69-24

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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PRECAMBRIAN ROCKS OF DEER RIVER MAP-AREA, MANITOBA (54E, F, K, L)

(Report and 12 figures)

H. H. Bostock

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ABSTRACT

Deer River map-area lies between 57° and 59°N and 92° and 96°W.

The oldest rocks are folded basic to acid volcanic and associated sedimentary rocks mostly in the almandine-amphibolite metamorphic facies. Hybrid rocks derived from the volcanics and sediments, were formed during emplacement of later plutonic rocks that range from quartz diorite to granite. K/Ar age determinations on muscovite and biotite from a granodiorite on South Knife River are 1,660 and 1,670 ± 55 m.y. respectively.

Clastic sediments are folded and have undergone lower to upper greenschist facies metamorphism but are not known to be intruded by granitic rocks.

Aeromagnetic anomaly patterns suggest that diabase belonging to the Mackenzie dyke swarm intrudes the granitic rocks but no outcrops of diabase are known.

Precambrian rocks are nonconformably overlain by nearly flat lying, predominantly carbonate rocks of lower Paleozoic age.

Two occurrences of fluorite in granitic rocks are reported. A calcareous metasiltstone bearing laminae of hyalophane and uvarovite with associated chromite, is described.

PRECAMBRIAN ROCKS OF DEER RIVER MAP-AREA, MANITOBA

INTRODUCTION

LOCATION AND ACCESSIBILITY

Deer River map-area lies on the southwest margin of Hudson Bay between latitudes 57° and 59°N and longitudes 92° and 96°W. The Canadian National Railways line from Winnipeg to Churchill bisects the area from south to north. Churchill is also served by Trans Air which operates daily flights on a year round basis from Winnipeg through The Pas and Thompson, Manitoba. Lamb Airways with main base at Thompson, Manitoba, operates small aircraft from Churchill airport and from Farnworth (Landing) Lake a few miles by road southwest of Churchill.

Good gravel roads extend between Churchill and a rocket range about 10 miles east along the coast. Comparable roads connect Churchill with the wharves, and also with Farnworth Lake a few miles to the southeast. A road of lower quality extends south for 16 miles from the rocket range to Twin Lakes. Winter roads connect the railroad near Herchmer and the junction of Churchill and Little Churchill rivers; and connect Churchill and Nueltin Lake via Caribou and Little Duck lakes (northwest of the Deer River map-area).

Lakes suitable for float plane landings are widely scattered throughout the map-area but along much of the coast there is a zone some 15 miles wide in which lakes are absent or too small for landing. In the northwest quarter of the area, where outcrops are most numerous, many lakes are too small or too shallow for all but the smallest aircraft. Landings are possible on parts of Seal and Churchill rivers but over most of the latter the current is swift enough to render landings hazardous. Break-up of Farnworth Lake varies from the first week in June to the first week in July.

The larger streams are navigable by canoe but the smaller creeks tend to be obstructed by fallen trees and log jams. The lower Churchill River was for some years used as an access route to the interior by the fur trade but its swift current, rapids at Portage Chute, and the persistence of ice along its banks late into the summer induced many early travellers to portage from the Churchill near its junction with Little Churchill River to the headwaters of Deer River. The latter returns by a somewhat easier course to the Churchill estuary some 25 miles above Churchill.

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Tide range along the coast is about 12 feet and this combined with the very gently sloping, boulder-strewn character of the shore, makes reconnaissance of the coast by boat difficult.

GEOLOGICAL INVESTIGATIONS

Previous Work

The first geological exploration within the map-area was by Robert Bell in 1878 (Bell, 1881) who examined outcrops along the Churchill River. He reported the presence of coarse, greyish red to light reddish syenitic gneiss, in some parts porphyritic, passing into a somewhat fine-grained red gneiss, which resembles hard altered red sandstone, for 23 miles upstream from the junction of Little Churchill River. Downstream from this junction he noted the same locally porphyritic reddish syenitic gneiss in which "the strike could hardly be recognized". Three miles upstream from Portage Chute the syenitic gneiss was found to be overlain by rather coarse, greyish, rusty, flat-lying sandstone. The latter constitutes the lower member of the Portage Chute Formation (Nelson, 1963) of Middle (?) or Upper Ordovician age. Farther downstream and higher in the section Bell noted very "crumbling" earthy limestone giving way to less earthy, dolomitic rocks. Bell examined subgreywacke, quartzite and conglomerate outcropping in the vicinity of Churchill and suggested that, "as a convenient name for present purposes they might be called the Churchill Quartzites". He noted a prominent subsidiary fold structure that surrounds Churchill Harbour and suggested that it might be an anticline. He compared the 'Churchill Quartzites' with similar rocks in Nova Scotia. Among other observations Bell noted boulders in Button Bay and Churchill estuary that included rocks that he compared to "the unaltered group of the east coast of Hudson Bay in the neighbourhood of Manitounuk and Nastapoka Sounds".

J.B. Tyrrell (1898) visited Churchill on returning from his epic exploration of the interior via the west coast of Hudson Bay. He observed ripple-marks and the abundance of crossbedding in the 'Churchill Quartzites' which he believed to be feldspathic. He also noted that fragments of red 'Cambrian' (probably Proterozoic) rocks are present along the coast of Hudson Bay to the north but that they diminish in size and number toward Churchill. He remarked on the absence of similar rocks in gravel banks along Deer River.

O'Sullivan (1906) explored Deer River reporting yellowish limestone in the river bed 87 miles below Deer Lake and suggested it extended to the confluence with the Churchill River. McInnes (1913) remarked on the presence in the valleys of the Hayes and Nelson rivers of boulders resembling rocks of Proterozoic age that occur along the eastern shores of Hudson Bay.

Shortly afterward Alcock (1916) examined the rocks of the lower Churchill River region and his descriptions of both the Precambrian and Paleozoic rocks agree with those of earlier explorers.

Savage and Van Tuyl (1919) made observations on Paleozoic rocks along Nelson River immediately south of the map-area. They divided the Paleozoic rocks there into: – Nelson River and Shamattawa formations of Ordovician age; and Port Nelson Formation of Silurian age.

Miller and Youngquist (1947) described fossils collected near Churchill and suggested that Ordovician strata occur along both North and South Knife rivers.

Williams (1948) examined the 'Churchill Quartzites' and noted that they are commonly made up of about 70 per cent fairly well rounded quartz and 30 per cent interstitial sericite. No feldspar or ferromagnesian minerals were noted. A quartzite pebble included in these rocks was found to be composed of 95 per cent quartz and 5 per cent sericite. He suggested that the structure surrounding the harbour, if not overturned, is a syncline. From a study of the drift he suggested that Silurian rocks underlie the immediate Churchill area.

Nelson (1963) described Ordovician and Silurian formations on Nelson, Churchill, North and South Knife rivers. He suggested that Churchill River be selected as the type section for the Ordovician rocks and divided the section (from bottom upward) as follows: – Portage Chute and Surprise Creek formations of the Bad Cache Rapids Group; Caution Creek and Chasm Creek formations of the Churchill River Group; and Red Head Rapids Formation. The overlying Silurian rocks were assigned to the Port Nelson Formation.

In 1961 Kennco Explorations (Canada) Ltd. drilled a vertical diamond-drill hole (Kennco No. 5) at 57°09'N, 93°14'W, or about 9 miles northwest of North Seal Creek in the southeast corner of the map-area. The hole penetrated 337 feet of overburden, and 516 feet of Paleozoic rocks of which the basal 4.6 feet are sandstone and the remainder carbonate rock. Log records show that 101.4 feet of Precambrian rock were penetrated commencing at 636 feet below sea level. From top to bottom these include: 22.4 feet of altered basic rock, andesitic or quartz dioritic near the top and gabbroic near the bottom; 25 feet of fine-grained grey gneiss with occasional thin bands of epidotized granitic gneiss 22 feet of dioritic gneiss, and 32 feet of granodioritic gneiss. Muscovite from a sample of the granodioritic gneiss has been dated by the K-Ar method at 1,665 m.y. (Stockwell, in Lowdon et al., 1963).

Hobson (1967) made two refraction seismic profiles in the Nelson River region which indicated that drift may be 500 feet thick along the coast north of the Nelson estuary and that Paleozoic rocks may be 1,855 feet thick.

Field Work

The Deer River map-area was mapped in 1967 as part of Operation Winisk, a helicopter-supported mapping project that covered the Hudson Bay Lowlands and adjacent Precambrian terrain. Work started August 15th and ended August 30th.

Members of the Geological Survey of Canada participating in Operation Winisk within the Deer River map-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 provides a final report on the Precambrian rocks of the Deer River area in detail commensurate with the time and area involved in Operation Winisk. It is intended to complement final reports to be published on stratigraphy and paleontology of the Paleozoic rocks, and on the Pleistocene geology by the officers concerned (see previous paragraph).

Delineation of contacts within areas underlain by Paleozoic rocks are largely the product of their work. A preliminary report on Operation Winisk is in Sanford, Norris and Bostock (1968).

Traversing in the area was carried out with the aid of a Bell 47G-4 helicopter, however low drift-covered areas when possible were first reconnoitred for outcrop by Cessna-180. Paleozoic sections on Churchill, and on North and South Knife rivers were traversed by inflatable rubber boats. Outcrops accessible by road were examined with the aid of trucks rented at Churchill.

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance and information provided by other members of the staff of the Geological Survey of Canada who participated in Operation Winisk. 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; Spectrographic Analyses - K.A. Church; Mineral Identification by X-ray powder diffraction - M. Bonardi; Clay mineral analysis - R.N. Delabio; Electron probe analysis - G. Plant.

TOPOGRAPHY AND DRAINAGE

Deer River map-area lies at the northwest extremity of the Hudson Bay Lowlands. Like most parts of the Lowlands it is extensively drift-covered with maximum depths of overburden probably approaching 500 feet near Nelson River estuary (Hobson, 1967). Drainage is entirely eastward into Hudson Bay.

The southwestern third of the map-area is topographically higher than the remainder and is outlined by a prominent arcuate raised beach concave to the southwest. Marine shells along this beach at 465 feet above sea level, probably a few tens of feet below marine limit, have a radiocarbon age of 7,270 $\pm$ 120 years (Dyck and Fyles, 1964). Behind this beach, near the south border of the map-area, the land surface rises with the slope reaching about 100 feet per mile but northwest of Churchill River the slope is less pronounced. Throughout the southwest quarter of the map-area the highland surface is very gently rolling with hill tops between 700 and 800 feet above sea level. Maximum elevation is just over 800 feet near the centre of the western margin of the map-area. The highland is deeply incised by Churchill and Little Churchill rivers along which the tree covered banks are commonly at least 200 feet high.

Lowlands, which lie east and northeast of the prominent raised beach, are interrupted only in the Churchill region. There subgreywacke of unit 5 forms bare, ice-rounded, wave-washed hills with summits up to a little more than 150 feet above sea level. Southeast of Churchill at Twin Lakes, glacial deposits form a small elevated area up to about 125 feet above sea level. Lesser topographic features are raised spits and beaches. With these exceptions the southern lowland plain rises gradually to the base of the prominent raised beach where maximum elevations near 400 feet are reached.

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* From sections measured on Churchill River after Nelson (1963)

x Maximum estimates based on data from Operation Winisk

The two physiographic regions are least distinct in the northwestern part of the map-area where they merge in a gentle northeastward slope. North of the dividing beach scattered outcrops appear in stream beds, along lake shores and as low rounded knobs projecting through the muskeg. North of North Knife River, near Seal River, and along the west margin of the map-area boulder fields become increasingly common.

GENERAL GEOLOGY

INTRODUCTION

The oldest rocks (1) in Deer River map-area are of Precambrian age (Aphebian or earlier), and include acid to basic volcanic rocks and siltstones now partly in the greenschist but mostly in the lower almandine-amphibolite facies. They are intruded by granitic rocks, and locally have been subjected to migmatization.

Slightly to moderately altered plutonic rocks (2, 3 and 4) comprise massive granite, quartz monzonite, granodiorite, and quartz diorite. Hybrid rocks are in part derived from unit 1 and are typically deformed. Biotite and muscovite concentrates from slightly altered quartz monzonite on South Knife River have K-Ar ages of 1, 670 $\pm$ 55 and 1, 660 $\pm$ 55 m.y. respectively.

Clastic sediments presumably of younger Precambrian age, including rocks called "the Quartzites at Churchill" by Bell (1881), are here referred to as unit 5. They are folded and have undergone lower to upper greenschist facies metamorphism, but are not known to be intruded by granitic rocks.

At least one diabase dyke (6), although not observed in outcrop, is suggested by aeromagnetic anomaly trends. This dyke strikes northwestward and is therefore compatible with the Mackenzie dyke swarm (about 1, 200 m.y., Fahrig et al., 1965).

Precambrian rocks are nonconformably overlain by nearly flat lying, predominantly carbonate rocks of lower Paleozoic age. These include the Bad Cache Rapids Group (7), and the Churchill River Group (8) of late Middle (?) and Upper Ordovician age; and the Severn River (9) and Ekwan River (10) formations of Middle Silurian age.

Glacial and postglacial marine and alluvial deposits (11) are extensive and up to 500 feet thick.

PRECAMBRIAN ROCKS

Pre-Granitic Metamorphic Rocks (Unit 1)

Mafic volcanic rocks (1a)

Mafic rocks of volcanic origin (1a) form the greater part of a remnant up to 4 miles wide that extends for 8 miles southwestward from the north margin of the map-area along Seal River. To the west of these volcanic rocks is a narrower belt of metasedimentary rocks (1c).

The mafic volcanic rocks consist primarily of fine-grained, dark green, massive to slightly schistose amphibolite with intercalated masses of medium-grained, dark green hornblende gabbro. Breccias, probably flow breccias, and thin interbedded mafic, pyrrhotite-bearing metasiltstone beds are also present.

In thin section the amphibolite is seen to consist chiefly of hornblende with pleochroic formula: x- pale yellow ochre, y- olive green, and z- green to blue-green. Lesser amounts of calcic oligoclase and/or epidote are seen, and quartz is present in some specimens. Sphene, leucoxene, apatite, opaque minerals, and locally carbonate are accessory minerals. Pale green chlorite is associated with local veins and fractures.

The presence of metamorphic hornblende and calcic oligoclase indicates that these rocks are at least in the upper greenschist facies of metamorphism. The presence of the diopside-tremolite-epidote assemblages in metasiltstone (1c) immediately west of these volcanic rocks, and migmatization along their eastern and southern borders suggests that they probably are in the lower almandine-amphibolite facies.

Folding of the mafic volcanic rocks along northward-trending axes is suggested by thin, steeply dipping interbedded mafic metasiltstones, and by local vertical schistosity. Along the southern margin of the remnant the above trends merge with a southeasterly trending zone of hybrid, recrystallized, irregularly gneissic rocks partly derived from unit 1. Along the east margin however, amphibolite is intruded by leucocratic granitic rocks with less obvious recrystallization and development of gneissosity. This relationship indicates that the mafic volcanic rocks are older than the surrounding plutonic rocks.

Acid to intermediate volcanic rocks (1b)

Acid to intermediate volcanic rocks are present near and along Seal River in a large remnant that extends eastward for about 16 miles from the west margin of the map-area. At the west margin of the area it may be as much as 10 miles wide but to the east the pattern of aeromagnetic anomalies suggests that it tapers out. The easternmost known outcrop is on Seal River about 8 miles from the west margin of the map-area.

The acidic rocks, which occur southwest of Seal River, are foliated, fine grained, and pink to grey, with quartz phenocrysts up to 1 1/2 mm in diameter, and less abundant pink feldspar phenocrysts up to 3 mm or more. The intermediate rocks, along Seal River, are slightly darker coloured with subacicular amphibole. To the northeast, close to plutonic rocks, massive, fine-grained biotite-quartz-feldspar rock is present.

In thin section the acid volcanic rocks are seen to consist chiefly of a fine-grained mosaic of quartz and alkali feldspar including twinned albite. Minor chlorite, muscovite, and a few minute flakes of biotite were observed. Phenocrysts of recrystallized quartz, commonly 1.5 mm in diameter and altered, and untwinned alkali feldspar phenocrysts up to 3 mm in diameter are moderately abundant. Fine-grained intermediate volcanic rocks have as major constituents calcic oligoclase, quartz, biotite and porphyroblastic hornblende in needles up to 2 mm in length. The latter have pleochroic formula: x- pale yellow-ochre, y- deep olive-green, z- deep blue-green, and an optic axial angle smaller than that in the basic volcanic rocks. Massive, fine-grained biotite-quartz-feldspar rock near the northeast margin of the remnant contains oligoclase porphyroblasts up to 1.5 mm in length.

That metamorphism of intermediate volcanic rocks (1b) along Seal River reached at least the upper greenschist facies is suggested by the growth of porphyroblastic hornblende and the presence of oligoclase. Acid volcanic rocks near the southwest margin of the remnant may be of lower metamorphic grade because albitic plagioclase is present and amphibole absent. Fine-grained, massive, granitic rocks, found at two places within the north and central-western parts of the remnant are probably recrystallized equivalents of unit 1b.

Foliation, which is common in rocks of unit 1b, strikes nearly east and dips steeply both north and south. Locally intermediate volcanic rocks are intruded by fine-grained dykes relatively richer in amphibole. Along Seal River they are cut by small bodies of granitic rock. On a rocky island in Seal River, 11 1/2 miles east of the west boundary of the area mapped, a granitic dyke cuts rocks of intermediate composition believed to be of volcanic origin (1b), and is in contact with a basic dyke which also cuts the intermediate rocks. Where the dykes are in contact basic schlieren are present in the granitic rocks and the basic dyke appears to be recrystallized. In some places massive fine-grained leucocratic to mesocratic rocks appear to have been derived from rocks of unit 1b by recrystallization. These relationships indicate that unit 1b is older than the granitic rocks to the north.

Sedimentary rocks (1c)

Pre-granitic metamorphic rocks of sedimentary origin (1c) are present in the northwestern part of the map-area at two places along Seal River. The westernmost of these, as suggested by aeromagnetic data, forms a belt 8 miles long and less than one mile wide. Outcrops are present only at the southwestern extremity of this belt. Farther down Seal River unit 1c forms a second belt with intermittent outcrop, less than one mile wide, along the west margin of basic volcanic rocks (1a).

The westernmost of these sedimentary rocks were observed at three outcrops. The farthest downstream of these outcrops is composed chiefly of cream to grey, laminated metasiltstone with a few dark green beds. The rocks are fine grained and in outcrop, appear to be nonporphyroblastic but microscope study reveals small garnet porphyroblasts. A little over one mile upstream, on the opposite bank of the river, similar rocks in a low-lying outcrop, are phyllitic with small, dark green, chlorite porphyroblasts in some beds. About 3 miles farther upstream the rocks are schistose and garnets are readily visible.

As seen in thin section, specimens from all three exposures are fine grained with garnet porphyroblasts. However there is a progressive westward increase in grain size of both porphyroblasts and matrix with garnets reaching 1 mm or slightly more in the westernmost exposure. Angular quartz, biotite, chlorite, and garnet are common to all specimens. Calcic albite is present in the specimen from the eastern outcrop whereas calcic oligoclase is present in that from the west. Sericite and a few grains of potash feldspar occur in specimens from the middle and eastern exposure. Unknown opaque minerals, pyrite, zircon, tourmaline, and sphene-leucoxene are present in one or more specimens.

The metamorphic grade of sedimentary rocks (1c) on upper Seal River increases westward. This is indicated by increase in grain size, increase in foliation, and changes in mineralogy in that direction. Rocks in the eastern outcrop, as suggested by the quartz-biotite-chlorite-garnet-albite assemblage are at upper greenschist facies, whereas the appearance of calcic oligoclase in the rocks from the western outcrop suggests that the rocks there may have reached lower almandine amphibole facies. More detailed investigations may indicate that metamorphism of map-units 1b and 1c in this region is related to emplacement of granitic rocks in the northwest corner of the map-area.

Dips in unit 1c on upper Seal River are moderate to steep and increase westward. Foliation, dipping more steeply than bedding, is apparent in the eastern outcrops. The three attitudes obtained suggest the presence of a synform whose axis bends sharply northward down the valley of Seal River.

On lower Seal River metasedimentary rocks lie along the west margin of a remnant of basic volcanic rocks (1a). These rocks were examined west of Seal River near the north margin of the map-area, and again about 2 miles south of Seal River. At the former locality fine-grained laminated metasiltstone consists of dark green and light grey laminae with local pyrrhotite concentrations. A foliated, dark green bed is seen in thin section to consist primarily of hornblende similar to that in the massive amphibolites of unit 1a. This bed is however, distinct from the massive amphibolites in containing a little biotite, and more epidote and quartz; calcic oligoclase, opaque minerals, and sphene are lesser components. Similar metasiltstones at the south end of the belt include in addition some grey, quartz-rich, metasiltstone-bearing lenses and laminae of bright, emerald-green garnet (uvarovite) up to two millimetres thick.

Under the microscope the normal laminated metasiltstone was found to contain hornblende (similar to that of the massive amphibolite), quartz, calcic oligoclase, and smaller amounts of biotite with accessory leucoxene, apatite, chlorite and unknown opaque minerals. The grey metasiltstone, however, consists of quartz-rich laminae that alternate with laminae of varied mineralogy. The latter chiefly contain quartz, diopside, garnet, tremolite and clinozoisite. Bright green uvarovite (CaO 14%, Fe total 10%, Cr_2O_3 10%, MnO 6% by semiquantitative spectrographic analysis), or hyalophane (barium-potassium feldspar 8-9% BaO by electron probe analysis, form major constituents of individual laminae. Scattered chromite ~~grains~~ are associated with laminae containing uvarovite. More rarely, an epidote-like mineral, possibly tawmawite (chromium-bearing epidote) with small or moderate negative 2V and distinctive green and orange pleochroism has developed near chromite grains. Clinozoisite is associated with diopside-tremolite laminae. Brown, pleochroic sphene is unusually abundant in some laminae and apatite and zircon are accessory minerals.

The calc-silicate bearing metasiltstone is in the lower almandine-amphibolite metamorphic facies (Turner and Verhoogen, 1960) as indicated by the assemblage diopside-tremolite-epidote. The normal metasiltstone, which contains calcic oligoclase-blue-green hornblende-epidote, is at least locally (adjacent to the calc-silicate metasiltstone) and probably elsewhere, in the same metamorphic facies.

Metasedimentary rocks of unit 1c at the north and south limits of the remnant on lower Seal River dip eastward from 70 to 75 degrees. Rocks of apparently similar attitude and lithology were observed from the air in the central part of the remnant and it is therefore considered that the metasediments are continuous along the west margin of the massive amphibolite (1a). The structural relationship between units 1a and 1c, however, is not known.

Metasedimentary rocks of unit 1c are believed to be of the same general age as the metavolcanic rocks (1a and 1b) with which they are both spatially and lithologically associated. Direct evidence of the sequence in which they were deposited is lacking. On upper Seal River unit 1c appears to increase in metamorphic grade toward the granitic rocks exposed in the northwest, whereas on lower Seal River similar rocks are migmatized and intruded by granitic rocks. Unit 1c is therefore considered older than the granitic rocks (3).

Paragneiss (1d)

Regularly bedded paragneiss, lithologically distinct from other metasediments of unit 1 and from metasedimentary remnants observed in hybrid rocks (unit 4), is present at two outcrops on South Knife River near the west margin of the map-area. Most of the outcrop is at or near water level with the quartz-rich parts and pegmatite forming distinct ridges.

Approximately 500 feet of southward-dipping, micaceous to quartzitic paragneiss is exposed in beds up to 8 to 10 feet thick. Both muscovite and biotite are present in most beds and biotite is abundant in some. In a few beds pale pink garnet is present with biotite. Muscovite porphyroblasts with numerous quartz inclusions, up to 1/2 inch in diameter, are present in some quartzofeldspathic beds. A drag fold, indicating upward movement of beds to the north, plunges 15 degrees eastward near the southern end of the most prominent outcrop. The same outcrop is intruded, parallel to bedding, by a pegmatite dyke 8 feet thick.

Under the microscope this paragneiss is fine to medium grained, anhedral, and equigranular to seriate or porphyroblastic. Quartz content is between 85 and 90 per cent in some beds but is much less in others. Microcline-rich beds contain some reversely zoned plagioclase with oligoclase rims and altered albitic cores. Biotite and muscovite are minor to major constituents but garnet is present only in some beds. Cordierite and a few acicular grains with positive elongation resembling sillimanite were observed in a quartz-rich bed. Zircon is the only common accessory mineral.

The assemblage quartz-microcline-biotite-oligoclase-cordierite indicates that the paragneiss has undergone almandine-amphibolite facies metamorphism (Turner and Verhoogen, 1960). The presence of sillimanite would indicate that upper almandine amphibolite facies has been reached.

Paragneiss (1d) is thought to be older than granitic rocks (3) because it is cut by pegmatite which is presumably related to granitic rocks (K-Ar age 1,660-1,670 m.y.) that are exposed about 2 miles to the east on South Knife River. The paragneiss may be related to similar gneisses mapped by Taylor (1958) approximately on strike 20 miles away in the Shethanei Lake map-area to the west.

Dioritic Plutonic Rocks (Unit 2)

Quartz diorite (2b) and granodiorite (2a) are exposed chiefly in the region surrounding the mafic volcanic rocks north and south of Seal River along the northern margin of the map-area. They are also present in small remnants of hybrid rocks (4) on Churchill and Little Beaver rivers.

The dioritic rocks are chiefly medium grained and grey to grey-green. Weathered exposures are grey or white where they have been periodically covered by swamp waters.

Under the microscope the dioritic rocks show average grain size ranging from about 1 to 4 mm. Textures are subhedral to anhedral and equigranular to slightly porphyroblastic. Serrated grain boundaries, large quartz grains reduced to a mosaic of finer interlocking grains, and slight to moderate foliation, are common features.

The dioritic rocks are characterized by the presence of plagioclase (An_4 to An_{44}), quartz, and biotite. Of 15 specimens examined, 8 contained calcic oligoclase as the major mineral, 3 contained andesine, 2 contained sodic oligoclase, and 2 contained albite. Microcline is present in the granodiorite but is absent from some quartz diorite. Although chlorite and epidote are very common in most specimens they are absent from some. Hornblende with pleochroic formula: x- pale yellow-ochre, y- olive-green, z- blue-green, is relatively rare and epidote appears instead in many thin sections. Muscovite is present in some granodiorite near Seal River. Carbonate, though rarer, forms up to several per cent in some specimens. Apatite, zircon, sphene and opaque minerals are common accessories.

The wide range in plagioclase compositions, extensive formation of chlorite and epidote, and the local appearance of appreciable carbonate in the dioritic rocks indicates that they have undergone extensive but variable alteration. This widespread alteration, and the local existence of agmatite composed of dioritic fragments in a granitic matrix, suggest that the dioritic rocks formed before emplacement of the granitic rocks.

Granitic Plutonic Rocks (Unit 3)

This map-unit includes quartz-bearing chiefly phaneritic rocks in which approximately one third or more of the feldspar is microcline. The map-unit therefore includes granite, quartz monzonite, and granodiorite which are differentiated only where observed on the ground. Granodiorite (3c) is probably more leucocratic than granodiorite (2a) but because the rocks appear to be intergradational in composition, and because air observations are hampered by the nature of the weathered surface and the type of lichen cover, this degree of overlap in units 2 and 3 has been adopted.

The granitic plutonic rocks outcrop mainly in two large areas: (1) between Seal River and North Knife River in the northern part of the map-area and (2) along Churchill River in the southern part of the map-area. Smaller bodies are present north of Seal River in the northwest corner of the map-area, on Seal River west of the basic volcanic rocks, on South Knife River, on Little Beaver River, and on Little Churchill River at the south margin of the map-area. Although the early explorers (Bell, 1881; Alcock, 1916) reported syenite along the Churchill River none was seen during the present survey.

The granitic rocks are fine to coarse grained, and grey-white to pinkish buff or red. Typically they weather grey to red but low outcrops in swampy areas commonly have a bright white surface. Outcrops along rivers are typically stained black. At places along Churchill River the granite is subporphyritic to porphyritic and at Portage Chute microcline phenocrysts have slight preferred orientations. Elsewhere the rock is more or less equigranular. Inclusions, schlieren or segregations of granodioritic composition were noted at some outcrops, and slight foliation is present at many.

Under the microscope the majority of granitic rocks are fine grained to medium grained with most showing average grain size 3 mm or less. Coarse-grained rocks with average grain size 5 mm or greater are found chiefly in the northern part of the area along and near North Knife River where it approaches the Paleozoic-Precambrian contact. With the exception of subporphyritic rocks noted above, textures are subhedral to anhedral and equigranular to seriate.

The granitic rocks are characterized by the presence of quartz, microcline, plagioclase (An_3 to An_{26}) and biotite. Chlorite with grey or anomalous blue birefringence is present in small to moderate amounts in almost all specimens examined. Muscovite is most common in granitic rocks in the northern part of the area near Seal River, and on South Knife River, but is also present locally on Little Beaver River and Churchill River. Hornblende and epidote are rarer but either may be present at widely scattered localities. Where observed hornblende has pleochroic formula: x- pale yellow-ochre, y- olive-green, z- deep blue-green. Apatite, zircon and opaque minerals are ubiquitous accessory minerals. Sphene is common and carbonate and leucoxene less so. Fluorite was observed as an accessory constituent of granite in one specimen from upper Churchill River, and as purple veins cutting a granite outcrop north of North Knife River (for analysis see p. 31). Red garnet was found locally in the granitic body on South Knife River.

Granitic rocks are typically slightly to moderately altered as suggested by partial and variable sericitization of alkali feldspar, local partial alteration of plagioclase and mafic minerals to epidote, by widespread crystallization of chlorite, and by the local presence of carbonate.

Age relations The granitic rocks (3) have been shown to be younger than the volcanic and sedimentary rocks of units 1a, b, c, and are probably younger than the paragneiss 1d. They are at least locally younger than dioritic rocks (2) with which they form agmatites. Granitic rocks (3) are not known to intrude rocks of map-unit 5. Aeromagnetic anomalies (see Geol. Surv. Can. map

7144G) suggest that granitic rocks (3) are intruded by diabase dykes (6) of the Mackenzie swarm (dated at 1,200 m.y., Fahrig, et al., 1965)

Plutonic rocks lying immediately west and south of the map-area which probably include rocks equivalent to map-units 2, 3 and 4, give K-Ar ages ranging from 1,610 to 1,840 m.y. (Wanless, et al., 1967). These ages correspond to the age of the Hudsonian Orogeny (Stockwell, in Lowdon et al., 1963), and reflect either the time of emplacement of plutonic rock, or the time of last metamorphism.

Within the map-area, muscovite from granitic gneiss obtained from 948 to 950 feet depths in Kennco No. 5 drillhole has been dated at 1,665 m.y. (K-Ar) (Stockwell in Lowdon et al., 1963). Muscovite and biotite concentrates obtained during the present work from quartz monzonite on South Knife River have been dated (by the K-Ar method) at 1,660 ± 55 and 1,670 ± 55 m.y. respectively. The age data therefore indicate that the quartz monzonite is the same age, Aphebian, as plutonic rocks immediately south and west of the map-area.

Hybrid Rocks (Unit 4)

Hybrid rocks are best exposed in a large area west of Seal River in the northwest corner of the map-area. Elsewhere they form small bodies along the margins of the metavolcanic rocks (1a), remnants within large bodies of granitic rocks, and zones of intimate intrusion within bodies of dioritic rock.

In outcrop these hybrid rocks consist of remnants of sedimentary, dioritic, and possibly some volcanic rocks intimately intruded by granitic material in variable proportion. This assemblage has been subjected to plastic and/or solid flow and recrystallization in varying degrees to produce an heterogeneous, partly massive and partly gneissic, schistose, or foliated group of rocks which broadly approximate granodiorite in composition. These rocks are fine grained to medium grained, locally porphyroblastic, and are variable in colour from grey through grey-green, buff or red to white. Commonly they weather grey, rusty or white but are stained black in stream beds.

Under the microscope the hybrid rocks show average grain size up to about 2 mm. Feldspar porphyroblasts, present in many specimens, are up to 10 mm in length. Textures are subhedral to anhedral and massive to strongly foliated. Both quartz and feldspar crystals in some specimens have serrated borders.

Quartz, plagioclase (An_6 to An_{32}, chiefly An_{18} to An_{28}) and either biotite or chlorite are present in all specimens examined. Microcline is present in most specimens but hornblende was found only locally in hybrid rocks. About 15 per cent of colourless pyroxene accompanies green-brown hornblende and sodic andesine in a remnant of amphibolitic gneiss on Churchill River about 15 miles upstream from its junction with Little Churchill River. Epidote is present in some schistose rocks derived from quartz diorite. Carbonate is more widespread than in other plutonic rocks and in one specimen from northwest of Seal River forms about 15 per cent. Apatite, zircon, sphene and opaque minerals are common accessories.

Most hybrid rocks have probably undergone lower almandine-amphibolite facies metamorphism and some may have reached slightly higher grades as suggested by local coexistance of clinopyroxene, greenish brown hornblende, and sodic andesine. Later lower grade metamorphism is suggested by the development of chlorite and locally of albite-epidote.

Bodies of hybrid rocks commonly lie adjacent to more massive granitic rocks (3), and their granitic component is therefore probably coeval with the widespread massive granitic bodies. The nongranitic component, which is commonly penetrated or included by the granitic component, is therefore older than the granitic rocks of unit 3. As metamorphic rocks of unit 1 have bodies of hybrid rocks along their margins and locally appear to pass gradationally into hybrid rocks along strike, it is apparent that the older component of the hybrid rocks has at least locally been derived from unit 1. Granulite, older than metasediments intruded by granite, has been reported in the Caribou River area to the north (Davison, 1966) but similar rocks have not been recognized as remnants in the hybrid rocks. It seems likely therefore that most of the older component of the hybrid rocks has been derived from pre-existing bodies of unit 1.

Post-Granitic Metasedimentary Rocks (Unit 5)

Metasedimentary rocks that are not known to be intruded by granite, but which are in the greenschist metamorphic facies, are exposed at Churchill; along and near North Knife River, and in isolated outliers on Herriot Creek, between the North and South Knife rivers near their junction; and on Seal River. At Churchill these rocks have been called 'Quartzites at Churchill' or 'Churchill Quartzite' since their first investigation by Bell (1881). The same rocks have been called the 'Churchill Formation' on the geological map of Manitoba (Geol. Surv. Can., Map 850A; 1946). Although the latter rocks lie more or less on strike with those on North Knife River, fine-grained clastic sediments, not exposed at Churchill, become progressively more prominent westward in sections exposed along North Knife River. The present survey has not provided sufficient detail to permit a convincing correlation of rocks at Churchill with those along North Knife River or with those in the outliers. These postgranitic metasedimentary rocks are described together as unit 5 because they appear to have been deposited during the same interval of time. This interval lies between the age of the latest granitic intrusion and deposition of late Middle or early Late Ordovician sediments. However, because the rocks of unit 5 are commonly tightly folded (all regions have local steep dips) and no evidence of severe folding younger than the Hudsonian Orogeny is known in this area, the writer prefers the hypothesis that these rocks are all of late Aphebian or early Helikian age. No critical evidence is known to indicate that any part of unit 5 is substantially older or younger than the rest; nevertheless it remains possible that the grouping contains rocks of more than one age.

Terminology

In reconnaissance geology of the Precambrian Shield it has been convenient to apply the term 'quartzite' to metamorphosed arenaceous rocks composed largely of quartz. In this sense nearly all of the arenaceous rocks of unit 5 might be called quartzite. Such a statement however says little regarding how much and what type of impurity accompanies quartz. Where data are readily available information that bears on the origin and correlation of the rocks concerned is conserved by adopting a more detailed classification. In this report therefore, arenaceous rocks, that have undergone greenschist facies metamorphism, are subdivided into three categories. These categories are based on definitions adopted by Pettijohn (in Krumbein and Sloss, 1956) for sedimentary rocks, but the boundary between quartz-rich and quartz-poor, nonfeldspathic rocks has been shifted to conform to a discontinuity in descriptive data obtained for rocks from the Deer River area.

Each of 28 thin sections of metamorphosed arenaceous rocks from unit 5 was analyzed by 500-point mineral count and was classified in one of the following categories:-

quartzite:-	an arenite containing more than 87 per cent of quartz, but less than 10 per cent of feldspar.
feldspathic quartzite:-	an arenite containing 10 to 25 per cent feldspar, 55 to 90 per cent quartz, and 0 to 20 per cent sericite, chlorite, biotite, etc.
subgreywacke:-	an arenite containing 15 to 87 per cent quartz, less than 10 per cent feldspar, and 3 to 75 per cent sericite, chlorite, biotite, etc.

The distribution of lithologies thus obtained is:- quartzite 7, feldspathic quartzite 2, and subgreywacke 19.

Lithology

Churchill region In the immediate Churchill region unit 5 forms a range of hills that project through Paleozoic cover for some 18 miles west and 10 miles east of Churchill. Within this region it consists of grey or blue-grey to grey-white, chiefly coarse-grained subgreywacke that contains scattered pebbles and cobbles. There are beds and lenses of conglomerate (mainly east of Churchill River) and these are particularly abundant toward the eastern limits of exposure near the base of the exposed part of the section. White quartzite containing more than 90 per cent quartz is rare, and was observed chiefly in a distinctly bedded outcrop west of Churchill believed to represent the youngest beds exposed in the Churchill region.

Scattered cobbles in the Churchill region are commonly 2 inches, and rarely as much as 10 inches, in diameter (see Fig. 6). They are predominantly composed of white quartzite-subgreywacke that is lighter coloured than the matrix, but grey subgreywacke pebbles are also numerous. No pebbles of plutonic rocks are known. In places white cobbles possess a grey rim that may be slightly enlarged in the direction of elongation of the cobble (see Fig. 2), but the reverse relation in which grey cobbles possess bleached rims in contact with surrounding subgreywacke has also been noted. Rare cobbles, more angular than most, contain contorted beds of light grey subgreywacke in a darker host. In exposures near the eastern limits of outcrop where conglomerate beds and lenses (see Fig. 3), are common, pebbles are in places elongate parallel to slight foliation in the rocks and at high angles to bedding (see Fig. 4). Darker pebbles show a higher degree of distortion and/or rotation than do lighter coloured pebbles.

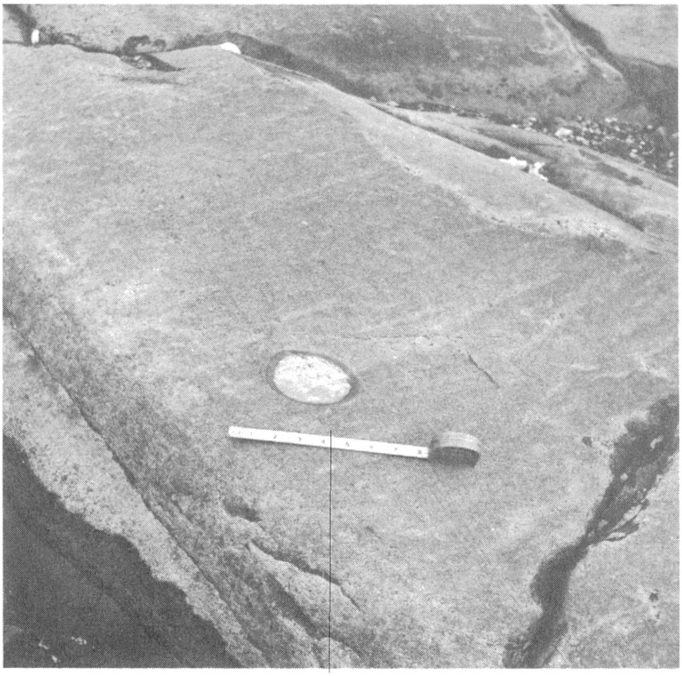

Figure 2.

Isolated white quartzite cobble with dark grey rim in subgreywacke of unit 5 near Fort Churchill, Manitoba. (138296)

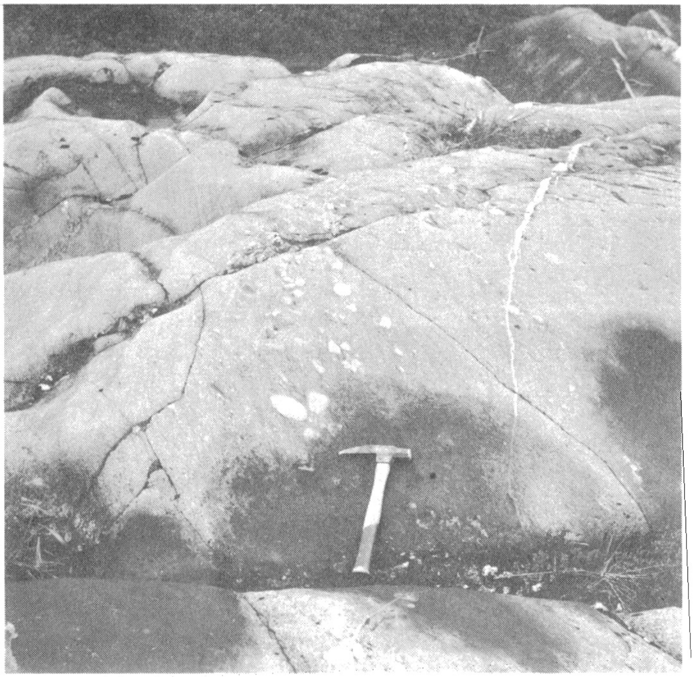

Figure 3.

Typical conglomerate lense in subgreywacke of unit 5, west of Fort Churchill, Manitoba. (138291)

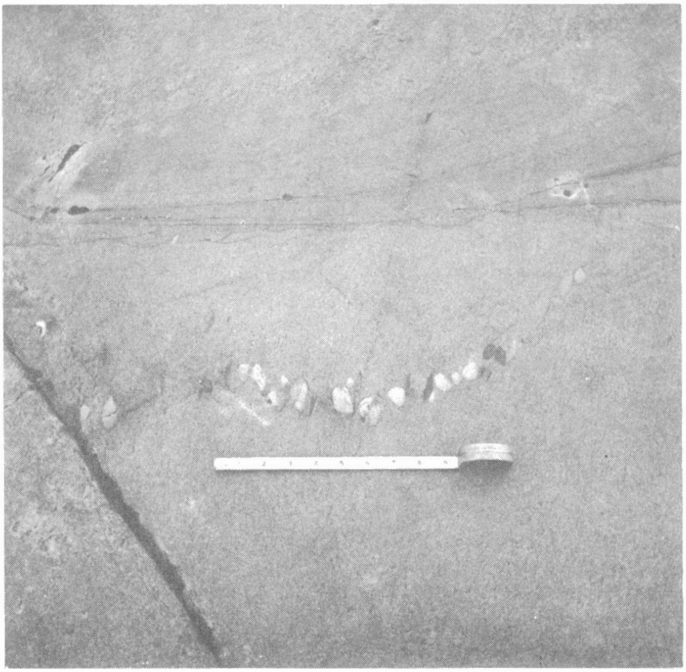

Figure 4.

A pebble lense in subgreywacke of unit 5, east of Fort Churchill, Manitoba. Darker pebbles particularly show elongation at high angles to bedding. (138293)

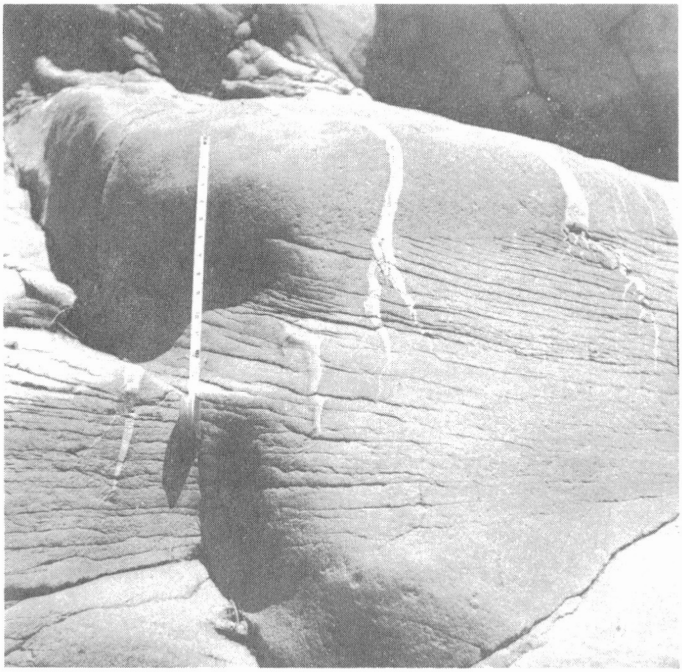

Figure 5.

Crossbedding in subgreywacke (unit 5) near Fort Churchill, Manitoba. The outcrop is penetrated by quartz veins. (138286)

Figure 6. Distinctly bedded, crossbedded, grey and white, subgreywacke-quartzite on the right overlies more massive grey subgreywacke typical of unit 5 on the left. The view is from the air looking eastward with Churchill River and Churchill harbour about 6 miles away in the background. (138304)

Crossbedding (see Fig. 5) is abundant in units up to ten or more feet thick, but is difficult to see on dry unweathered surfaces. On the east side of the hills three miles northwest of Mosquito Point, crossbeds in relatively thin grey and white units are particularly well exposed in the highest beds in the section. Between 400 and 500 feet or more of these beds lie conformably on more massive and faintly crossbedded, grey subgreywacke (see Fig. 6). Foreset beds throughout the Churchill region are predominantly westward facing, and therefore appear to indicate westward current flow. Although distortion of beds is locally evident, nevertheless in many places the crossbeds are consistent and undistorted in appearance. Their evidence combined with the westward decrease in abundance of conglomerate lenses supports an hypothesis of predominant westward current flow.

Quartz veins are present at many localities within unit 5 but principally in the Churchill region. These consist of white quartz with local concentrations of specular hematite and more rarely a mineral that weathers robins-egg blue (lazulite, confirmed by X-ray method, F. C. Taylor pers. comm.). Bell (1881) reported tiny pyrite grains in some veins and green copper carbonate in one. He also reported small specimens of a blue mineral which he believed to be lazulite, a hydrated magnesium-iron-aluminium phosphate.

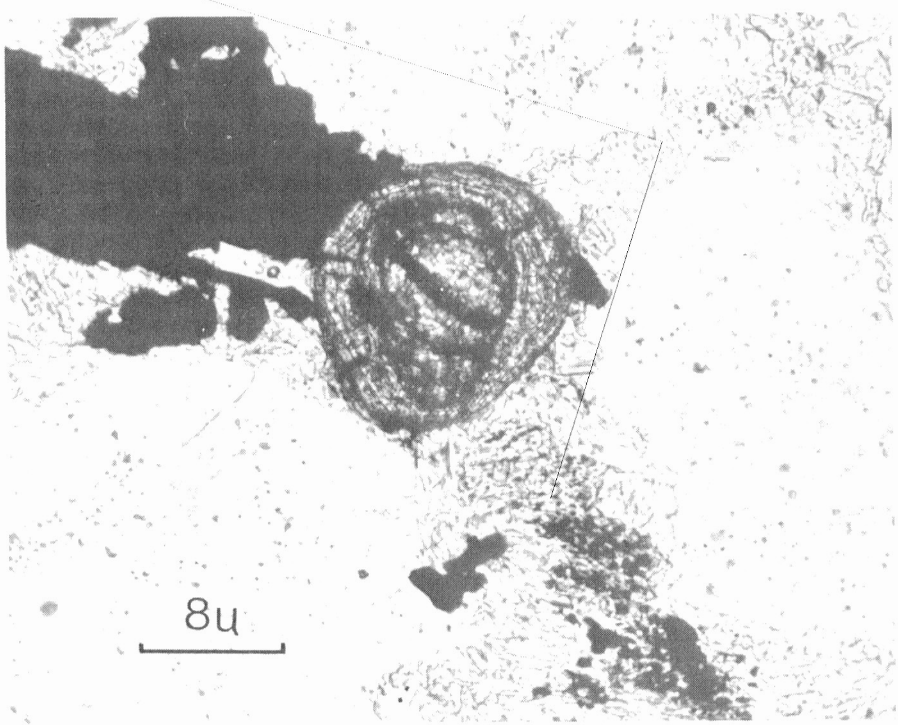

Figure 7. Rounded zircon crystal with fractured translucent outer shell, from unit 5 near Churchill, Manitoba. The opaque mineral is specular hematite. (200876-B)

Under the microscope the subgreywacke shows common grain size up to about 1 mm with occasional grains up to 2 or 3 mm. No general eastward increase in grain size accompanying increase in number of conglomerate beds was detected in subgreywacke. Larger rounded or subrounded quartz grains, in some cases formed of single crystals and in others of a mosaic of finer interlocking crystals, are present in a mosaic or finer, more angular quartz, sericite and chlorite. Boundaries of detrital quartz grains are commonly serrate and some of the larger grains have a zone marked by trains of dusty inclusions. Representative specimens were stained on polished faces to detect successively potash feldspar and plagioclase. Staining suggested that not more than a few grains of feldspar are present on each surface. These are probably represented in thin section by rare, nearly opaque, severely argillized grains. Slight foliation may be evident through preferred orientation of muscovite-sericite or deformed quartz grains.

The principal accessory mineral is specular hematite which locally forms 4 or 5 per cent of the rock. Zircon is common and tourmaline

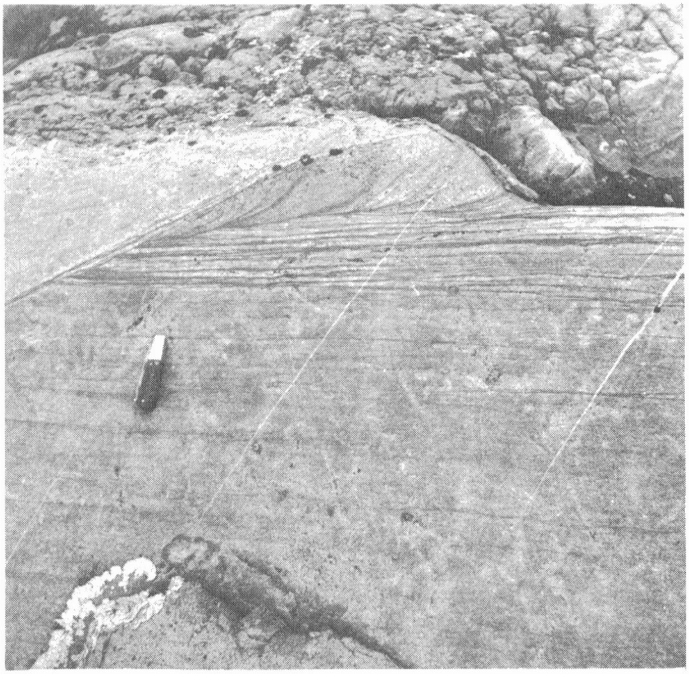

Figure 8. Laminae of specular hematite in subgreywacke of unit 5 near Churchill, Manitoba. (138277)

is present in some thin sections. Many zircon crystals appear altered and in several specimens zircon crystals are surrounded by a delicate outer transparent shell (see Fig. 7). Tourmaline occurs as very small prismatic crystals displaying characteristic dichroism in the sericitic fraction of the matrix. Sphene was observed in one thin section. Specular hematite is locally concentrated in lenticular laminae up to about 1 cm (see Fig. 8) thick. Accessory zircon, detrital amphibole, and leucoxene were found in addition to quartz and hematite in one such lamina.

Western 'Knife rivers' - Herriot Creek Unit 5 is fairly well exposed and steeply dipping along North Knife River from the southern contact of the Paleozoic westward to the west boundary of the map-area. In the east, outcrops are mostly low lying except where the river has worn a short gorge through a thick quartzite-subgreywacke unit. Farther west the river has cut a canyon some 20 or more feet deep in near-vertical slates. Midway between North and South Knife rivers, north of the mouth of Matonabee Creek, a long, low ridge of subgreywacke and feldspathic quartzite outcrops in a few places but is mostly covered by glacial deposits and angular blocks. On Matonabee Creek just above its junction with South Knife River a small rounded outcrop of blue-grey subgreywacke is exposed in the creek bed. On Herriot Creek arkosic conglomerate sandstone and feldspathic quartzite form a group of small outcrops that project through the swamp beside the creek.

West of the Paleozoic contact on North Knife River unit 5 consists predominantly of reddish, cream and grey laminated siltstones with interbeds and lenses of greenish to grey, medium- to coarse-grained quartzite and subgreywacke. West of an island in the river, about 800 feet of medium- to coarse-grained subgreywacke and quartzite with some beds of quartz-pebble conglomerate are exposed in uninterrupted outcrop. Beds range in thickness from several feet or more down to laminae, but in parts of the outcrop are vaguely or only faintly defined. Ripple-marks were observed on two bedding planes only. Crossbedding in units one foot or less thick is common in the westernmost 50 feet of the section. Thin beds and lenses of pebble-conglomerate, locally containing distinctive bluish quartz pebbles, are present in the eastern quarter of the section but do not appear in the easternmost 50 or 60 feet. Rusty weathered pits produced by solution of carbonate cement are present locally in the subgreywacke. Quartzite is more abundant in these exposures than it is in the Churchill region.

For the next 20 miles westward the river crosses similar siltstones and slate with interbedded subgreywacke, and quartzite. About 12 miles southwest of the Paleozoic contact a creamy-white sandstone is poorly exposed in the river bank. This rock has a white argillaceous matrix composed of 66 per cent kaolinite and 44 per cent illite by clay mineral analysis. It contains at least one bed of slightly coarser sandstone, one inch thick, in finer sandstone and has a slight fissility that intersects bedding at a high angle. This sandstone may represent a more porous quartz-rich part of unit 5 in which feldspar has been altered to kaolinite by groundwater, or into which kaolinite has been washed by groundwater. On the other hand it may be a small outlier of the Portage Chute Formation of late Middle or early Late Ordovician age. Farther west grey, blue and black slates with siltstone laminae predominate.

The Herriot Creek outcrops consist mainly of coarse-grained to very coarse grained sandstone that weathers light grey to pinkish buff. Locally grey feldspathic quartzite and light buff-pink bands are interlaminated in units up to a foot or more thick. Pink feldspar fragments mostly less than 3 mm in diameter are common and comprise up to 3 per cent or more of some beds. Conglomerate beds and lenses containing quartzite cobbles up to about 10 cm in diameter and less numerous granitic, gneissic and dark coloured, fine-grained pebbles were noted. Structures resembling crossbedding are present in some sandstone units. The beds dip southward at 60 degrees.

Under the microscope the quartzite and subgreywacke units are medium to coarse grained with larger grains commonly from 1 to 2 1/2 mm across. The latter are usually well rounded to subangular and may have serrated margins; smaller grains tend to be angular and in many cases are fragments of larger grains. In the quartzite quartz grains tend to form interlocking mosaics. Only one specimen of siltstone was examined and this contained angular quartz fragments up to 0.1 mm in diameter.

The quartz content of the arenites of unit 5 ranges from 72 to 95 per cent with the remainder chiefly sericite, muscovite and/or chlorite. Albite is sparingly present in two of four beds examined from the thick subgreywacke unit on North Knife River. Microcline forms nearly 15 per cent of feldspathic quartzite near the west end of the ridge separating the North and South Knife rivers north of Matonabee Creek, but was not found in frost-heaved blocks from the east end of this ridge. Metamorphic biotite is present in the thick subgreywacke unit on North Knife River, on the ridge to the southwest, and possibly in the Herriot Creek outcrop. Opaque minerals occur in some but not all specimens. Carbonate is present in several specimens from North Knife River near the Paleozoic contact.

Accessory minerals include zircon, apatite, tourmaline and monazite. No evidence of secondary growth was observed on zircon. Tourmaline is rare but occurs as broken detrital grains and in one specimen as a patch of crystals in sericitic matrix. An unknown detrital mineral extensively altered to chlorite was noted in quartzite on North Knife River near the Paleozoic contact.

Northern outliers Rocks of unit 5 are present in a basin-like structure between the North and South Knife rivers near their confluence. Similar rocks are poorly exposed in the bight formed by Seal River where it loops northward into the Caribou River area. Rocks of the basin-like structure comprise subgreywacke, argillaceous siltstone and quartzite. Conglomerate is seemingly absent in this region. The best exposure, which is on the southwest margin of the basin, consists of about 1,400 feet of section in which the lowermost 250 feet are moderately well exposed white to grey, medium to very coarse grained subgreywacke and quartzite in beds up to about 2 1/2 feet thick. Asymmetrical ripple-marks were observed on some bedding surfaces. The succeeding 450 feet consist of grey to grey-green laminated argillaceous siltstone containing several locally crossbedded subgreywacke beds up to 1 1/2 feet thick. The upper 700 feet are better exposed and consist predominantly of locally crossbedded, grey to light grey subgreywacke and quartzite. Elsewhere in the basin only subgreywacke and quartzite were observed.

In thin section the coarser grained rocks are seen to be chiefly subgreywacke. Quartz content is from about 35 per cent to 90 per cent. The ratio of quartzite to subgreywacke appears to be intermediate between that along North Knife River and that in the Churchill region. Larger grains in the specimens examined are rounded to angular and range up to about 0.9 mm. Serrated grain boundaries are present in some specimens. Quartz grains are set in a matrix composed chiefly of sericite and chlorite, with some larger muscovite crystals. Locally, where muscovite flakes are disoriented and distorted around quartz grains, they may be detrital. Biotite, though not always present, may form up to 10 per cent of the rock. Feldspar, mostly microcline with some twinned oligoclase, forms about 5 per cent of a specimen from steeply dipping subgreywacke near the north margin of the basin. A few extensively sericitized grains observed elsewhere may also represent feldspar. Opaque minerals, chiefly hematite, are present in most specimens. Rarely carbonate rimmed by hematite is interstitial between quartz grains.

Zircon, tourmaline, and apatite are common accessory minerals. Delicate translucent haloes similar to those seen locally on zircon from the Churchill region were observed surrounding some zircon grains. Tourmaline is present in relatively large crystals compared to those found elsewhere. Blue cores are visible within orange-brown rims on larger crystals and some of these larger crystals are broken suggesting detrital origin. Apatite is present as inclusions in detrital quartz grains and locally as larger crystals associated with hematite or hematite-carbonate patches.

Near Seal River there is a large exposure of grey to white weathering, medium- to coarse-grained subgreywacke and quartzite in beds up to 2 feet thick. Several hundred feet of section with gentle northward dips are exposed. Although siltstone fragments were found in drift at the base of the outcrop no siltstone or conglomerate was observed in place. Ripple-marks are present but crossbedding is poorly developed.

One specimen of subgreywacke from this locality when examined in thin section was found to consist of quartz grains up to about 1 mm in diameter in a matrix of smaller quartz grains, sericite and chlorite. Quartz forms about 85 per cent of the specimen. Biotite, minor opaque minerals and accessory zircon and apatite were observed.

Metamorphism

Unit 5 is characterized by greenschist facies metamorphism. This is indicated by the presence of chlorite in 21 of 28 specimens examined representing all major parts of the map-area in which the unit is found. The assemblage quartz-muscovite, which predominates in the remaining specimens, is nondiagnostic. The latter is found chiefly interspersed between localities bearing quartz-muscovite-chlorite near Churchill and probably reflects a combination of low metamorphic grade and slightly different chemical composition in these rocks.

About half the chlorite-bearing specimens also contain biotite. As the components necessary to form biotite are already present in the assemblage quartz-muscovite-chlorite, biotite-bearing specimens may be assumed to belong to a slightly higher metamorphic grade (the quartz-albite-epidote-biotite subfacies; Turner and Verhoogen, 1960). This subfacies is restricted to the northern outliers, the eastern section of the Knife River area, and perhaps the Herriot Creek outcrop. Notably it does not appear in the rocks near Churchill which therefore belong to the quartz-albite-muscovite-chlorite subfacies (Turner and Verhoogen, 1960).

Structural Geology

At most of its more southerly exposures unit 5 is steeply dipping to near vertical or overturned. In the northern outliers, however, deformation is for the most part less severe and dips range chiefly from 15 to 40 degrees. Except in part of the basin-shaped remnant between the North and South Knife rivers, the strike of bedding is predominantly eastward.

Churchill region Faint foliation is apparent both in outcrop and thin section at many Precambrian outcrops in the Churchill region. Evidence of deformation is locally emphasized where conglomerate pebbles have been distorted and/or reoriented. At one such locality along the coast near the rocket launching site, distorted pebbles and foliation strike about 33 degrees with steep dip. Faults of limited displacement are suggested by short linears that are related to abrupt changes in shoreline, abrupt changes in outcrop elevation, and abrupt changes in width of exposure.

Bedding in the Churchill region dips mostly in southerly directions at from 40 to 80 degrees. Abundant crossbedding along the main ridge from the eastern extremity just beyond Halfway Point to the southwest extremity 4 miles beyond Holcroft Lake, indicates that the rocks are right-way-up. A second, lower, and extensively tree-covered ridge extends parallel to the main ridge for about 6 miles southwest of Mosquito Point. Crossbeds observed some 4 miles southwest of Mosquito Point on this ridge are overturned. About 2 miles west of Holcroft Lake at the extreme southwest end of the northern ridge, beds swing sharply southward and it appears that the two ridges may be continuous beneath the drift. The structure is therefore interpreted as a major syncline about 3 miles across with its southern limb overturned. The southern limb of this syncline is not exposed on the east bank of the Churchill River and it is therefore not immediately clear whether this structure continues east of the river.

The northern limb of the syncline, which continues both east and west of Churchill River, is crumpled about Churchill harbour forming a subsidiary syncline that plunges steeply southward. This structure is not evident in the southern limb which is sharply truncated by Churchill River. At the rocket launching site however, near the eastern limit of the northern ridge and some 3 miles south of it, a large isolated crossbedded outcrop contains southward-facing beds that are nearly parallel to those of the northern ridge. This outcrop is considered to be a faulted repetition of beds exposed to the north because the stratigraphic interval represented by their separation is considerably greater than the estimated thickness of unit 5 in this region. If this is true the synclinal structure west of Churchill River may be replaced by a system of faults east of the river.

<u>'Knife rivers' region</u> The course of the North Knife River in its central and western reaches is nearly parallel to the regional strike, and consequently little stratigraphic interval can be seen although outcrops are abundant. The rocks along this part of the river strike eastward to southeastward and dip from 60 to 90 degrees with southward dips predominating. Tight folding is evident near the Paleozoic contact in an exposure of interbedded siltstones and quartzites. There a competant quartzite bed in slaty siltstone up to 9 feet thick forms a whaleback plunging westward at 2 to 10 degrees in which the limbs, though only partly exposed, are dipping at 45 degrees or more at the base of exposure (<u>see</u> Fig. 9).

The distribution of siltstone-slate and quartzite-subgreywacke-conglomerate exposures suggests that there is a westward increase in proportion of fine-grained clastic sediments, and that the major subgreywacke unit at Churchill may intertongue with siltstone in this direction. Thus the coarse clastic part of unit 5, which is about 2,400 feet or more thick at Churchill, has no exposures more than 800 feet thick on North Knife River, and in the basin-like remnant between the North and South Knife rivers the coarse clastics appear in two thinner units separated by some 450 feet of siltstone-bearing rocks.

Both the Churchill and eastern North Knife River sections have conglomerate and thin-bedded crossbedded units; however direct comparison requires that the crossbedded unit in the coarse clastics on North Knife River be on top and the conglomerate be near the base of the exposed section.

Figure 9. Folded quartzite and siltstone of unit 5 on North Knife River. (138299)

Although the evidence is not good there is some suggestion in the crossbeds on North Knife River that this is not true.

Northern outliers Near the junction of North and South Knife rivers rocks of unit 5 outcrop in a nearly circular basin-like pattern. Bedding tops face inward and dip mainly between 30 and 40 degrees, except along the northern margin of the basin where the bedding steepens to 70 degrees. On Seal River unit 5 appears to form a similar body which is less well exposed. There, northward dips of from 15 to 25 degrees were noted along the south boundary of outcrop. Similar rocks, apparently near the centre of the body, in the Caribou River area to the north, dip northward at 55 degrees (Davison, 1966).

Age relations

Unit 5 is nowhere exposed in contact with the lithologically distinct and generally more basic sedimentary and volcanic rocks of unit 1. It is inferred to be younger than these rocks because it is not known to be intruded by granite, whereas the sedimentary rocks of unit 1 are both intruded and migmatized by granitic rocks. The relatively lower metamorphic grade of unit 5 compared to most of unit 1 is consistent with this age difference.

Unit 5 is thought to be younger than the granitic rocks (3) because, in spite of the widespread exposure of the latter, granitic dykes are not known to intrude it. It may lie unconformably on granitic rocks north of North Knife River because blue-grey quartz pebbles observed in the rocks of unit 5 on eastern Knife River are similar in colour to quartz in coarse-grained granite exposed some 4 miles to the northwest, and may have been derived from this granite. It may also lie unconformably on granitic rocks and paragneiss (1d) near South Knife River as subgreywacke along the southern margin of this unit locally contains unusually large amounts of microcline for which these rocks appear to be the most likely source.

The presence of granitic rocks younger than unit 5 was postulated by Alcock (1916) because the rocks at Churchill are closely folded and are locally penetrated by numerous quartz veins. Granitic rocks poorly exposed along South Knife River and less altered than most plutonic rocks within the map-area, would appear most likely to fall in this younger category. However, the K-Ar age of 1,660 to 1,670 $\pm$ 55 m.y. determined on muscovite and biotite concentrates from these granitic rocks indicate that they were involved in the Hudsonian Orogeny as were plutonic rocks in neighbouring areas to the west. Thus, if unit 5 is in fact intruded by granitic rocks (not exposed), it was probably deposited during or before the Hudsonian Orogeny. If however, as now seems more likely, unit 5 is not cut by granitic rocks, then it probably corresponds in age to the dying phases of Hudsonian tectonism which presumably were responsible for the locally severe folding and low grade metamorphism which it has undergone.

Age relations between the diabase dykes and unit 5 are uncertain. Aeromagnetic anomaly patterns, on which the inferred presence of a diabase dyke is based, do not penetrate areas underlain by unit 5. This however, may be because the magnetic susceptibility of the latter is locally high enough to mask the diabase.

Thickness

The absolute thickness of unit 5 is uncertain because its contacts with older or younger Precambrian rocks are not exposed. A minimum estimate of the thickness of coarser clastics however can be derived from the section exposed near Churchill. Measurements made with a steel tape at Cape Merry and west of Fort Churchill gave estimates of about 2,000 and 2,500 feet respectively. These localities do not include 400 to 500 feet of thinly crossbedded rocks from the highest part of the section exposed west of Churchill harbour. The composite minimum thickness of section in the Churchill region is therefore about 2,400 feet.

The thickness of unit 5 west of the Paleozoic contact is even less well known. On North Knife River a quartzite-subgreywacke unit, including minor conglomerate, is about 800 feet thick (based on pace count), but its upper and lower contacts are not exposed and it is separated from neighbouring outcrops by extensive stretches of overburden. About 1,400 feet of section (based on pace count) are exposed in an outlier between the North and South Knife rivers near their junction. This section, from the base up, comprises about 250 feet of subgreywacke-quartzite, about 450 feet of siltstone-rich section, and about 700 feet of better exposed subgreywacke-quartzite. Here again, however, neither upper nor lower contacts are exposed. In summary therefore, unit 5 attains a minimum thickness of between 2,400 and 3,000 feet in the Churchill region, but because neither top nor bottom are exposed the true thickness cannot be estimated. Thinner sections are exposed in other regions but no conformable contacts with younger or older rocks are known.

Correlation

Rocks lithologically similar to unit 5 are present in the Shethanei Lake map-area (Taylor, 1958) immediately to the west, in the Nejanilini Lake map-area (Davison, 1967) and in the Caribou River map-area (Davison, 1966) immediately to the north of the present map-area. Similar rocks, so far as is known, are not exposed in the Northern Indian Lake map-area (Kretz, 1959), nor in the Herchmer area included in the present study.

In the Shethanei Lake map-area Taylor (1958) recognized two groups of sedimentary rocks with lithologies resembling those of unit 5. The older group, which he believes is widespread, is overlain unconformably by the Great Island Group which is confined to the northeast corner of the Shethanei Lake map-area where dolomite and calcareous dolomite have been found in addition to clastic sedimentary rocks. He also reports that slate of the Great Island Group, particularly along the south side of Great Island, has been complexly folded, but that none of the rocks of this group is known to be intruded by granite. Therefore, although the Great Island Group cannot be correlated with any part of unit 5, its deposition is subject to the same limits in time as are known for unit 5.

Rocks exposed along North Knife River immediately west of Deer River map-area are lithologically similar to those along the same river to the east. The former are however, tentatively assigned by Taylor (1958) to an earlier map-unit which elsewhere in the Shethanei Lake map-area is cut by granite. Further information is required to clarify the relations between these rocks.

Davison (1966) has tentatively correlated rocks exposed on Seal River in the Caribou Lake map-area immediately north of the Deer River map-area with those of the Great Island Group. Although the rocks mapped by Davison are finer grained and more steeply dipping than those in the Deer River map-area, it seems likely that exposures on either side of the map boundary belong to the same unit because elsewhere subgreywacke and quartzite are known to be interbedded with metasiltstone.

Origin

The lithology, sedimentary structures, and stratigraphic relationships of unit 5 in the Churchill region suggest that it is of alluvial origin. It may have accumulated in water of increasing depth as suggested by the decrease in thickness of crossbedded units (Allen, 1967) between the main mass of subgreywacke and the uppermost beds exposed west of Churchill. If evidence for westward current flow be accepted (i.e. that from crossbedding and distribution of conglomerate) then the constituent sediments were derived from a major source that contributed sedimentary detritus east of Churchill.

Unit 5 exposed along North Knife River lies more or less on strike with the rocks at Churchill although they are separated by 20 miles of drift. It is a reasonable speculation therefore, that they belong to the same unit. The rocks along North Knife River are characterized by a considerable proportion of siltstone and slate which are not exposed at Churchill, and they have a higher proportion of quartzite to subgreywacke. These features suggest less active currents and greater distance from the main source of sediment for rocks deposited in the Knife Rivers region as compared with those deposited about Churchill. Possibly therefore unit 5 along North Knife River represents an extension of the alluvial system postulated at Churchill. It is nevertheless true that sediment of local origin was contributed to the depositional environment in the 'Knife' rivers region as is indicated by the local presence of bluish quartz pebbles and locally abundant feldspar detritus.

The northern outliers of unit 5 may be related to the rocks at Churchill in a similar way. These rocks however are commonly less severely folded and are less clearly on strike with the rocks at Churchill than are the exposures along North Knife River.

Diabase (Unit 6)

Diabase dykes are not known to outcrop within the map-area, but at least one (central northwest corner of the map-area) and probably several dykes may be inferred from aeromagnetic anomaly patterns (see Geol. Surv. Can., Maps 7139G, 7142G, 7143G, 7144G). These dykes trend northwestward and are therefore parallel to the Mackenzie swarm of about 1,200 m.y. with which they have been correlated (Fahrig, *et al.*, 1965).

PALEOZOIC ROCKS

The Paleozoic rocks in the Deer River map-area will be the sub ject of papers by members of Operation Winisk concerned respectively with Ordovician and Silurian strata. Contacts shown on map (Fig. 1) within regions underlain by Paleozoic rocks, are the results of their work. Descriptions by Sanford and Norris of units 7 to 10 may be obtained from the preliminary report on Operation Winisk (Sanford, Norris and Bostock, 1968).

The Precambrian-Paleozoic Contact

Paleozoic strata of upper Middle (?) Ordovician and Upper Ordovician age directly overlie Precambrian rocks on Churchill River and on North Knife River. Ordovician rocks of the same age also unconformably overlie Precambrian rocks at 636 feet below sea level in Kennco No. 5 vertical diamond-drill hole near the south border of the map-area. Rocks of Middle Silurian age are exposed in direct contact with the Precambrian rocks of unit 5 in the Churchill region.

On Churchill River near Portage Chute, sandstone of Member 1 of the Portage Chute Formation is exposed in contact with granite. There, vertical limestone bluffs with sandstone at their base (Members 1 and 2 of the Portage Chute Formation) rise directly from the smooth, water-worn granite surface in the river bed. Alcock (1916), who traversed the river by canoe, noted that irregularities in the surface of the unconformity do not exceed 10 to 20 feet.

On North Knife River, siltstones of unit 5 with nearly vertical cleavage are overlain by the nearly flat lying sandstone of the Portage Chute

Figure 10. Nearly flat lying sandstone of the Portage Chute Formation overlying nearly vertically cleaved siltstone of unit 5 on North Knife River. (138298)

Formation (see Fig. 10). Patches of quartz-bearing breccia up to one foot or more thick with pyritic matrix are present along the unconformity. Farther upstream, about 12 miles to the southwest of the Paleozoic contact, a creamy-white sandstone with kaolinite-rich matrix is poorly exposed in the river bank. This may also be part of the Sandstone Member of the Portage Chute Formation. The disposition of the outcrop with respect to neighbouring slaty siltstone exposures of unit 5 would then indicate that it was either deposited in a depression on the Precambrian surface or was down-faulted slightly subsequent to deposition.

At Churchill, steeply dipping rocks of unit 5 are directly overlain by flat-lying to gently dipping dolomitic limestone of the Severn River Formation. Along the coast, near Fort Churchill, a small knob of subgreywacke, exhibiting marked exfoliation, penetrates sharply through gently seaward-dipping dolomitic limestone (see Fig. 11). Fragments of subgreywacke are locally present in the Silurian rocks near the contact. Nearby, a carbonate fissure-filling in subgreywacke (first noted by Tyrrell, 1898) contains Silurian fossil fragments. At several other places, both east and west of Churchill, Silurian rocks are exposed within short distances of the Precambrian hills, and at these localities they commonly contain up to about 25 per cent of quartz sand.

Figure 11. Dolomitic limestone of the Severn River Formation in contact with a small knob of subgreywacke of unit 5 near Fort Churchill. The latter exhibits marked exfoliation on surfaces exposed to weathering. (138285)

ECONOMIC GEOLOGY

Prospecting activity until recently appears to have been concentrated along Seal River, particularly in unit 1, and in the Great Island Group immediately west of the map-area (Johnston, 1935; Taylor, 1958; Davison, 1966). No economic mineral deposits however, have so far been found.

PRE-GRANITIC METAMORPHIC ROCKS (Unit 1)

In unit 1 gossan stains are developed along thin metasiltstone bands between massive amphibolite bodies south of Seal River. Pyrrhotite was the only sulphide mineral recognized in association with these gossans. Pyrrhotite is also present in thicker bodies of laminated mafic metasiltstones along the west margin of the basic volcanic rocks. The writer observed a short trench about 2 feet deep in these rocks near the north boundary of the map-area. There pyrrhotite forms scattered lenses up to 1 mm by 5 mm, but gossan stain is scarcely detectable on the weathered surface.

Near the southwest extremity of unit 1c on lower Seal River a grey metasiltstone contains quartz, calc-silicates, lenses of bright green uvarovite garnet (10% Cr_2O_3) and laminae of hyalophane (8-9% BaO). Scattered chromite grains are also present. The combination of elements appears to be geochemically unusual, and it is likely that they have been brought together coincidentally; chromium by detrital accumulation of chromite, and barium either by detrital accumulation or by direct precipitation from waters in which the present sediments were deposited. In either case the present mineral assemblage is largely due to superimposed almandine-amphibolite facies metamorphism. The association of hyalophane with dark brown pleochroic sphene is similar to that in gneisses near the Broken Hill lead-zinc-silver deposits in New South Wales (Nockolds and Zies, 1933) (Segnit, 1946).

Further examination of unit 1 should include a search for additional chromite concentrations that might lead to the source of this mineral. Investigations should also include an awareness that base metal deposits may exist in association with this unit.

GRANITIC PLUTONIC ROCKS (Unit 2)

The occurrence of fluorite in veins and as an accessory mineral in granitic rocks (unit 3) in the map-area is of interest because of the widespread presence of fluorite as a gangue mineral in ore deposits elsewhere. In so far as its presence indicates that hydrothermal solutions were present in this area during and after emplacement of the granitic rocks, it provides an inducement to closer examination of the area. As a first step in this direction two elements that are normally concentrated in late granitic fluids, tin and beryllium, were determined spectrographically in six hand specimens of granitic rocks from various parts of the Deer River map-area. The results are listed in Table 1.

The abundance of beryllium and tin in granitic rocks (granites and granodiorites) is given by Vinogradov (1962) as 5.5 ppm and 3.1 ppm respectively. The granitic rocks of the Deer River map-area therefore appear to be close to normal for beryllium but in part below normal so fas as tin is concerned. No relation between the concentration of either tin or beryllium is however, indicated by the analyses.

Purple fluorite, hand-picked under binocular microscope from veins cutting specimen No. 4, was also analyzed spectrographically. In addition to the major elements, calcium and fluorine, minor amounts of silicon, magnesium and aluminum, 0.041 per cent yttrium, and trace amounts of strontium, barium, zirconium, iron and ytterbium were detected. Silicon, magnesium and aluminum reported in some fluorite analyses are considered by Deer, Howie and Zussman (1962) to be probably due to impurities or inclusions. These authors note that yttrium and cerium are the chief substitutions to be expected, but cerium is not present above the detection limit (0.050%) in the sample analyzed. Purple fluorites may contain up to one per cent of strontium (Deer, Howie and Zussman, 1962), however, the trace recorded in the Deer River fluorite is less than 0.002 per cent.

UNIT 5

No occurrence of ore minerals of direct economic interest was noted in unit 5 within the map-area. Thinly disseminated pyrite apparently

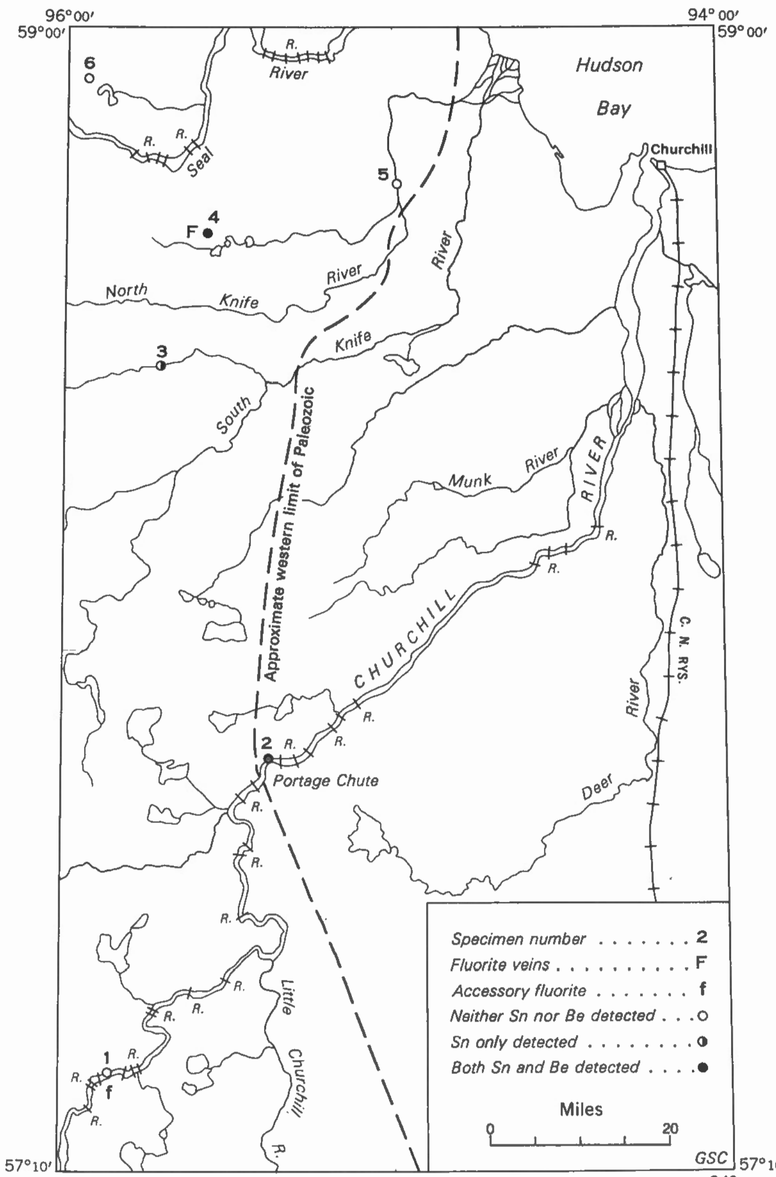

Figure 12. Location of granitic rock specimens analysed for tin and beryllium.

Table 1

Beryllium and tin contents of some granitic rocks
from the Deer River area

Specimen number	Location (south to north)	Remarks	ppm* Be	ppm* Sn
1.	upper (southern) Churchill River	Massive, equigranular, medium-grained, red-stained, chlorite 3%, granite; albite, accessory fluorite.	<3.0	<0.4
2.	Portage Chute, northern Churchill River	Massive, porphyritic, medium-grained, red-buff, biotite 5%, granite; intermediate oligoclase, argillized spots, accessory zircon abundant.	4.6	2.9
3.	western South Knife River	Massive, equigranular, medium-grained, grey-white, muscovite-biotite 7%, quartz monzonite; sodic oligoclase, accessory garnet.	<3.0	2.8
4.	north of western North Knife River	Massive, equigranular, medium-grained, buff, biotite > muscovite 5% granite; albite, cut by purple fluorite veins.	3.2	1.7
5.	northeast North Knife River	Massive to gneissic, coarse-grained, light greenish grey, muscovite > chlorite 3%, granite; albite, accessory carbonate.	<3.0	<0.4
6.	northwest of Seal River	Massive, equigranular, medium-grained, buff-white, muscovite > biotite 4%, quartz monzonite to granodiorite; sodic oligoclase.	<3.0	<0.4

*Expected to be accurate to within 15 per cent of the value reported.

associated with fractures was observed in subgreywacke near the east margin of exposure in the Churchill region, and minor amounts of chalcopyrite are reported from quartz veins within unit 5 at Churchill by Bell (1881).

Small amounts of antimony, copper, zinc, gold and nickel are reported (Milligan, 1955) in samples derived from surface X-ray drillcore from the Great Island Group (possibly equivalent to unit 5) on Seal River immediately west of Deer River map-area. These elements are present in a series of interbedded slates and quartzites in which minute stringers of arsenopyrite, parallel to bedding, are widespread.

Up to 47 per cent of metallic iron is reported by Milligan (1955) in red to bluish black shale in the Great Island Group. High magnetic anomalies known and believed to be associated with iron-formation (Davies, et al., 1962; Bower, 1960) are present respectively astride the northeast margin of the Great Island Group, and northeast of the Deer River map-area beneath Hudson Bay about 45 miles from Churchill. Whether these iron-formations are older or younger than the granitic rocks (3) is not known.

The general lithology of unit 5 bears some resemblance to the uranium-bearing Elliot Group of the Blind River area described by Roscoe (1957). The Matinenda Formation, which forms the basal and major part of the Elliot Group is, like the eastern exposures of unit 5, a coarse clastic sediment with sericite-chlorite forming most of the matrix between clastic grains. Both contain conglomerate, appear to be of alluvial origin, and have associated deeper water facies (if the siltstones of the North Knife River region are correlative to the rocks at Churchill). There are however, notable differences that are discouraging so far as uranium prospecting in the Churchill region is concerned. These are listed in Table 2.

Table 2

Significant Differences between Unit 5 at Churchill
and the Matinenda Formation of the
Elliot Lake-Blind River area, Ontario

Matinenda Formation	Unit 5
(1) Quartz and plutonic rock pebbles are widely represented	(1) Pebbles are of sedimentary rocks chiefly quartzite and subgreywacke
(2) Feldspar is an important clastic constituent	(2) Feldspar is rare
(3) Pyrite is abundant in coarse-grained samples and is associated with radioactive minerals	(3) Detrital pyrite is absent and specular hematite is the chief iron-bearing constituent. No radioactivity was detected

These differences are significant because they indicate that the constituents of unit 5 at Churchill were derived from a quite different type of source area than were those that form the Matinenda Formation. If the uranium associated with the latter is of detrital origin there is then correspondingly less chance of its having been available in the source area from which unit 5 was derived. This factor may not be applicable to the more western parts of unit 5. In addition, however, the common presence of hematite in unit 5 is indicative of higher oxidation potential than is associated with uranium minerals in the Blind River ores. As uranium minerals decompose readily under weathering it is correspondingly less likely that they could have persisted in this region.

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