GEOLOGICAL SURVEY OF CANADA

PAPER 70-42

DEPARTMENT OF ENERGY, MINES AND RESOURCES

GEOLOGICAL NOTES ON AQUATUK RIVER MAP-AREA, ONTARIO WITH EMPHASIS ON THE PRECAMBRIAN ROCKS

(Report, 16 figures and 3 tables)

H. H. Bostock

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ABSTRACT

Archean granodiorite gneiss within a complex of granitic rocks are the oldest rocks in the area. Above these are rocks of Aphebian age – a siliceous carbonate unit disconformably overlain by a succession of iron-formation, greywacke and siltstone. Diabase and gabbro sills intrude the sedimentary rocks. Drift cover is widespread and extensive use was made of aeromagnetic data to extend geological observations. No economic mineral deposits were noted but there are indications of iron-formation and copper.

RÉSUMÉ

Les roches les plus anciennes de la région sont des gneiss granodioritiques de l'Archéen au sein d'un complexe de roches granitiques. Elles sont sous-jacentes à une unité de carbonate siliceux datant de l'Aphébien et recouverte en discordance par une succession de roches ferrifères, de grauwacke et de siltstone. Les roches sédimentaires sont pénétrées de filons-couches de diabase et de gabbro. La région est largement recouverte de drift et on a eu largement recours aux données aéromagnétiques pour compléter les observations géologiques. Aucun gîte minéral d'intérêt économique n'a été décelé, sauf certains indices de formations ferrifères et cuprifères.

GEOLOGICAL NOTES ON AQUATUK RIVER MAP-AREA, ONTARIO WITH EMPHASIS ON THE PRECAMBRIAN ROCKS

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Aquatuk River map-area lies between latitude 53°30' and 56°N and longitude 80°30' and 86°W and is bounded by Hudson Bay on the north, James Bay on the east, and approximately by Ekwan River on the south.

The area may be reached most conveniently by chartered aircraft from Moosonee, Ontario. Heavy or bulky freight can be shipped by sea to Winisk on Hudson Bay, or to Attawapiskat on James Bay south of the map-area; it can be flown to the abandoned landing field at Big Owl south of Cape Henrietta Maria; or it can be sledded by tractor train to any point along the coast during the winter.

Winisk, the largest Indian settlement in the map-area, is served by light aircraft from Moosonee, and Big Trout Lake. The village at Hawley Lake is frequently visited by light aircraft but has no regular service. Moosonee, some 250 miles south of the map-area at the southwest corner of James Bay, is the nearest rail head. Passenger trains, operated by the Ontario Northland Railway, reach Moosonee six times a week during the summer and three times a week during the winter.

No roads of consequence exist within the map-area. The larger streams are navigable by canoe but the smaller creeks tend to be obstructed by fallen trees and log jams. Extensive areas of muskeg and lakes, although hindering summer travel, facilitate operation of motorized toboggans during the winter. Tide range, which reaches about 11 feet at Winisk, but somewhat less farther east and south, combined with gently sloping boulder strewn shores, makes coastal reconnaissance by boat difficult.

GEOLOGICAL INVESTIGATIONS

Previous Work

The first geological exploration within the map-area was by Dowling (1905) who ascended the Ekwan River and reached Sutton Lake by way of Washagami River. He described 90 feet of iron-bearing sediments overlain by 150 feet of trap at Sutton Narrows which he believed to be of Cambrian age. He reported analyses indicating the magnetite-rich slates in the section contain as much as 68 per cent metallic iron. He compared these rocks to

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similar rocks occurring along the east coast of Hudson Bay previously described by A. P. Low (1903). Dowling collected fossils from the Silurian rocks outcropping along lower Ekwan River, and on Hawley Lake, and noted that his Indian guide had described "what seemed undoubtedly to be limestone" of similar character at Cape Henrietta Maria. He remarked on the unusual depth of Sutton and Hawley Lakes which he found to be up to 210 and 160 feet respectively. He noted that marine shells are present in surficial deposits 90 feet above lake level and surmised that only the tops of the neighbouring trap-covered hills had remained above sea level during the post-Pleistocene marine maximum.

McInnes (1909) descended Winisk River in 1903 after travelling northward by canoe from the Canadian Pacific Railway near Lake Superior. He noted that about 70 feet of Silurian limestones outcrop in the lower reaches of the Winisk and that these rocks in one place apparently lie unconformably on older limy quartzites and slates which he suggested might be correlated with Cambrian rocks described by Dowling (1905) at Sutton Lake.

Savage and Van Tuyle (1919) traversed the Winisk and Ekwan Rivers and collected fossils from the Paleozoic rocks. They named and described the Ekwan River and Severn River Formations which are exposed on these rivers and noted the absence of Ordovician rocks over the Precambrian inlier near Winisk. The latter feature they ascribed to post-Ordovician erosion rather than to nondeposition.

Hawley (1926) in the summer of 1924, explored the Precambrian rocks in the area immediately surrounding Sutton and Hawley Lakes for the Nipissing Mining Company. His purpose was to assess the area as a potential source of silver and iron ores. He was unable to find any silver-bearing minerals and believed the iron-rich strata to be too thin and scattered to be of value. Hawley described both the gabbro-diabase and the underlying sediments in detail. He discovered the dolomite which underlies the iron-formation and the chert breccia which separates them locally. He also suggested that these rocks might belong to the same series that outcrop on Belcher Islands and along the southeast coast of Hudson Bay.

In the interval between 1924 and the 1950s little work (in the area) appears to have been done. Subsequently, with the erection of the Mid-Canada line, a series of doppler stations was built across the map-area from Winisk on the west, to Big Owl on James Bay south of Cape Henrietta Maria, and Bear Island in James Bay. Although one of these sites (Wachi near Winisk) is situated on top of a diabase knob the existence of outcrop at the site appears to have remained unknown to geologists.

Sjörs (1961) visited Hawley Lake during the summer of 1957 under the auspices of the National Museum of Canada. Although concerned mainly with the character of vegetation of the area, Sjörs also made aerial observations of outcrops which he believed to be diabase, southeast of the area investigated by Hawley.

Nelson and Johnson (1966) synthesized available data pertaining to the Phanerozoic geology of the Hudson Bay region and included on their map some previously unpublished locations of Precambrian rocks southeast of Winisk and on Aquatuk River.

Hobson (1967) mapped Precambrian topography in Hudson and James Bays on the basis of a series of refraction seismic profiles. Within the map-area these sections lie roughly: (1) along Winisk River, (2) along the coast of James Bay, (3) southwest from Cape Henrietta Maria, and (4) along

Ekwan River. The data are of particular interest because they suggested some surprisingly great depths to seismic "basement" southwest of the Sutton Lake-Nowashe Lake belt of Precambrian outcrop. Depths reported by Hobson at inland stations however, appear in many cases to be too large (up to about 226 feet within the map-area). These errors arose because elevation control was not available in the James Bay and Hudson Bay Lowlands at the time of Hobson's survey, and the estimates of station elevation used in his survey appear to be systematically too low when compared with more recent data from the Surveys and Mapping Branch.

Present Work

Aquatuk River map-area was mapped as part of Operation Winisk, a helicopter-supported reconnaissance mapping project that covered the Hudson Bay Lowlands and adjacent Precambrian terrain. Work in Aquatuk River area started on July 5th and ended August 1st, 1967.

Members of the Geological Survey of Canada participating in Operation Winisk within the Aquatuk River area and their responsibilities are as follows: H. H. Bostock - Precambrian; L. M. Cumming - Ordovician; B. S. Norford - Silurian; B. V. Sanford and A. W. Norris (head of Operation)- Devonian; B. G. Craig and B. C. McDonald - Pleistocene.

The present paper is a final report on the Precambrian rocks of the Aquatuk River area and is intended to be complementary to final reports to be published on stratigraphy and paleontology of the Paleozoic rocks, and on the Pleistocene geology. A preliminary report on Operation Winisk is in Sanford, Norris and Bostock (1968).

Traversing in the area was carried out with the aid of two Bell 47G-4 helicopters. Low drift-covered areas were reconnoitered for outcrop by Cessna-180. Inflatable rubber boats were used on Hawley Lake and on major rivers.

TOPOGRAPHY AND DRAINAGE

Aquatuk River map-area lies at the northeast extremity of the Hudson Bay Lowlands and as in most parts of these lowlands the countryside is typically monotonously even, and most regions are poorly drained with numerous shallow lakes and widespread bogs. Overburden is probably thickest along the west margin of the map-area near and south of Winisk River. There the seismic refraction profiles of Hobson (1968) suggest a maximum thickness of about 350 feet. Elsewhere depth to bedrock appears to be mostly less than 250 feet.

The central part of the map-area is higher than the surrounding country and forms a broad rise some 100 miles long and 50 miles wide that is outlined roughly by the 400-foot contour. This rise lies astride the Cape Henrietta Maria Arch (Norris and Sanford, 1968), a broad subdued promontory that stretches inland from Cape Henrietta Maria to the southwest corner of the map-area. The major axis of the rise and its highest points, lie along Sutton Ridges, an imposing southwest-facing cuesta that crosses the Cape Henrietta Maria Arch at right angles in the vicinity of Sutton and Hawley Lakes. Lesser outcrop ridges between the branches of Aquatuk River, and southeast of Winisk, have had less influence on the form of the rise. Regional slopes (derived from 100-foot topographic contour spacing) reach 100 feet in 3 miles on the northeastern flank of the rise but are generally much less elsewhere.

The dominant topographic feature within the map-area is Sutton Ridges, which reaches a maximum elevation between 400 and 500 feet above the surrounding countryside (900 to 1,000 feet above sea level) 10 miles east of Sutton Lake. Within 10 to 15 miles on either side of Sutton and Hawley Lakes the hills commonly rise to between 700 and 800 feet above sea level.

Unconsolidated sediments of Quaternary age locally form minor topographic features that have been extensively wave-washed over all but the higher parts of the map-area. Where outcrops of Precambrian rocks lie close to such deposits they are commonly located at the points of prominent beach spits.

The main drainage pattern within the map-area is roughly controlled by the Cape Henrietta Maria Arch which forms an irregular northeast-southwest divide between streams flowing northward to Hudson Bay and those flowing eastward to James Bay. Most lakes in the area have little accompanying valley and many are shallow. Sutton and Hawley Lakes however, are marked exceptions to this generalization. Sutton Lake reaches a maximum depth of 210 feet (Dowling, 1905) and the valley which it occupies is continuous with the valley of Little Ekwan River to the south. The present drainage of the lakes however, is to the north, and the southward flowing Little Ekwan is obviously an underfit stream.

ACKNOWLEDGMENTS

The author is grateful to L. D. Ayres of Ontario Department of Mines who kindly read and criticized an early version of the aeromagnetic interpretation of the map-area. He also wishes to acknowledge data contributed by the laboratory staff of the Geological Survey of Canada as follows: Radiometric K/Ar age determinations – R. K. Wanless and R. D. Stevens; mineral identification by X-ray powder diffraction – M. Bonardi; carbonate analysis by X-ray powder diffraction – D. G. Fong; laboratory photography– F. J. Cooke.

GENERAL GEOLOGY

The oldest rocks exposed within the Aquatuk River area are of Archean age. These comprise gneisses of granodioritic composition (intruded by granite dykes) that lie within a complex of granitic rocks ranging from granite to granodiorite. The latter are mostly heterogeneous, several lithologies of different composition being present at most observation sites. Foliation is absent, weak, or developed in one phase only. Two granodiorites have been dated by the K-Ar biotite method at 2505 $\pm$ 65-70 m. y.

Proterozoic sedimentary rocks of probable Aphebian age on the crest and flanks of the Cape Henrietta Maria Arch are divided into two formations; the Nowashe Formation (2), a siliceous carbonate unit, disconformably overlain by the Sutton Ridges Formation (3), a unit composed chiefly of iron-formation, greywacke and siltstone. Chert breccia-conglomerate occurs in irregular bodies along the disconformity at Sutton Lake. These sedimentary rocks are intruded by diabase and gabbro sills also of Proterozoic age. Regional metamorphism is of very low grade in the Proterozoic rocks; dips are mostly low in the central and southern part of the map-area, but near Winisk River evidence derived from aeromagnetic anomalies and a single outcrop suggest that the rocks are folded.

ARCHEAN BASEMENT COMPLEX

Granitic Gneisses (1a)

Gneisses of granodioritic composition are exposed immediately north of Opinnagau Lake. They form a band some 4 miles wide that strikes N75^{o}E cutting across the belt of exposed Archean rocks (mostly composed of unit 1b) nearly at right angles.

As seen in outcrop these rocks weather buff-brown due in part to occasional exposure to forest fire. They are medium grained and greenish grey with a slight olive tinge on fresh surfaces. Schistosity and gneissosity are well developed, the latter comprising lenticular bands of varying composition up to 6 inches across.

A single specimen of gneiss examined in thin section is medium grained (2 mm), seriate, and composed principally of plagioclase (An_{30}) with abundant quartz and about 5 per cent microcline. Mafic minerals are biotite and chlorite. Small porphyroblastic patches of chlorite showing two remnant directions of cleavage are pseudomorphic after amphibole. Accessory apatite is present and several grains of an argillized mineral were noted. The mineral assemblage and texture of these gneisses indicates that they have been recrystallized under upper greenschist or lower almandine amphibolite facies conditions, but were apparently affected by later lower grade alteration.

One outcrop examined on the ground was found to be cut by a pair of parallel shear zones up to 18 inches wide striking N30^{o}E and dipping vertically. Peripheral drag structures indicating left lateral displacement are present. Medium-grained granitic dykes have been intruded and deformed along these shears. The gneisses are therefore older than at least some of the granitic rocks and are thought to be remnants of sedimentary rocks of Archean age. Observations from the air suggest that the gneisses are more extensively penetrated by granite than was evident on the ground.

Massive Granitic Rocks (1b)

Massive granitic rocks form the principal lithology underlying a broad subdued ridge that extends from the headwaters of Swan River northwest to a point some 10 miles southeast of Sutton Ridges. They lie on either side of the band of Archean gneiss (1a) that crosses this ridge nearly at right angles.

This unit comprises a complex of rocks ranging from granite to quartz diorite, quartz monzonite and granodiorite being much the most abundant. At ground observation sites the rocks are medium to fine grained and heterogeneous, several lithologies, commonly without recognizable cross

TABLE OF FORMATIONS

EON	ERA	PERIOD OR EPOCH	FORMATION OR GROUP	LITHOLOGY	MAXIMUM THICKNESS
Phanerozoic	Cenozoic	Pleistocene and Recent		peat, silt, gravel, sand, clay, till	up to (350')
			Unconformity		
		Middle Silurian	Attawapiskat unit 9 Ekwan River unit 8 Severn River unit 7 (may include some Redhead Rapids)	limestone and dolomite limestone and dolomite limestone and dolomite	100'+ (171') (169')
			Unconformity		
		Upper Ordovician	Churchill River Group unit 6 Bad Cache Rapids Group unit 5	limestone (dolomitic limestone basal sandstone)	(290') (140')
			Unconformity		
Proterozoic	Aphebian		unit 4	diabase-gabbro	300'
				Intrusive Contact	
			Sutton ~~Ranges~~ Ridges Formation unit 3	4) Jaspilitic and slaty iron-formation; minor conglomerate and greywacke 3) Jaspilitic and slaty iron-formation with interbedded minnesotaite chert, some riebeckitic iron-formation and minor interbedded siderite, minor conglomerate 2) greywacke, siltstone argillite; minor conglomerate 1) chert breccia-conglomerate quartzite; minor slate	~60' ≈ 35' ~230' ~ 85'
				Unconformity	
			Nowashe Formation unit 2	dolomite, cherty dolomite, stromatolitic dolomite, some siliceous calcareous argillite, limestone and dolomitic limestone	~250'
			Unconformity		
Archean			unit 1	granodiorite, quartz monzonite, some granite and quartz diorite gneiss	

Note: Thickness contained by brackets are derived from seismic investigations (Hobson, 1968) or from wells drilled outside the area mapped (Norris and Stanford, 1968); other thicknesses are estimates from outcrop.

PAPER 70-42 ERRATUM

In the Table of Formations, page 6, the term 'Sutton Ranges Formation' appears. This should read 'Sutton Ridges Formation'.

cutting relations, being present. Patches of one lithology approaching outcrop size are common and contacts are difficult to project, or to visualize in three dimensions. Some patches of slightly biotite-rich rock appear to constitute dykes whereas others are inclusions in a less mafic granitic host. Although medium-grained dykes of granite or quartz monzonite were observed, pegmatite appears to be rare. Foliation is absent, poorly developed, or present in one lithological component only. Weathered rock surfaces are white to buff or red stained.

Under the microscope the major constituents of the rocks are plagioclase (An_{4-30}), microcline showing grid twins, and quartz. Microcline is commonly more abundant than plagioclase in quartz monzonite and some rocks may therefore approach granite in composition. Traces of microcline are present in one specimen of quartz diorite examined. Minor constituents are chlorite, biotite, carbonate, amphibole (x – pale ochre, y– brownish green, z – blue-green),epidote, and muscovite in order of decreasing abundance. Accessory minerals are apatite, magnetite, zircon, hematite, sphene and leucoxene also in order of decreasing abundance. A mineral of low birefringence and refringence, possibly a zeolite, was observed in one thin section from the southeast end of the exposure of the granitic rocks.

Alteration of the granitic rocks is suggested by the appearance of chlorite at the expense of amphibole and biotite, and by the presence of epidote and carbonate. The latter mineral is present in amounts up to several per cent in 4 of 6 specimens examined.

The minimum age of the granitic rocks (determined by the K-Ar biotite method on two granodiorites from central and southeastern exposures of massive granitic rocks) is 2505 ± 65 m.y. corresponding to that of the Kenoran Orogeny, and is typical of ages determined in the Cat Lake Belt (Stockwell *et al.*, 1970) west of the Paleozoic cover.

PROTEROZOIC ROCKS

Proterozoic sedimentary and basic igneous rocks are exposed in a discontinuous southeast trending belt extending from Winisk River through Nowashe Lake to James Bay. From the west shore of James Bay they probably continue northeasterly to Bear Island and may be present on Sunday Island. Similar and obviously related rocks outcrop near Aquatuk River some 27 miles north-northeast of Sutton Lake. Proterozoic rocks as a whole are best exposed along Sutton Ridges in the vicinity of Sutton Lake although some lithologies can only be examined elsewhere.

The Proterozoic rocks are divided into three map-units which in general terms comprise a lower carbonate unit (2), an upper unit composed chiefly of greywacke, siltstone and iron-formation (3), and a unit composed of basic sills (4) intrusive into these rocks. Units 2 and 3 are distinct sedimentary facies across the crest and flanks of the Cape Henrietta Maria Arch, that are separated from exposed rocks of similar age by extensive tracts of sea and younger deposits. It is likely furthermore, that all the major exposures of these rocks, limited though they may be, are known. Formal names are therefore proposed, the Nowashe Formation for unit 2 and the Sutton Ridges Formation for unit 3, recognizing however, that these formations may be subject to revision when drilling is eventually undertaken.

Nowashe Formation

The Nowashe Formation (unit 2) is most extensively exposed immediately west of Nowashe Lake after which it is named. No specific type section is proposed in view of the limited extent of continuous outcrop and the difficulty in making close correlation between widely separated outcrops. It is likely however that the most complete section to be obtained from surface exposure may be pieced together through more detailed examination of the exposures at Nowashe Lake.

The Nowashe Formation is also exposed along the southwest-facing front of Sutton Ridges west of Sutton and Hawley Lakes, near Aquatuk River some 27 miles northeast of Hawley Lake, and in a small inlier on Winisk River. Similar (i.e. carbonate) rocks are reported by Burns (1952) on Sunday Island in northern James Bay.

The base of the Nowashe Formation is not exposed and the thickness is therefore unknown. The top of the formation however is exposed at Sutton Ridges where it is overlain disconformably by chert breccia-conglomerate of the succeeding Sutton Ridges Formation (3).

Description of Exposures

Nowashe Lake: The Nowashe Formation is intermittently exposed over an area of about 2 square miles on either side of a large pond immediately west of Nowashe Lake. East of the pond five feet of fine-grained, buff weathering, pinkish dolomite in beds up to 18 inches thick with cherty to argillaceous partings form a small sinuous bluff projecting above the muskeg. West of the pond, grey to buff weathering, fine-grained, grey dolomite is widely but poorly exposed. Beds examined are up to one foot thick but more commonly are 4 to 6 inches. Stromatolites are present locally (see Fig. 1E), and patches of blue-grey chert form up to about 20 per cent of some beds. A stromatolite collected from a small bluff near the middle of the outcrop area is identified by H. J. Hofmann as cf. *Paniscollenia Korolyuk* (SH-V type of Logan *et al.*, 1964). Bedding strikes from N40°E to N50°E and dips gently northwestward at angles up to 12 degrees. The section represented, including rocks exposed on both sides of the pond, is estimated at 250 feet or more.

Sutton Ridges: The Nowashe Formation is known at two places along the southwest-facing front of Sutton Ridge; at Birch Hill, a prominent rounded butte-like hill lying in front of the main cuesta 10 miles northwest of Sutton Lake, and again about 1 mile northwest of the lake.

At Birch Hill Hawley (1926) reports only 5 feet of dolomite exposed, however he observed that the overlying chert breccia is very thin and forms a mantle that cuts obliquely across the dolomite section. During the present work, only one foot of buff weathering, very fine grained, massive, dark grey dolomite was found to be clearly in place, but this lies amid the trees some distance down slope from the top of the chert breccia. As there is reason to believe (discussed later) that the upper surface of the dolomite at Birch Hill lies immediately below the chert breccia even at the highest exposures of the latter, the thickness of dolomite beds may be interpreted to be close to 60 feet or more at this locality.

About one mile northwest of the northwest extremity of Sutton Lake the Nowashe Formation forms a southward-facing cuesta about 25 feet high.

There at least 35 feet of buff weathering, fine-grained, grey to brown, cherty, laminated to massive dolomite strikes north 75 degrees west and dips gently northward at about 4 degrees. Beds in the dolomite range from laminae to one foot thick, and are typically separated by thin lenticular cherty bands that are commonly patchy. Chert is most abundant near the top of the bluff, and is concentrated in long narrow lenses up to 4 or 5 inches thick on the uppermost exposed bedding surface. These lenses occupy troughs of similar depth that plunge nearly directly down dip. Clusters of rosette-like cherty concretions with delicate grey and white banding are present in these troughs (see Fig. 1A-F), and are described by H. J. Hofmann as, "unidentifiable small siliceous concretionary masses, possibly stromatolites". Stromatolitic beds are most common near the top of the cuesta bluff (see Fig. 1A). Many stromatolites form isolated heads of circular plan (see Fig. 1C and D), but some are compound (see Fig. 1B). One specimen collected from this locality is identified by H. J. Hofmann as, Stratifera sp., with small bodies Nucleella sp. (LLH-S type of Logan et al., 1964). Stylolites are reported to be sparingly present on a few horizons (Hawley, 1926).

Aquatuk River: The Nowashe Formation is poorly exposed amid the trees near Aquatuk River about 27 miles northeast of Hawley Lake. Fine-grained, grey-white, limy dolomite with 3/4 inch lenticular argillaceous laminae is present in frost heaved fragments directly underlying frost heaved iron-bearing rocks of the Sutton Ridges Formation. A few feet stratigraphically below this occurrence is about 30 feet of intermittently exposed interbedded limestone and siliceous dolomite. Beds are commonly one half to one inch thick with limestone weathering grey in base relief, and dolomite weathering buff brown. The rocks strike north 40 degrees east and dip southeast at 10 degrees.

Winisk River: The Nowashe Formation is exposed in a small inlier on the southeast bank of Winisk River 18 miles above Winisk. The lowest 20 feet of section present are best exposed and lie on a point projecting into the river (see Fig. 2). These consist of interbedded fine- to medium-grained dolomite, siliceous dolomite, and siliceous to limy argillite in beds up to 19 inches but mostly 2 to 4 inches thick. Some beds are nodular (see Fig. 3). Similar rocks, directly overlying those on the shore are less well exposed and lie inland. These comprise an additional section of between 16 and 30 feet and were described by McInnes (1906) as more calcareous than those along the shore.

The section is folded forming at least two anticlines with axial planes dipping southward and crestal lines plunging gently westward. Steepest dips are 48 and 55 degrees on the north-facing limbs. The rocks are thoroughly indurated in contrast to the overlying Paleozoic rocks exposed nearby. Quartz-calcite veins were reported by McInnes (1909).

Sunday Island: Sunday Island, a small island lying in the central northern part of James Bay 67 miles nearly due east of the mouth of Lakitusaki River, was not visited during Operation Winisk, but is described by C. A. Burns (1952) who visited it during a cruise into northern Hudson Bay under the leadership of T. H. Manning. It is important because the rocks exposed there suggest correlation of the Nowashe Formation with rocks exposed farther to the northeast along the east coast of Hudson Bay.

Figure 1. Stromatolites in the Nowashe Formation.

Figure 1A. Cherty dolomite, stromatolitic near the top, one mile northwest of Sutton Lake. (GSC 138233)

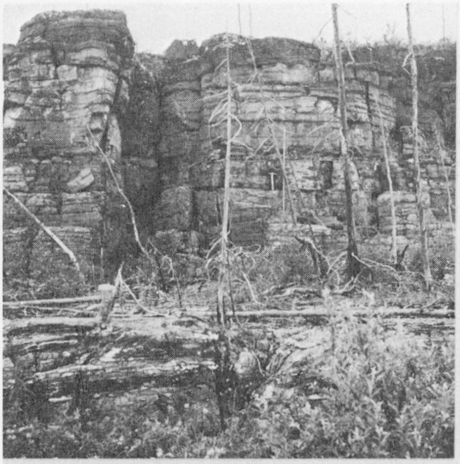
Figure 1B. Hemispherical stromatolite with small satellitic heads from the same locality. (GSC 138234)

Figure 1C. Discoid stromatolite in section, from the same locality. (GSC 138246)

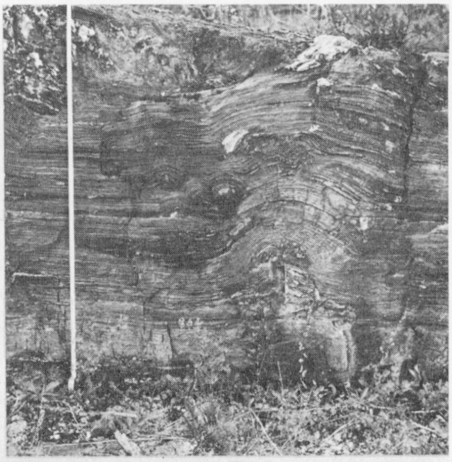
Figure 1D. Discoid stromatolites in plan showing circular to ovoid outlines, from the same locality. (GSC 138247)

Figure 1E. Plan view of stromatolites from unit 3 near Nowashe Lake. (GSC 138216)

Figure 1F. Chert concretions, possibly stromatolites, from a bedding plane trough at the upper limit of exposure of unit 3 one mile northwest of Sutton Lake. (GSC 138243)



A



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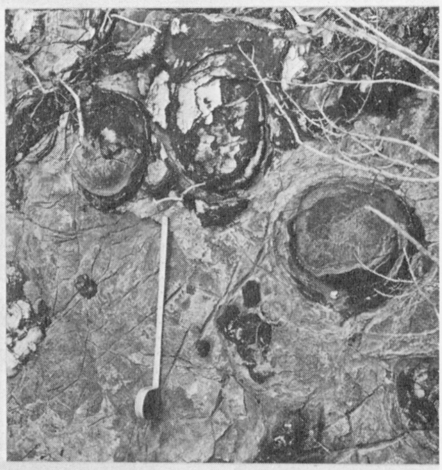

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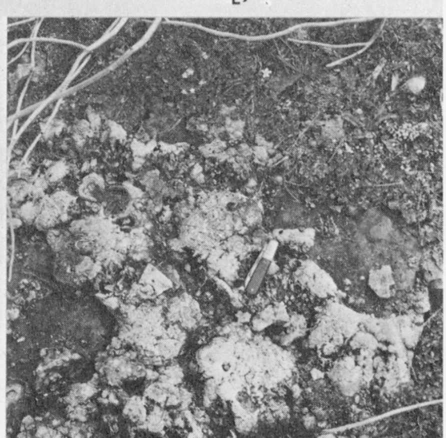

F

Figure 2. View looking eastward at folding in interbedded dolomite and argillite of the Nowashe Formation on Winisk River (GSC 138222, 138223).

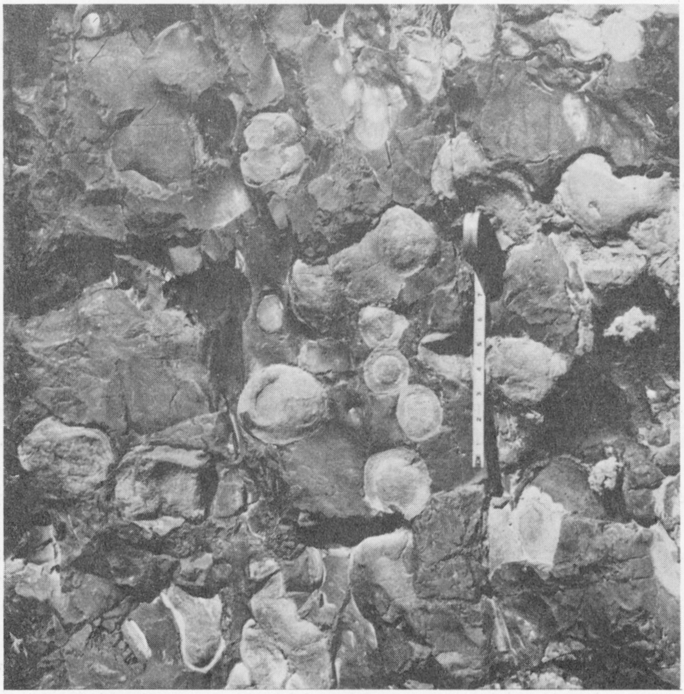

Figure 3. Plan view of light buff dolomite nodules in grey-green argillite of the Nowashe Formation on Winisk River. (GSC 138224)

Burns (1952) reports:

"Sunday Island, which lies 15 to 20 miles east of Bear Island, is about 1/2 mile long from north to south, and 1/4 mile wide from east to west. Sedimentary strata dip gently north, forming small scarps facing southwards. The rocks comprise thin-bedded, blue weathering limestone; buff, sandy limestone; and an underlying buff weathering, ripple-marked limy sandstone. Some of the limestone beds contain algal-like structures, which are concentric in plan. These forms have been observed at Long Island, Hudson Bay, and in many places in Proterozoic-type rocks on the Canadian Precambrian Shield.

"The attitude and lithology of these rocks suggest that they form a part of the Proterozoic series of rocks that fringe the south and southeast shores of Hudson Bay. Glacial polishing, striae, and grooves are prominent. The grooves strike south 25 degrees east."

Microscopic Descriptions

One specimen of siliceous dolomite from near the top of a dolomite bluff about one mile northwest of Sutton Lake was examined in thin section. It is composed of laminae of dolomite of varying grain size up to 0.6 mm but mostly less than 0.2 mm. Quartz in grains up to 0.25 mm is concentrated in some laminae. These grains consist of single quartz crystals, of quartz with radiating extinction patterns, and of very fine grained quartz. Dolomite crystals adjacent to quartz are commonly somewhat larger than more remote crystals in the same bed. A few thin quartz fracture fillings intersect dolomite laminae at large angles.

Two specimens representing nodular dolomite and dolomitic argillite from near the base of exposure of Winisk River were examined in thin section. The dolomite consists of anhedral transparent to translucent dolomite crystals up to 0.5 mm but mostly 0.2 mm in diameter. Irregular lenses of very fine grained material of low birefringence are present locally within the nodular dolomite and scattered pyrite crystals are present along one of its contacts with dolomitic argillite. A little chlorite and steel-grey opaque mineral (probably magnetite) is present along fractures which penetrate dolomite and terminate in minor folds or flow structures along the dolomite-argillite contacts. Argillite adjacent to nodular dolomite consists of very fine grained material of low birefringence containing scattered carbonate subhedra about 0.25 mm in length. Rare angular silt particles of quartz or feldspar are present.

Specimens representing the major exposures of the Nowashe Formation were subjected to carbonate analysis by X-ray diffractometer. The data obtained are shown in Table 1.

Alteration of rocks of unit 2 consists principally of recrystalization of carbonate, however at the Winisk River outcrop chlorite and magnetite (?) have formed in microscopic fractures in dolomite, and quartz-calcite veins are reported (McInnes, 1909). Other features that might be attributable to regional metamorphism have not been recognized.

Sutton Ridges Formation

The Sutton Ridges Formation is named after Sutton Ridges where all the known members of the formation are exposed; and the Sutton Ridges section is designated the type section. The complete section is not present at one outcrop but can be pieced together from exposures at Sutton Lake and immediately to the west.

The Sutton Ridges Formation at Sutton Ridges is divided into 4 members that comprise in general terms from the base of the section upward: (1) chert breccia, quartzite; (2) greywacke, siltstone, argillite; (3) minnesotaite-bearing jaspilitic iron-formation; (4) jaspilitic iron-formation. Near Aquatuk River only the upper 3 members are recognized. In the southeastern part of the map-area near Nowashe Lake, minor quartzite overlain by a much thickened section of greywacke and siltstone (member 2) is exposed; and farther east near James Bay iron-bearing siltstone and overlying siderite-bearing, riebeckitic iron-formation are thought to represent a transition between members 2 and 3. The proposed correlation of members 1 and 4 throughout the map-area is shown in Figure 4.

TABLE 1

Carbonate analyses of specimens from map-unit 3
(analyst D.G. Fong)

Locality	Lithology	dol:cal	Impurity
Nowashe Lake	buff weathering grey dolomite	100:00	3 per cent quartz
Sutton Lake	buff weathering grey dolomite	100:00	tr. quartz
Aquatuk River	grey-white limy dolomite	53:47	nil
	buff weathering siliceous dolomite	95:5	25 per cent quartz
	grey weathering grey limestone	5:95	5 per cent quartz
Winisk River	grey-buff weathering grey, finely crystalline dolomite	100:0	tr. quartz
	buff weathering, pink, finely crystalline dolomite	100:0	tr. quartz
	buff weathering, light grey, very finely crystalline, siliceous dolomite (interlaminated grey argillite excluded)	dol. calc tr. siderite	20 per cent quartz
	greenish grey, siliceous, calcareous argillite	1:5 tr. siderite	quartz predominates
	greenish grey, siliceous argillite (surrounds dolomite nodule)	2:1 tr. siderite	unknowns predominate
	dolomite nodule	95:5	tr. quartz

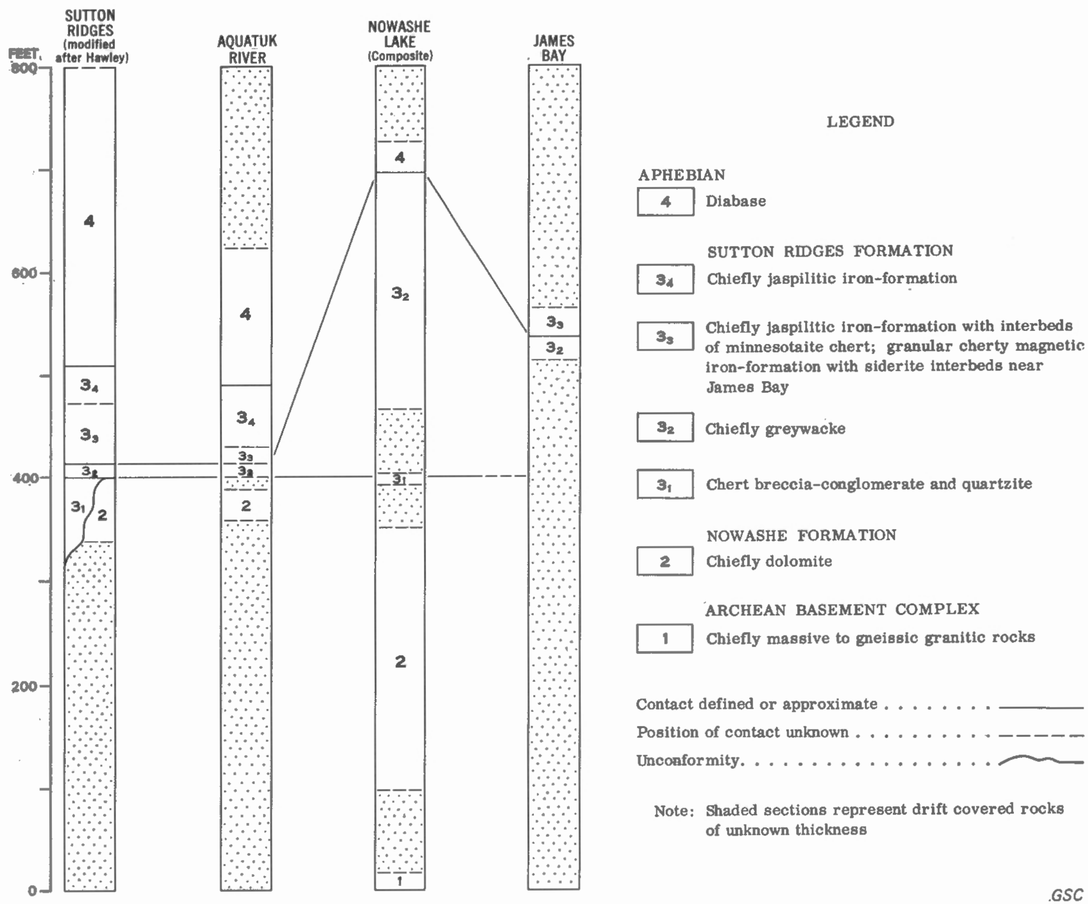

Figure 4. Stratigraphic sections showing correlation of some Precambrian rock units.

The Sutton Ridges Formation disconformably overlies the Nowashe Formation (2) at Birch Hill (Sutton Ridges) and is disconformably overlain by Paleozoic rocks at Hawley Lake. Although the true thickness is in doubt because of emplacement of the diabase and uncertainty regarding the relationship between rocks above and below the diabase, the section below the diabase (excluding the discontinuous chert breccia member) does not greatly exceed 110 feet. Near Nowashe Lake however, the greywacke-siltstone member is estimated to be 230 feet or more thick. The thickness of individual members and of the formation as a whole therefore varies from place to place.

Chert Breccia - Quartzite member

Chert breccia and some chert conglomerate, which directly overlie the Nowashe Formation, are exposed only at Sutton Ridges. These rocks form discontinuous bodies that truncate bedding in the underlying siliceous dolomite. They are overlain by thin slates or quartzite succeeded by greywacke. Chert breccia is exposed northeast of North Washagami Lake, at Birch Hill, and at the far southeast end of Sutton Ridges. Clean quartzite lenses occur within the chert breccia at several localities, and a few feet of similar quartzite lie on top of the breccia at the southeast end of Sutton Ridges. Similar quartzite in an isolated outcrop near Nowashe Lake appears to lie stratigraphically beneath greywacke and siltstone.

Description of Exposures

North Washagami Lake: Near North Washagami Lake a small rounded bluff and some adjacent outcrop of chert breccia are present. Pink, buff, cream-coloured, grey and greenish brown chert fragments mostly less than 3 inches in diameter form about 15 per cent of the rock. Some chert fragments are laminated and many have alteration halos about one quarter inch thick in which the chert is bleached. Chert fragments are enclosed in a sandy matrix and some patches of clean quartzite are present. With the exception of the overlying diabase sill no other beds appear to be exposed in the immediate vicinity of this breccia. If the body is nearly flat lying it is at least 17 feet thick.

Birch Hill: At Birch Hill 10 miles northwest of Sutton Lake, chert breccia-conglomerate consists chiefly of dark grey to light creamy grey or translucent fragments, pebbles, and cobbles of chert up to about 1 foot across that are commonly better rounded than the fragments in the North Washagami breccia. A few angular fragments of laminated grey-green chert and some of chert breccia were observed. Reddish alteration rims are present about some fragments. No evidence of sorting by size was observed. The matrix consists of tough grey-green chert or argillaceous material containing variable proportions of sand grains.

The chert breccia at Birch Hill was described by Hawley (1926, p. 18) as an irregular discontinuous cap up to 5 feet thick on dolomite (Nowashe Formation) beds which it truncated at low angles. This observation appears to be substantiated because, although the contact exposures seen by Hawley were not observed during the present work, a joint face penetrating the breccia was found to show an area of horizontally bedded dolomite that may be a projection from the dolomite floor. If so the disposition of the breccia, conglomerate between the uppermost and lowermost dolomite exposure suggests that the breccia-conglomerate cap truncates about 40 feet of dolomite section.

Sutton Ridges, southeast: At the southeast end of Sutton Ridges the chert breccia was examined on a steep boulder-strewn, southwest-facing hillside (see Fig. 5). There, chert fragments contained are mostly angular and chiefly similar in lithology to those at Birch Hill. The matrix is light grey and distinctly sandy. About 50 feet above the base of exposure there is a bed or lense of white weathering, medium-grained quartzite 7 feet thick in the breccia. In the next 28 feet above, the breccia appears more variable, lense-like bodies of grey-green to grey slate are present, chert fragments are commonly smaller, and the matrix is locally purple-brown to grey-green. About 8 feet of light pink-buff to light green quartzite overlie the breccia and dip about 5 degrees easterly, but the contact was not observed. If the chert breccia body forms a layer parallel to these overlying beds its thickness may be estimated at close to 85 feet or more.

Nowashe Lake: Near Patchepawapoka River about 7 miles northwest of Nowashe Lake a low isolated outcrop area underlain by medium-grained, slightly brown-weathering, light greenish quartzite is present. A few roughly ovoid patches of creamy white chert up to 3 inches in diameter were observed in the quartzite. Bedding although not directly evident is strongly suggested by coarse regular jointing that dips eastward at about 6 degrees. On the assumption that these joints do represent bedding roughly 7 feet of section are exposed. The strikes and dips here and in the greywacke-siltstone section exposed 1 1/2 miles to the northeast are such as to suggest that the quartzite underlies the greywacke.

Microscopic Descriptions

Two specimens of chert breccia, one from Birch Hill and one from the southeast end of Sutton Ridges, were examined in thin section. The Birch Hill specimen consists of angular dark grey to light grey chert fragments in a dull grey siliceous matrix. Under the microscope chert fragments are seen to be massive, brecciated or vaguely banded, banding being due to concentrations of green chlorite in patches up to 0.75 mm diameter. Similar material forms the matrix except that very fine grained opaque particles and numerous rounded quartz grains up to 0.75 mm diameter are present. The specimen from the southeast end of Sutton Ridges was taken from reddish brown breccia near the top of the exposure. It consists of angular light grey to white chert fragments up to one inch in diameter in a fine-grained reddish brown matrix containing smaller chert fragments and clear rounded quartz grains (see Fig. 10F). Under the microscope some chert fragments show concentric laminae of slightly varying silica grain size. Some fragments have fractures containing chlorite. Scattered quartz grains are rounded and up to 0.7 mm but mostly 0.4 mm and less. The cement is in large part hematite, the remainder being fine-grained silica.

Figure 5. Large, weathered, joint blocks of chert breccia (Sutton Ridges Formation) at the south-east end of Sutton Ridges. Rocks on ridges along skyline are diabase. (GSC 138250)

A specimen of quartzite from near Nowashe Lake examined in thin section consists of 95 per cent quartz grains commonly 0.6 mm in diameter with 3 per cent microcline and 2 per cent chlorite, minor plagioclase and accessory zircon and tourmaline. Rounded outlines, visible in both quartz and microcline grains within the crystal mosaic, demonstrate secondary growth of these minerals (see Fig. 10E).

Greywacke - Siltstone member

Greywacke, typically slightly calcareous and locally with abundant hematite cement, is present in all regions of exposed Proterozoic rocks except that near James Bay where similar but finer grained iron-rich detrital rocks are present. Greywacke overlies a few feet of grey to green slate and argillite near Sutton Lake and at Birch Hill but elsewhere may lie directly on dolomite (2), on chert breccia, or on quartzite. It is overlain by jaspilites bearing interbedded minnesotaite cherts at Sutton Ridges and Aquatuk River; near Nowashe Lake a thick greywacke-siltstone section is capped directly by diabase. Near James Bay iron-rich siltstone thought to be equivalent to greywacke is succeeded by riebeckitic granular iron-formation bearing thin siderite interbeds.

Description of Exposures

Sutton Ridges: At Birch Hill about 15 feet of poorly exposed medium-grained, laminated, olive green greywacke is separated from chert breccia by a short covered interval (occupied by 6 feet of thin bedded slate, Hawley, 1926). Farther southeast, one mile from Sutton Lake, about 2 feet of buff to grey weathering light green greywacke (see Fig. 6) with faintly outlined minor crossbedding overlie 5 feet of buff-cream weathering, cherty to sandy grey argillite near the base of map-unit 3.

In a section 1 1/2 miles west of Sutton Lake Hawley (1926) recorded 20 feet of "interbedded dark grey quartzites and red to grey siliceous limestone in thin beds with small amounts of iron oxides; and thin bedded green slates" below jaspilites. In a section at the southeast end of Sutton Ridges he reports 5 feet of "hard dark grey quartzite with a small percentage of magnetite" also below jaspilites. It seems probable that these rocks belong to the same greywacke sub-unit exposed at Birch Hill.

Aquatuk River: Near Aquatuk River, 27 miles north-northeast of Hawley Lake, the Sutton Ridges Formation is exposed along the concave northwest-facing side of an arcuate diabase-capped cuesta-like ridge. Frost heaved fragments of olive green to reddish weathering laminated greywacke containing disseminated magnetite were observed directly above the uppermost exposure of the Nowashe Formation (2) beneath the central-northern part of the ridge. Several feet of olive brown-weathering magnetite-bearing greywacke with interlaminated argillite was observed in an isolated outcrop at the lowest exposure seen beneath the west-central part of the ridge. Beds strike north 85 degrees west and dip 17 degrees south.

Nowashe Lake: North of Patchepawapoka River about 8 miles northwest of Nowashe Lake, and 1 1/2 miles northeast of a quartzite outcrop, an extensive but intermittent exposure of grey, green, or purple, commonly buff-weathering, greywacke and purple-brown argillite-siltstone is present beneath diabase. The greywacke appears most abundant in the upper half of the section. Two thin beds of chert-pebble conglomerate containing grey and reddish chert pebbles up to 3 inches in diameter were observed near the base and near the middle of the exposure respectively. Beds of greywacke and siltstone are mostly 1 foot or more thick. The rocks dip up to 10 degrees northeastward and about 230 feet of section are represented.

About 1 1/2 miles northeast of Nowashe Lake red-brown to purple siltstone with a few lenses of greywacke about one inch thick is exposed at its contact with diabase. Beds appear to dip 5 to 10 degrees northwestward but probably they have been disturbed during emplacement of the diabase. Only a few feet of section are represented. Similar rocks with a strong slaty cleavage striking N18°W and dipping 27 degrees to the east parallel to bedding form scattered exposures on low ground about 4 miles northeast of Nowashe Lake. Diabase dykes up to 1 foot thick are intruded parallel to cleavage.

James Bay: Southeast of Nowashe Creek and about 12 miles from James Bay purple-brown hematitic argillite and siltstone with scattered bands of slaty iron-formation about 2 inches thick are exposed intermittently over an area about 5 miles by 2 miles (see Fig. 7). Contacts between slaty iron-formation siltstone are gradational where they were observed. The rocks dip up to 10 degrees northeast but are exposed on a gently northeastward sloping hillside so that as little as 15 or 20 feet of section only may be represented. Neither upper nor lower contacts were observed.

Figure 6. Greywacke (Sutton Ridges Formation) one mile northwest of Sutton Lake. (GSC 138232)

Figure 7. Purple-brown hematitic argillite with scattered bands of slaty iron-formation (Sutton Ridges Formation) near James Bay. (GSC 138217)

Bear Island: Bear Island lies in James Bay about 56 miles due east of the mouth of Lakitusaki River and about 65 miles northeast of the James Bay exposures of siltstone within the map-area. The island was not visited during Operation Winisk but the rocks exposed there are described by Burns (1952).

Burns reports:

"Bedrock comprises nearly flat-lying sedimentary strata, which locally have dips of 15 to 30 degrees and northeasterly strikes. These sedimentary rocks are green weathering, thinly bedded argillaceous quartzite, slightly iron-stained greenish greywacke, and thinly bedded intercalations of limy sandstone. At least three southerly striking faults were identified".

Microscopic Descriptions

Greywacke from all major occurrences was examined in thin section. Minerals present and their approximate percentages based on 500 point counts are given in Table 2. The classification of sandstones adopted by Krumbein and Sloss (1956) has been applied to sub-unit 2 of this report, however no special terminology has been applied to rocks with appreciable carbonate or iron content that do not fit strictly within this classification.

TABLE 2

Modal analyses of greywacke from member 2

	Birch Hill	Sutton Lake	Aquatuk River	Nowashe Lake 1	Nowashe Lake 2	Nowashe Lake 3
Quartz	59	49	36	57	51	49
Microcline	16	04	09	09	08	09
Plagioclase	10	03	01	02	tr	05
Chlorite and sericite*	13	30	tr	23	12	23
Carbonate	01	08	--	01	14	06
Iron oxides	01	06	54	03	13	06
Chert fragments	--	tr	tr	05	02	02
Apatite	tr	--	tr	tr	tr	tr
Zircon	tr	tr	--	tr	tr	tr
Tourmaline	--	tr	--	--	tr	--

* Fine-grained minerals in matric resembling chlorite and sericite in thin section.

The greywackes are typically medium grained with both rounded and angular grains (see Fig. 10C); however grain size in the specimens from Sutton Lake and Aquatuk River is slightly coarser (about 0.5 mm in diameter) than that in the specimens from the Nowashe Lake area (0.3 mm). Plagioclase was determined by extinction angle and all grains examined are either albite or oligoclase. Carbonate from the Birch Hill specimen is calcite (determined by X-ray). The matrix consists chiefly of chlorite-sericite-like material, hematite, limonite, and carbonate in varying proportions in different places. It varies from very fine to medium grained with carbonate in particular tending to be recrystallized in patches surrounding several grains of quartz or feldspar (see Fig. 10C).

A greywacke lense in siltstone northeast of Nowashe Lake is similar to greywacke elsewhere except that flakes of intergrown chlorite and muscovite are present and several usually delicate, angular quartz grains were observed. Purple-brown, iron-bearing siltstone from near James Bay consists of quartz, chlorite, plagioclase, microcline and biotite in order of decreasing abundance in a matrix of very fine grained hematite-silica. Individual clasts are up to 0.1 mm in diameter. Mud-ball-like agglomerations of silt grains up to 0.15 mm in diameter and a few fragments of fine-grained hematite-rich material up to 1.7 mm were observed.

Minnesotaite-bearing Jaspilitic Iron-Formation Member

Red to dull grey or mottled jaspilite, and cherty to blue-grey slaty iron-formation with interbeds of dull greenish grey minnesotaite-bearing chert (member) overlie greywacke at Sutton Ridges and near Aquatuk River. Minnesotaite-bearing chert beds are commonly one foot or less thick, but they may be closely spaced or isolated. They are overlain by similar iron-formation in which minnesotaite-chert beds were not recognized and steel blue magnetite-bearing slates appear to be more abundant. The upper contact of the minnesotaite-bearing jaspilitic iron-formation member is therefore not precisely known and it may be intergradational with the succeeding member. The minnesotaite-bearing member is not exposed in the Nowashe Lake region but it is thought to be represented by interbedded riebeckitic and magnetite-rich granular siliceous iron-formation with a few siderite interbeds, which overlie iron-bearing siltstone near James Bay.

Description of Exposures

Sutton Ridges: At Birch Hill the minnesotaite-bearing jaspilitic iron-formation member consists of 10 feet of dull grey cherty to slaty iron-formation overlain by 20 feet of grey-green minnesotaite-bearing chert in beds up to one foot thick separated by slaty partings. A few widely scattered anhedral crystals of pyrite (pyritohedra) up to 1 cm in diameter were observed in the latter beds. These rocks directly overlie greywacke (member 2) and are succeeded by about 20 feet of iron-formation in which no minnesotaite chert was recognized.

At the foot of the main ridge one mile southeast of Birch Hill a six-inch bed of reddish weathering, grey granular minnesotaite chert was found about 30 feet above the base of the exposed section. Scattered outcrops

Figure 8. Tilted and deformed minnesotaite-bearing iron-formation (Sutton Ridges Formation) in unusually thick laminated beds along the west-facing ridge near Aquatuk River. (GSC 138264)

of red and grey-green mottled jaspilite including some steel grey slaty iron-formation were found below the minnesotaite-bearing rock. About 23 feet of similar section in which no minnesotaite chert was recognized, lie above the latter rocks and below diabase.

One mile northwest of Sutton Lake an isolated exposure of grey minnesotaite chert about one foot thick was found roughly 10 feet above the base of the exposed section (i. e. approximately 10-15 feet above the base of unit 3). A further 16 feet of iron-formation in which no minnesotaite chert was recognized, is intermittently exposed beneath diabase.

The minnesotaite-bearing jaspilitic iron-formation member probably occurs in the basal part of the jaspilitic section 2 miles west of the south end of Hawley Lake (see Hawley, 1926) and may be present near the southeast end of Sutton Ridges where Hawley reports 5 feet of dark red jaspilite and magnetic slate overlying 5 feet of dark grey quartzite.

Aquatuk River: Jaspilite with a few beds of grey minnesotaite chert up to 6 inches thick is exposed sporadically on the flats beneath the west central part of the diabase-capped ridge near Aquatuk River. The member appears to be about 15 or more feet thick at this locality but the lower contact was not found. It is overlain by bright red and grey jaspilitic iron-formation with some blue grey slate in which no minnesotaite chert beds were recognized. The rocks dip about 5 degrees southward beneath the diabase.

Along the west base of the north-central part of the ridge about 45feet of grey to reddish, fine-grained iron-formation with magnetite-rich laminae is coarsely jointed parallel to bedding (see Fig. 8). The rocks dip 30 to 35 degrees southeastward beneath diabase and a pronounced slaty cleavage is developed close to the contact. Although all the rocks at this exposure appear to have been altered as a result of emplacement of the diabase, they are considered part of the minnesotaite-bearing jaspilitic iron-formation member because minnesotaite was identified (by X-ray) in beds remote from the diabase contact and tremolite in those adjacent to it.

About 2 miles farther north an isolated outcrop on the east side of the ridge comprising 20 feet of section was visited. There 15 feet of jaspilite in beds up to 16'inches thick are overlain by 5 feet of alternating chert and slate in beds up to 10 inches thick. The section dips 52 degrees westward and has a pronounced slaty cleavage dipping 85 degrees westward. The presence of tremolite and garnet (identified by X-ray), insofar as they may reflect the break down of Mg-Fe carbonate and possibly minnesotaite by contact metamorphism, suggest that these rocks belong to the minnesotaite-bearing jaspilitic iron-formation member.

James Bay:- Bright blue riebeckitic and grey granular cherty iron-formation with lenses and laminae of steel grey magnetic slate, and a few interbeds of brown weathering siderite overlie red-brown iron-bearing siltstone at the northwest corner of a large outcrop area near James Bay. Riebeckitic and cherty iron-formation form beds up to about 2 feet thick and commonly have gradational contacts. Sideritic beds including chert and magnetite laminae reach 18 inches in thickness. At least 30 feet or more of section are intermittently exposed but neither upper nor lower contacts were seen. Because these rocks appear to overlie siltstone similar to some greywacke in the greywacke member and contain carbonate interbedded with granular iron-formation, they are thought to be related to the minnesotaite-bearing jaspilitic iron-formation member elsewhere.

Microscopic Descriptions

Minnesotaite cherts that occur in the lower part of the iron-formation section overlying the greywacke member, were found to consist chiefly of very fine grained intergrowths of quartz and acicular to subacicular minnesotaite (identified by X-ray - see Fig. 9C, E, F). Magnetite is present in some specimens and dolomitic ankerite (identified by X-ray) was found in a specimen from near Aquatuk River. Some specimens are granular with granules reaching as much as 2.0 mm in diameter; others show ovoids and breccia fragments, visible only in thin section, vaguely outlined by slight changes in texture or colour. Magnetite, where present, typically forms parts of granules being distributed either asymmetrically in very fine grained patches within granules, or densely and uniformly throughout granules. In some granular specimens minnesotaite more coarsely crystalline than elsewhere forms acicular crystals that penetrate from granule surfaces into chert interstices (see Fig. 9F). Cherty rocks (see Fig. 8) on the northwest side of the northwest-facing ridge near Aquatuk River remote from the diabase sill are composed of irregular laminae of chert, magnetite and chert-minnesotaite (determined by X-ray - see Fig. 9C). Adjacent to the sill rocks-of similar megascopic appearance are slightly schistose and consist

Figure 9.	Photomicrographs of rocks from the Sutton Ridges Formation.
Figure 9A.	Quartz-magnetite-calcite granules in iron-formation one mile northwest of Sutton Lake. Calcite-magnetite occur in thin rims about quartz-magnetite cores. (GSC 200911-X)
Figure 9B.	Quartz-magnetite-calcite granules in a bed adjacent to that shown in 9A. Calcite-magnetite rims are thicker, and quartz-magnetite cores thinner than in the adjacent bed (calcite, grey; quartz, white). (GSC 200911-Z)
Figure 9C.	Quartz-magnetite-minnesotaite iron-formation 35 feet from a diabase contact near Aquatuk River (quartz, white; minnesotaite, grey). (GSC 200911-D)
Figure 9D.	Quartz-magnetite-tremolite iron-formation close to a diabase contact (same locality as 9C) (quartz, white; tremolite, grey, as porphyroblast right centre, and as needles). (GSC 200911-G)
Figure 9E.	Granular minnesotaite-magnetite chert from a bed 6 inches thick in jaspilite east of Birch Hill. (GSC 200911-O)
Figure 9F.	Same as 9E showing minnesotaite crystals projecting from granule surface into cherty matrix. (GSC 200911-J)

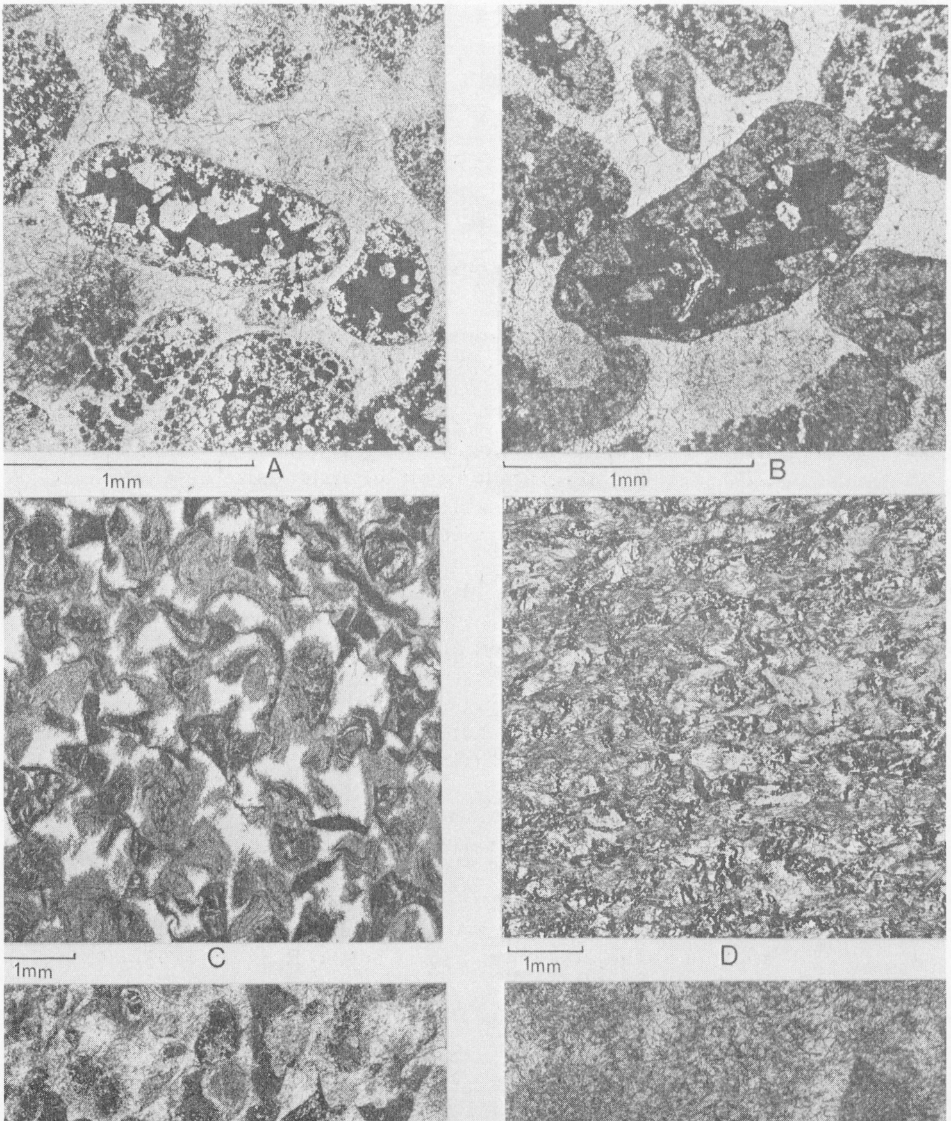
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Figure 10. Photomicrographs of rocks from the Sutton Ridges Formation.

Figure 10A. Laminated stilpnomelane-rich "greywacke" directly beneath diabase at Birch Hill. Stilpnomelane is most abundant in magnetite-rich laminae. (GSC 200911-H)

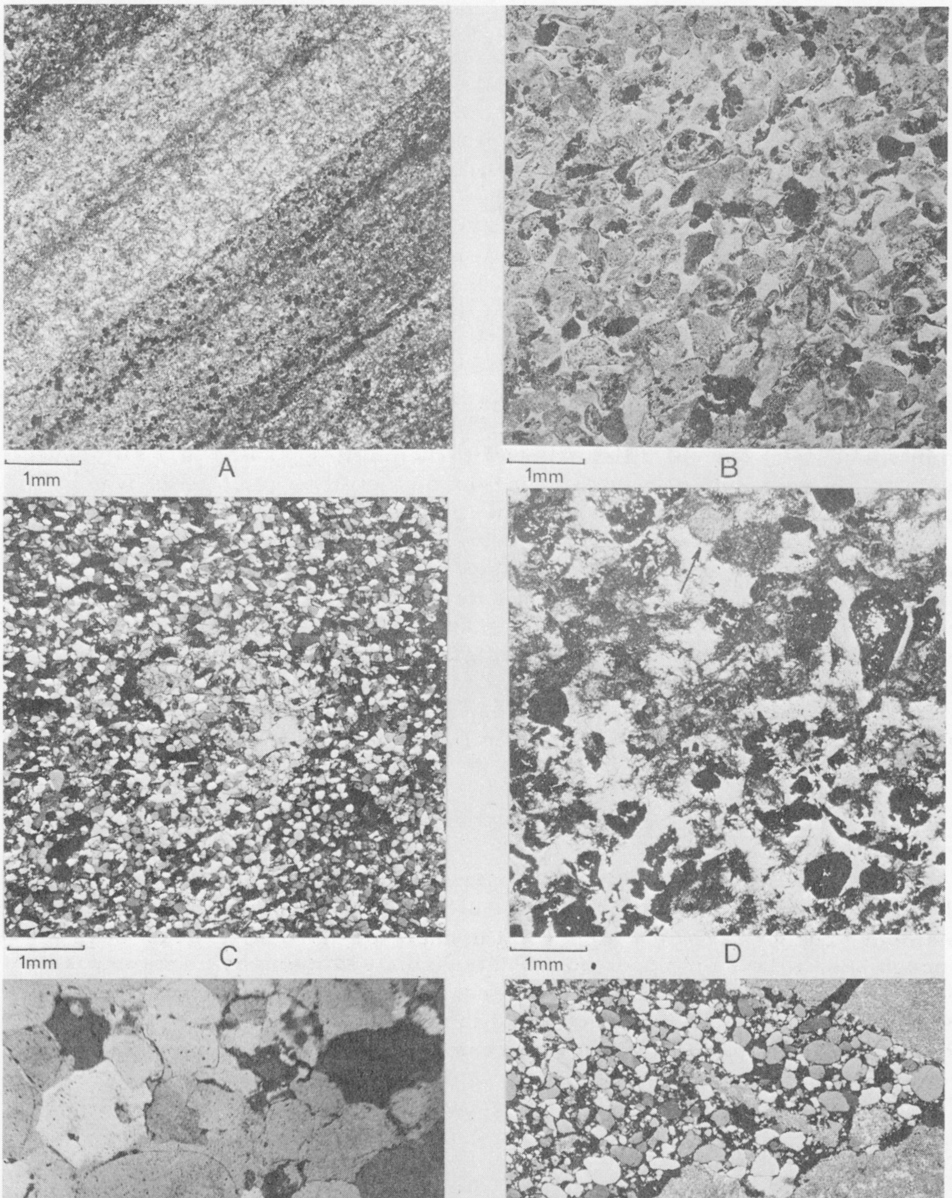
Figure 10B. Granular iron-formation bearing granules of varied mineralogy. Carbonate granules, either magnesite or ankeritic dolomite, are recognizable through their high relief (left centre). Specimen from near Aquatuk River. (GSC 200911-I)

Figure 10C. Calcareous greywacke showing angular to rounded quartz grains locally enclosed in carbonate cement (left centre) near Nowashe Lake (crossed nicols). (GSC 200911-A)

Figure 10D. Granular, riebeckitic iron-formation (3) near James Bay. Arrow (upper centre) indicates a granule largely replaced by fibrous riebeckite. (GSC 200911-Q)

Figure 10E. Quartzite from near Nowashe Lake showing rounded outlines of detrital quartz grains in quartz cement (crossed nicols). (GSC 200909-D)

Figure 10F. Chert breccia with hematitic cement from near the top of the section at the southeast end of Sutton Ridges (crossed nicols). (GSC 200911-M)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chiefly of quartz, magnetite and tremolite (see Fig. 9D). The latter occurs as porphyroblasts up to 1.0 mm long that are surrounded by needles also apparently tremolite. Farther north on the east side of the ridge jaspilitic rocks consist chiefly of silica, magnetite and tremolite. Locally fine-grained, nearly colourless garnet (cell edge 12.0545 $\pm$ 0.005, hydrogrossularite?) is present. Outlines of siliceous granules up to 1.2 mm in diameter in a more coarsely grained siliceous matrix are visible in some beds; in others magnetite, acicular tremolite and garnet form irregular fine-grained patches of varying size in a matrix of mosaic quartz.

Jaspilites that lie below the highest observed minnesotaite cherts are composed chiefly of silica-magnetite-hematite granules in a fine-grained cherty matrix. Granules are mostly 0.5 to 1.2 mm in diameter. Dusty silica rims showing cellular patterns, possibly resulting from replacement of carbonate by silica, are present in some beds. Locally, sheath like aggregates of stilpnomelane (with yellow-brown pleochroism) were observed within granules but not in the siliceous matrix. One specimen from near the base of the jaspilitic section near Aquatuk River contains small chert fragments and many normal silica-magnetite-hematite granules in a siliceous matrix. In addition however, fine-grained pale green to olive-brown granules, and patches and granules of carbonate were observed. Several grains of carbonate were determined by X-ray to be magnesite and others were found to be ankeritic dolomite (see Fig. 10B). Some light green granules consist chiefly of very fine intergrowths of talc-silica (determined by X-ray), other darker olive green granules are mostly stilpnomelane-silica (determined by X-ray); and still other granules may contain other fine-grained minerals whose ratio to silica is too small to determine from standard powder patterns. A few green granules were observed with irregular to sigmoid shapes.

Jaspilitic Iron-Formation Member

Jaspilitic iron-formation apparently containing more steel grey slate than the underlying rocks of the minnesotaite-bearing jaspilitic iron-formation member, but in which no minnesotaite chert or carbonate beds were recognized, forms the uppermost Proterozoic sedimentary rocks exposed at Sutton Ridges and along the west-central ridge at Aquatuk River. Similar or possibly related rocks were not found in regions to the southeast where they may have lain in part above the horizons of diabase intrusion and have been removed by erosion.

Description of Exposures

Sutton Ridges: At Birch Hill about 20 feet of thin-bedded jaspilite, in which bright red sand-sized jasper granules are present in a greenish grey matrix, overlie minnesotaite-bearing chert beds. Hawley (1926) noted interbedded black slates at the top of the section. Where examined during the present work 5 feet of fine-grained, dark brown-green "greywacke" were found above jaspilite and directly beneath diabase. Similar rock was observed in frost-heaved blocks at the base of the diabase ridge 4 miles northwest of Birch Hill.

About 2 1/2 miles north northeast of Birch Hill a section is exposed in a small butte-like hill comprising 35 feet of bright red and grey jaspilite and steel grey iron-formation overlain by diabase. Beds are mostly 3 inches or less thick and dip northward at 7 degrees.

One mile northwest of Sutton Lake at least 10 feet of steel grey to bright red slate and red to black jaspilite beds are poorly exposed above the highest observed minnesotaite chert and below diabase.

Hawley (1926) described 95 feet of jaspilitic, slaty, and cherty iron-formation 2 miles west of the south end of Hawley Lake of which the base is not exposed. The upper 35 feet and possibly more of this section appear to be free of minnesotaite chert and therefore are probably part of the jaspilitic iron-formation member. The contact between these rocks and the overlying Severn River Formation of basal Middle Silurian age is poorly exposed on the west shore of Hawley Lake about 1/4 mile north of Sutton Narrows (see Fig. 11).

Aquatuk Rivers: Below the central western diabase ridge near Aquatuk River the highest recognized minnesotaite chert beds are succeeded by 60 feet of iron-formation consisting of bright red and grey jaspilite with interbedded blue-grey slate (see Fig. 12). Beds are chiefly less than one foot thick.

Microscope Description

Jaspilite from above the highest observed minnesotaite chert beds consist chiefly of silica-magnetite-hematite granules in fine-grained siliceous matrices. Granules commonly reach about 1.0 mm in diameter. Carbonate granules are a minor constituent in many specimens, and where determined by X-ray these proved to be calcite. One crystal of carbonate with a distinct (-)2V about 10 degrees was observed in thin section, but coexisting carbonate was identified as calcite by X-ray. Some beds contain granules in part composed of stilpnomelane, in others granules with external limonitic rims were observed.

At the top of the jaspilitic section near Sutton Lake Hawley (1926) observed oolitic beds, however although a few delicately banded magnetite-silica oolites were seen in a thin section from jaspilite near the top of the section 1 mile west of Sutton Lake, no true oolitic beds were seen in the sections examined during the present work. One specimen also from near the top of the section one mile west of Sutton Lake contains beds of rudely zoned granules (see Fig. 9A and B). In these granules quartz-magnetite cores are surrounded by calcite-magnetite rims; and the ratio of core to rim varies between beds.

Map-unit 4 (diabase-gabbro)

Diabase-gabbro bodies are intermittently exposed along a northwest-trending belt from east of Nowashe Lake to Sutton Ridges. A second belt of outcrops extends from the Aquatuk River outcrop area northwest to Wachi, a Mid-Canada line doppler site 20 miles southeast of Winisk. Individual outcrop areas or groups of outcrops commonly show northwest elongation and it is therefore supposed that the diabase is localized along fractures parallel to these belts. Interpretation of diabase between exposures has for the most part been deliberately restricted because it is felt that thick diabase sections would likely be expressed in outcrop. Aeromagnetic anomalies in the vicinity of diabase outcrops have been interpreted as due to Proterozoic iron-formation because tested diabase samples have low magnetic susceptibility. Some liberty has been taken with these principles of interpretation in the vicinity of Hawley Lake where a graben structure may have resulted from collapse following more extensive diabase intrusion.

Wachi (20 miles southeast of Winisk): Diabase outcrops at Wachi form a prominent hill about one mile long with an elongate off-shoot that extends about 1/2 mile eastward from its north end. The rock is fresh, medium-grained, equigranular, massive diabase. Patches of epidote and coarse-grained diabase are present locally on top of the hill. Columns are well developed along the west margin of the hill and the dip of column axes varies from 60 to 75 degrees outward near the top to about 30 degrees outward near the base (see Fig. 13). Dark cobbles and boulders observed from the air, presumably diabase, predominate over alluvium composed of Paleozoic rocks in the creek valley to the west.

About 5 miles southeast of Wachi, greenish grey, medium-grained, massive diabase is less well exposed in a low hill surrounded by swamp land. Altered pyroxene or hornblende crystals up to 1.5 cm long are visible locally. Jointing suggests that the outcrop may form part of a northeastward dipping sheet.

Near Wachi Creek about 5 miles still farther southeast dark brown weathering, greenish grey, altered, massive diabase forms several low rounded outcrops. A little pyrrhotite is present.

Aquatuk River-Sutton River: One mile southeast of Sutton River and 10 miles north of Hawley Lake lies an extensive ridge of diabase with scattered low outcrops about 2 miles to the west. One ground observation made at the northern base of the ridge outcrop revealed fresh, medium-grained, dark green, equigranular diabase, however much of the ridge appears lighter coloured from the air. (The lighter colour is interpreted to reflect a greater degree of deuteric alteration as was observed on the ground at most other localities.)

Farther southeast, about 8 miles from Sutton River, a discontinuous diabase-capped ridge stretches eastward to a point 2 miles northwest of Aquatuk River. From there it extends northeastward for a further 8 miles. The diabase is grey-green, chiefly medium grained, and porphyritic with altered light green glomerocrysts reaching one third to one inch in diameter consisting of closely packed altered plagioclase crystals. Diabase in the southern part of the ridge forms a sheet roughly 40 feet thick lying on top of jaspilite (unit 3, member 4) and dipping gently southward. Diabase in the eastern part of the ridge appears to be 125 feet or more thick in places, but underlying rocks have been tilted and locally deformed (see Fig. 8) so that the structure of the diabase is not immediately evident. There is some suggestion however, that the diabase contact along the northeastward-trending part of the ridge cuts downward to the north into minnesotaite-bearing rocks (member 3 of unit 3)

Sutton Ridges: A gently northeast-sloping diabase-capped cuesta (known as Sutton Ridges) extends for 19 miles northwest, and for 13 miles southeast, of Sutton Narrows. Along the northeast margin of this cuesta

Figure 11. Dull red jaspilite (Sutton Ridges Formation) at Hawley Lake overlain by Paleozoic rocks (7). (GSC photo 138266)

Figure 12. Jaspilitic iron-formation (Sutton Ridges Formation) overlain by diabase near Aquatuk River. (GSC photo 138262)

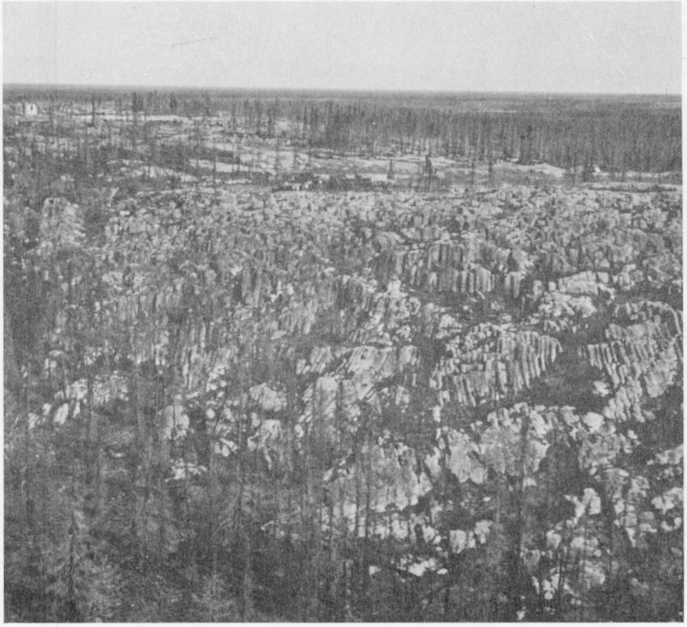

Figure 13. Columnar diabase (unit 4) at Wachi, 20 miles southeast of Winisk. Columns dip outward near the base of the hill but are nearly vertical toward the top. Forty-five gallon oil drums at the top of the hill provided fuel for the doppler site (Wachi) just visible at left margin of the figure. (GSC 138238)

diabase dips gently beneath the muskeg cover but along the steeper southwest margin it can locally be seen to overlie Proterozoic sediments of map-units 2 and 3. In places it is as much as 300 feet or more thick (Hawley, 1926).

The diabase is chiefly brown weathering, grey or olive green, medium grained and equigranular, but porphyritic varieties are known near Sutton Narrows and near the northwest end of Sutton Ridges. Fine-grained diabase is present near contacts. Alteration is commonly evident by the presence of variable proportions of epidote and chlorite. Minor pyrite is rare.

Northwest of Sutton Narrows the diabase is in places divided into at least two layers by discontinuous zones of fine-grained basic rock and associated inclusions of Proterozoic sedimentary rocks. On the southwest face at the extreme northwest end of Sutton Ridges medium-grained, grey-green, massive diabase at least 35 feet thick at the base of exposure is separated from porphyritic diabase above by a very fine grained zone 15 to 20 feet thick. At the base of the latter, discontinuous outcrop of iron-formation up to 8 feet or more thick with beds and cleavage dipping steeply into the hillside is present. A fine-grained basic dyke 5 feet thick intrudes these sediments. Two layers are also evident about 5 miles northwest of Sutton Lake where medium-grained, olive green, massive diabase at the base of the exposure is separated from slightly finer grained apparently more altered diabase above by a zone of very fine grained basic rock. An inclusion of iron-formation 3 feet thick was observed at one place at the base of the upper layer. At the southeast end of the same hill an apparently tabular body of iron-formation about 15 feet thick was observed from the air at approximately the same horizon within the diabase. A 35-foot section of jaspilitic iron-formation exposed beneath diabase on a small butte-like hill well within the diabase ridge 2 1/2 miles north of Birch Hill may represent a similar body Hawley (1926) observed a fine-grained zone within the diabase about 50 to 100 feet above its basal contact in the same region.

About 5 miles southeast of Sutton Narrows a traverse from the base of exposure to the top of the ridge revealed no variations, the rock being entirely medium-grained, light grey-green, massive diabase. The thickness of the diabase at the southeast end of Sutton Ridges was estimated from barometer readings to be 230 feet, however Hawley's estimate of 300 feet or more elsewhere is probably closer to the maximum thickness.

The basal contact of diabase rolls slightly in conformity with the underlying sediments; however locally, as at Sutton Narrows, it is reported to cut sharply across beds of iron-formation (Hawley, 1926). Furthermore the position of this contact within the underlying sedimentary sequence appears to rise irregularly from each end of Sutton Ranges toward the middle. Thus 50 feet and more of the upper part of the Sutton Ridges Formation intervenes between chert breccia or dolomite and diabase near Sutton Narrows whereas there appear to be about 20 feet or less of these rocks where chert breccia is exposed at each end of Sutton Ridges. Nevertheless aeromagnetic anomalies indicate that magnetic iron-formation (possibly overlain by diabase) persists for some distance beyond the northwestern limit of diabase exposure.

Hawley (1926) summarized reasons for believing that the diabase is intrusive rather than extrusive. Although the basal contact broadly viewed may cut obliquely through part of the Proterozoic section at a low angle as described above (Hawley noted sharp local truncations of Proterozoic sediments), the intrusion appears best described as a sill rather than as a dyke. Hawley further argued that the fine-grained horizons which he observed west of Hawley Lake indicate that the sill is compound in this region, a lower intrusion having been succeeded after a short interval of time by an upper one. Discovery of inclusions of Proterozoic rocks along a similar horizon and of tabular bodies of Proterozoic rocks near it, well within the intrusion, tend further to support Hawley's conclusions.

Opinnagau Lake: About 20 miles northeast of Opinnagau Lake three prominent diabase hills reaching elevations close to 200 feet above the swamp land to the northeast extend for some 5 miles in a southeasterly direction. The upper surface of these hills dips gently north-northeastward and the upper surface of the diabase passes beneath overburden in that direction. The southwest slope, although heavily drift covered at the northwest end of the hills, is much more abrupt to the southeast where there is a bluff about 100 feet high.

Light grey-green, medium-grained, massive, equigranular, diabase was observed near the summit at the west end of the hills. Both plagioclase and pyroxene appear altered and pyrite crystals in patches up to 1.3 cm were observed.

Two smaller exposures of diabase lie close to outcrops of Archean basement near the top of a broad rise some 6 miles southwest of the main diabase ridge. Although their basal contacts were not observed these appear to be part of a nearly flat-lying sheet.

Nowashe Lake: About 8 miles northwest of Nowashe Lake diabase overlies gently northwest dipping Proterozoic sediments. Near the contact the diabase rises abruptly in a bluff about 20 feet high but continues to rise gently behind so that the maximum thickness is probably considerably in excess of this. The diabase examined at one locality near the contact is fine grained, grey-green, equigranular and massive with a light brown weathered surface.

Stretching northwest for 12 miles from a point 3/4 of a mile north of Nowashe Lake are a series of rounded heavily tree-covered diabase exposures. At one landing at the south end of this region medium-grained, brownish green, equigranular, massive diabase was observed.

Diabase with purple siltstone (3) exposed along its western margin is present 1 1/2 miles east of Nowashe Lake. The diabase appears to form a dyke-like body at least 50 feet wide striking northwest, however no contacts were found. The rock is brown weathering, medium grained, grey-brown equigranular and massive. A few fine-grained, poikilitic patches of pyrite up to about 5 mm are present. About 3 miles farther east, narrow, fine-grained diabase dykes up to one foot thick intrude slaty siltstone. These dykes strike north 18 degrees west parallel to cleavage in the siltstone.

Rounded, low-lying diabase outcrops are present in an area some 6 miles long and 3 miles wide 7 miles east of Nowashe Lake. A dyke-like body of diabase about 50 feet thick strikes north near the west margin of the outcrop area. The body forms a distinct ridge with intermittent diabase felsenmeer along its east margin. It consists of medium-grained, grey-green, equigranular massive diabase at its core but is distinctly finer grained along its margins. Disseminated iron sulphide is present. Although textural evidence supports the hypothesis that the body is a dyke it is not clear whether it represents a late stage diabase intrusive into earlier diabase or a normal diabase intrusive into sediments at the margin of a larger area of diabase.

Microscopic Descriptions

The diabase is characterized by the presence of plagioclase, pyroxene, chlorite, quartz, opaque minerals and apatite in order of decreasing magnitude. All specimens save that from the dyke 7 miles east of Nowashe Lake contain epidote. Carbonate is present in about 50 per cent of the specimens examined and sericite is present in some. About 2 per cent of amphibole is present in three of four specimens examined from the Wachi-Aquatuk River lineament but no amphibole was observed elsewhere and none is reported from the Sutton Lake region by Hawley (1926). A brown, biotite-like mineral with dark brown absorption parallel to cleavage (thought to be stilpnomelane) is present in sheaths in a specimen from Wachi, and in one from near the base of the diabase at Sutton Ridges. In the latter specimen stilpnomelane appears to be restricted within plagioclase and pyroxene, and does not occur in quartz- or epidote-rich areas. Plagioclase is more or less severely altered in all specimens examined but remnants of sodic andesine can be found in most specimens. The extreme range observed was sodic oligoclase to sodic labradorite. Opaque minerals consist of both iron sulphide and magnetite-ilmenite. Sphene-leucoxene overgrowths are common in some specimens. An unusual specimen of medium-grained, dark green, equigranular, fresh-looking diabase from the north base of the diabase ridge near Sutton River contains 17 per cent of subhedral quartz crystals with internal graphic intergrowths of potash feldspar. Chlorite in the same specimen contains interleaved biotite.

Textures in the diabase are locally gabbroic but typically they are moderately to strongly ophitic. Plagioclase crystals reach lengths about 4 mm in some non-porphyritic specimens but are mostly 2.5 mm long or less.

Metamorphism of the Proterozoic Rocks

Contact metamorphism of the Proterozoic rocks is clearly indicated by tremolite needles in iron-rich sediments near the contacts of the Sutton Lake and Aquatuk River diabase sills. Stilpnomelane in moderately coarsely crystalline form both within granules and in nongranular rocks near the diabase contacts, may also reflect increased temperatures resulting from emplacement of the diabase sills.

Regional metamorphism on the other hand, is not clearly evident. A variety of fine-grained minerals, which occur in iron-formation more remote from diabase exposures, including talc, minnesotaite, stilpnomelane, riebeckite, and chlorite-sericite, may reflect regional metamorphism; they may reflect extended effects of contact metamorphism; or they may in part have formed during diagenesis. Impure siliceous dolomite, which typically outcrops farthest from diabase exposures, shows little alteration other than recrystallization. Although outcrops of the latter lithology are few, they suggest that regional metamorphism is absent or of very low grade.

Partial alteration of primary diabase minerals principally to epidote chlorite and leucoxene is more or less uniform over broad areas but, as previously pointed out, the alteration of the underlying sediments is minimal except near diabase contacts. It is likely therefore that alteration of the diabase is dueteric and that the diabase magma was emplaced in a volatile-rich condition.

AGE RELATIONS AND CORRELATION

Archean plutonic rocks lying along the southwest margin of the main Precambrian inlier have been dated in two places by the K-Ar biotite method at 2505 $\pm$ 65-70 m.y. The basement complex in this part of the area therefore consists of rocks originally formed during the Archean Eon that underwent metamorphism and may have been intruded by granitic rocks during the Kenoran Orogeny (mean age 2490 m. y., Stockwell, 1964), but which have not since been subjected to significant metamorphism.

The Archean basement complex is overlain by the Nowashe and Sutton Ridges Formations that have been extensively intruded by diabase. The Sutton Ridges Formation is overlain by the Severn River Formation of Middle Silurian age (and possibly by rocks of Upper Ordovician age), however the quartz-bearing diabase intrusions, which are not known to penetrate Paleozoic rocks anywhere in the Hudson Bay Lowlands, indicate that the Nowashe and Sutton Ridges Formations are almost certainly of Precambrian age. Direct evidence therefore limits the origin of these formations to the Proterozoic Eon.

Diabase bodies, which intrude the Proterozoic rocks at Sutton Ridges, and northwest of Nowashe Lake, have been dated at 1055 $\pm$ 90 and 1455 $\pm$ 170 m. y. respectively by the K-Ar whole rock method. Because the rocks are deuterically altered these dates can be regarded as minimum dates of intrusion only. Insofar as they are probably less than true ages they suggest that at least part of the diabase, which forms southeast striking sills parallel to the Mackenzie dyke swarm (1200 m. y., Fahrig et al., 1965), is older than that dyke swarm. They indicate that the Nowashe and Sutton Ridges Formations are of Paleohelikian age or older, however a more precise age estimate can probably be obtained through correlation of these formations with the Belcher Group.

Correlation of the Proterozoic rocks at Sutton Ridges with the Nastapoka Group (Leith, 1910) (equivalent to the upper part of the Manitounuk Group, Bell, 1879; Eade, 1966) was suggested by Dowling (1905), and this suggestion was followed by Hawley (1926) who also compared the exposures at Sutton Ridges with rocks described by E. S. Moore (1918) on Belcher Islands. In particular Hawley pointed out that dolomite, and the overlying iron-bearing sequence may have equivalents in the middle and lower parts of the Belcher Group, and that the absence of great thicknesses of sediments between these units is accounted for by the erosional unconformity, in part represented by chert breccia, that separates them. On Belcher Islands iron-formation and volcanic rocks including diabase intrusions are overlain by a thick unit of greywacke and argillite with some tuff in the lower part (7,000 feet or more, Jackson, 1960), which megascopically resembles rocks exposed northwest of Nowashe Lake. The latter however appear to contain no tuff or volcanic detritus and are overlain by diabase. Equivalents of the greywacke on Belcher Islands are therefore probably not exposed in Aquatuk River map-area although they may exist in the drift-covered area southwest of Cape Henrietta Maria. Delineation of the Proterozoic sedimentary rocks within the map-area and their extension to the islands in northern James Bay produces a continuous belt of outcrop of similar lithologies that may be extended eastward to the nearest exposures of the Manitounuk Group on Long Island east of the mouth of James Bay. This belt passes remarkably close to the limits originally projected by Hawley and tends to substantiate the conclusions which he drew.

Although the Nowashe and Sutton Ridges Formations are probably correlative to parts of the Belcher Group a similar relation between diabase bodies cutting these rocks is less certain. Diabase sills intrusive into the Belcher Group are thought to be related to volcanism recorded in the unit immediately overlying iron-formation on Belcher Islands, and emplacement preceded folding (Jackson, 1967). However, although volcanic rocks above iron-formation may be indicated by aeromagnetic and gravity anomalies west of Cape Henrietta Maria, no such volcanic rocks have been found exposed in the map-area. Furthermore, the K-Ar whole rock age (1055 $\pm$ 90 m. y.) from the Sutton Lake sill and that from the Nowashe Lake sill (1455 $\pm$ 170 m. y.) admit the possibility that these rocks are significantly younger than the age attributed to volcanism within the Belcher Group. However, because the sills of map-unit 4 appear to have been emplaced in a volatile-rich condition, and a likely source of volatiles may be found in a recently deposited sedimentary envelope, the writer favours the hypothesis that emplacement of the sills followed deposition of the Sutton Ridges Formation fairly closely.

Dating of the Belcher Group through K-Ar whole rock ages of basic sills and volcanic rocks within the Belcher Group has been attempted by Jackson (1967), and Hofmann and Jackson (1969). Dates obtained fall into two groups (830 to 1054 m. y.) and (1620 to 1693 m. y.). Jackson favours the hypothesis that the older dates represent a period of very low grade metamorphism of the Belcher Group probably related to folding during the Hudsonian Orogeny (1735 m. y. - mean age, Churchill Province, Stockwell, 1964). The younger group is believed to reflect a thermal event which accompanied emplacement of fresh trap dykes. The present correlation therefore, together with the interpreted unconformable relationship between the Nowashe Formation and adjacent Archean granitic rocks (K/Ar biotite 2505 m. y.), indicates an Aphebian age for both the Nowashe and Sutton Ridges Formations.

Deposition of Aphebian rocks of the Labrador and Cape Smith Fold Belts, and of probable Aphebian rocks of the Belcher and Manitounuk Groups in one extended geosyncline was suggested by Bergeron (1957) on the basis of similarity of lithologies and apparent continuity of structure. The discovery of additional outcrop of similar lithologies between Sutton Ridges and Long Island on the east coast of James Bay suggests that the proposed geosyncline may be extended at least as far west as Winisk River. Direct comparison between iron-formation in the Sutton Ridges Formation and the Sokoman iron-formation of the Knob Lake area lends further support to this contention because minnesotaite-bearing cherts appear in the lower parts of both iron-bearing sequences, and development of riebeckite has taken place locally in both areas. Similar Aphebian rocks, suggested by aeromagnetic anomalies west of Winisk, apparently continue in the subsurface as far as Shagamu River. Still farther west they may have been removed by erosion, or they may in part have been involved in higher grade metamorphism related to the Hudsonian Orogeny.

Regional Interpretation

The Aquatuk River map-area, in spite of its nearly 18, miles of surface, has only some 10 distinct areas of exposed Precambrian rocks. Nevertheless, the map-area has been covered by reconnaissance gravity, siesmic, and aeromagnetic surveys, and these provide some restriction of conditions which may exist where no outcrop is present; but in many places it appears that several alternative interpretations may be almost equally likely. As a multiplicity of interpretations are impossible to show clearly on a map the choice is made which appears most likely to the writer, whereas alternatives are discussed in the text. To this extent the map (Fig. 16 in pocket) is not a geological map in the sense typical for areas where better exposure is present, but rather is an illustration to accompany the geological discussion in the text. The pre-Pleistocene geology of the map-area is thus perhaps more fairly shown on Map 17-1967 (accompanying Sanford *et al.*, 1967).

Gravity Interpretation

The Aquatuk River map-area is included within the regional gravity surveys initiated by the Observatories Branch (Innes et al., 1967). Although this data is necessarily of broader scale than the aeromagnetic coverage some pertinent interpretation of near-surface Precambrian rocks has been made. Thus after discussion of gravity highs over the Hudson Bay region north of Belcher Islands, Innes et al., 1968, stated:

> "That near-surface basic volcanic rocks are the source of positive anomalies to the south is much less speculative. An east-west gravity traverse across Belcher Islands shows a local increase in gravity to the west over large exposures of heavy volcanic rocks (Jackson, 1960). It is also likely that the large positive anomaly area centered about 60 km. west of Cape Henrietta Maria is caused by basic flows and/or intrusive rocks. The southwestern limit of the anomaly is some 100 km. inland near Sutton Lake, where Proterozoic sedimentary rocks capped by diabase sills are exposed through a window in the Paleozoic cover. The diabase at Sutton Lake has been estimated to be less than 100 metres thick (Hawley, 1926), and therefore it contributes very little to the total gravity field. However, as these Precambrian rocks all dip gently to the north and east toward the Hudson Bay coast, they may thicken sufficiently in these directions, as much as 2 to 3 km. to account for the higher gravity values."

The writer, on the basis of seismic and aeromagnetic data, prefers the hypothesis that these volcanic rocks, if they do form a continuous layer between Sutton Lake and Cape Henrietta Maria, are not present at the surface of Precambrian rocks throughout this area. However, a depth-to-anomaly (aeromagnetic) calculation near the coast of Hudson Bay in the region where the gravity anomaly is highest, suggests that volcanic rocks may approach the surface in a northward concave crescent west of Cape Henrietta Maria.

Seismic Interpretation

Reconnaissance seismic refraction studies were used to outline topography on the upper surface of Precambrian rocks in the Hudson Bay Lowlands by Hobson (1967). More recently improved topographic control within the map-area has permitted closer estimation of elevations at the seismic stations, particularly those remote from the sea. The corrected depth (below sea level) to seismic "basement" together with the local estimate of elevation used in the correction are shown on Figure 16. Allowing for thickness of overburden, Hobson's studies indicated that Paleozoic rocks might be as much as 500 to 1,000 feet thick over much of the present map-area. On the other hand recognition of outcrops of Severn River Formation over most of this area (Sanford et al., 1968) suggested that Paleozoic rocks are mostly thin (200 feet or less was thought probable on the Cape Henrietta Maria Arch at that time). More recent work has suggested that the Redhead Rapids Formation (Upper Ordovician) is very widespread and might be present within the map-area; however even if these Ordovician rocks are included the thickness of Paleozoic cover on the Arch (estimated on stratigraphic considerations) does not exceed 500 feet. It seems likely therefore that the seismic data have not detected the Paleozoic-Proterozoic unconformity but have recognized some deeper discontinuity.

Seismic "basement" defined by Hobson (1967) south and west of Cape Henrietta Maria is characterized by fairly uniform seismic velocities (19, 000 to 20, 600 f. p. s.). Seismic velocities close to this interval have also been determined on the Shield, beneath Paleozoic rocks, and in areas where both Paleozoic and Proterozoic rocks may be expected. The simplest interpretation is that these velocities represent crystalline rocks of Archean basement. However, to the extent that other (Proterozoic) rocks might produce velocities in this range the simpler interpretation is in doubt. Such velocities might be produced by massive volcanic rocks, iron-formation or Proterozoic carbonate, but it seems less likely that they would be found in arenaceous greywacke or siltstone. Proterozoic siliceous carbonate rocks appear to be seismically indistinguishable from Paleozoic carbonate just south of Winisk inlier. Farther north seismic basement in the Winisk estuary is at 1,010 feet whereas anomalies probably due to iron-formation (15 miles west of Winisk) are calculated to lie at 660 feet below ground level. If iron-formation lies above seismic "basement" in this area then the most likely level of volcanism, which lies immediately above iron-formation by analogy with Belcher Islands, would also lie above seismic basement. On this meagre evidence the hypothesis that seismic "basement" may represent Archean basement may be slightly preferred.

South of the map-area along Attawapiskat River seismic "basement" shelves westward from 1,600 feet near Akimiski island through 1,325 feet below ground level at 83 degrees W to shallower depths farther west. The larger depths are greater than the expected thickness of Paleozoic rocks in this area and suggest the presence of Proterozoic rocks above seismic "basement". Because these rocks lie well to the south of the northeast dipping iron-formation, and are south of the gravity high (Innes et al. , 1967), they are most likely correlative to carbonates of unit 2. A trough containing Proterozoic carbonates may therefore project southward from Hudson Basin near the west coast of James Bay into the Moose River Basin.

Aeromagnetic Interpretation

Introduction

Recent Geological Survey aeromagnetic maps (7268G, 7269G, 7275G, 7276G, 7281G, 7282G) cover the Aquatuk River map-area at a scale 4 miles to one inch, and in many parts they provide the only clues to the underlying geology. In order to interpret these maps to best advantage the magnetic susceptibility of a number of samples collected in the field has been mea sured, depth to anomaly calculations have been made, and anomaly patterns over drift covered areas have been compared with patterns over Precambrian terrain where the geology is known. As Paleozoic strata consist of nearly flat-lying nonmagnetic beds it has been assumed that their contribution to the magnetic anomaly patterns will be negligible (i. e. it will be similar to that of lowering the ground level by an amount equal to their thickness).

Magnetic susceptibility measurements were made on 23 specimens of Proterozoic iron-formation (3) and diabase (4) to see if these two lithologies could be distinguished on the basis of the relative intensity of aeromagnetic anomaly which they produce. The data (see Table 3) show that almost all diabase from the area is of surprisingly low magnetic susceptibility whereas the iron-formation, though variable, shows moderate to high susceptibility where magnetite is visible. Insofar as magnetic remanence may be expected to vary directly as magnetic susceptibility, the data suggest that recognizable anomalies will occur over iron-formation but not over diabase. This suggests that the pronounced aeromagnetic anomaly patterns near exposed diabase are due to known or inferred underlying Proterozoic iron-formation. On the other hand there is some suggestion that the magnetic susceptibility of the least altered diabase specimens is slightly greater than that of those more altered. To the extent that this indicates still higher susceptibility in unaltered diabase, aeromagnetic anomalies might be expected where diabase is unaltered. However, the prevalence of altered diabase in outcrop, and poor correlation between diabase outcrop and high aeromagnetic anomalies when close comparison is made, suggest that there will be few such anomalies.

The depth to dyke-like or dipping sheet-like bodies responsible for aeromagnetic anomalies may be calculated using the method of McGrath and Hood (1968). The depth calculated depends on the assumption that the causative body approximates an ideal form. The method is further limited insofar as a given anomaly may lie within, rather than at the surface of, a lithologic or map-unit. The calculated depths are thus likely to be significant only when several produce a coherent pattern. An attempt has been made to establish such patterns across the northern and northeastern parts of the map-area where seismic data are most abundant, using thirteen depth-to-anomaly calculations made for the writer by P. H. McGrath. The data are fewer than desirable however, and the inferences drawn from them can therefore only be regarded as "best guesses".

Comparison of aeromagnetic and geological maps in areas where Precambrian rocks are well exposed (both within and outside the present map-area) has suggested that several generalizations regarding aeromagnetic interpretation within the map-area may be made. These comprise the following:

(1) Pronounced aeromagnetic anomaly trends reflect parallel structural trends in rocks at or near the earth's (bedrock) surface.

(2) Unusually high curvilinear anomalies (15,000 gammas or more above background) are interpreted as representing steeply dipping Archean iron-formation (see Fig. 14 (9)). Somewhat lower aeromagnetic anomalies (15,000 to 5,000 gammas above background) in east-trending belts that locally include Archean iron-formation (as indicated above) are considered to reflect continuations of the same Archean rocks in which concentrations of magnetite may be less. Inherent in this generalization is the assumption that the structural complexity and metamorphic grade of Proterozoic iron-formation throughout the map-area are truly represented by the nearest exposures of Proterozoic rocks described. That is to say complex folding and moderate or high grade regional metamorphism related to the Hudsonian Orogeny are thought to be absent where Archean iron-formation has been interpreted.

(3) Short wavelength, high and low anomalies commonly producing a subisotropic birdseye pattern, and with magnetic intensity typically lower than (2) above (3,000 gammas above and below background), are due to gently dipping Proterozoic iron-formation (see Fig. 14-3 and 14-10). (This depends on lack of correlation between aeromagneitc anomalies and diabase bodies within the present map-area.)

(4) Scattered, high and low aeromagnetic anomalies (see Fig. 14-7) in a conspicuous east-west belt north of Ekwan River, and west of Opinnagau Lake are thought to represent underlying rocks of granulite metamorphic facies (C.K. Bell, pers. comm., 1969).

(5) Continuous or discontinuous, linear aeromagnetic lows, which locally transect or offset regional trends, are interpreted as faults (see Fig. 14-2 and 14-8).

Other anomaly patterns are of more conjectural origin, but will be considered in the following section where available geological information from the surrounding terrain will be applied to their interpretation.

Interpretation of the distribution and structure of Precambrian rocks within the map-area will consider first the Proterozoic strata which are most widely exposed. Aeromagnetic patterns and trends corresponding to known Proterozoic strata will be extrapolated into surrounding areas covered by Paleozoic rocks and/or drift. The distribution of the Archean rocks will then be inferred from truncation and interference patterns in aeromagnetic anomalies along the margins of areas underlain by Proterozoic rocks.

Proterozoic Rocks

The distribution of exposed Proterozoic rocks follows a discontinuous northward concave belt that stretches southwestward across James Bay, westward to Nowashe Lake, and thence northwestward through Sutton Lake to the Winisk inlier. Similar rocks appear within the curvature of this belt near Aquatuk River. Aeromagnetic anomaly patterns characterized by short wavelength (birdseye type), high and low intensity anomalies (chiefly less than 3,000 gammas above and below background), typically of more or less heterogeneous orientation, roughly follow this outcrop distribution as far as Sutton Lake (see Fig. 14-3 and 14-10). From James Bay to northwest of Nowashe Lake however, prominent discontinuities appear in this anomaly pattern which divide the anomaly belt into blocks. These blocks have rather sharp southwestern limits and are accompanied on the southwest by a peripheral zone of low anomaly. To the northeast aeromagnetic anomaly gradients tend to be lower and anomalies are broader. This disposition of anomaly patterns is thought to have arisen through faulting with northeastward tilting of the blocks. It is consistent with the observed attitudes of unit 3 east of Nowashe Lake where dips are northeasterly in spite of the more nearly east-west trend of the anomaly belt as a whole. Proterozoic iron-formation anomaly patterns near Nowashe Lake, locally lie to the east or northeast of diabase outcrop (see Fig. 14-10). This configuration is thought to indicate that the diabase has penetrated "down section" toward the southwest edge of the Proterozoic basin, and has in effect overflowed the preserved edge of the iron-formation.

TABLE 3

Magnetic susceptibility of diabase and Proterozoic iron-formation compared

Sutton Ridges Formation	Susceptibility ($\times 10^{-6}$ cgs. units)
1. Granular, cherty, riebeckite-magnetite I. F. (near James Bay)	80,000
2. Dense hematite-magnetite I. F. (Sutton Lake)	80,000
3. Dense hematite-magnetite I. F. (Sutton Lake)	80,000
4. Cherty granular hematite-magnetite I. F. (Aquatuk River)	60,000
5. Grey magnetite-bearing slate (Sutton Lake)	56,000
6. Magnetite-bearing minnesotaite chert (Aquatuk River)	26,000
7. Granular, hematite jaspilite (Aquatuk River)	2,700
8. Magnetite-bearing cherty grey jaspilite (near James Bay)	2,700
9. Hematitic argillite (near James Bay)	2,200
10. Minnesotaite chert (Sutton Lake)	200
11. Red and grey banded jaspilite (Sutton Lake)	100
12. Greywacke (Nowashe Lake)	0
Diabase	
1. Medium-grained, slightly altered, strongly ophitic (Wachi)	3,600
2. Medium-grained, slightly altered, gabbroic dyke (east of Nowashe Lake)	1,900
3. Fine-grained, altered (Sutton Lake)	1,000
4. Medium-grained, altered (northeast of Opinnagau Lake)	100
5. Medium-grained, altered (Sutton Lake)	100
6. Medium-grained, altered (5 miles southeast of Wachi)	100
7. Medium-grained, altered (10 miles southeast of Wachi)	100
8. Medium-grained, altered, strongly ophitic (Sutton Lake)	100
9. Medium-grained, altered (Nowashe Lake)	100
10. Fine-grained, altered (north of Nowashe Lake)	100
11. Medium-grained, altered (near Aquatuk River)	100

From Nowashe Lake to northwest of Opinnagau Lake anomalies present are not typical of Proterozoic iron-formation and are probably due to anomalous rocks in shallowly buried Archean basement. Exposures near Patchepawapoka River indicate that unit 3, member 2 (greywacke siltstone) is abnormally thick in this area and deposition of the magnetic iron-rich facies may have been prevented by influx of clastics and dilution.

Near Sutton Lake and Aquatuk River exposures, the aeromagnetic anomaly pattern due to shallow, flat-lying Proterozoic iron-formation is extensive. Preservation of this iron-formation on the crest of the Cape Henrietta Maria Arch is probably due partly to diabase cappings, and partly to the erosion-resistant nature of the unfolded, magnetite-rich facies of iron-formation which is widespread in this area. One or other of these lithologies probably lies close to surface (i. e. is without Paleozoic cover) locally along northeast-facing slopes above the 300-foot contour. As strata exposed near Sutton Lake dip northeastward and those near Aquatuk River dip southward the area between appears to be underlain by a structural basin. Diffuse aeromagnetic patterns near the centre of this basin are bounded on the northeast and southwest by discontinuous aeromagnetic lows that might reflect faults (see Fig. 14-4), and on the northwest and southeast by gradational boundaries. Iron-formation may therefore be down faulted in the central part of the basin forming a northwest-striking graben in which deformation in the longitudinal section has been accommodated by monoclinal folding without major rupture. The structure inferred is analogous to the better exposed Rockinghorse Lake graben in the central Slave Province where diabase overlies Proterozoic sediments of the Goulburn Group which in turn rest on Archean basement (Bostock, 1967).

North of the Aquatuk River exposures, an aeromagnetic pattern of short wavelength and high relief, but with more extended linear anomalies is present (see Fig. 14-5). These anomalies strike west-northwestward toward Wachi where they intersect a more northerly striking trend of diabase outcrops at an angle of about 35 degrees. The anomalies are thought to reflect the presence of Proterozoic iron-formation because they lie adjacent to exposed iron-formation near Aquatuk River, and because the intersection with the trend of diabase outcrops suggests that they do not represent diabase. Furthermore they are similar in form to aeromagnetic anomalies immediately north of the Winisk inlier (see Fig. 14-1) for which an iron-formation source (discussed below) is better documented. The clearly defined trend produced by these anomalies differs from the more nearly isotropic pattern over approximately flat-lying iron-formation evident at Sutton Lake. The linear trend, and the asymmetry of anomaly profiles at right angles to the anomaly trend (high gradient to southwest and lower gradient to the northeast) is thought to reflect an unusually steep northeastward dip of the strata in question. Interpretation therefore suggests that a rapidly thickening section of Proterozoic rocks lies to the northeast of this trend. To the southwest low aeromagnetic relief indicates that rocks of low magnetic susceptibility are close to the surface. These are likely to be carbonates of unit 2 near the iron-formation anomalies but might include nonmagnetic Archean granite more remote from these anomalies.

Between Winisk inlier and the doppler site at Wachi there appears to be an "along strike" discontinuity in aeromagnetic patterns. This will be discussed following interpretation of the Precambrian rocks immediately north and west of the Winisk inlier.

Immediately north of the Winisk inlier a west-northwest striking belt of aeromagnetic anomalies (see Fig. 14-1) suggests the presence of a synclinal remnant of Proterozoic iron-formation. This belt is 45 miles long by 10 miles in width with minor outlying anomalies at either end. It is characterized by bands of short wavelength, high and low intensity linear anomalies. On the north and south an outer rim of low anomalies is succeeded by an inner rim of high anomalies. The principal feature of the central part of the anomaly belt is an asymmetric low anomaly with gradients somewhat steeper along the northern, than along the southern edge.

Interpretation of this anomaly belt suggests three possibilities:

(1) It might represent diabase near the surface.
(2) It might reflect a basement high underlain by gneissic rocks of fairly high magnetic susceptibility.
(3) It might represent Proterozoic iron-formation more intensely folded than that exposed near Sutton and Hawley Lakes.

The first consideration seems unlikely because:

(1) The mean susceptibility of rocks causing two of the anomalies from this belt, calculated in depth calculations, is higher than the highest susceptibility measured on diabase specimens.
(2) Depth-to-anomaly calculations indicate that the magnetically anomalous rocks are close to the surface and the anomaly pattern suggests that they are folded. Furthermore direct evidence of folding is present in the Winisk inlier (see Fig. 2) immediately to the south. If the magnetically anomalous rocks comprise a major (structurally competent) diabase sheet close to the surface, then the irregularities produced in it by deformation would lead one to expect outcrop because of the erosion resistant nature of diabase elsewhere. To the extent that thinly banded, folded iron-formation might be expected to be less resistant to erosion, its presence appears most consistent with the observed lack of outcrop.

The suggestion that the anomaly belt represents a raised area in the Archean basement is unlikely because:

(1) Seismic depths to basement (Hobson, 1967) suggest that Proterozoic rocks 3 miles south of the anomaly belt are approximately 400 feet thick (allowing for an estimate of overburden and Paleozoic cover). These rocks should dip southward from such a basement high. Although the Winisk inlier is rather small (only 1 1/2 fold wavelengths being clearly exposed) to permit estimation of regional dip, a southward dip is not evident (see Fig. 2).
(2) The distribution of anomalies within the belt appears related to its borders in a symmetrical way and the limits of the belt are rather sharp. This is not typical of gneiss belts in the country to the south.
(3) Local linear anomalies in the anomaly belt have precisely the same trend as fold axes in Proterozoic rocks exposed in the Winisk inlier at the south margin of the belt. Because the folded Proterozoic rocks show no clear evidence of metamorphism the anomalies in the postulated Archean basement rise would have to belong to an older period of deformation or metamorphism. Because a pronounced difference in age of folds and immediately adjacent aeromagnetic anomalies requires a coincidence difficult to accept if the two show precisely parallel trends, it seems

more likely that folding in the Winisk inlier and that suggested by the aeromagnetic anomalies are of the same age. In this case the magnetically anomalous rocks must be as young or younger than those of the Winisk inlier.

Certain peculiarities of the anomaly belt are consistent with the suggestion that it represents a folded synclinal remnant or Proterozoic iron-formation:

(1) The anomalies originate near the surface (depths determined on two anomalies on the northern rim of the belt are within 200 feet of ground level), and the rocks which they represent lie either slightly above or slightly below those exposed in the Winisk inlier (unit 2). By analogy with Sutton Lake, magnetic iron-formation may be expected within a few feet above the top of unit 2.
(2) The pattern of rim anomalies (outer low anomalies, and inner high anomalies) suggest that layers (beds) dip inward toward the axis of the proposed syncline. Some layers on the northern rim however may be overturned.
(3) Folds of the Winisk inlier plunge gently westward toward the broadest section of the inferred syncline.

If the synclinal hypothesis argued above is accepted then the northward overturned folds exposed in the Winisk inlier (<u>see</u> Fig. 2) appear contrary to what might be expected if folding arose from drag due to flexure-slip on the south limb of the major structure. On the other hand the northward overturned folds in the Winisk inlier may have developed as a result of northward sliding of the overlying beds toward the axis of the syncline under the influence of gravity.

North of the proposed syncline there exists a nearly east-west zone up to 8 miles wide of low aeromagnetic relief punctuated by two broad but high anomalies. Although no calculations have been made on these latter anomalies they are thought to arise from deep seated bodies. The otherwise low level of relief is thought to reflect the presence of siliceous argillaceous carbonates of unit 2. Between this zone and the coast of Hudson Bay a series of west-northwest striking linear anomalies are prominent. One depth to anomaly calculation in this region and two immediately west of the map-area range from 40 to 265 feet below ground level. One anomaly about 15 miles west-northwest of Winisk provides a depth of 660 feet. In the Winisk estuary however the depth to seismic "basement" is 1,010 feet. As the latter represents either the Archean-Proterozoic contact or some shallower discontinuity it is perhaps more likely that the anomalies represent Proterozoic rocks. Insofar as rocks responsible for the linear anomalies come close to the surface near the west margin of the map-area, and no independent evidence of Archean rocks in this area is known, the iron-formation hypothesis appears satisfactory; nevertheless the alternative interpretation, that the linear anomalies represent Archean rocks, seems only slightly less likely.

From Winisk River east to Wachi low aeromagnetic relief is punctuated by scattered anomalous areas of shore wave-length anomaly type thought to represent Proterozoic iron-formation. The discontinuous aspect of these anomalous areas may in part result from an irregular culmination separating nearly east-west aeromagnetic trends to the west from trends of more southeasterly orientation to the east.

From Cape Henrietta Maria south and west to the belt of shore wave-length anomalies believed to represent near surface Proterozoic iron-formation, a vast drift-covered area is characterized by low aeromagnetic relief. Along the crest of the Cape Henrietta Maria Arch within this area both aeromagnetic and seismic "basements" lie near 900 feet. Available data suggest that this (combined) basement dips gently to the northwest and southeast away from the Arch with depths of about 1,100 feet along James Bay and about 1,200 feet inland south of Hudson Bay. Nearer to the coast of Hudson Bay, from Cape Henrietta Maria west to longitude 84° 30', there exists a northward concave belt of low linear aeromagnetic anomalies, whereas anomaly trends farther south are more nearly east-west. One anomaly in this (northern) belt is calculated to be 100 feet below ground level. The belt of northward concave anomalies therefore appears to include rocks higher in the section than does the aeromagnetic-seismic basement farther south.

Volcanic rocks have been interpreted (Innes et al., 1967) on the basis of gravity work near and southwest of Cape Henrietta Maria, and by correlation with Sutton Lake and Belcher Islands such volcanic rocks may be expected to appear relatively high in the Proterozoic section (immediately above Proterozoic iron-formation). The appearance of aeromagnetically slightly anomalous rocks near the coast of Hudson Bay west of Cape Henrietta Maria may therefore indicate the presence of Proterozoic volcanic rocks. To the extent that these rocks appear to lie substantially above seismic "basement" they tend to support the hypothesis that combined seismic-magnetic "basement" farther south represents a substantially deeper horizon, most likely the upper surface of Archean rocks. This hypothesis suggests that the iron-formation would be relatively close to the surface on the crest of the Cape Henrietta Maria Arch. The low intensity of anomalies over most of the northeastern part of the arch therefore appears to require that such iron-formation be mostly of nonmagnetic facies, or that a thickened section of greywacke-siltstone (member 2) is present in place of iron-formation; but the very broad high anomalies in the vicinity of Kinushseo and Lakitusaki Rivers may be due to magnetic facies more deeply buried than that farther west and south.

On the other hand it is perhaps possible that both anomalies and seismic "basement" reflect volcanic rocks, and that the upper surface of these volcanics dips southeastward. Some of the aeromagnetic anomalies to which the depth has been calculated would then be assumed to lie within the volcanic pile which could under this hypothesis include the 2 to 3 kilometres of basic rock necessary to account for the entire gravity anomaly (Innes et al., 1968). The overlying rocks, characterized by lower seismic velocity, would consist largely of Proterozoic greywacke analogous to the thick section of greywacke on Belcher Islands (Jackson, 1960).

To summarize the distribution of Proterozoic rocks it is proposed that these younger Precambrian rocks are thickest to the northeast of the line that follows the northeastern limits of shallow, short wavelength (Proterozoic type) iron-formation anomalies (upon which the distribution of map-unit 3b is based) from the coast of Hudson Bay north of Wachi to the coast of James Bay some 6 miles south of the mouth of Opinnagau River. Within this area Proterozoic greywacke, younger than the diabase unit 4, may be present over iron-formation; or the Proterozoic section may thicken predominately by increase in the proportion of carbonate rocks, unit 2. In the vicinity of this line magnetic facies of iron-formation to the southwest may change to nonmagnetic iron-formation facies or greywacke-siltstone to the northeast; however some broad anomalies to the northeast of this line may represent more deeply buried magnetic iron-formation. Volcanic rocks younger than iron-formation are thought to exist near the surface along the coast of Hudson Bay near Cape Henrietta Maria. A third alternative, which may account for the high gravity anomaly on the northeastern Cape Henrietta Maria Arch, suggests that the volcanic rocks are thick near the coast of Hudson Bay and extend southward at depth where they may be overlain by greywacke. These suggested relations are illustrated in hypothetical sections, Figure 5.

The southwestern limit of continuous Proterozoic cover is thought to lie close to the Sutton Ridges lineament projected from west of Nowashe Lake to Winisk River. Farther west it may follow the trace of a prominent east-west aeromagnetic lineament interpreted as a Precambrian fault. Southeast of Nowashe Lake the position of the southern limit of continuous Proterozoic cover is not known; still farther east (beneath James Bay) it eventually passes between Sunday and Bare Islands (Burns, 1952 reports granitic rocks on the latter). Large depths to basement determined seismically west of Akimiski Island (Hobson, 1968) admit the possibility that the Sutton Ridges Group may continue southward near the west coast of James Bay beneath Paleozoic rocks into the Moose River Basin. Outliers of Proterozoic rocks, which may exist west and south of the Archean-Proterozoic contact, will be discussed in conjunction with the Archean rocks.

Archean Rocks

Archean rocks are believed to lie at shallow depth beneath a thin cover of Paleozoic, and local outlying Proterozoic sediments in the southwestern third of the map-area beyond the southwestern limit of exposed Proterozoic rocks. They are exposed only in a small area near Opinnagau Lake.

Southwest of exposed Proterozoic rocks, aeromagnetic anomaly patterns characterized by more or less east-west oriented anomaly belts are present. Near Aquatuk Lake these east-west belts, with anomalies of relatively long wavelength, continue eastward through an area in which more or less isotropic patterns of shorter wavelength typical of Proterozoic iron-formation (exposed immediately to the north) are superimposed (see Fig. 14-6). Farther south, east-west anomaly belts strike directly into an area of exposed Archean rocks. The east-west anomaly belts along the southwest margin of exposed Proterozoic rocks therefore probably represent Archean rocks which can locally be recognized through thin Proterozoic cover by their differing anomaly pattern. The contrast in anomaly patterns in this area probably in part reflects the much higher degree of deformation and metamorphism which may be expected in the Archean rocks as contrasted with that evident in the Proterozoic rocks exposed nearby.

Along the Sutton Ridges lineament northwest of Aquatuk Lake there is a narrow belt of low aeromagnetic relief that separates exposed Proterozoic rocks from the eastern margin of the east-west (Archean type) anomaly pattern. Low aeromagnetic relief of this type suggests that rocks of low magnetic susceptibility lie close to the surface, most likely non-magnetic leucocratic Archean granite, or carbonate rocks of unit 2. The proximity of exposures of unit 2 to this belt of low aeromagnetic relief

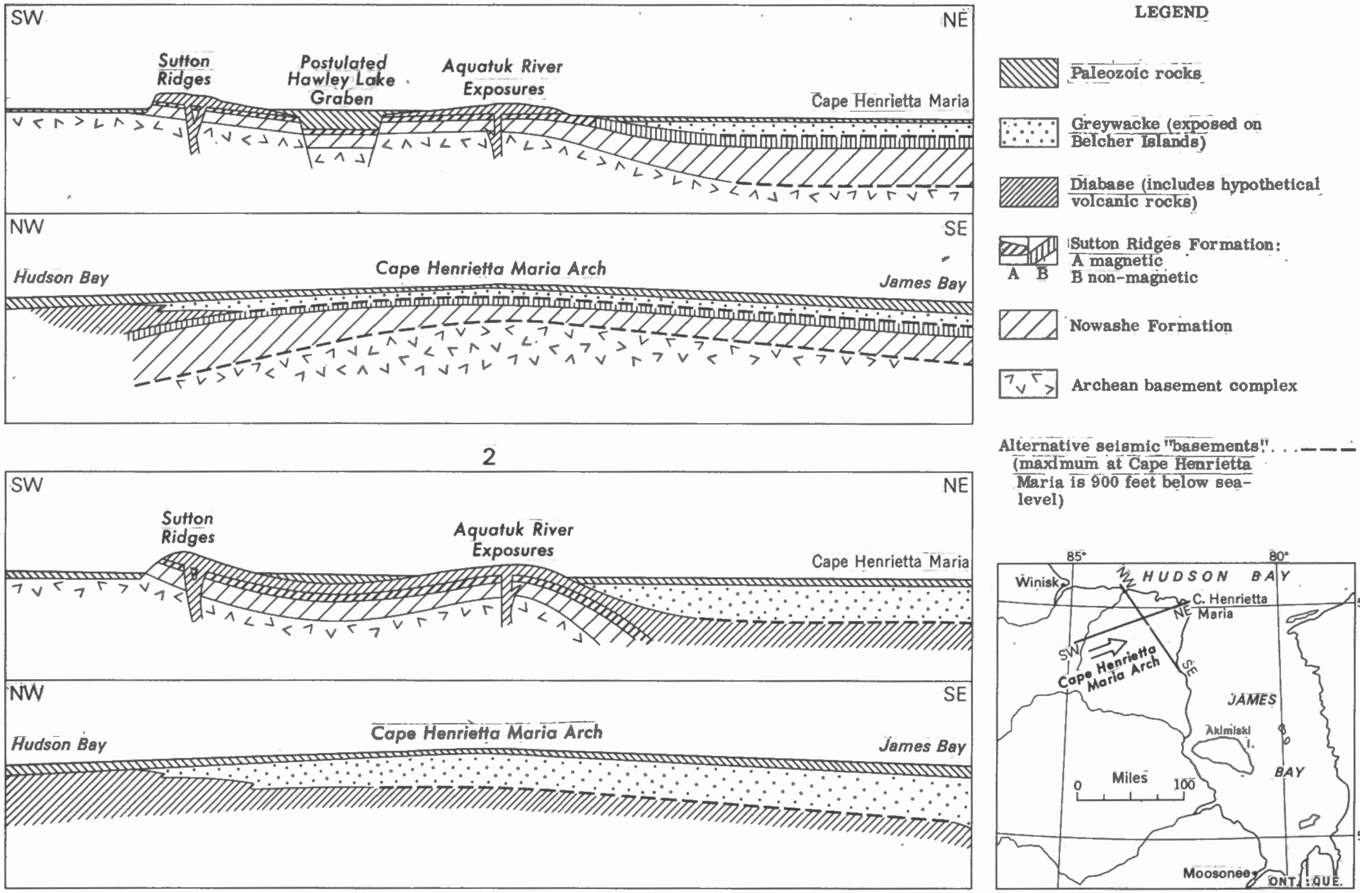

Figure 15. Hypothetical sections through Cape Henrietta Maria Arch illustrating alternative structures in Proterozoic rocks. GSC

however, favours the interpretation that the gradational but rather rapid attenuation of the east-west anomaly belts to the west results from a thickening section of overlying Proterozoic carbonate (unit 2). On this basis the Archean-Proterozoic contact has been projected northwestward along the line of attenuation of east-west anomaly belts as far as Winisk River.

North of Winisk inlier Proterozoic rocks (units 2 and 3) have been interpreted (see previous section); but the discussion suggests that they become thinner or have been removed by erosion farther south. Hobson's (1968, interpretation A) seismic data indicate that an important seismic unit may pinch out between the seismic station on Winisk River immediately south of Winisk inlier and that on Winisk River 8 miles west of the map-area. Within this interval, intersecting the line between seismic stations at a rather low angle, there exists a rather broad regional lineament composed of high anomalies on the north and somewhat irregular low anomalies on the south. This lineament separates an extensive region characterized by relatively higher uniform aeromagnetic relief in east-west oriented anomaly belts on the south, from a region of low relief in which anomalous areas of varied character are scattered to the north. Furthermore the lineament appears to truncate some anomaly trends in the southern region west of the map-area. Although the character of the lineament is complex, and other structural-lithologic features are probably responsible for its principal aeromagnetic characteristics, nevertheless the data allow that the lineament includes a Precambrian fault zone. The Archean-Proterozoic contact is therefore projected along a possible fault following the trace of the low aeromagnetic anomalies at the southern margin of the lineament eastward to the point where it crosses Winisk River.

In the southern part of the map-area north of Ekwan River, contorted but generally east-west trending anomalies, locally of very high magnetic intensity (over 15,000 gammas above background, see Fig. 14-9) are thought to indicate the presence of Archean iron-formation. These anomalies tend to be single, relatively broad, and curvilinear in contrast to the subisotropic, or multiple linear, relatively narrower anomalies which predominate in areas of exposed Proterozoic rocks. Such differences probably reflect higher metamorphic grade and closer folding to be expected in Archean rocks in comparison with those of Proterozoic age. Nevertheless, to the extent that it is possible (though there is no known supporting evidence within this part of the map-area) that east-west belts of Hudsonian folding and metamorphism exist in the southern part of the map-area even near exposures of undeformed Aphebian cover, the present interpretation can be regarded as a likely hypothesis only.

From the above argument it has been inferred that the more or less east-west oriented aeromagnetic anomaly patterns along the south and southwest limits of exposed and interpreted Proterozoic strata are due to Archean rocks. The area covered by similarly oriented anomalies extends southwestward to a major southeast-striking regional discontinuity that passes across the southwest corner of the map-area (see Fig. 14-8). This discontinuity is characterized by a linear aeromagnetic low and shows characteristic distortion of anomaly patterns on either side. For this reason it is interpreted as a fault of right lateral displacement (Ayres et al., 1969).

Where the east-west anomaly pattern can be seen through the subisotropic pattern due to Proterozoic iron-formation it may be interpreted with some confidence as due to Archean rocks. Farther west in the vicinity of the southwestern aeromagnetic discontinuity (beyond the map-area), the definition of east-west aeromagnetic anomaly trends becomes locally more distinct. This may reflect the presence of parallel oriented Proterozoic fold belts (see Ayres et al., 1969), or it may be due to a change in lithology or degree of alteration and deformation of Archean rocks near the bounding discontinuity. Near the southwest corner of the map-area, but north of the southwest boundary discontinuity an east-west trending belt of anomalies of distinctive character has been interpreted as perhaps due to gneisses of granulite metamorphic facies (C.K. Bell, pers. comm.; see Fig. 14-8). These gneisses lie on strike with retrograde Archean gneisses (unit 1a) exposed near Opinnagau Lake. If these gneisses are correlative to the suggested granulites farther west, and have undergone retrograde metamorphism during the Kenoran Orogeny, then there is an indication that a block of early Archean crust has been preserved in this part of the map-area.

Thin unfolded nonmagnetic remnants of Proterozoic rocks (likely composed of unit 2) may persist within the region of east-west anomaly trends without producing a readily detectable change in the aeromagnetic pattern. To the extent that these rocks become thicker they may be expected to broaden and reduce the intensity of aeromagnetic anomalies due to Archean rocks. This type of change is evident immediately southwest of Opinnagau Lake where seismic depth to basement is large (Hobson, 1968; 569 feet below sea level as corrected). The section of combined Paleozoic and Proterozoic sediments suggested is 716 feet. An outlier of carbonate rocks (unit 2) lying beneath Paleozoic cover has therefore been suggested in this region.

Summary of Faulting

Two interpreted fault zones, one near Winisk River and the other in the southwest corner of the map-area, produce clearly defined aeromagnetic lineaments. The southwestern of these zones is characterized by peripheral drag shown by aeromagnetic anomalies that suggest right lateral movement, but the magnitude of movement is not known.

A further series of lesser, north- to northwest-striking faults, which are commonly not followed by aeromagnetic lows, has been inferred mainly from abrupt discontinuities in aeromagnetic patterns along the margins of areas underlain by magnetic iron-formation in the southeastern part of the map-area. Direct evidence for such faulting may be found in the observation of "at least three southerly striking faults" on Bear Island by Burns (1952); and in the abrupt change in lithology and attitude of Aphebian sediments on either side of Nowashe Lake. These faults do not disrupt aeromagnetic trends in the basement even where the projected fault intersects such trends at high angles. Nor do these faults affect attenuation of aeromagnetic patterns on one or other side of their projections beyond areas underlain by iron-formation. It seems likely therefore that movement along them has been relatively small, but that vertical displacements up to several hundred feet, sufficient to produce differential preservation of nearly flat-lying iron-formation may have occurred. Distribution of diabase exposures in northwest oriented groups strongly suggests that fractures of this orientation have localized emplacement of diabase.

ECONOMIC GEOLOGY

IRON

Aeromagnetic anomalies suggest that Archean magnetic iron-formation is present in the southern part of the map-area and one anomaly in particular merits further investigation if iron ore is sought. This anomaly extends some 10 miles in an arc concave to the southwest from 53°38'N, 83°29' W to 53°32'N, 83°17'W, and reaches a maximum approximately 31,000 gammas above local aeromagnetic background. A depth calculation made at a point near the north end of the anomaly indicates that the iron-bearing rocks there may be at or near the surface. Frost-heaved Paleozoic rocks and smaller fragments of Precambrian slate and greywacke (L.M. Cumming pers. comm.) are present at the surface less than a mile north or the northern edge of the anomaly.

Hawley (1926) reports that iron-formation in the Sutton Lake region varies in thickness from 10 to about 100 feet. Examination of the exposures near Aquatuk River suggests that similar thicknesses are present farther north on the Cape Henrietta Maria Arch. Steel grey beds rich (up to 68 per cent iron, Dowling, 1905) in magnetite-hematite, though distributed through the section are thin and make up only a small part of it. Hawley estimated that the average content of iron in the best section at Sutton Narrows is not over 30 per cent and the present work suggests that it is typically less elsewhere.

The absence of secondary iron enrichment was noted by Hawley (1926) and none was observed during the present work. Furthermore it is evident that the iron-bearing rocks were covered by Silurian sediments during most of the Phanerozoic Eon, and insofar as these may have prevented the downward circulation of groundwater during favourable periods of surface weathering the prospect that enriched Proterozoic iron-formation is present in areas covered by overburden appears unfavourable.

AMPHIBOLE ASBESTOS

Amphibole asbestos (crocidolite) is associated with riebeckite occurrences in Precambrian iron-formations in Australia (Trendall, 1966); at Knob Lake (Conn, 1961), and although no fibrous riebeckite was observed at the outcrop examined near James Bay it is possible that some has developed in surrounding areas. Nevertheless the prospect appears poor because iron-formation of unit 3 is chiefly granular and no commercial deposits have so far been found in granular riebeckitic iron-formation. Furthermore the development of fibre elsewhere appears to require deformation of favourable beds at a critical period during diagenesis. Such deformation is not evident in the outcrops examined.

COPPER

Hawley (1926) observed that fracturing of the Proterozoic rocks in the Sutton Ridges area was most common and veins most abundant in close proximity to Sutton Lake. He describes a quartz-calcite vein on the portage between Sutton and Hawley Lakes carrying considerable chalcopyrite with small amounts of pyrite, bornite and occasional malachite and azurite. The vein averages 2 inches in width but its length is unknown.

Hawley (1926) also reported small amounts of pyrite and chalcopyrite occurring in calcite veins associated with a small trap sill at the "North Narrows" on Hawley Lake. He reported the same minerals as forming many tiny veins in a chert bed 1 1/2 inches thick 25 feet below diabase one quarter mile north of Sutton Narrows.

The association between copper mineralization and intrusion of the diabase at Sutton Ridges was suggested by Hawley (1926). Insofar as diabase bodies at Sutton Lake and near Aquatuk River may be part of an extensive sill system centred about Hawley Lake, the prospect that similar and perhaps better developed copper mineralization occurs within these limits appears possible. Such mineralization will however be covered by glacial deposits and likely by Paleozoic limestones. Adequate evaluation of the area will therefore require geophysical methods and drilling.

LEAD-ZINC

Direct evidence of lead-zinc deposition within Aquatuk River map-area has not been found, but might hardly be expected in view of the small area of bedrock exposed. Nevertheless the presence of the Cape Henrietta Maria Arch, a basement high throughout early Paleozoic (see Norris and Sanford, 1968), and probably much of Proterozoic time, overlapped by sedimentary formations in large part carbonate with which several unconformities are associated, provides a possible initial target for prospecting for these metals (for comparison with the southeast Missouri lead district and description of similar structures as prospecting guides see: Snyder and Gerdemann, 1969; Callahan, 1967).

Insofar as the Proterozoic rocks are concerned, lead-zinc mineralization is known in the Manitounuk Group south of Richmond Gulf near the east coast of Hudson Bay where it occurs as disseminated deposits at several localities (Stevenson, 1968). Possible correlation of the Manitounuk Group with the Sutton Ridges and Nowashe Formations may therefore suggest the presence of lead-zinc within the Proterozoic basin at the time the latter formation was being deposited. If this is true two further features of Aquatuk River map-area are of particular interest: the unconformities above and below the Nowashe Formation, and the possible deepening of the Proterozoic basin (and accompanying facies changes?) along the northeast limits of magnetic iron-formation (unit 3b, Fig. 16) as interpreted from aeromagnetic maps. Further investigation of these features appears worthwhile if lead-zinc deposits are sought.

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