, higher grade, manganiferous shale at base.
		14.47	19.7	Greenish-gray siliceous and cherty bed, 1 foot thick.
80		7.74	22.3	Reddish-brown, poorly laminated, siliceous and somewhat manganiferous shale containing bementite nodules; a little red shale.
				Dark red, poorly laminated, siliceous and somewhat manganiferous shale, with a few beds of green shale; contains scattered ovoids of braunite.
70				Red and green slate with a few beds of hematitic and manganiferous shale.
		12.30	22.6	Reddish-brown, laminated, manganiferous shale with a little lighter red, lower grade shale; contains ovoids of bementite; near base veinlets of carbonate and bementite (?) along beds form prominent banded rock.
60		10.45	26.5	Banded red hematitic shale with a little green shale; iron content high but manganese content low.
50		7.75	17.5	Gray and greenish-gray shale with a little red shale and with thin beds of darker red, manganiferous shale.
40		4.81	16.3	Dark-red and light-greenish-gray banded shale with a little red shale at base and top.
				Reddish-brown manganiferous shale.
				Gray and purplish-red shale.
30		3.11	11.9	Dark-gray and greenish-gray shale.
20		2.50	9.7	Shear zone in black shale.
10		3.21	11.0	Light-greenish-gray and dark-gray shale irregularly banded and mottled.
0		2.08	8.0	Light-green shale with one band of dark shale containing carbonate veins and lenses.

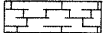
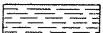
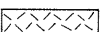
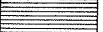
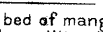
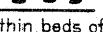
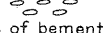
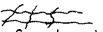
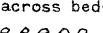
EXPLANATION OF SYMBOLS







#### EXPLANATION OF SYMBOLS

-  Impure limestone
-  Gray and green shale and slate
-  Red shale and slate
-  Manganiferous and hematitic shale
-  Single thin bed of manganiferous and hematitic shale
-  Ovoids and thin beds of braunite
-  Ovoids of bementite
-  Veinlets of carbonate along and across beds
-  Bed of volcanic ash

attitude are known only at the north tip of the deposit, where test pitting and diamond drilling have been extensive. Poorly exposed sandy limestones lying northeast of this fault appear to belong to the series of similar beds overlying the intraformational conglomerate.

The Dudley ore body was first prospected by the State of Maine in 1941. In the latter part of 1942 the Manganese Ore Co. began more extensive prospecting, and up to the end of 1943 it had explored the deposit by means of 26 diamond drill holes, 17 trenches, three 50-foot shafts, one large test pit, and many small test pits. The ore body has been proved on the surface for a distance of 4,600 feet, and has been shown to extend to depths of several hundred feet without marked change in width or attitude (see plate 16). In the deepest hole drilled, the continuity of the ore body to a depth of more than 640 feet below the surface was established. The ore body is widest in the northern part, and its width gradually diminishes southward. In the southernmost prospect trench it is thin, but it seems to continue southward at least as far as point B in plate 13, and a few pieces of ore float, together with the geologic relations, suggest that it may extend as far south as the Ashland-Mapleton road, passing close to the Roberts farmhouse.

Table 2. Dimensions of the Dudley ore body in 17 cross-sections

Cross Section	Surface width (in feet)		Average Surface Grade		Width at 100-foot depth (in feet)		Average Grade at 100-foot depth		Dip of Ore body
	Above 5% ore	Above 10% ore	Above 5% ore	Above 10% ore	Above 5% ore	Above 10% ore	Above 5% ore	Above 10% ore	
1	200	80	11.5	14.7	141	57	9.3	14.4	63°
2	145+	130+	14.6	15.4	146	100	10.8	13.4	61°
3	170+	130	14.8	17.4	157	108	10.8	12.5	?
4	130+	120	16.7	18.5	165	84	11.6	13.4	62°
5	170	120	12.9	14.0	122	82	10.4	12.0	60°
6	120+	100	11.6	11.8	138	101	10.2	11.6	?
7	?	?	11.5	13.7	153	66	10.1	12.9	60°
8	140+	130+	12.3	13.4	166	118	10.5	11.6	?
9	170+	80+	11.2	12.0	143	80	9.7	11.7	72°
10	160+	110+	14.3	17.5	140	72	10.2	11.7	76°
11	140+	100+	10.1	11.2	144	67	9.1	11.0	?
12	80+	60	12.4	13.7	62	17	9.0	15.5	80°
13	?	?	?	?	46	18	9.2	10.7	77°
14	?	?	?	?	64	?	7.2	10.4	?
15	50+	40	12.6	13.5	?	?	?	?	?
16	40	40	12.0	12.0	?	?	?	?	?
17	40+	30	11.1	12.9	?	?	?	?	?

Of all the deposits of the northern district, the Dudley contains the highest-grade ore. Analyses of manganese and iron content of 628 10-foot samples of oxidized and unoxidized ore are shown in plate 6. The width of the ore zone in 17 cross sections, at the surface and at a depth of 100 feet, for ore above a 5 per cent cut-off and also for that above a 10 per cent cut-off, is shown in table 2. The location of each section is shown on plate 16. In calculating widths and grades of ore, thin zones below the cut-off value have been included if the ore on either side was rich enough to bring the

composite above the cut-off grade. Thin zones of high-grade ore have not been calculated separately, in the belief that zones would not be quarried separately unless they were more than 20 feet thick.

The reserves of manganese at the Dudley deposit are large. All ore from the north end of the deposit to the southernmost drill hole (plate 16) has been measured to a depth of 200 feet within a 15 per cent limit of error. The ore zone between the southernmost drill hole and the southernmost trench probably extends to a depth of 200 feet, but the estimate of the width and grade of the ore below the zone of oxidation may be considerably in error. The ore south of the southernmost trench is not considered as a reserve, because it is unprospected and surface evidence indicates that it is probably not of minable width. The data on reserves of manganese at the Dudley deposit are shown in Table 1.

#### *Higgins deposit*

The other of the two manganese deposits in Aroostook County that have been diamond drilled is on the farm of R. R. Higgins, 1.3 miles east of Mapleton (plate 2, No. 18). The manganiferous zone extends north from the Mapleton-Presque Isle Highway to the Bangor & Aroostook Railroad tracks, a distance of 2,000 feet (plate 17).

The rock enclosing the manganiferous zone is a green slate containing red layers 1 to 6 inches thick. Some 400 to 600 feet to the west, the slates are in contact with platy limestones. Dikes, from a few feet to 40 feet thick, of a fine-grained alkalic rock composed mainly of sodic plagioclase and chlorite<sup>1</sup> intrude and locally metamorphose the slates, but the manganese mineralization is independent of this igneous activity.

Glacial drift covers the ore zone everywhere except along the railroad track, so that there are almost no surface indications of the deposit. It has, however, been prospected by the Manganese Ore Co. Four drill holes inclined at 45° were put down in 1943 to vertical depths of 50 to 150 feet, and a fifth hole, the location of which is not known to the writer, was drilled in 1944. Eight trenches were also dug, only the northernmost and southernmost of which were still open at the time of the writer's visits. Analyses of the samples from these trenches reveal zones of ore 15 to 60 feet in thickness. In the drill cores the best ore, which analyzes over 10 per cent manganese and 16 per cent iron, is a dark, hematitic shale with thin black laminae, cut by a few veins of mangandolomite. At the surface the bedding and joint surfaces of much of the ore are stained with black manganese oxide. The ratio of iron to manganese in this deposit is lower than in any other for which data are available (see plate 7). The zones of high-grade ore must be lenticular and not long, for few of them can be projected with any assurance between

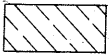
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<sup>1</sup>Milton, Charles: personal communication.

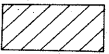
## EXPLANATION



Dike



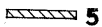
Limestone



Slate



Zone of manganiferous shale above 5 percent grade. Figure indicates average percentage of manganese. A, B and C indicate manganiferous zones referred to in text



5  
Prospect trench. Number referred to in text

+10

Point referred to in text

45

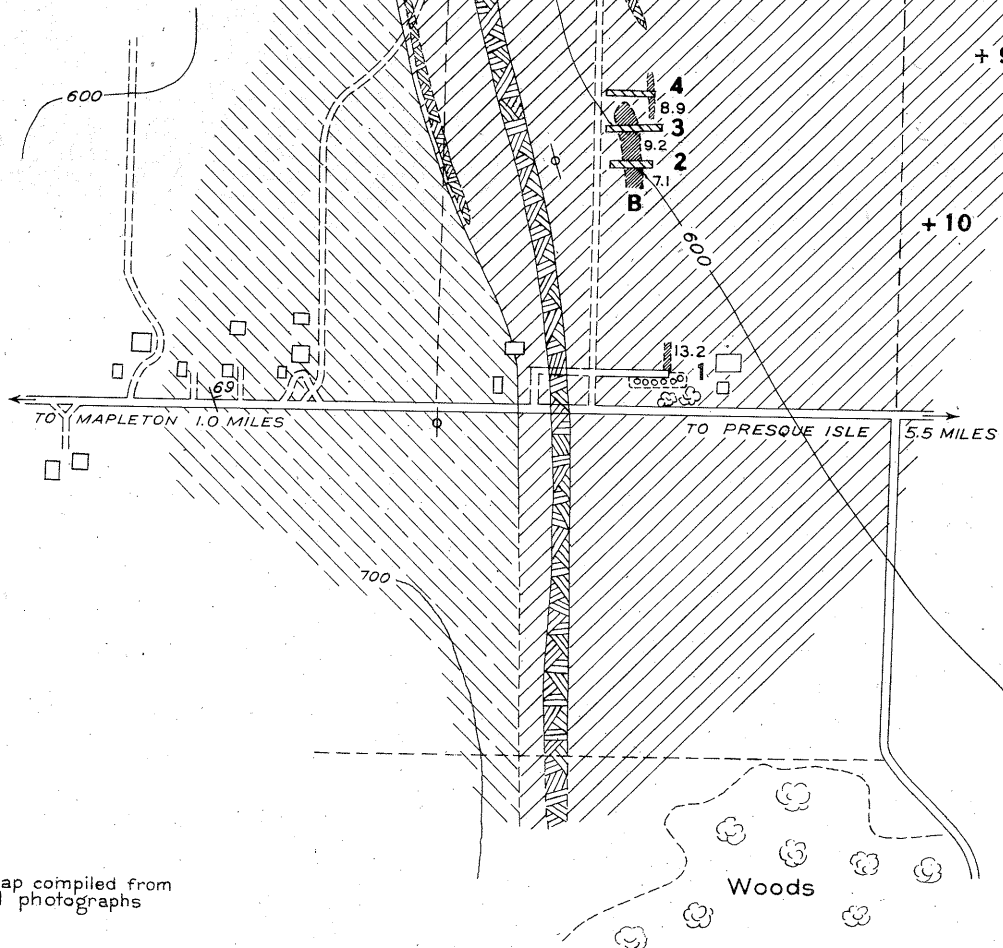
Drill hole showing direction and angle of drilling

69

Strike and dip of beds

69

Strike of vertical beds



Base map compiled from  
aerial photographs

500 0 500 1000 Feet  
Contour interval 100 Feet  
Contours are approximate

GEOLOGIC MAP OF THE HIGGINS DEPOSIT

trenches spaced 200 feet apart. The best ore zone in the trenches is at the north end of the prospect and is from 30 to 40 feet wide (plate 17, A). In the three trenches in which it is recognized it analyzes 11.6 per cent, 11.5 per cent, and 15.4 per cent manganese. Another ore zone is 50 feet wide in trench 2 and 60 feet wide in trench 3 and averages 8.2 per cent manganese (plate 17, B).

In the inclined drill holes which crossed ore zone A at vertical depths of about 50 feet, the ore at the north end of the zone is 20 feet thick and has a manganese content of 9.5 per cent, while at the south end it is 10 feet thick and has a manganese content of 8.8 per cent. The best ore zone encountered in drilling is at the extreme east end of trench 7 (plate 17, C). At the surface this zone is 40 feet thick and averages 15.5 per cent manganese; at a vertical depth of 100 feet it is 38 feet thick and averages 9.3 per cent manganese. It dips 86° E. This zone may be longer than shown on plate 8, for it lies too far east to have been encountered in any other trench or in the eastward-trending drill hole at trench 5.

The ore zones in trenches 5, 6, and 7 probably are not the same as those in trenches 1, 2, 3, and 4. The attitude of the country rock and of the dikes, which here seem conformable with the bedding, suggests that if the northern ore zones continue southward farther than shown, they would lie east of trenches 1, 2, 3, and 4. Little ore float is visible on the surface to assist in the tracing of any of these zones, and the solution of this problem must await further prospecting.

Trench 8, which lies on the edge of a swamp, reached bedrock at only one point. The rock was slightly manganiferous hematitic shale. No manganiferous float is exposed at the surface on the A. M. Dicker farm, south of the Mapleton-Presque Isle road, and no prospecting has been done there. Manganese-stained rock is said to have been plowed up at points 9 and 10 of plate 17, on the farm of W. B. Waddell, but there was little evidence of ore at either place at the time of the writer's visit.

The Higgins deposit is composed of lenses of ore that may average 10 to 15 per cent manganese at the surface but only 7 to 10 per cent below the zone of oxidation. The lenses pinch and swell rather markedly both along the strike and downward. None is known to be continuous for more than 400 feet longitudinally, but not enough evidence is yet available to indicate the full length of the more promising ore zones on the surface or their thickness and grade at depth.

The only assured ore at the Higgins prospect is that in zones A and B above a depth of approximately 20 feet. Ore in zone C, with an average manganese content of 10.5 per cent for a length of 100 feet and to a depth of 100 feet, may be considered probable ore.

#### *Frenchville prospect*

The Frenchville prospect is on the farm of Sid Morin, 0.4 mile northeast of the Frenchville church and 600 feet northwest of the



highway (plate 2, No. 19). The main ore showing is on the north-west side of a small knob (figure 5), but float is traceable for 200 feet to the north, and there is a little float 400 feet north of the knob.

Geologically the Frenchville prospect is different from all others, in that the manganiferous shales lie only a few feet above the fine-grained sandstones which form the basal part of the Silurian slate series. The sandstone dips beneath the ore zone at an angle of  $55^\circ$ .

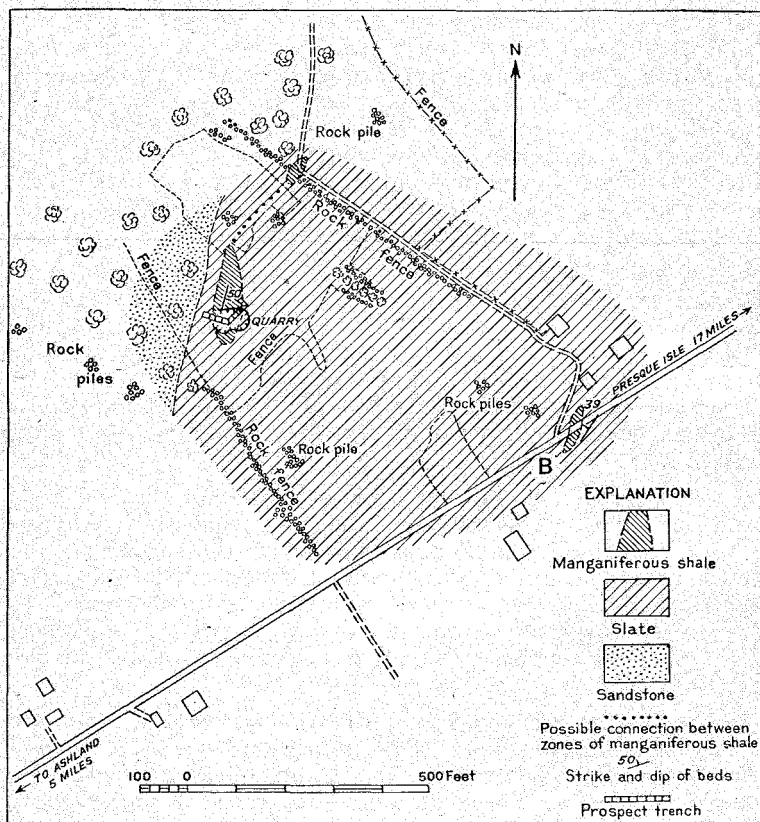


Figure 5: Pace and compass map of the Frenchville prospect.

The prospect was trenched by the State of Maine in 1941, and a shallow pit has also been dug into the ore zone, apparently to obtain rock for road metal. Eckstorm reports that an 18-foot sample from the west end of the trench analyzed 5.7 per cent manganese and 10.6 per cent iron. A 72-foot sample at the east end of the trench analyzed 14.2 per cent manganese. This latter sample, however, was taken in a section of the trench that was almost U-shaped, and across beds dipping  $30^\circ$  to  $60^\circ$  to the east, so that the true thickness of the zone represented by this sample is probably not more than 30 feet.

The best-looking ore is a laminated, slightly calcareous, red and black shale. Considerable green and gray gnarled shale with manganese stain is also present.

Red and gray manganese- and iron-stained shale and thin-bedded limestone is exposed in the road at point B of figure 5. A northwest dip of  $39^{\circ}$  at this point suggests that this may be the same ore zone as that previously described, cropping out here on the east limb of a synclinal fold, but exposures are not adequate to check this interpretation. The exposure in the road is only 20 feet wide, and only a few beds appear to contain appreciable quantities of manganese and iron.

The zone of ore at the Frenchville prospect, which may average 12 per cent manganese at the surface, is at least 25 feet thick, 100 feet long, and 20 feet deep, and its dimensions may be somewhat greater.

#### *Other prospects*

Red shale heavily stained with manganese is reported to have been turned up by the plow on the farm of A. J. McLean, in the northwestern part of Woodland Township (plate 2, No. 20). At the time of the writer's visit no manganiferous float was exposed on the surface, and attempts to locate an ore zone by digging were unsuccessful.

Showings of ore have been reported on the farm of Robert Dudley, near Packard School, in the northern part of Mapleton Township (plate 2, No. 20). This deposit was not looked for, as ore float is said to be exposed only at times of deep plowing.

Rock showing traces of manganese-oxide stain are common at other places in the northern district, but no other deposits having potential economic importance are known within the area covered by plate 2. There probably are other deposits, however, in the woodlands west of the northern district, and possibly also north and south of the district. The present interest in manganese in this region is expected to lead to the discovery of other similar deposits in adjoining areas that are as yet unexplored.

### *Central District*

#### *Hovey Mountain prospects*

Of the reported prospects on Hovey Mountain, the only one visited is in flat woodlands near the crest of the ridge (fig. 2, No. 1), on land owned by the Penobscot Development Co. The country rock on the ridge crest is a green slate locally containing red interbeds. The manganese ore is of two kinds: a heavy massive red hematitic shale with thin black laminations, and a very tough, gnarled, greenish-gray, siliceous limestone. Both kinds are stained with black manganese oxide along bedding and joint surfaces. The two are inter-

bedded with each other and also with the country rock. The ore zone trends N. 25° E. and stands vertical. Small folds are visible in several outcrops, but the amount of thickening of the ore zone by folding seems to be small. The ore zone was traced by float 300 feet south-southwest and 200 feet north-northeast from the principal outcrops. It curves somewhat toward the northeast in the latter direction.

The only analyses of Hovey Mountain ore are of two grab samples collected by Mr. Harrer. The first was a composite of a well-exposed 25-foot width of ore, and the second was of an unusually red, jaspery type of ore. The analyses follow:

Sample	Mn (per cent)	Fe (per cent)
1	9.20	32.3
2	7.02	29.5

The unusually high ratio of iron to manganese is noteworthy. In this respect this ore more closely resembles the iron deposits at Woodstock, New Brunswick, than it does the other manganese and iron deposits in Aroostook County.

Outcrops and float at this deposit show that the ore zone is at least 25 feet wide and 200 feet long, and it may be 50 feet wide and 500 feet long. Continuation of ore to a depth of 20 feet seems reasonably assured and ore of somewhat lower grade may be expected to continue downward to the practicable depth of mining.

Mr. Dan Brewer, who guided the writer to Hovey Mountain, says that the deposit described above is not the largest on the mountain. Another deposit is supposed to lie near by, on or near the crest of the ridge, but this second deposit, though looked for, was not found.

#### *Lower Maple Mountain prospect*

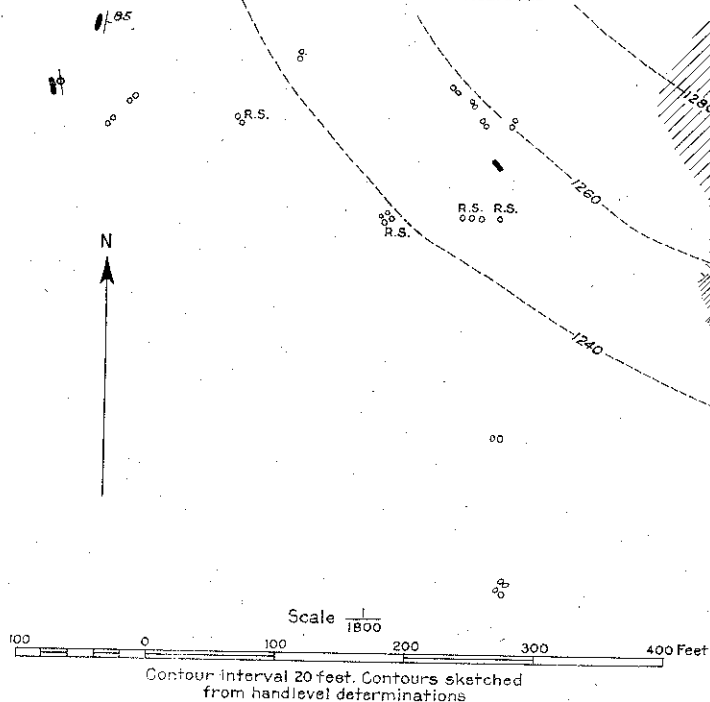
Manganese ore has been found at two places on Maple Mountain. The deposit named the Lower Maple Mountain prospect is in the woods near the base of the mountain on the northwest slopes (fig. 2, No. 2). The ore is a red, fine-grained, laminated, heavy rock, resembling jasper, and stained black in places with manganese oxide. The ore zone is bordered on the northwest, and probably also on the southeast, by barren green slate. The beds strike N. 44° E. and dip 70° SE.

The ore zone is poorly exposed, but judging from a few outcrops and some float, it appears to be about 115 feet wide. It was traced 300 feet southwestward, but it could not be followed to the northeast.

An assay of a single grab sample indicated that the ore is of unusually high grade. It resulted as follows: 15.0 per cent manganese, and 18.0 per cent iron.

## EXPLANATION

- Outcrop of maganiferous shale  
 Abundant float of maganiferous shale  
 Zone of maganiferous shale  
 Outcrop of red shale  
 Abundant float of red shale  
 Zone of interbedded maganiferous shale and red and green shale  
 Outcrop of gray shale  
 Trench of Manganese Ore Co., 1944. Figures show footage and average analysis of rock containing plus 9% Mn.  
 Trench of State of Maine, 1941  
 Geologic contact  
 Steeply dipping fault. Direction of displacement not known  
 Axis of syncline  
 Dip and strike of beds  
 Strike of vertical beds



GEOLOGIC MAP OF UPPER MAPLE MOUNTAIN DEPOSIT

Base from transit survey of Manganese Ore Co.  
 Grade of ore from analyses of Manganese Ore Co.  
 Geology by R.L. Miller.

At present, however, none of it can be considered as assured ore, for the 115-foot zone may contain so many concealed barren interbeds that it would not be minable. Although data on this deposit are very meager, its possible great width and high grade make it worthy of further exploration.

Prospecting of the Upper Maple Mountain deposit by the Manganese Ore Co. in 1944 showed that the beds on Maple Mountain are strongly folded. Showings of ore float between the Upper and Lower Maple Mountain prospects suggest that the latter may be a continuation of the west ore-zone of the Upper Maple Mountain deposit, which has been deflected or displaced by folding or faulting.

### *Upper Maple Mountain Deposit*

On the crest and southwest slopes of Maple Mountain in Township D, Range 2 is a large deposit of manganiferous rock, which compares favorably in grade with the Dudley deposit. It was first prospected by Eckstorm in 1941 at which time three trenches were dug and composite samples analyzed. It was visited briefly by Mr. Harter of the Manganese Ore Co. and the writer in 1943, and by A. E. Walker, also of the Manganese Ore Co. and the writer in 1944. At the time of the writer's visit in 1944 the upper part of the deposit had been exposed in several trenches, and numerous analyses of 10-foot samples from the trenches had been made. The approach of winter prevented the completion of the prospecting program, however, so that the full extent of the deposit is still not known. Neither has any diamond drilling been done to determine the depth of the ore body or the grade of the manganiferous rock below the zone of surface enrichment.

Plate 18 is a partial geologic map of the deposit showing the writer's interpretation of the structure and geologic relations. The country rock of Maple Mountain is dominantly green and gray slate with some interbedded red slate. The slates are folded and locally strongly contorted. They have probably also been cut by small faults, although only one mappable fault was recognized and traced with any degree of assurance.

The manganiferous zone is interbedded with the slates and has been folded with them. It consists of even-bedded, thinly laminated, hematitic and manganiferous shale, which is dark red, or nearly black in color and is conspicuously heavier than the barren slate. Thin layers of jaspery-looking bright red shale are interlayered with the manganiferous shale and give some of the rock a strongly banded appearance. This type of rock is illustrated in the photograph (plate 5B), which was, however, taken at the northern of the two outcrops near the west edge of plate 18. The red shale bands are most numerous in the low-grade ore, and rare or absent in the best ore.

All the chemical analyses of manganiferous rock at the Upper Maple Mountain deposit are of 10-foot trench samples, and are therefore of oxidized ore. The highest-grade sample contained



18.91 per cent manganese but most of the samples of "ore" contain between 10 and 14 per cent manganese. The richest iron-bearing sample contained 39.0 per cent iron, but most of the samples of "ore" contain between 20 and 30 per cent iron. The ratio of iron to manganese in the Upper Maple Mountain deposit is higher than at any other well-prospected deposit in Aroostook County. This is shown in plate 7, in which the curve representing the average of the iron-manganese ratio in all analyses of Upper Maple Mountain rock lies above the corresponding curves for the other six deposits graphed. For low and intermediate percentages of manganese the percentage of iron in Maple Mountain ore is approximately 4 per cent more than in the same grade of manganiferous rock at the Dudley and Gelot Hill deposits, which have the next highest iron-manganese ratio. For ore above 14 per cent manganese, however, the ratio falls and the highest grade of Maple Mountain ore has almost the same iron-manganese ratio as does comparable grade ore from the Dudley deposit.

The iron in the Maple Mountain ore is largely if not entirely in the form of hematite. In this respect it resembles the ores of the northern manganese district, and differs from the southern district ores which contain abundant magnetite as well as hematite. The manganese minerals in the Maple Mountain ores are disseminated through the hematitic shale and are so fine grained as to be invisible to the naked eye. Presumably the primary manganese is contained in the minerals, braunite and bementite, for the rock does not seem to differ from the other Aroostook ores that have been studied in this section, in all of which these are the dominant ore minerals. Black manganese oxide, which has formed by the oxidation of the primary manganese minerals, coats many of the bedding and joint surfaces. Enrichment of the ore by oxidation does not appear to have progressed as far in the Maple Mountain surface ores as in the Dudley surface ores, so that the fall in grade below the zone of weathering would probably be somewhat less at Maple Mountain than at the Dudley deposit. No quantitative data showing the percentage of enrichment of the surface ore at Maple Mountain are available, however, as no diamond drilling or deep test pitting has been done.

On the crest of Maple Mountain, the ore body has been folded into a tight syncline which has its apex about 200 feet east of the highest point of the mountain and which plunges to the southwest. The main ore zone is traceable as a continuous belt around the nose of the syncline, although the width varies somewhat due to minor folding and to changes in dip. On either side of the belt of richest ore is a belt in which ore of good grade in layers a few inches to several feet thick is interbedded with red or green slate with low manganese content. Green slate is more prominent in the interbedded zone underlying the best ore and red slate is dominant in the overlying interbedded zone. A few feet of strikingly banded red and white slate are very conspicuous in the overlying interbedded zone and form a useful horizon marker.

The east limb of the syncline was traced in trenches for nearly 500 feet from the apex of the fold and scattered outcrops indicate that it continues in a general south-southwest direction for at least another 300 feet. Throughout this distance the zone of best ore maintains a fairly constant width of about 70 feet and, except where locally contorted, the beds dip inward toward the axis of the syncline at angles of from  $60^{\circ}$  to  $85^{\circ}$ . The west limb of the syncline is traceable from Trench AA' to EE' but a few feet farther west it is apparently displaced by a fault. West of the fault the ore zone appears to be present in the western part of Trench FF' and also in the southern half of Trench EE' in both of which the beds are folded and locally contorted. The ore zone near the southern end of trench HH' may be a continuation of the main ore zone. If so, either it has thinned and the interbedded zones above and below have changed character or else unrecognized isoclinal folding and faulting have disrupted the orderly succession of the strata. Scattered outcrops and showings of float suggest that a zone of ore is continuous from the southern part of trench HH' westward to the outcrops of ore at the west edge of plate 18, but changes in dip and strike indicate that the beds would be folded or faulted or both in this area. Two other isolated outcrops of good ore lie south of trench HH' but their relation to other ore zones shown on the map is unknown. More prospecting is necessary before the zone or zones of good ore on the southwest slopes of the mountain can be accurately traced.

The depth of the Maple Mountain deposit is not known. The steep to nearly vertical dips that prevail in almost all exposures show clearly that the deposit is not merely superficial. Abundant evidence of folding is present but the folds are not sufficiently regular or continuous to predict how the beds will behave at depth. It seems reasonable to assume, however, that the main ore zone will average at least 100 feet in depth along the major syncline except at the apex of the fold, and it probably goes considerably deeper along the east limb which maintains a fairly uniform strike and steep dip from the apex of the fold to the south edge of the map.

Using a cut-value of 9 per cent manganese, the width of the ore zones in each of the trenches for which analyses are available has been shown on plate 18. It should be noted that the belt of interbedded ore and slate overlying the good ore zone in trenches BB' and DD' is partly or entirely included in the plus 9 per cent rock, but it is entirely excluded in trench AA'. This is due to variations from trench to trench in the amount of low grade and barren slate included with the good ore in the interbedded zone. Some 10-foot samples in the interbedded zones are as high in manganese as most of the ore in the main ore belt, but others fall below 9 per cent manganese. Where the average of 10-foot samples is maintained above 9 per cent, occasional lower-grade samples have been included on the theory that the separation of thin layers of lower grade from higher grade ore would not be practicable in mining. The unusual length of plus 9 per cent rock in trench EE' is due to the fact that the trench

lies at a low angle to the strike of the beds and the direction of strike also changes from northwest to northeast so that the beds are probably repeated in the trench.

The reserves of manganese in the deposit are uncertain because the full extent and depth of the manganiferous zones are unknown as is also the grade of the primary manganiferous rock below the superficial mantle that has been weathered and enriched by oxidation. For purposes of a first approximation of the tonnage of plus 9 per cent manganiferous rock the following assumptions have been made: 1. The ore zones maintain essentially the width shown at the surface to a depth of 100 feet. 2. The grade of ore below 20 feet is 1 per cent lower in manganese than the superficial oxidized ore. Using these figures 1,263,000 long tons of manganiferous rock would be present, which would average about 10 per cent manganese and about 25 per cent iron. No rock lying west of the fault on plate 18 or south of the edge of the map has been included in this estimate, because the extent of the good grade of ore in these areas is relatively unknown.

Even though the information now available indicates a large tonnage of manganiferous rock on Maple Mountain, the remoteness of the deposit from highways and railroads makes it unlikely that it will be utilized until other more favorably situated deposits such as the Dudley have been exploited.

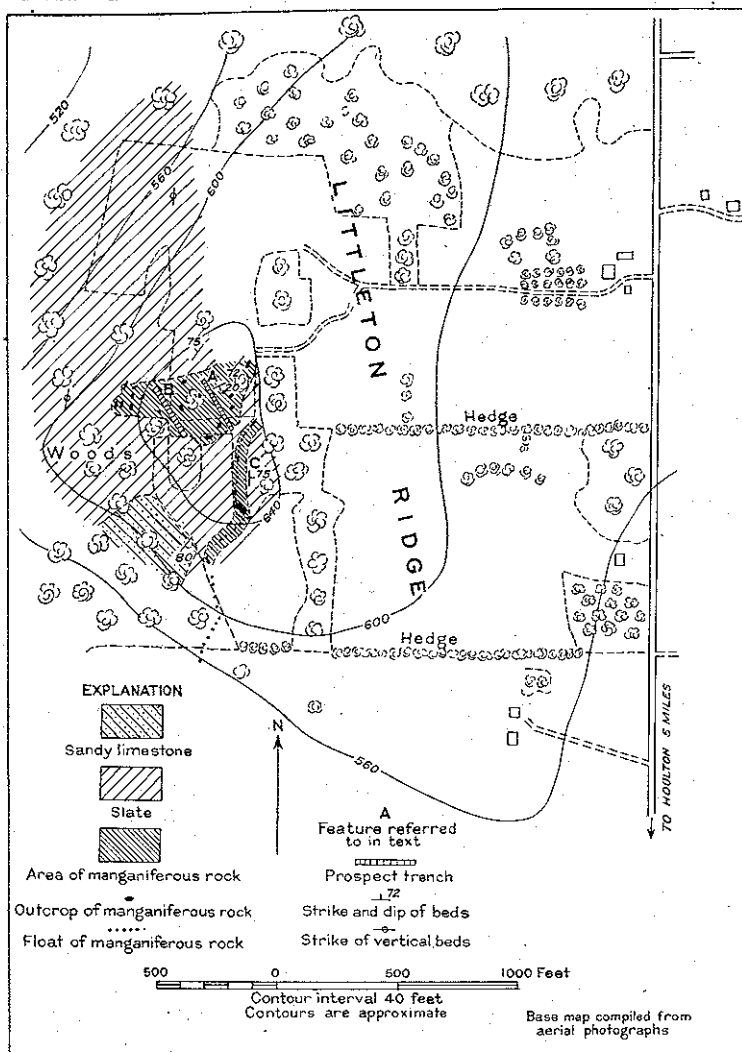
### *Southern District*

#### *Littleton Ridge deposit*

On Littleton Ridge, a conspicuous prominence in the southwestern part of Littleton Township, lies the richest and perhaps the largest deposit in the southern district (plate 4, No. 1). The deposit is mainly on the farm of Mary Haggerty, but it crosses onto the Abernathy farm and may continue south onto the M. Clark farm.

The country rock in the vicinity of the deposit consists dominantly of green slates, which are strongly folded and faulted, but even-bedded sandy limestone is exposed southwest of the deposit (plate 19). The nature of the bedrock east of the deposit is entirely unknown because of lack of outcrops.

The ore body is in two parts, apparently unconnected, which contain ore of markedly different character. The larger part, on the Haggerty farm, which has been prospected by two trenches, consists of a very tough, massive-bedded, faintly laminated calcareous quartzite. The rock is non-magnetic and has a slight greenish cast, and some beds are stained to a moderate extent with black manganese oxide. In neither of the two trenches was the northern edge of this ore body exposed. The ore sampled over a length of 230 feet in trench A (plate 19) and of 260 feet in trench B averaged 9.3 per cent manganese and 18.7 per cent iron. The almost unweathered



GEOLOGIC MAP OF LITTLETON RIDGE DEPOSIT

appearance of most of this ore indicates that there has been little surface enrichment, and that the ore below the water table would be but little lower in grade than that on the surface. The structure of this part of the ore body is not clear. The deposit is cut off on the west by barren slates, but to the northeast it disappears under the surface mantle. The attitude of the beds and the shape of the deposit suggest a complex overturned syncline plunging northeast, but drilling will probably be necessary to determine the structure and hence the expectable depth of the ore in this area.

The second ore body is a linear zone on the Abernathy farm, extending 800 feet almost due north and south. Though locally contorted, this deposit seems to be essentially homoclinal; it dips eastward at angles of  $70^{\circ}$  to  $90^{\circ}$ . At point C the manganiferous zone was between 55 and 67 feet wide. In a few places it contains beds of ore similar to that in the first ore body, but most of the ore here is a dark, thin-bedded, heavy, manganiferous shale carrying abundant magnetite. The zone becomes more strongly magnetic southward. The grade of the ore is indicated only by two grab samples, which average 8.8 per cent manganese and 28.8 per cent iron. At the surface the ore is oxidized and probably enriched, and it is therefore presumably leaner below the water table.

Although its form and extent are not adequately known, the Littleton Ridge deposit appears promising and is likely to be prospected more thoroughly. In the absence of subsurface data and because of the complexity of the structure, ore reserves at this deposit have been calculated only to a depth of 50 feet, though the ore bodies may well extend deeper.

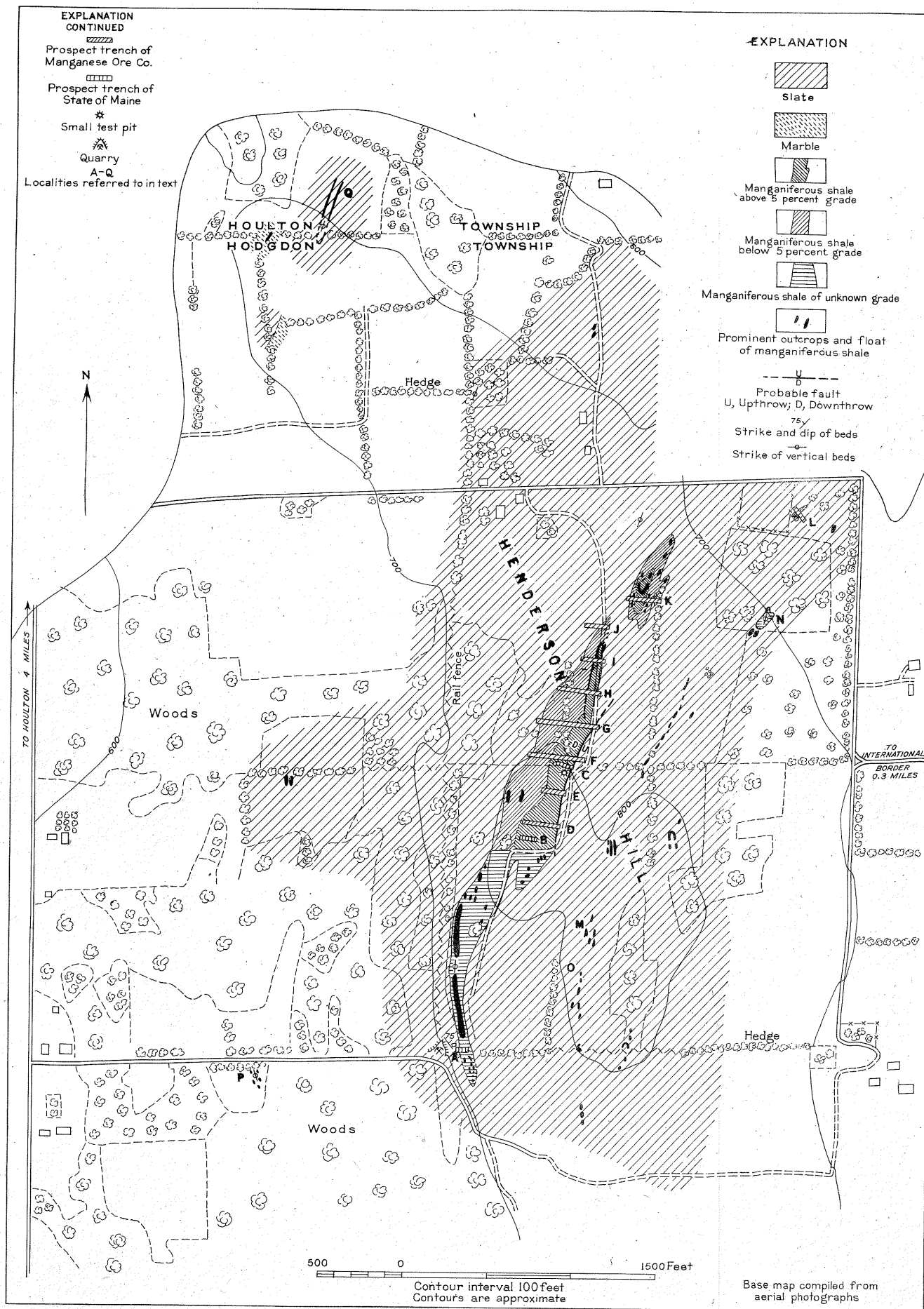
A small outcrop on Back Ridge Road, just north of Twin Brook and 0.8 mile southwest of the Littleton deposit, is the same type of ore as that in the Haggerty zone of the Littleton deposit. It is unlikely that manganiferous rock is continuous between the two localities, but the occurrence lends hope that other deposits similar to those on Littleton Ridge may be found elsewhere in the vicinity.

#### *Prospects north of Henderson Hill*

Two small prospects lie north and northeast of Henderson Hill, in Houlton Township (plate 4, No. 2).

The prospect farther to the north, which is on the Harkins farm on the southwest side of Hovey Hill, contains typical magnetite-rich, dark shale interbedded with green slates. The main ore zone strikes due north, and is traceable by float for a distance of nearly 300 feet. It does not outcrop, but Eckstorm, in 1941, dug a trench across the southern part of it. A 21-foot sample which he collected, analyzed 5.4 per cent manganese and 16.3 per cent iron. A little float was found on a knob 800 feet farther north, but it clearly did not come from the main ore zone. This deposit is too small and of too low grade to be important.





GEOLOGIC MAP OF HENDERSON HILL DEPOSIT AND ADJACENT PROSPECTS

The other prospect is on the farm of Colie London, on the Houlton-Hodgdon Township line (plate 20, Q). Two bands of manganiferous slate, trending north-northeast and about 35 feet apart, are traceable for 400 feet. Each is from 5 to 20 feet wide. Both probably represent the same stratum, duplicated at the surface by a synclinal fold plunging northeast. A grab sample of the ore analyzed 8.8 per cent manganese and 19.1 per cent iron. The ore zones appear too thin to be commercial.

#### *Henderson Hill deposit*

Exposures of manganiferous shale and slate are abundant on Henderson Hill in Hodgdon Township, especially on the farm of Harry Thwaites (plate 4, No. 3). The rocks in this vicinity are strongly folded. Two faults were mapped, and many more are probably present (plate 20). The discontinuity of most of the ore showings is partly due to this folding and faulting, but some of the smaller showings represent thin lenses of ore whose longitudinal extent was never more than a few score feet.

In 1941 Eckstorm prospected the deposit for the State of Maine, and in 1943 the Manganese Ore Co. dug additional trenches. The main ore zone is traceable for 2,800 feet, from State of Maine trench A to Manganese Ore Co. trench J (plate 20). The ore body at trench K may represent a continuation of the main ore body, offset to the east by a fault. The ore in this zone consists of heavy, laminated, reddish-brown to black shale, some beds of which contain abundant sparkling crystals of magnetite. Interbedded and infolded with this higher-grade ore are layers of weathered, manganese-stained shale whose light weight indicates that it is of low grade, and also layers of green slate almost entirely barren of manganese and iron. The interbedding and folding are so complex that the high-grade zones could not be mined separately except at prohibitive cost. The attitude of the beds and of the axial planes of the folds in the Manganese Ore Co. trenches D to J is highly variable, but in general both trend north-northeast and have nearly vertical dips.

Only three 10-foot samples from these trenches contained more than 10 per cent manganese. By assuming a cut-off value of 5 per cent ore and neglecting all ore zones less than 30 feet wide, a belt of ore at the surface can be delimited whose width varies from 210 feet in trench D to 60 feet in trench I (see plate 20), and which has an average manganese content of 7.0 per cent. On raising the cut-off value to 7 per cent, the width of the minable zone falls to 120 feet in trench D and to 30 feet in trench G, and the manganese content of the ore rises to 7.8 per cent. The iron content of different grades of ore from Henderson Hill is shown in plate 7. If ore of the grade here present ever becomes minable, the larger tonnage made available by using the lower cut-off would probably more than balance the higher milling costs per ton of manganese.

South of trench B the main ore zone is offset to the west, but it continues southward to trench A. In this southern segment the

zone appears to be somewhat narrower than at trench D but apparently contains ore of about the same grade. If the northern part of the ore body is minable, the southern part also is probably minable.

How deep the ore body extends is uncertain. It is bounded on the east by a fault, against which the ore may die out in depth. Moreover, the dip of the ore body as a whole may be gentler than the dips of the individual beds and folds on which readings were taken. It seems reasonably safe to assume that this deposit extends downward at least 50 feet, but because of the bounding fault it may not continue to such great depths as do most of the deposits in the northern district.

Ore encountered in trenches K and L and float showings elsewhere on Henderson Hill (M) come from zones too lean or too small to be significant. A small area of good ore crops out at N, which might be mined if the main Henderson Hill deposit is ever worked.

Ore of 7.0 per cent grade to a depth of 20 feet for the area shown in yellow in plate 12 is considered assured. This ore is probably minable to a depth of 50 feet with slightly diminished grade—estimated at 6.5 per cent. There is also geological evidence indicating ore of similar grade between trenches A and B.

#### *Prospects between Henderson Hill and Westford Hill*

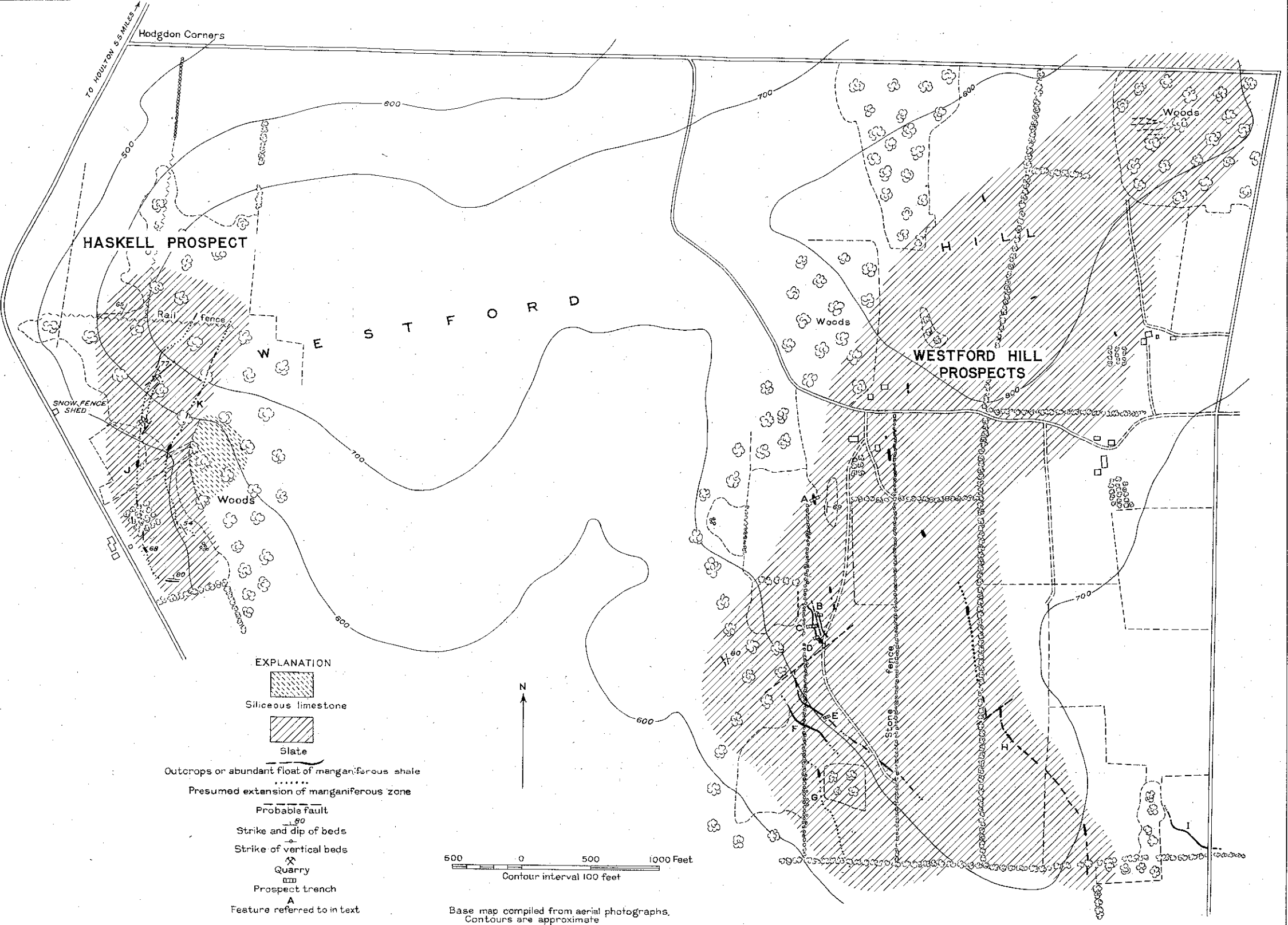
Six prospects lie in the lowland between Henderson Hill and Westford Hill (plate 4, No. 4). They have not been trenched, but exposures are adequate to indicate that none are of large size.

The one nearest Henderson Hill (plate 20, No. P) is on the Stanley London farm. Manganese-stained shale has been dug up by the plow in a cultivated field for a distance of about 100 feet. A few pieces of good ore have been piled along the fence, but the chips of ore showing in the soil at the time of the writer's visit were only of fair grade.

Ore occurs in two zones on the George Henderson farm, west of the north-south highway and a mile west-southwest of Henderson Hill. The larger zone, 600 feet west of the road, consists of manganese-stained shale and is apparently about 30 feet thick, but none of the float from this zone seemed to be of good ore.

Manganese-stained calcareous shale crops out on the Ernest Tournay farm, half a mile south of Henderson Hill. Eighteen feet of beds are exposed, none of which appear from inspection to consist of good ore. Pieces of magnetite-rich ore of better grade were picked up near by. Manganese-stained float is said to be prominent on the surface after plowing at a number of places on a line between this exposure and the east end of Henderson Hill (plate 20).

On the Billy Atherton and Ralph Sloat farms, northeast of Westford Hill, an ore zone trending north was traced for 500 feet. It consists of a gray, manganese-stained, somewhat gnarled siliceous limestone, and appears to be about 10 feet wide.



GEOLOGIC MAP OF WESTFORD HILL AND HASKELL PROSPECTS

The Atherton-Sloat prospect nearly lines up with the Fred London prospect, 1,500 feet to the south, where there is a zone of strongly folded manganese-stained shale, the width of which is not over 20 feet.

Manganese-stained slate is exposed on a small knob on the Theodore Griffin farm, half a mile east of Westford Hill. Near the abandoned house next west of the Griffin place, one small outcrop and a number of loose pieces of good ore show in the road, and a little ore float is visible in the fields south of the road.

Although the prospects described above are almost on a line between Henderson Hill and Westford Hill, they seem to represent separate lenses of manganiferous beds in the same general series of slates, rather than any zone or zones of manganese ore extending continuously between the two larger deposits. None are considered commercial.

### *Westford Hill prospects*

There are small outcrops and concentrations of manganese-stained float on the northeast part of Westford Hill (plate 4, No. 5, and plate 21), and a number of more extensive manganiferous zones on the southeast slope of the hill. Only the latter, which lie on the farms of Paul Jackins and of Mrs. P. L. Ebbett, are economically important.

Westford Hill consists mainly of green slate, strongly folded and much faulted, but in places it includes massive beds of micaceous sandstone, a number of which were mapped by White.<sup>1</sup> The ore consists of dark-brown to black, heavy, manganese-stained shale and gray, laminated, siliceous limestone. The former type, which is the lower in grade, is considerably weathered at the surface. The latter type is marked with narrow red, gray, and greenish-white bands. Its matrix is unlaminated and contains abundant magnetite. The ore zones as a whole are strongly magnetic, and most of them can be traced by means of the dip needle across covered intervals.

Eckstorm, in 1941, dug six trenches in the Westford Hill deposits. Five of these trenches were found and are shown in plate 13. The small ore zone at A analyzed 8.9 per cent manganese and 15.9 per cent iron for a width of 42 feet. The ore body in trench B seems to be repeated by a strike fault and to be the same as the one in trenches C and D. The ore is largely of the heavy, laminated shale type but includes some infolded and interbedded low-grade shale. The width of the zones is between 25 and 40 feet, but this includes some duplication by folding. The average of Eckstorm's analyses of channel samples is 9.6 per cent manganese and 23.1 per cent iron. A grab sample collected at this trench by the Manganese Ore Co.

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<sup>1</sup> White, W. S. op. cit.



analyzed only 3.3 per cent manganese and 19.8 per cent iron. The channel sample should be more nearly accurate than the grab sample, and the appearance of the ore supports the higher figures.

The ore zone at trench E is traceable for a longer distance than the zones mentioned above but is probably not as wide. A 12-foot sample, which does not represent the full width of the zone, contained 8.8 per cent manganese and 18.3 per cent iron. The ore zones at F, G, H, and I were traced partly by outcrops but mainly by float and with the dip needle. None seems wide enough to be economically important, though some contain ore that appears to be as good as any in trenches B, C, D, and E.

Although in most places the Westford Hill ore zones probably extend to considerable depths, folds and faults are so abundant in the region that continuity in depth cannot be taken for granted but must be verified by drilling. For this reason tonnage estimates are reasonably accurate only to 20-foot depths, though the ore is assumed to extend to a depth of at least 50 feet. The only ore zones that seem thick enough to mine are those exposed in trenches B, C, and D.

#### *Haskell prospect*

Ore zones a mile east of those just described are exposed on the Haskell place at the west end of Westford Hill, in Hodgdon Township (plate 4, No. 6, and plate 21). The country rock is a green slate, with which layers of heavy, gray, laminated, magnetite-rich ore are interbedded. The western of the two major ore zones (plate 20, J) is well exposed in two quarries near the southwest tip of the hill. It is traceable, by means of outcrops and float and by its magnetic effect, northward to the crest of the ridge and southward onto flat land near the highway. Two separate belts of ore 45 feet apart are exposed in the lower quarry. The western belt is more than 20 feet thick, but it contains some interbedded low-grade to barren slates. The eastern belt contains 14 feet of good ore and a considerably greater thickness that appears to be of low grade. Eckstorm analyzed a 61-foot sample of ore from the western belt and a 51-foot sample from the eastern belt; neither sample represents the full width of the ore zone. A grab sample of Haskell ore taken for the Manganese Ore Co. has also been analyzed. The results of the three analyses are as follows:

Sample	Mn (per cent)	Fe (per cent)
Western zone trench	7.68	18.4
Eastern zone trench	7.33	14.6
Composite grab sample	8.36	17.7

The eastern ore zone (plate 21, K) is well exposed only in small ledges at the base of the hill, and it was traced by float and by its magnetic effect for 1,600 feet. It is thinner than the western zone and seems to be economically unimportant.

Many tight folds affect the ore zones, and faults offset them in at least two places. The structure is so complex that the behavior of the beds beneath the surface cannot be predicted.

Ore reserves at the Haskell prospects are small, because the ore zones are probably too thin to be minable. Between the two quarries, one zone about 25 feet wide seems reasonably assured, and this zone would probably average about 7.5 per cent at the surface and perhaps nearly 7.0 per cent below the oxidized zone.

#### *Daggett Hill prospect*

About fifty years ago a manganiferous iron zone was worked for iron on the farm of Donald Tidd, near the crest of Daggett Hill in Hodgdon Township (plate 4, No. 7). No bedrock is exposed now in the small pit, but float of manganiferous shale, mixed with a few pieces of good ore, may be followed for 500 feet southward. The zone of good ore is probably thin, for much of the ore is magnetite-bearing, yet the effect of the concealed ore body as a whole on the dip needle is slight. Narrow zones of manganiferous rocks crop out in the east-west road across the top of the ridge, and manganiferous rocks are also said to occur north of the road. None of the Daggett Hill prospect appears to be of economic importance.

#### *Nickerson prospects*

Manganese ore crops out in several places on the farm of Chester Nickerson, on U. S. Highway No. 1, south of Westford Hill (plate 4, No. 8). The westernmost exposure is in a road cut on the east side of the highway. Beds of manganese-stained, gray, magnetite-rich, laminated, sandy shale are there thrown into a series of folds, which plunge at an angle of 30° in the direction S. 70° E. The width of the manganiferous exposure is 70 feet, but the thickness of the beds involved is less than half that. Similar ore, likewise strongly folded, is exposed in a prominent knob 500 feet east of the road. The alignment of folds suggests that the ore zone is continuous under the glacial cover between the road cut and this knob, but this continuity has not been proved. Eckstorm trenched and sampled both these exposures, and three of his samples have been assayed. Sample 1 represents 48 feet of ore from the road-cut exposure; sample 2 represents 88 feet of ore from the knob. Sample 3 represents 38 feet of the best ore in sample 2, but it is not clear whether these 38 feet are continuous or whether they represent high-grade beds from different parts of the 88-foot cut. Sample 4 is a composite grab sample taken for the Manganese Ore Co. Analyses of these samples are given below.

Sample.	Mn (per cent)	Fe (per cent)
1	9.0	14.0
2	8.1	17.0
3	11.2	20.9
4	9.1	21.5

Manganiferous rock of similar type is also exposed in a pasture near the edge of a wood 900 feet south of the knob just mentioned. One small area seemed to be very short, but a belt farther east was traced for 150 feet by means of float, and another was traced for 150 feet with the dip needle into the swamp to the south. The zone is folded and seems to be 10 to 20 feet wide. It has not been sampled.

The manganese reserves on the Nickerson farm are not large, but it seems reasonable to believe that ore zones having an average width of 50 feet and a depth of 20 feet extend for at least 50 feet on either side of the two exposures that were sampled.

#### *Gardner prospect*

A zone of manganese-stained siliceous limestone crops out on the farm of James Gardner, in northwestern Hodgdon Township (plate 4, No. 9). The zone appears to be about 10 feet thick and was followed for 400 feet along a northeasterly course. The ore resembles the high-grade ore of Littleton Ridge. Analysis of a grab sample shows very low manganese but high iron content. The zone is so thin as to be economically unimportant, but the ore is probably of better grade than is indicated by the one analysis, which gave 1.52 per cent manganese and 23.5 per cent iron.

#### *Benn prospect*

At the George Benn prospect, in northwest Hodgdon Township, there are six showings of manganese ore (plate 4, No. 10). All of these are small, but collectively they may have some importance, for it is possible that a continuous belt of ore may extend between two or more of them. However, surface evidence, though scanty, favors the view that the exposures represent only thin and short lenses of ore.

The better-appearing ore is a manganese-stained siliceous limestone, but manganiferous shale is also present. Eckstorm, in 1941, dug a trench across the zone farthest to the southwest, and a 23-foot sample of ore taken by him analyzed 7.0 per cent manganese and 18.0 per cent iron. A composite grab sample taken by the Manganese Ore Co. from the small exposures to the north analyzed 8.9 per cent manganese and 16.1 per cent iron.

This prospect is difficult to evaluate on surface evidence. The deposits in it cannot be very large or of very high grade, but they may be somewhat larger than the present showings suggest. No estimates of the tonnage at this prospect can be made.

#### *Stewart prospect*

Near the crest of a prominent knob in eastern Linneus Township, on the farms of J. Stewart and J. Hannan, is what is known as the Stewart prospect (plate 4, No. 11). Here, in strongly folded and somewhat faulted green slate striking about N. 65° E., are several beds of dark magnetitic and hematitic shale stained with manganese oxide (plate 22).

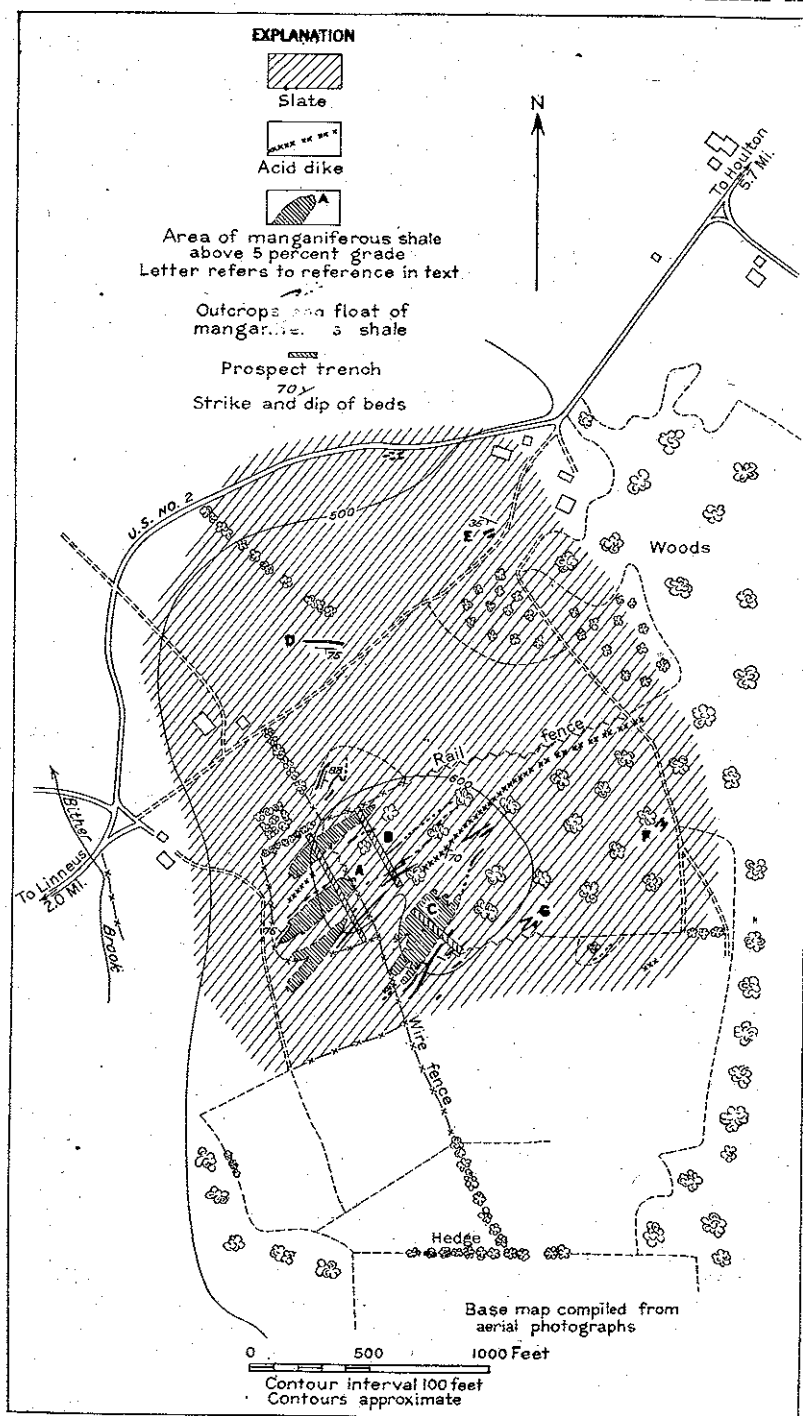
The ore is so prominently exposed at the surface as to give the deposit an appearance of size and richness which prospecting fails to bear out. Three trenches dug by the Manganese Ore Co. in 1943 cross almost the full width of the manganiferous zone. These trenches revealed much greater widths of barren rock than of manganiferous rock, although the manganiferous beds, being resistant, were the more prominent in outcrops. This is shown in the photograph (plate 14B). The shallow parts of the trench in the foreground and center background are of manganiferous slate, but the deep part of the trench between the two resistant zones is of nearly barren slate. Streaks of high-grade ore are present, but most of them are less than 10 feet wide. Those mappable at the surface are shown in plate 22.

The richest 10-foot sample that was analyzed contained 9.6 per cent manganese, but many of the manganiferous zones contain only 4 to 6 per cent manganese. With a cut-off of 5 per cent, a zone of "ore" 80 feet wide averaging 7.4 per cent manganese was found in the middle part of trench A, and another zone 40 feet wide averaging 7.3 per cent manganese lies near the northwest end of the same trench. Only the latter zone is traceable to trench B, where it is 30 feet wide and averages 6 per cent manganese. Nowhere in the rest of trench B are there any zones more than 20 feet thick that average more than 5 per cent manganese. In trench C a continuous zone 150 feet wide, starting at the northwest end of the trench, averages 6.5 per cent manganese. The iron content of the manganiferous rock in all three trenches averages 17.6 per cent. (See also plate 7).

The manganiferous zones are continuous for more than 500 feet along the strike. Because of intricate folding, the behavior of the ore beds in depth is unpredictable. With a cut-off of 5 per cent, ore of 7.0 per cent grade seems reasonably assured to a depth of 20 feet for the enclosed areas shown on plate 22. Ore of a somewhat lower grade probably extends to a depth of 50 feet. Assuming a workable depth of 20 feet and a falling off of 1 per cent in the manganese content of the ore below the water table, the deposits would yield about 22,000 tons of manganese, but the ore is so lean that it may never be commercial.

#### *Adams Mountain prospects*

Manganiferous beds crop out on Adams Mountain in Linneus Township (plate 4, No. 12). The exposures of these rocks on Adams Mountain are on the M. Adams farm, and those north of the mountain are on the Harry Brewer farm. The country rock is a greenish slate, strongly folded, with the beds striking about N. 70° E. Beds of manganiferous calcareous shale crop out on the west side of the hill, and some ore float and a magnetic zone are found on the north side. The ore beds are strongly folded in zig-zag fashion. The general trend of the manganiferous belt is probably about north-south, though the axes of small folds strike nearly east-west. No single ore zone was traceable for more than a few score feet, but float of



GEOLOGIC MAP OF STEWART PROSPECT

manganiferous rock is found nearly to the crest of the hill. A composite grab sample from the ore zones on the west side of the hill analyzed 5.3 per cent manganese and 18.3 per cent iron.

The ore exposed on the north side of the highway, on the Brewer farm, contains abundant magnetite. The ore beds are strongly folded; in general they strike east-west and are nearly vertical. The full width of the zone was not exposed but is more than 27 feet. A sample representing a width of 25 feet was taken by Eckstorm, and a grab sample by the Manganese Ore Co. The analyses follow:

	Mn (per cent)	Fe (per cent)
Channel sample...	8.3	26.1
Grab sample.....	9.3	25.6

A strong magnetic high in the ditch southeast of the ore outcrop may indicate a continuation of this ore zone, but no other evidence of a possible extension of the zone was found in any direction from the outcrop.

Ore reserves are small at these prospects; the Adams Mountain zones are probably too narrow to work, and the available evidence indicates that the Brewer farm zone is very short.

#### *Drew Lake prospects*

On the shore of Drew Lake are two small magnetite deposits near the contact between siliceous limestone and granite (plate 4, No. 13). The magnetite-bearing beds carry some manganese stain. No assay of the manganese content is available, but an almost identical deposit 10 miles to the west contained less than 5 per cent manganese. Both of the deposits at Drew Lake are thin and of no economic value.



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GORHAM CAMPUS**

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"First Annual Report on the Geology of the State of Maine"

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Edward H. Perkins, Assistant Geologist, 1930.

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Copies obtainable on request to the Maine Development Commission, Augusta, Maine.

