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OCCURRENCE OF MANGANESE IN EASTERN AROOSTOOK COUNTY MAINE

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OCCURRENCE OF MANGANESE IN EASTERN AROOSTOOK COUNTY, MAINE

BY

WALTER S. WHITE

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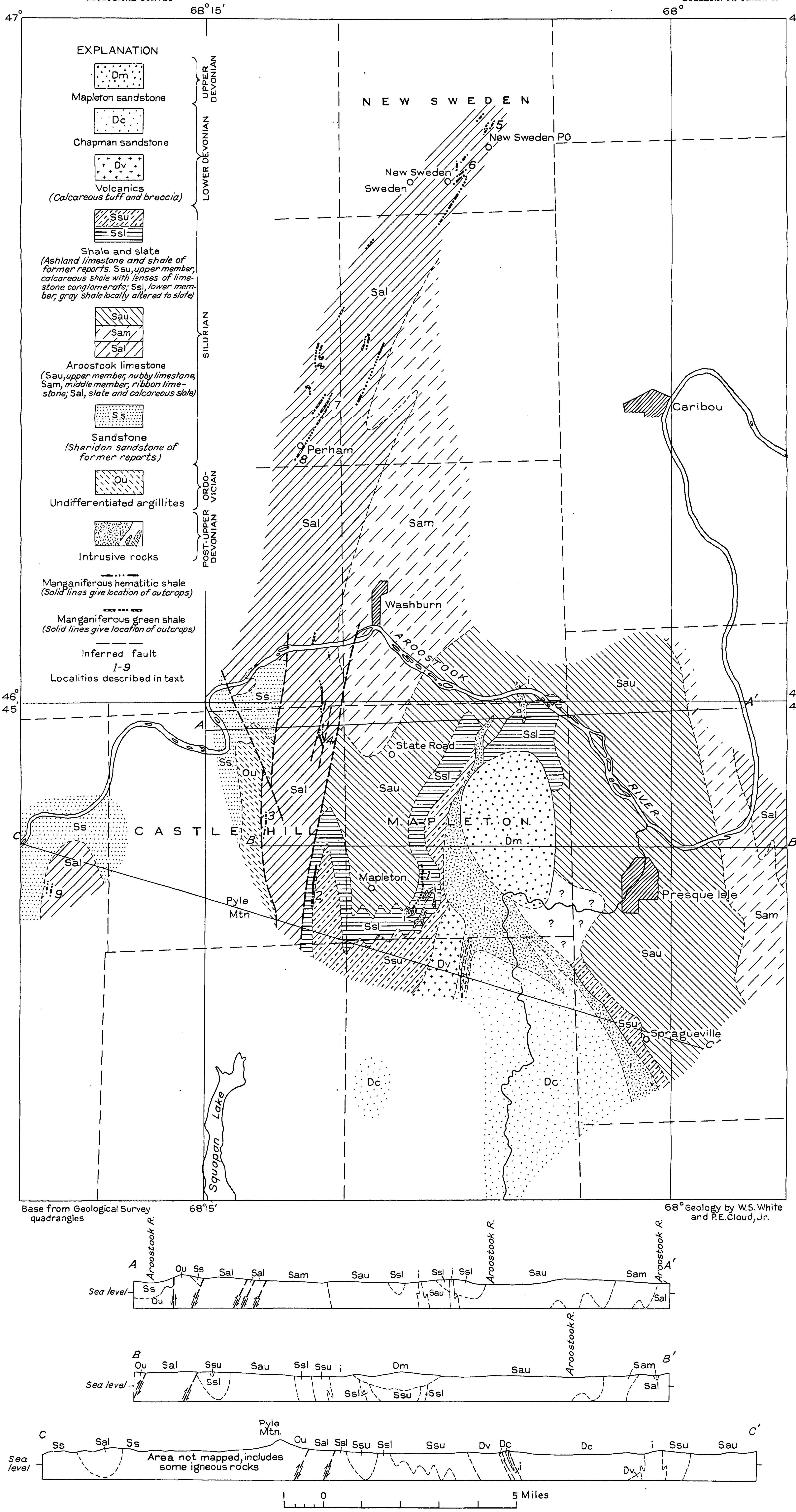

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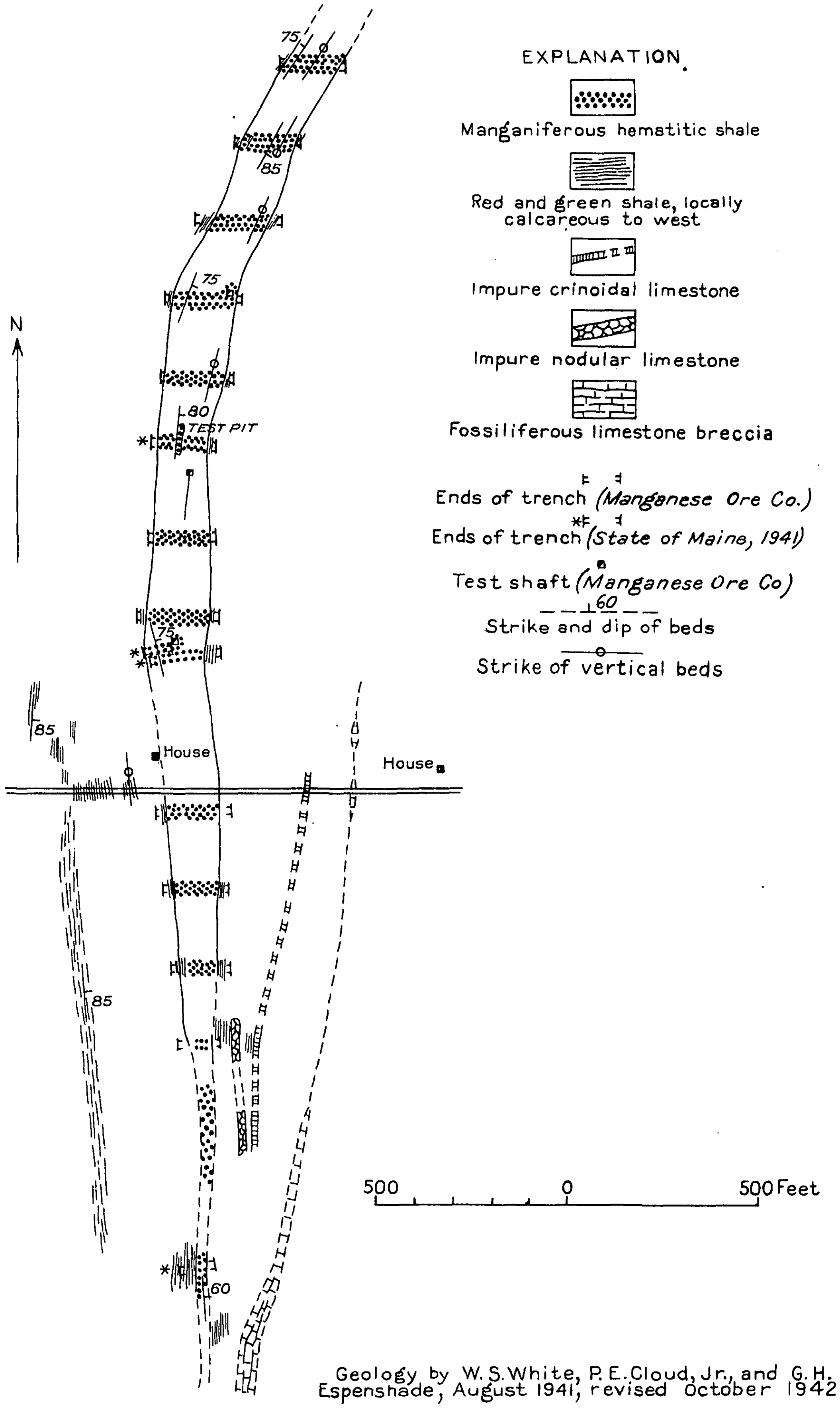

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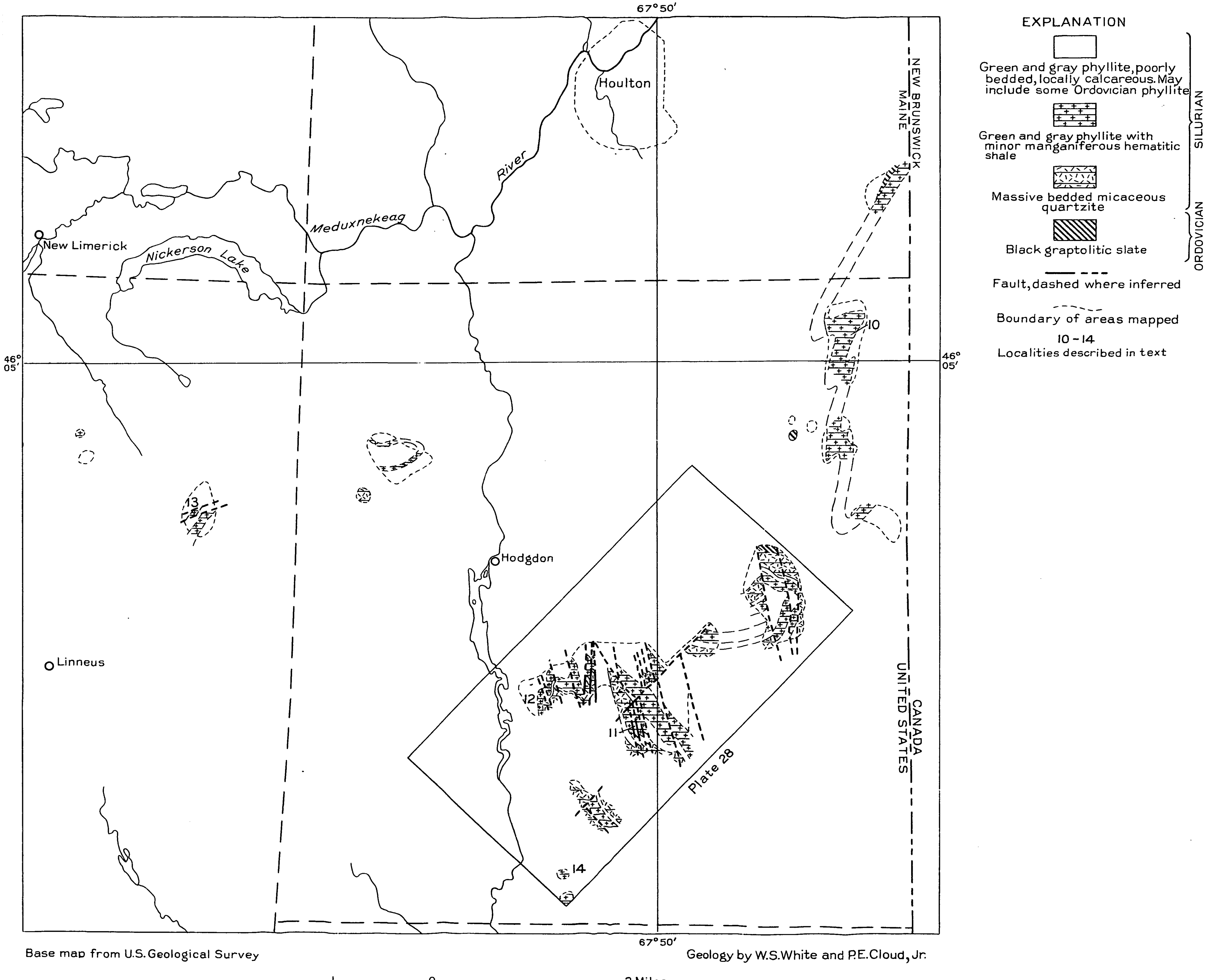

DISTRIBUTION OF MANGANIFEROUS HEMATITIC SHALE IN SOUTHERN HALF OF HOULTON QUADRANGLE, MAINE

OCCURRENCE OF MANGANESE
IN EASTERN AROOSTOOK COUNTY, MAINE

By Walter S. White

ABSTRACT

Manganiferous rocks are found in two areas in eastern Aroostook County, Maine, one west and northwest of Presque Isle and the other south of Houlton. The manganiferous deposits are sedimentary lenses, up to 150 feet thick and half a mile long, in middle Silurian argillite. The rocks of both areas are much deformed, but the deformation is less intense and the continuity of the deposits therefore greater in the Presque Isle area than in the Houlton area. The dip of the rocks at most deposits is steep to vertical.

Below the zone of oxidation the manganese occurs as carbonate and as the silicates braunite and bementite. These minerals are primary constituents of the shales and should continue downward to the limits of the sedimentary units that contain them. One deposit, which has been explored by drilling to an average depth of 130 feet, contains about 11 percent of manganese, but most of the deposits probably contain between 6.5 and 9 percent. There are many millions of tons of these manganiferous shales in the county. Some of the deposits contain 20 percent or more of iron, mostly as hematite and limonite, and magnetite is abundant in the Houlton area.

In parts of the deposits above the water table about 30 percent of the manganese occurs as a heavy stain of secondary oxides along joints and parting planes. The manganese oxides partly replace the primary rock minerals for a distance of 1 to 3 millimeters from cracks in the rock. At the one deposit from which drilling data are available, manganese oxides are found on only a few fractures below the water table, which is at a depth of 20 feet, and none were seen in rocks from below 45 feet. It is estimated that there may be over 1,700,000 tons of partly oxidized manganiferous shale in the region.

Some of the deposits are overlain by a thin zone, probably about a foot thick, that is richer in manganese than the underlying oxidized rocks. At the deposit explored by drilling, the average manganese content of the deposit as a whole is 76.4 percent of the average as determined from surface samples. The surface enrichment is believed to have taken place before the last advance of the Pleistocene ice, which may have scraped off the enriched part of many deposits. There are probably less than 100,000 tons of enriched rock in all the scattered deposits of the region.

There is a very much greater tonnage of low-grade unenriched manganiferous rock in Aroostook County, but it cannot be utilized until methods of extraction have been improved.

INTRODUCTION

Manganiferous rocks occur in two areas in Aroostook County, in northeastern Maine (see fig. 14). One of these areas lies west and north of Presque Isle (pl. 24) and the second south

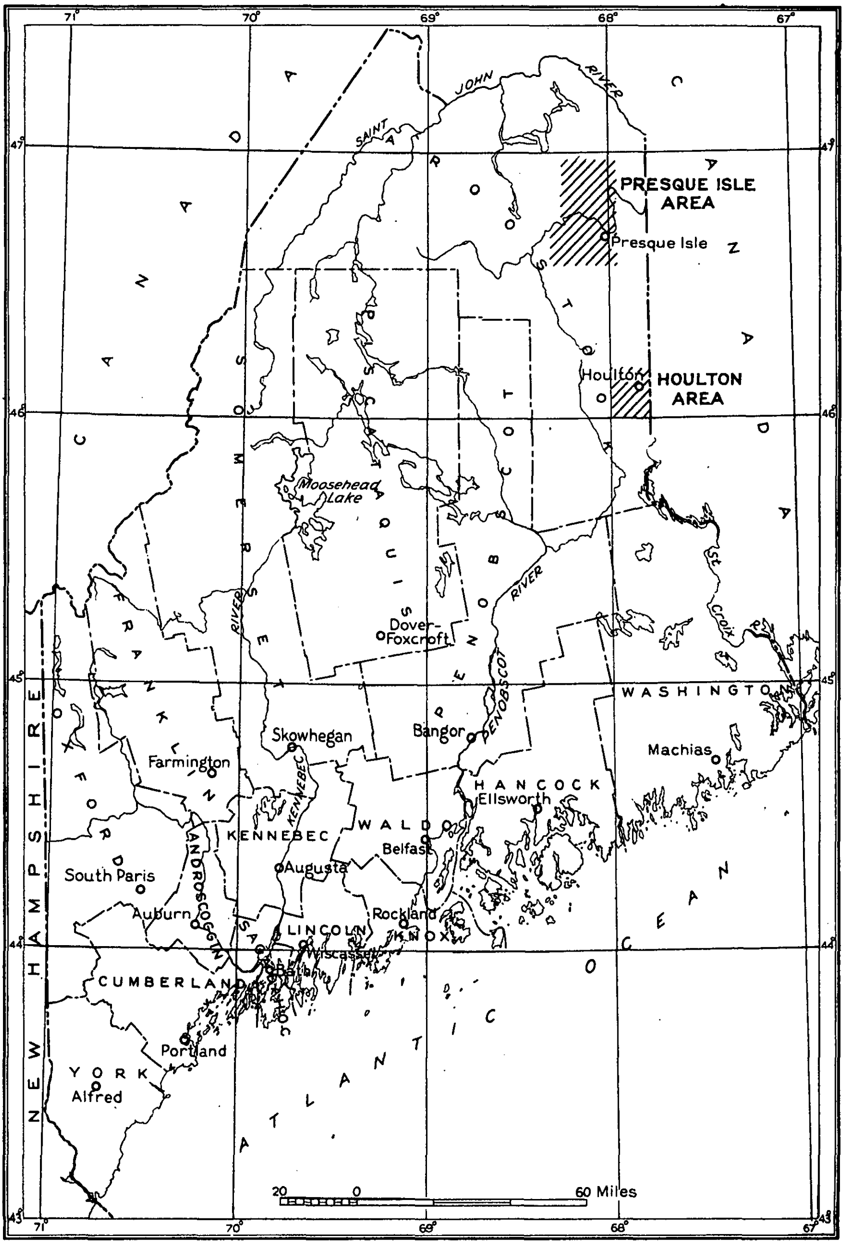

Figure 14.--Index map of Maine showing location of Presque Isle and Houlton areas.

of Houlton (pl. 26). No manganese-bearing material has yet been mined, but two deposits near Presque Isle have been partly explored by diamond drilling. The nature and size of the other deposits can be inferred only from small natural exposures and shallow trenches. Most of the manganese localities described were originally discovered by Mr. Olof Nylander of Caribou and Mr. Harry Thwaites of Hodgdon.

During the summer of 1941 these areas were partly mapped by the writer and Preston E. Cloud, Jr., under the direction of Josiah Bridge. At the same time Mr. Paul F. Eckstorm was employed by the State of Maine to trench and sample all the larger deposits and many of the smaller ones. The trenching and prospecting done by Mr. Eckstorm were of great assistance to the work of the Geological Survey, and the State of Maine has generously permitted publication of its results.

In the fall of 1942 the Manganese Ore Co. began exploratory diamond drilling on two deposits, one in Castle Hill township and another in Mapleton. The writer made two brief visits to the area at that time, and the subsurface data made available by drilling have been incorporated in this report. He is deeply indebted to Mr. A. E. Walker, geologist in charge of the exploratory work, for much valuable material and information.

Valued help has been given by several members of the Geological Survey. Preston E. Cloud, Jr., and Josiah Bridge performed much of the field work upon which this report is based. T. A. Hendricks has aided materially in appraising the economic possibilities of the deposits, and the writer has profited from discussions of the geologic problems with D. F. Hewett and G. F. Loughlin. H. G. Ferguson, F. C. Calkins, and D. F. Hewett have reviewed the manuscript critically. The petrography of the manganese in several specimens from drill cores was studied by Charles Milton. J. Axelrod made X-ray

examinations of two minerals, and K. J. Murata made a spectrographic analysis of a mineral specimen.

GEOLOGY OF THE MANGANESE DEPOSITS

Presque Isle area

General geology

The sedimentary deposits of the Presque Isle area (pl. 24) range in age from Ordovician to Upper Devonian. The sequence of the formations and their lithologic features are summarized in the stratigraphic table on the following page.

The thickness of the middle Silurian rocks as given in the stratigraphic table appears excessively large. The figures in the table represent measurements made in cross sections, without allowance for thickening or thinning by minor folding and faulting, and may be two or three times the true thickness. Exposures are not adequate, however, to serve as a basis for reliable correction factors. A second reason for the excessive apparent thickness may be the erroneous separation of different sedimentary facies of the same stratigraphic units. Specifically, it is possible that the rocks mapped as the lowest member of the Aroostook limestone actually are equivalent to the shales above the Aroostook. The succession of formations presented in the table is based on the simplest interpretation of the stratigraphy and structure in the light of what is known at the present time, but more detailed field work might show the need of revising this interpretation.

West and south of Presque Isle there is an igneous complex made up of many small, narrow, subparallel intrusive bodies of andesite, trachyte, and quartz trachyte porphyries. Most of the contacts between rock units trend north to northwest.

The sedimentary rocks are much folded and faulted (see structure sections, pl. 24) but the deformation is not

Sequence and character of the rocks in the Presque Isle area

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
		Slight unconformity	
Middle Silurian	Shale and slate.1/	Upper member blue and gray calcareous shale with limestone lenses; lower member greenish argillite with thin calcareous layers.	5,000±
	Aroostook limestone.	Upper member gray, nubbly argillaceous limestone; middle member ribbon limestone; lower member slate, partly calcareous.	18,000±
	Sandstone 2/..	Sandstone and conglomerate with a little slate and calcareous argillite.	5,000±
		Marked angular unconformity	
Middle Ordovician	Undifferentiated gray-blue calcareous siltstone, greenish argillite, black shale, and chert. Three fossil zones recognized.		Unknown

1/ 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).
2/ Sheridan sandstone of Williams and Gregory (Williams, H. S., and Gregory, H. E., op. cit.).

uniformly intense. Structural differences caused by differences in lithologic character can be recognized between the northern and southern parts of the Presque Isle area. South of the Aroostook River, where massive sandstones are involved in the deformation, the folds are open and plunge at low angles. The axis of a broad syncline trending north-south lies halfway between Mapleton and Presque Isle, and farther west are a narrow anticline and syncline of similar trend. These folds plunge to the south except in the area underlain by the

Mapleton sandstone, which lies unconformably upon the older rocks in a structural basin. North of the Aroostook River, and in eastern Castle Hill township south of the river, the rocks are dominantly argillites and thin-bedded limestones. The bedding dips steeply and folds are prevailingly small. Nearly isoclinal folds several hundred feet across were found at many places in the lower, argillaceous member of the Aroostook limestone between New Sweden and the Aroostook River, but such folds are difficult to identify except where their noses are exposed. Minor folds, less than 10 feet from crest to crest, are rare except in the middle Silurian ribbon limestone and the manganiferous shales. Large and small folds alike plunge steeply both to the north-northeast and south-southwest. Slaty cleavage is well developed in argillaceous rocks north of the village of State Road. It generally dips steeply to the west, and at most places its relation to bedding shows that the rocks lie on the east limb of an anticline.

Outcrops west of Mapleton and State Road indicate at least two large faults of northerly trend. Each of these faults has the older rocks on the west side, and both are probably reverse faults dipping steeply to the west. Minor faults of the same type were found at several places, but they could be traced for only a few tens or hundreds of feet.

Manganese deposits

Manganiferous rocks are found at three stratigraphic horizons in the middle Silurian series, one being in the greenish argillite immediately above the Aroostook limestone and two in the lower slate and calcareous slate member of the Aroostook limestone (see p. 129). The distribution of outcrops of manganiferous rocks is shown in plate 24. The manganese-bearing rocks are well bedded and locally contorted, and the deposits are elongate parallel to the regional and local strikes of bedding. The dips are consistently greater than 60° and prevailingly almost vertical. In the higher of the two manganiferous horizons of the Aroostook limestone and in the greenish argillites above that formation, the manganese is intimately associated with red hematitic shales. The lowermost manganiferous horizon is characterized by a heavy, dark green, thin-bedded chlorite-carbonate rock containing very little hematite.

The manganiferous rocks crop out only at scattered points. Failure of a given deposit to crop out for a long distance along the strike may be due to structural complication, to stratigraphic lensing, or to concealment by glacial cover, whose average thickness at various places in Aroostook County, except in swamps and gravel-covered areas, ranges from 2 to 8 feet.1/ The manganiferous shales generally crop out, however, in larger and higher exposures than the surrounding rocks, and they should therefore be exposed, if they are present, in areas where there are outcrops of other rocks. Where manganiferous rocks are not exposed but are not too deeply buried, the soil immediately overlying them has a characteristic dark olive-drab or purple color and contains abundant black-stained shale fragments. Because of such indications, and of the relative thinness of the glacial cover, it is possible to trace zones of manganiferous rocks at many places in cultivated areas where outcrops are few or wanting. It seems reasonable, on the whole, to attribute the apparent discontinuity of the zones only in small part to concealment by glacial cover, at least within areas now under cultivation above the valley floors. The discontinuity is probably due mainly to lensing and faulting. One deposit, 2 miles west of State Road, is clearly cut off by a fault at the south end, and many other deposits may be similarly interrupted. Most deposits

1/ Hurst, L. A., Knobel, E. W., and Hendrickson, B. M., Soil survey of the Aroostook area, Maine: U. S. Dept. Agr., Advance Sheets, Field operations of the Bur. of Soils, 1917, p. 19, published 1921.

show marked differences in thickness at different points along the strike (pl. 25), which suggests that they are lenslike. If the manganiferous zones were originally laid down as sedimentary layers that were continuous over large areas, the fact would probably be apparent despite glacial cover and structural complications; it is believed, therefore, that the manganiferous rocks were probably deposited as scattered small lenses.

Deposits associated with hematitic shale.--The hematitic shale is interbedded with red, gray-green, and green argillite. The stratigraphic zones containing hematitic shale are commonly 5 to 30 feet thick; their greatest observed thickness is about 150 feet (pl. 25). Such zones contain, on an average, 25 or 30 percent hematitic shale, and probably nowhere contain more than 50 percent. Individual beds of hematitic shale, separated by nonhematitic shale, range in thickness from a fraction of an inch to about 20 feet; their average thickness is 1 or 2 feet.

Diamond drilling on a deposit of hematitic shale at the M. S. Dudley farm in Castle Hill township has made it possible to study the mineral composition of this type of deposit with the aid of unoxidized material. Specimens collected from several drill cores were examined petrographically by Charles Milton, to whom the writer is indebted for identification of many of the minerals in the deposit. This laboratory study has been supplemented by detailed assay data of the Manganese Ore Co. and by petrographic examinations made by the writer on oxidized material collected before the drilling.

The rocks are typically made up of thin layers ranging in thickness from a fraction of a millimeter to about 25 centimeters. The average grain size is about 0.02 millimeter. Each layer contains an intimate mixture of two or more minerals, and the boundaries between individual grains are generally vague.

The manganese minerals known to occur below the zone of oxidation are braunite ($3(Mn,Fe)_2O_3 \cdot MnSiO_3$), bementite, and manganiferous carbonate. Some braunite has been positively identified, and the most abundant of the manganese minerals, which occurs in dense aggregates with iron oxide and calcitic carbonate in the heaviest hematitic layers, is believed to be braunite. Relatively pure braunite, identified by X-ray study, occurs locally in red shale, where it forms discontinuous layers a quarter to half an inch thick. The layers where interrupted have rounded ends, and they appear, when examined under the microscope, to cut across the bedding of the rock. The microscope also reveals that the cores of some masses of braunite consist partly of well-crystallized bementite. The braunite is dark brownish-black and rather lustrous. Only a negligible quantity of braunite occurs in this manner, but the Dudley farm deposit, to judge from its average manganese content and from visual estimates, contains 10 or 11 percent of what is believed to be braunite.

Bementite, which probably makes up 1 or 2 percent of the deposit, is mostly associated with carbonate in small pods or nodular masses and in cross-cutting veinlets. Many of the nodular masses contain collophanite. Bementite and some material that is probably bementite occur as disseminated particles and as irregular masses in some of the hematitic shale.

White to pink carbonate is an abundant constituent of the deposits of hematitic shale. It occurs both as a sedimentary constituent of the rocks, generally associated with iron oxide or chlorite, and as veinlets and stringers that cross the bedding. Some of the veinlets follow microfaults. There seems to be a wide range in the composition of the carbonate. Most of it is essentially calcite and effervesces with cold dilute HCl; much of it, however, gives a bead test for manganese, and some of it has the pink color and the optical properties of a carbonate close to rhodochrosite. It is estimated that possibly 2 percent of the manganese in the Dudley farm deposit is present as carbonate, and that about 25 percent of the deposit is carbonate.

About 27 percent of the manganiferous zone at the Dudley farm deposit is Fe_2O_3. The red color of the rocks indicates that a large part of the iron occurs as hematite, but a little limonite is visible under the microscope. The iron oxide is a major constituent of some of the heaviest layers, and more or less of it is present in all the layers.

Apart from the carbonate, the principal nonmetallic minerals of the deposit are the silicates chlorite and sericite. Chlorite is intimately mixed with the other minerals in the hematitic beds. The interbedded red and green shales consist largely of sericite and chlorite and contain scattered grains of detrital quartz. A few heavy dark-green beds, mostly at the west side of the deposit, consist mainly of chlorite and slightly manganiferous carbonate. Biotite is present in a few places. Collophanite (hydrous calcium phosphate, $Ca_3P_2O_8.H_2O$) is found with carbonate and bementite in irregular areas and nodules, and the sludge and core from one drill hole were found to contain, on the average, 0.67 percent of phosphorus. Barite forms the inner part of the rounded bleb of greenish carbonate in a specimen of red shale.

A layer of volcanic ash 1 to 2 inches thick was noted at the Dudley farm in one drill core and in two trenches on the surface. Should this ash prove to belong to a single continuous layer in the deposit, it would serve as an excellent reference plane for detailed stratigraphic and structural studies. It consists, according to Charles Milton,[2/] mainly of crystals of sodic plagioclase in a matrix of what is probably montmorillonite, derived from fragments of glass. Strongly pleo-

2/ Personal communication.

chroic biotite and stubby prisms of apatite are abundant, and small fragments of slightly altered rhyolite can also be identified.

The manganiferous rocks and adjacent strata are strongly oxidized at the surface. The rocks are coated and partly replaced along bedding planes and joints by extremely fine grained black manganese oxide. Shales that are largely composed of hematite are not noticeably replaced; in them the manganese oxide forms mere films, readily scraped off, on relatively fresh rock. Rocks, however, that contain abundant carbonate, chlorite, or sericite are partly replaced to distances of 1 to 3 millimeters from cracks in the rock. Oxides are particularly noticeable along fractures that follow carbonate veinlets. Fissile shales with closely spaced partings appear megascopically to be almost completely replaced, but it is apparent from analyses of surface rocks that, even if all the manganese is calculated as MnO_2, manganese oxide only locally forms more than 40 percent of the rock. In thin sections the incompleteness of the replacement is evident. Within the black-stained areas along cracks there are small islands of unreplaced rock; quartz, in particular, is hardly anywhere corroded. The extent to which the braunite is oxidized is not known.

Although most of the statements in the preceding paragraphs are based solely on observations made at the Dudley farm deposit, this deposit is believed to be typical, qualitatively, of all the bodies of manganiferous hematitic shale in the Presque Isle area. There are probably differences in the relative proportions of certain lithologic types and mineral constituents, but in general the rocks exposed at the surface are similar at all the deposits.

Deposits associated with chlorite-carbonate rock.--The lowest manganiferous strata, which are in the Aroostook limestone, differ primarily from the others in being almost free from hematite. The individual manganiferous zones range in thickness from 5 to 50 feet and average about 15 feet. In a field 1.4 miles N. 26° E. of Perham there are three manganiferous zones, separated by gray sericitic phyllite, within a stratigraphic interval of 140 feet, but here the aggregate thickness of the manganiferous rocks is only 55 feet. At this and a few other places it is difficult to determine whether two or more closely parallel streaks of manganiferous rock, separated by phyllite, represent different beds or a single bed repeated by folding or faulting.

The manganiferous rocks are made up of alternating light and dark green layers, and are noticeably heavier and harder than the typical shales of the area. The layers range in thickness from a fraction of a millimeter to about 10 centimeters.

The lighter-green layers are largely composed of a very fine grained, greenish, calcitic carbonate, which effervesces with warm dilute HCl and generally gives a bead test for manganese and iron. The darker layers consist largely of chlorite with small quantities of carbonate and 5 to 10 percent of quartz. The carbonate apparently makes up 15 to 30 percent of the individual manganiferous zones. In several specimens of shale chlorite is oriented parallel to the axial planes of small folds. Three or four hematitic layers a few millimeters thick were found at two deposits.

The rocks are stained at the surface with black manganese oxide, but in general the stain is not so dark as in the hematitic shales. There are fewer cracks and closely spaced bedding planes than in the hematitic shales, and consequently the amount of replacement by manganese oxide is less. The rock is partly replaced for as much as 3 millimeters from cracks in the carbonate layers but generally for not more than a millimeter in the chloritic layers.

Houlton area

General geology

In the Houlton area (pl. 26) geologic mapping was limited to the immediate vicinity of localities at which manganiferous rocks have been reported. The rocks in the small areas mapped are mostly green and gray phyllites and quartzitic phyllites, probably of Silurian age. Black graptolitic slate of Ordovician age was found at three places, but its relation to the Silurian rocks was not established. The manganiferous rocks are everywhere interbedded with gray phyllite, and at Westford Hill they occur a short distance stratigraphically below a thick series of quartzitic phyllite beds.

The structure is complex, and its character is perhaps most graphically illustrated by the detailed map of Westford Hill and vicinity (pl. 28), an area of better than average exposure. In this area the major folds strike northwestward, plunge steeply to the east or southeast, and are slightly overturned toward the southwest. Most of the dips recorded are to the northeast and steeper than 70°. These folds are cut by a set of faults, which strike north to northwest and seem to be reverse faults dipping steeply eastward. Along a later northeast-trending tear fault, of unknown dip, the north side seems to have moved relatively eastward about 1,200 feet. All the rocks have a well-developed fracture cleavage, which is generally vertical and strikes north to northeast. At many places the cleavage crosses the axial planes of major and minor folds at a high angle, and it is therefore believed to be younger than the folding.

The structure in other parts of the Houlton area is probably of the same type as that in the vicinity of Westford Hill.

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In the east-central part of the Houlton area, the distribution of outcrops suggests that a single bed of phyllite containing manganiferous rock extends from the Canadian border almost to Westford Hill. The folds mapped in this belt (pl. 26) are largely inferred, and the boundary lines of the belt have been drawn in such a way as to include over a hundred small outcrops of manganiferous rocks and no large areas of nonmanganiferous rocks. The strike of the bedding at most places here is slightly east of north. The outcrop areas mapped are largely on hills, and the lower parts of the valleys contain few, if any, exposures.

Manganese deposits

The manganiferous rocks of the Houlton area are interbedded with gray Silurian phyllite. The phyllite is not generally well stratified, and its total thickness in the Houlton area is not known, but the part of it that contains all the manganiferous strata is about 300 to 1,000 feet in thickness. Between the stratigraphic limits of the highest and lowest manganiferous beds there may be many manganiferous zones, separated from one another by zones of barren phyllite. Because of the irregular interbedding, however, the manganiferous zones must be defined arbitrarily. Beds of manganiferous rock without interbedded phyllite may locally be as much as 12 feet thick, but thicker stratigraphic units contain larger percentages of barren rock. One large outcrop on the south side of Westford Hill (pl. 27) reveals a manganiferous zone 35 feet thick containing about 35 percent of phyllite, which is stained with oxides. On the west end of a hill 2 miles northeast of Linneus, a manganiferous zone 53 feet thick is 55 percent phyllite, partly stained. On Henderson Hill, 3½ miles southeast of Houlton, a zone 107 feet thick contains about 65 percent of phyllite, mostly stained. Stratigraphic units over

300 feet thick probably nowhere contain more than 15 percent of manganiferous rock.

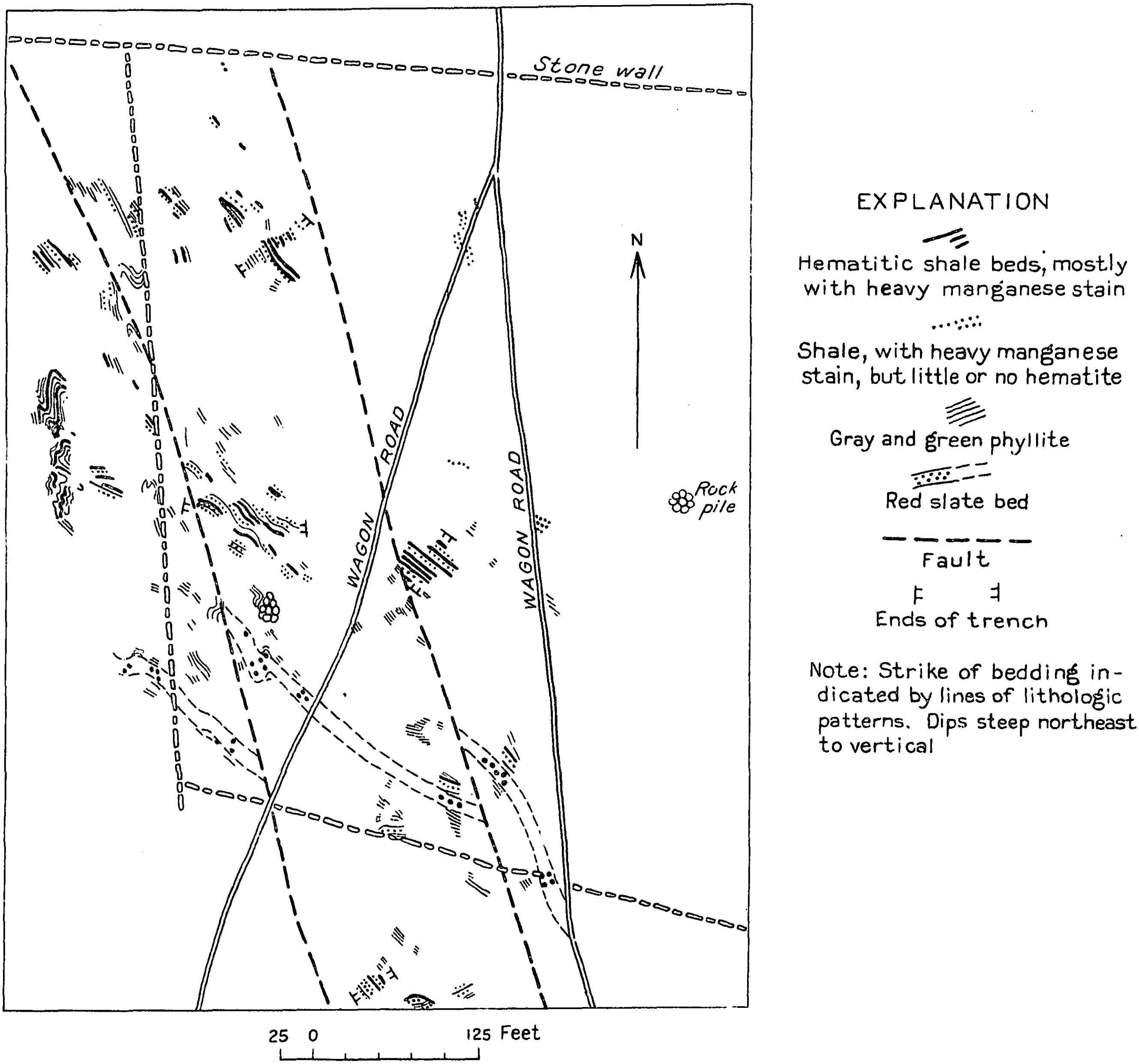
The manganiferous beds can be traced only for short distances along the strike, as may be seen in an outcrop map of an area with better than average exposures (see pl. 27). In general the exposures of bedrock are more extensive in the Houlton area than in the Presque Isle area, and if the manganiferous beds were continuous for distances of several hundred feet the fact should be readily apparent. The beds are much folded and faulted on a small scale, and the discontinuities along the strike are believed to be due in the main to faulting and folding, though some of them are probably due to stratigraphic lensing. Projection of bodies more than 50 feet along the strike from trenches or exposures is hazardous, and even where exposures are good few of the deposits can be traced for more than 250 feet along the strike. As the dip of the bedding and the plunge of the folds are generally steep, vertical discontinuity of the same order of magnitude as the horizontal can be expected.

The manganiferous rocks are typically made up of layers ranging in thickness from a fraction of a millimeter to about 30 centimeters. Each layer contains an intimate mixture of two or more minerals. The average grain size of different rocks ranges between 0.02 and 0.1 millimeter, but in places there are crystals of magnetite more than a millimeter across.

In the unoxidized rocks, manganese occurs as carbonate and as a mineral that is probably bementite. Possibly some manganese is present also in an opaque mineral such as braunite or hausmannite, but the metallic minerals were not studied in detail in polished secions or by chemical or X-ray methods. A specimen of manganiferous rock collected by G. F. Loughlin on Westford Hill was found by W. T. Schaller to contain magnetite and hematite, but apparently all the manganese was in rhodochrosite. Autoradiographs of two specimens collected by the writer from the Houlton area were made at the Massachusetts Institute of Technology under the direction of Dr. C. Goodman. The manganese, made radioactive in a cyclotron, appears white in prints made from a photographic plate exposed to the treated surface. All the manganese appears to be in those parts of the specimens that contain carbonate; areas occupied by sericite, chlorite, and opaque minerals are dark in the prints. It thus appears that a larger proportion of the manganese is present as carbonate in the rocks of the Houlton area than in the hematitic shales of the Presque Isle area.

White carbonate occurs in layers, nodules, and veinlets. The layers contain carbonate mixed with chlorite in different proportions, and some layers also contain sericite, quartz, and fine-grained disseminated magnetite. Nodules of manganiferous carbonate appear in thin section as round or oval patches up to 5 millimeters across, generally with sharp boundaries against the enclosing chlorite-sericite schist. Most of the nodules are pure carbonate, but the grain size in different nodules may be markedly different, even in the same specimen. In the nodules of one specimen, the carbonate has a radial-fibrous habit. The cores of manganiferous carbonate nodules in another specimen contained an unidentified black, opaque material, possibly secondary manganese oxide. An uncommon type of banded nodule seen in one thin section has a quartz rim surrounding a core composed of chlorite and rhombohedral crystals of carbonate. Carbonate veinlets, mostly less than a millimeter wide, are abundant in all the manganiferous rocks. Many are parallel to the banding of the rocks, but the majority are cross-cutting.

The carbonate is not uniform in composition. Some of it has refractive indices near those of rhodochrosite. Most of it effervesces weakly with cold dilute HCl but is shown by



OUTCROP MAP OF AREA ON SOUTH SIDE OF WESTFORD HILL

(LOCATION OF AREA SHOWN AT "A" ON PLATE 28)

many bead tests and the two autoradiographs mentioned above to be manganiferous. Without analyses of samples taken from manganiferous zones below the zone of oxidation, it is difficult to estimate either the average percentage of carbonate in the rock or the average manganese content of the carbonate. Allowing for enrichment in surface samples (see p. 144), and assuming that about 2 percent of the manganese is present in bementite and none in other minerals, the writer has estimated that the deposits contain, on the average, from 3 to 6 percent manganese as carbonate.

A mineral that is probably bementite is found in moderate quantity not only in some of the distinctly manganiferous rocks but locally in the interbedded phyllites. The mineral is reddish-brown in thin section, its birefringence is low, and its refractive indices are slightly below 1.65. It forms separate rounded grains up to 0.1 millimeter across, mostly scattered through chloritic layers, which may or may not contain sericite and specular hematite. In oxidized specimens the mineral is replaced by black opaque material, probably manganese oxide. How much of the supposed bementite there is in the manganiferous rock cannot be accurately estimated from a few thin sections of oxidized material, but there may be as much as 5 percent in some deposits.

It is estimated from the analyses of surface samples collected by Mr. Eckstorm that magnetite and specular hematite together make up, on the average, about 26 percent of the rock in the manganese deposits of the Houlton area. Both minerals occur more or less abundantly as fine-grained aggregates in certain layers, and crystals of magnetite are scattered through many of the chloritic and sericitic layers. There is probably more magnetite than hematite.

Chlorite and sericite are the principal nonmetallic minerals other than carbonate. They are abundant in the manganiferous strata and are the chief constituents of the interbedded phyllites. The chloritic and sericitic layers contain 10 or 15 percent of quartz. Hornblende was observed in one specimen of manganiferous rock, but no biotite was seen. Some outcrops contain a little pyrite. About 0.6 percent of phosphorus is present in the rocks, probably as apatite.

Secondary manganese oxides have the same mode of occurrence in the Houlton area as in the Presque Isle area, and they need not be further described. Locally there seems to be extensive replacement of phyllites by oxides; small fragments of phyllite are black to the core and appear on superficial inspection to be completely replaced, but under the microscope they generally show much unreplaced quartz, sericite, and chlorite.

ORIGIN OF THE MANGANESE DEPOSITS

The manganiferous rocks of Aroostook County were deposited as marine strata in middle Silurian time. The deposits at the Dudley farm and in Mapleton are closely associated with fossiliferous marine limestone and shale. Well-preserved graptolites were found in phyllite only a few feet from manganiferous beds on Westford Hill (pl. 28). The abundance of carbonate, the absence of coarse detrital material, and the regional distribution of the enclosing formations suggest that the beds were laid down as geosynclinal sediments at a considerable distance from shore. A lenticular bed of fossiliferous limestone conglomerate, about 200 feet stratigraphically above the Dudley farm deposit, was probably derived from the breaking up of a nearby reeflike structure and indicates that the sea was relatively shallow.

The manganiferous strata were probably deposited as discontinuous layers of irregular thickness. They are found at what appear to be three different stratigraphic positions in the Presque Isle area, but probably at only one in the Houlton area. It is not possible, on the basis of available evidence, to determine the extent to which individual deposits were laid down contemporaneously with one another.

The rocks of the region have been folded, faulted, and mildly metamorphosed, probably during late Devonian time. The chief differences in mineral composition between the manganiferous rocks in the Houlton and Presque Isle areas, notably the presence of magnetite and specular hematite near Houlton, can be attributed to a slightly higher grade of regional metamorphism in the Houlton area. All the manganiferous rocks are cut by numerous tiny veinlets, which are believed to have been formed, during the deformation of the rocks, by solution and redeposition of carbonate already present within the limits of the deposits. Vein quartz and pyrite are no more abundant in the manganiferous rocks than in the other lithologic units of the region.

The heavy stain of manganese oxides along joints and partings is clearly the result of relatively recent oxidation of the rocks, and appears to be related to the present water table. Within a few feet of the surface there has been a moderate enrichment of the deposits by addition of secondary manganese oxides, for at the Dudley farm deposit the average manganese content of the surface samples exceeds that of samples taken from depth to a far greater degree than would be expected to result solely from oxidation of manganiferous carbonates in place. In many places the enriched rocks lie below several feet of unoxidized till, and fragments of shale stained with manganese oxides can be found in till that appears quite fresh. It is probable, therefore, that a thin zone of leached rock has been stripped from the deposits by glacial action, and that most, if not all, of the enrichment took place before the last advance of the Pleistocene glaciers. On small cliffs in the Houlton area, where glacial plucking can be assumed to have removed more than the usual quantity of rock, the oxides are noticeably less abundant than elsewhere. This fact suggests that here both the zone of leaching and the underlying zone of enrichment were removed.

DEPTH OF OXIDATION AND ENRICHMENT

At the Dudley farm deposit, the only one from which drilling data are available, the decrease in the proportion of secondary oxide with depth is readily apparent. Above the water table, which is approximately 20 feet below the surface, there is abundant oxide along joints and bedding planes. The percentage of the total manganese that occurs as oxide probably ranges from about 90 in highly fractured and thin-bedded rocks to about 10 in the most massive rocks. The average for the whole zone above the water table is probably about 30 percent of the total manganese, but this estimate is based only on a brief examination of the drill cores and may be in error by as much as 10 percent manganese.

The average manganese content of the Dudley farm deposit as a whole is 76.4 percent of the average manganese content of surface samples taken within a few inches of the top of the bedrock; the surface samples, in other words, are 31 percent richer than the average. The depth to which this enrichment extends can only be estimated. Recovery of core in the upper few feet of drill holes was poor, and, as the zone is probably neither well defined nor uniformly thick, the depth of enrichment cannot readily be determined by inspection. Some evidence is supplied, however, by data from 13 drill holes that were begun within the assay walls of the deposit. The average manganese content of the whole deposit is 11.1 percent. The sludge and core above a depth of 7 feet [3] average 10.6 percent manganese. The average for depths of 7 to 14 feet is also 10.6 percent, and the average from 14 to 21 feet is 12.6 percent, or 1.5 percent greater than the average for the deposit. These figures suggest the possibility that there has been slight leaching in the upper part of the zone above the water table and slight enrichment in the lower. It is believed, however, that the variations are within the limits that can be attributed to the wide range in composition of the primary rocks. The averages are sufficient to show that the zone of enrichment is not thick enough to increase the grade of the upper 7 feet to any noteworthy degree.

No sharp line of demarcation was noted between the rocks above and below a depth of 20 feet, but very little manganese oxide was seen in drill cores from below this depth. Oxides are found to depths of at least 55 feet below the surface, but they are restricted to a very few fracture planes.

No data on the depth of oxidation and enrichment are available for other deposits. Certain generalizations may be made, however, from the evidence obtained at the Dudley farm and from the geologic history of the deposits. Secondary manganese oxides in about the same abundance as at the Dudley farm deposit can be expected down to the water table. The depth of the water table probably differs appreciably from place to place; in deposits near the tops of high hills—for example in those on Gelot and Capitol Hills in New Sweden and those in the Houlton area—the depth to water is almost certainly greater than in the Dudley farm deposit, which lies on a very gentle slope near the bottom of a valley.

The thickness of the zone of enrichment may be expected to differ in deposits with different topographic setting. Rocks

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3/ The holes were drilled at 45° to 40° from the horizontal, and samples taken from each 10 feet on the incline represent about 7 feet vertically.

exposed on high knobby hills, particularly on the south or plucked sides, have probably been more severely eroded by the Pleistocene glaciers than less-exposed deposits. If the surface enrichment of the manganiferous deposits preceded the last glacial advance, as seems probable, the enriched zone may well have been stripped from many deposits that were exposed to vigorous glacial erosion. The manganese content of surface samples from such deposits is probably more representative of the subsurface grade than are the surface samples from the Dudley farm. The writer saw no deposits that appeared to be less eroded than the one at the Dudley farm, but if such a deposit exists it might have a thicker zone of enrichment or might even be covered by a capping of leached rock.

RESERVES OF MANGANESE-BEARING ROCK

An estimate of the reserves at the larger deposits to the arbitrarily chosen depth of 10 feet is presented in table 5. The poor exposures and lack of subsurface data prevent the precise delimitation of the individual deposits. Some idea of their size may be gained, however, from the few natural exposures, and even more from the trenches dug under the auspices of the State. Where trenching has removed the overburden the exact width of most deposits can be measured, and at a few places the width can be determined rather closely without trenching. The length is more difficult to determine.

In giving estimates of reserves, the terms "indicated ore" and "inferred ore" are used in somewhat arbitrary senses. "Ore" signifies material that contains at least 7 percent manganese, although it is recognized that relatively small deposits of rock containing 7 percent manganese cannot at present be called "ore deposits" in the strict sense. Where two trenches are dug within a few hundred feet of each other and geologic conditions, such as uniform attitudes or

Table 5.--Estimated reserves at larger deposits to a depth of 10 feet

Deposit	"Indicated ore"					"Inferred ore"				
	Length (feet)	Average width (feet)	Tons	Surface grade (percent Mn)	Probable grade in depth (percent Mn)	Length (feet)	Average width (feet)	Tons	Surface grade (percent Mn)	Probable grade in depth (percent Mn)
Higgins farm.............	100	23	2,300	17.6	13	1,700	23	39,000	....	....
Dudley farm 1/...........	2,100	125	262,500	14.46	11.06	.....	...	....	....	....
Castle Hill Grange Hall..	800	30	24,000	9.2	7	500	30	15,000	....	....
	.....	...	....	.....	.....	700	40	28,000	....	....
Gelot Hill...............	900	105	94,500	8.7	8	400	42	16,800	12.2	10
Capitol Hill.............	100	40	4,000	12.9	11	.....	...	....	....	....
Perham, north of village.	1,200	32	38,400	7.6	6.5	1,200	30	36,000	....	6.5
Perham village...........	.....	...	....	.....	.....	600	40	24,000	....	6.5
Henderson Hill...........	450	115	51,800	7.7	6.5	1,200	131	157,000	7.9	6.5
Westford Hill............	400	35	14,000	10	8	.....	...	....	....	....
	150	95	14,200	7.5	7	.....	...	....	....	....
Daggett Hill.............	100	88	8,800	8.1	7	.....	...	....	....	....
Linneus township.........	200	30	6,000	7.5	7	.....	...	....	....	....

1/ Proved "ore" totals over 2,000,000 tons, to an average depth of 130 feet. The ore body undoubtedly extends deeper, and it may also be minable for a greater length along the strike. All data for this deposit were calculated from information supplied by A. E. Walker of the Manganese Ore Co.

manganiferous float, indicate that the manganiferous zone is continuous between them, the calculated tonnage of manganiferous rock is considered to be "indicated ore". Calculated tonnages based on projections of 50 feet from a single trench, or based on a short projection between a trench and a large outcrop are also called "indicated ore". Where the spacing of trenches is of the order of 1,000 feet and there is a possibility of structural or stratigraphic discontinuity or where projections have been made between one trench and float or small outcrops at some distance from it, the estimated tonnage is classed as "inferred ore".

The lack of subsurface data at all but one deposit makes it necessary to adopt an arbitrary means of representing the relative quantities of manganiferous rock present at the different deposits. Tonnages of indicated and inferred ore are calculated only to a depth of 10 feet below the overburden. Ten cubic feet of rock are assumed to weigh 1 ton. At most deposits, manganiferous rocks undoubtedly continue downward for many tens or hundreds of feet. The arbitrary depth of 10 feet has no relation to the zones of oxidation and enrichment at the different deposits; it is used solely as a convenient datum for tonnage estimates, without any implication that 10 feet is a limiting depth. The actual depth to which the manganiferous rocks might conceivably be mined at a given deposit might be greater or less than 10 feet, and would depend on the grade at depth, the method of mining, the chemical composition of the rocks, their structure, and possibly on other factors the effect of which cannot now be predicted.

The average manganese content of the surface rocks at various deposits, as presented in table 5, was calculated from trench samples collected by Mr. Eckstorm. Partial analyses of these samples are presented in table 6.

The trenches were not all dug at right angles to the strike of the rocks, chiefly because it was not everywhere possible to determine the strike beforehand. Some of the trenches, indeed, reveal folds and changes of strike. In determining the average grade for a trench, each analysis was weighted according to the thickness of the stratigraphic unit that it represented, and the weighted averages may differ materially from the numerical averages of the analyses in table 6. Where the trench was not at right angles to the strike, the total length of a sampling cut may exceed the width of the manganiferous zone at the place where the sample was taken.

Because of the enrichment in the upper parts of some deposits, the average percentage of manganese is likely to be greater in channel samples taken within a few inches of the top of the bedrock than in those taken at greater depth. In addition to the estimate of the grade at the surface, therefore, it seemed advisable that where possible a rough estimate of the probable grade at depth be given also for each deposit. These estimates, given in table 5, are based on consideration of the topographic position of each deposit and the amount of staining by secondary manganese oxides observed in the field.

It should be pointed out that the surface rocks at the Dudley farm deposit contain 11.4 percent manganese according to the State of Maine's sampling, and 14.46 according to the Manganese Ore Co.'s sampling. For essentially the same block of ground as is represented by the State's samples, the Manganese Ore Co.'s samples show an average manganese content of 14.17 percent. The samples were not taken at the same places, and the difference in the results might conceivably be due to any one of several geologic reasons. It seems more probable, however, that it is due to some difference in the method of sampling or of determining the manganese content. Until the reasons for the discrepancy are known, some doubt must attach to all the figures for manganese content in surface samples.

In summary, the probable reserves of manganiferous rocks can be roughly estimated from the data presented in table 5. There are many millions of tons of rock in depth that contain from 6.5 to 11 percent manganese, mostly in the form of carbonate and silicates. If the average depth of oxidation is over 20 feet, there may be over 1,700,000 tons of oxidized rock, also containing 6.5 to 11 percent manganese; but in this rock about 30 percent of the manganese may be in the form of secondary oxides. Lastly, if it is assumed that the average thickness of the zone of enrichment is 1 foot, there are about 85,000 tons of rock in which the maximum content of manganese is 17.6 percent and the average content about 9 percent. Over 50 percent of this manganese probably occurs as oxide.

ECONOMIC POSSIBILITIES OF THE DEPOSITS

The deposits of Aroostook County have, in the aggregate, so large a volume that they constitute a potentially important source of manganese. In a discussion of economic possibilities, the three categories of manganiferous rock noted in the summary statement of reserves should be treated separately.

The manganese in the zone of surface enrichment is more abundant and in a form more suitable for economic extraction than that in the lower parts of the deposits. The total tonnage of enriched ore, however, is probably too small to be worth mining by itself. The deposits are scattered over a large area, and probably not more than one or two of them contains enough ore to justify the construction of a mill. In addition, an overburden of glacial drift that averages about 4 feet in thickness would have to be removed.

Table 6.--Partial analyses of surface samples of manganiferous rocks of Aroostook County, Maine 1/

Locality	Percent Mn	Percent Fe	Percent P*	Percent S*	Percent insoluble†	Length of sample (feet)
Higgins	17.6	25.4	0.58	0.14	28.8	23.4
Dudley	‡ {10.6	24.0	....	....	32.2	60
	13.6}	22.4	0.82	0.03	32.0	65.7
	{8.5	23.7	....	....	36.6	72
	13.0}	18.8	....	....	35.8	37
	10.2	20.1	....	....	38.9	29.6
Castle Hill Grange Hall.	9.2	17.6	....	....	44.3	30.4
Gelot Hill	{8.4	27.3	....	....	29.3	16
	9.6	18.5	1.04	0.05	26.4	48
	8.9}	29.0	....	....	23.0	45
	12.2	26.2	....	....	26.8	42
	{8.7	21.8	....	....	32.5	45.5
	8.9}	28.6	....	....	23.2	55
Capitol Hill	{16.9	5.2	....	....	52.5	32
	12.1	18.8	....	....	39.2	48.8
	13.3}	20.7	....	....	33.3	14.5
Perham	7.6	13.0	....	....	44.3	33.6
	11.0	17.3	....	....	31.0	17.6
Ashland	14.2	15.3	....	....	34.2	72
Henderson Hill	{7.0	17.4	....	....	45.7	46.5
	16.5	18.2	....	....	42.1	23.5
	6.1	15.9	....	....	46.6	19
	7.8	20.5	....	....	38.3	43
	7.9	20.4	0.67	0.11	42.3	65
	6.3}	16.8	....	....	50.2	65
	{9.1	19.5	....	....	41.3	26
	8.6	19.6	....	....	42.0	50
	7.5}	19.4	....	....	40.6	24
Westford Hill	8.8	20.8	0.62	0.04	43.7	41
	10.3	25.4	....	....	33.4	80
	8.8	18.3	....	....	38.6	12
	{7.7	18.4	....	....	41.6	....
	7.3}	14.6	....	....	49.1	....
Linneus	7.0	30.7	....	....	23.6	44
	7.5	19.8	0.60	0.09	38.9	43
Daggett Hill	8.1	17.0	0.55	0.18	47.6	88

1/ Samples collected by Paul F. Eckstorm and analyzed by D. L. Guernsey at the Massachusetts Institute of Technology.

* Phosphorus and sulfur determined only where figures are given.

† Insoluble in concentrated hydrochloric acid.

‡ Figures joined by brackets represent samples taken from adjoining parts of the same trench.

The manganese-bearing material in the zone of oxidation, including the thin cover of enriched rock, is more promising. There are more than 500,000 tons of such material, averaging 11 percent manganese, at the Dudley farm deposit alone. Mill tests are now being conducted on carload samples of the ore, but no final statement of results is yet available. The Maine deposits of partly oxidized ore compare favorably in tonnage and grade with other low-grade manganese deposits in the United States, but considerable improvement in present methods of extraction may be necessary before these deposits can be utilized.

The Aroostook County deposits contain a tremendous tonnage of potential manganese ore below the zone of oxidation. Extraction of manganese from these rocks, however, is considerably more difficult than its extraction from the oxidized rocks. Whether it will be found practicable to mine the unoxidized manganiferous rock together with the oxidized will depend entirely on what new methods of recovery can be developed.

The abundance of iron oxide in the deposits suggests that they might be mined for manganiferous iron ore, as similar ores were mined at Woodstock, N. B., during the last century. The high silica and phosphorus content of the ore and the intimate mineral intergrowths are probably unsurmountable obstacles to the production of a smelting ore under present market conditions, but iron might form a valuable byproduct of manganese extraction. The rocks of the Houlton area contain magnetite and could easily be so treated as to produce a high-iron concentrate.

All of the larger deposits can readily be reached by roads, and none is more than 5 miles from a railroad siding.

FUTURE EXPLORATION

If the known deposits prove to be worth mining, additional ore deposits may be sought in two ways. First, the extent of the known deposits could be determined by trenching and drilling. Trenches should be put down to depths of at least 2 feet below the top of the bedrock, and a few test shafts would be advisable. Second, new deposits might be found along the projections of known deposits and within the stratigraphic zones known to contain manganiferous rocks. Geophysical methods could very profitably be used in this work. As the manganiferous rocks of the Houlton area contain magnetite, they can be detected with a dip needle.

DESCRIPTION OF DEPOSITS

Presque Isle area

Higgins farm (1)4/

Eighty feet south of the Bangor & Aroostook Railroad tracks and 1.35 miles N. 73° E. of the railroad bridge in Mapleton there were, in the summer of 1941, a trench and a small stripped area. The exposures revealed 23 feet of red manganiferous hematitic shale, bounded on the east and west by red and green argillites that lie, stratigraphically, not far above the Aroostook limestone. The bedding is vertical and strikes about N. 15° W. A sample across the manganiferous zone averaged 17.6 percent manganese, and some hand specimens of the rock show many thin bands of manganiferous carbonate. In the railroad cut northeast of the trench, a layer of manganiferous rock about 20 feet thick is exposed. Three more outcrops, all very small, were found between the trench and the highway 1,700 feet to the south. The outcrops are not alined parallel to the strike of the rocks or to one another, a fact which may be due either to structural displacement or to stratigraphic discontinuity.

The Manganese Ore Co. began to explore this deposit by drilling and trenching in the fall of 1942, but the develop-

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4/ Numbers in parentheses correspond to those designating localities in plates 24 and 26.

ment work had not progressed far enough at the time of the writer's visit to reveal any significant new facts.

Dudley farm (2)

The largest individual deposit of manganiferous shale in the Presque Isle area is on the Dudley farm, in Castle Hill township, 1.5 miles due west of the railroad bridge in Mapleton (pl. 25). The deposit trends nearly north-south in the southern part, but bends to about N. 30° E. in the northern part; the dip is 60° E. at the south end and steepens northward. The rocks belong to the lower part of the formation immediately overlying the Aroostook limestone.

Trenches dug by the State of Maine in 1941 and by the Manganese Ore Co. in 1942 show that for at least 2,200 feet along the strike the deposit is nowhere less than 100 feet wide. The average width for this distance is about 125 feet. The ore body tapers southward, apparently by lateral gradation into red shales, but it may continue northward for a considerable distance beyond the northernmost trench shown in plate 25. The trenching program was not completed at the time of the writer's visit. Information regarding vertical extent and grade has been obtained by diamond drilling. Holes were put down at 40° to 45° from the horizontal both eastward and westward from the midpoint of some of the trenches, and another hole at about the same angle was drilled from the east end of each of these trenches. Three test shafts, also, were sunk for the purpose of obtaining large samples down to a depth of 20 feet for mill tests. The exploration has shown the continuity of the manganiferous zone to depths of over 150 feet, with a probable average manganese content of 11 percent. There appears to be a body more than 2,000,000 tons of manganiferous shale more or less proved; but how much, if any, of this material can be mined commercially depends on the results of the metallurgical tests that are now being made.

Turner road (3)

On the west side of Turner road, in Castle Hill township, 3.2 miles N. 60° W. of the railroad bridge in Mapleton, there are several scattered outcrops of manganiferous hematitic shale that belongs to tne lowest member of the Aroostook limestone. The dip varies from steeply eastward to vertical. The manganiferous shales crop out at intervals for half a mile along a north-south line, but the average width of the zone is probably not more than 20 feet. No trenches were dug or samples taken at this locality.

Castle Hill Grange Hall (4)

In a small pasture a few hundred feet northwest of the Castle Hill Grange Hall and about 1.5 miles N. 70° W. of the railroad crossing at the village of State Road (Mapleton township), there are outcrops of manganiferous hematitic shale that belong to the lower member of the Aroostook limestone. The rocks strike northward and dip 80° W. to vertical. A trench about 500 feet N. 25° W. of the hall reveals about 30 feet of manganiferous rocks, containing on the average 9.2 percent manganese, which can be traced almost continuously for 800 feet in a field to the north and seem to maintain a fairly constant width. An outcrop still farther north along the strike suggests that the zone is cut off by a fault just north of the state road. A second band of manganiferous shales, which seems to be about 40 feet wide, lies 400 feet west of the first. It was not trenched or sampled, and detailed mapping failed to show whether it is a separate band or the first band repeated by faulting. It can be traced by a few scattered outcrops for about 700 feet.

Gelot Hill (5)

At the top of Gelot Hill, in New Sweden township, in an area extending about 900 feet north-northeast and 100 feet wide, the soil is dark and contains abundant float of hematitic shale. Two trenches dug across this area in 1941, after the writer had left the region, revealed a manganiferous zone with an average width of 105 feet and an average manganese content of 8.7 percent. The deposit may well continue farther north and south, but no estimate can be made of its extent.

Another trench 800 feet west-southwest of the top of the hill, in a similar stained area, revealed a zone 42 feet thick with an average manganese content of 12.2 percent. The zone, as traced by float, extends slightly east of north for at least 400 feet. Considerable shale is exposed between this zone and the top of the hill, but exposures are inadequate to determine whether there are two zones, or one zone repeated by folding or faulting.

Excellent exposures in the road 1,500 to 2,000 feet to the west and southwest reveal a few small hematitic bands, all less than 10 feet in width.

On Gelot Hill, and on Capitol Hill to the southwest, the distribution of outcrops suggests that the rocks are much faulted and folded, but the exposures are not sufficient for working out the structure. Adequate exploration of deposits on these hills would probably require trenching at smaller intervals than is necessary in other parts of the Presque Isle area.

Capitol Hill (6)

A long trench 4,000 feet N. 39° E. of New Sweden crosses a steeply pitching fold in 40 feet of hematitic shale and manganese-stained red slate. The average manganese content for 30 feet of this thickness is 12.9 percent. No other outcrops were seen in the immediate vicinity.

Manganiferous hematitic shale is exposed in road cuts 1,600 and 2,000 feet east of New Sweden, and in a field northeast of them. The manganiferous zone at these places is only a few feet thick.

At a point 350 feet east of the road and 0.65 mile south of New Sweden, a zone of red slate about 100 feet wide contains 5 to 10 feet of hematitic shale. Scattered outcrops of the zone were found for a quarter of a mile in both directions along a line trending N. 35° E. No trenches were dug, because very little manganiferous rock showed at the surface.

Deposit north of Perham (7)

Outcrops in a field, 400 feet east of a point on the dirt road 1.3 miles N. 26° E. of the railroad crossing in Perham, reveal a zone of manganiferous chlorite-carbonate rock 30 to 35 feet wide. The beds are crumpled, but in general they trend N. 25° E. and dip steeply east to vertical. This zone is flanked on each side by a narrower one. One of these, 12 feet wide, is separated from the middle zone by 15 to 20 feet of barren green phyllite; the other, 10 feet wide, is 60 to 75 feet from the middle zone. A sample taken across the middle zone contained 7.6 percent manganese. The zones can be traced by good outcrops for 1,200 feet along the strike, mostly to the south of an east-west farm road beside which the sample was taken.

At the top and on the south slope of the hill to the west a similar zone, about 30 feet wide, can be traced for about 1,200 feet by small outcrops. No trenches were dug or samples taken here.

Perham village (8)

A small opening 200 feet south of the store in the center of Perham partly reveals 40 to 50 feet of manganiferous chlorite-carbonate rock. The bedding strikes N. 15° E. and dips 60° NW. A sample taken across 17.5 feet of the richest rock contained 11.0 percent manganese, and the average for the whole zone is probably between 7 and 9 percent. Scattered outcrops suggest that the zone continues up the hill to the south for at least 600 feet and probably farther, but its width seems to decrease.

Frenchville (9)

Folded manganiferous hematitic shale and red shale crop out on a knob that is 0.9 mile N. 50° E. of Thornton School in Frenchville and about 8¼ miles due west of Mapleton. These rocks belong to the lower part of the Aroostook limestone and lie but a few hundred feet stratigraphically above the underlying sandstone formation. A long trench roughly parallel to the strike reveals about 20 feet of manganiferous rocks, which contain 14.2 percent manganese. The only other outcrop of manganiferous shale nearby is one about 5 feet wide in the middle of the state road 700 feet east-southeast of the knob.

Other deposits in the Presque Isle area

The Geological Survey party visited many deposits of manganiferous rocks exposed at other places in the Presque Isle area (pl. 24), but none of these deposits is equal to those described above in volume of ore exposed and probable manganese content, and they need not be described in detail. Further search for manganiferous rocks should be concentrated on the only two stratigraphic units known to contain them. Since most of the farmers in the region are aware of the possible value of the black-stained manganiferous rocks and are very helpful in imparting any information they may have regarding them, it is believed that all the important bodies and most of the minor occurrences in the cultivated areas have been mapped. Outcrops of sedimentary rocks are extremely rare and small in the adjoining wilderness. There, as one can see but a few yards ahead in the dense forest, search for outcrops would require many traverses spaced only a few feet apart, at a cost that seems unlikely to be repaid.

Houlton area

Henderson Hill (10)

The largest deposit of manganiferous rock in the Houlton area is on the west side of the top of Henderson Hill, 3,700 feet S. 60° E. of East Hodgdon and 4.13 miles N. 57° E. of the dam in Hodgdon village. The rocks have a fairly constant strike of about N. 15° E. and dip 80° E. to vertical. Individual bands of manganiferous rock appear to be more continuous at this locality than elsewhere in the Houlton area. The largest manganiferous zone, which has an average thickness of 115 feet, is exposed in two trenches 450 feet apart. A few small exposures in the woods between the trenches suggest that the zone is continuous. The average manganese content is 7.7 percent. A third trench, 1,200 feet to the south along the strike, exposes 130 feet of shale with an average content of 8.8 percent of manganese. Outcrops are inadequate to determine whether the body of manganiferous rock is continuous throughout the intervening 1,200 feet.

In a small patch of woods on the northeast side of the hill, near a public road, there is a small body 15 feet wide with an average manganese content of 8.3 percent. A few hundred feet still farther north, on the north edge of the patch of woods, another trench reveals a zone of about the same width, and according to the owner, Mr. Harry Thwaites, 9 feet of this zone contains about 18 percent manganese.

Westford Hill (11 and 12)

Trenches on the three largest outcrops in the Westford Hill area are shown in plate 27 (deposit 11, on the south side of Westford Hill). The average manganese content of the material exposed here is about 10 percent. This material forms bodies averaging 35 feet in width, but they are separated by faults and would have to be mined from three separate pits.

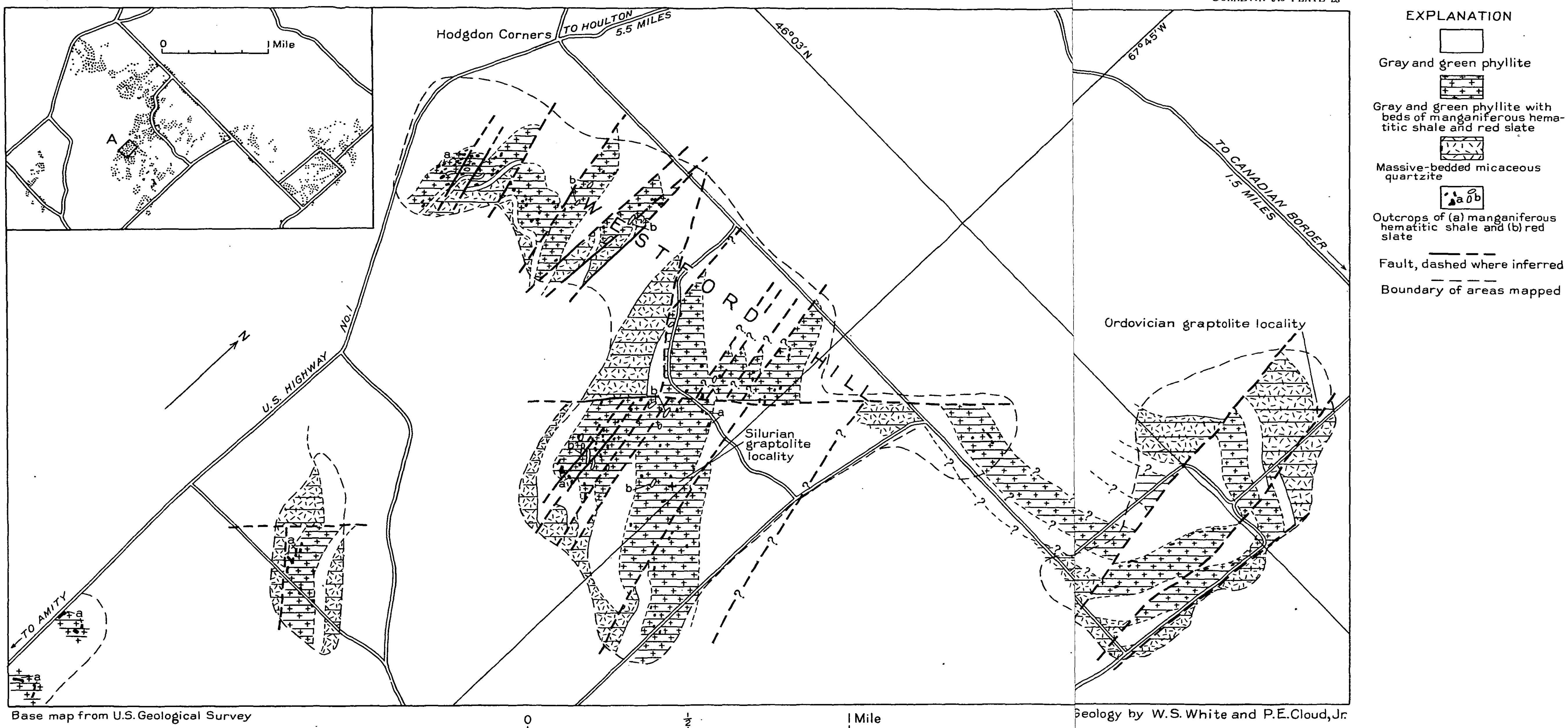
A small road-metal quarry at the base of the southwest corner of Westford Hill (deposit 12), 0.7 mile south of Hodgdon Corners, reveals about 95 feet of manganiferous rocks. Outcrops to the north suggest that that zone continues for at least 150 feet. The average manganese content is 7.5 percent. Scattered outcrops still farther north indicate that the width of the zone diminishes northward.

Daggett Hill (14)

Manganiferous rocks are exposed on a small knob 400 feet west of Route 1 and 2.32 miles S. 8° E. of Hodgdon Corners. A sample from a trench across the bedding, representing about 88 feet of strata, contained 8.13 percent manganese. A smaller sample representing 38 of this 88 feet contained 11.2 percent. The rocks are highly folded and may be repeated in the trench. As manganiferous rocks cannot be traced away from the knob, the deposit is probably small. West of the knob, in a road cut 70 feet long, 7 feet of manganiferous rocks are repeated several times by folding.

Linneus township (13)

The largest deposits seen in Linneus are on the west and southwest sides of the hill 2.2 miles N. 43° E. of the village.



Base map from U.S. Geological Survey

Geology by W. S. White and P. E. Cloud, Jr.

GEOLOGIC MAP OF WESTFORD HILL AREA, HODGDON, MAINE

("A" IN INSET MAP SHOWS LOCATION OF AREA SHOWN IN PLATE 27)

There are many outcrops of manganiferous rocks on the hill, but only one or two bodies of minable size. The largest is about 30 feet wide and has an average manganese content of 7.5 percent.

Other deposits in the Houlton area

In all, about 350 outcrops of manganiferous rocks were examined within the areas indicated in plate 26. At the great majority of these outcrops the manganiferous beds exposed were only a few feet thick and could be traced for only a short distance, and these showings are therefore neglected in calculating tonnages of manganiferous material. Many of them, however, lie near the larger deposits on Henderson and Westford Hills and on the hill in Linneus. Small ore bodies that lie near large deposits probably could be mined. At best, however, the cost of mining very small ore bodies must prove relatively high.

Township C, Range 2

A locality on a hill in Township C, Range 2, outside the area examined by the Geological Survey party, was visited by Mr. Eckstorm. Small samples collected by him had an average manganese content of 9.07 percent.