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DEPARTMENT OF ENERGY AND MINES

MINERAL RESOURCES DIVISION
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THE ARCHEAN PIKWITONEI GRANULITE DOMAIN AND ITS POSITION AT THE MARGIN OF THE NORTHWESTERN SUPERIOR PROVINCE (CENTRAL MANITOBA)

by
J.J.M.W. Hubregtse

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ABSTRACT

The Pikwitonei Granulite Domain is regarded as a metamorphically high-grade, perhaps deep crustal level of the Superior Province. The granulites do not constitute an early Archean basement to the lower-grade Archean greenstone belts of the Superior Province as has been suggested by some previous studies. The Pikwitonei Granulite Domain and the northwestern Superior Province are structurally and metamorphically contiguous, and are separated by an isograd, not an unconformity. The continuity between the rocks of the two areas is indicated by granulite facies metamorphism of Superior Province greenstone belts that cross into the Pikwitonei Granulite Domain.

The granulite facies metamorphism is Kenoran. The presence of rare sapphirine-bearing, and sillimanite-orthopyroxene-bearing gneisses indicates that the granulites belong to the intermediate-pressure group.

Field relationships indicate that the supracrustal rocks of the northwestern Superior Province and their granulite facies equivalents in the Pikwitonei region are the oldest rocks. An older basement has yet to be identified.

Intense late-Hudsonian deformation in the northwestern segment of the Pikwitonei Granulite Domain led to the formation of the "Thompson Mobile Belt", which separates the Superior Province from the Churchill Province. The side-by-side association of the Pikwitonei Granulite Domain, the Aphebian Molson dilation diabase dyke swarm, the "Thompson Mobile Belt" and the Superior-Churchill Provinces boundary is interpreted in terms of recurring processes of continental break-up and collision between late-Archean and middle Proterozoic times.

INTRODUCTION

This paper presents new data and reviews some of the earlier work on the granulites of the Pikwitonei region (Weber, 1976) of central Manitoba (Fig. 1). The main objective is to discuss the Archean segment of their history, their origin and their relationships to the low-grade Archean greenstone belt-gneiss terrane of the northwestern Superior Province.

The Pikwitonei granulites have been a matter of contention over the last decade. Bell (1971) has argued that the Pikwitonei granulites comprise a pre-Kenoran basement upon which the greenstone belts of the northwestern Superior Province were deposited unconformably. Bell referred to the basement complex as the "early Precambrian Pikwitonei Province". It may be inferred from Trush's (1960) definition of basement,

> *"a series of metamorphic and igneous rocks, generally with complex structures, unconformably overlain by sedimentary and volcanic strata", ("and volcanic" added by present author)*

that the effects of an orogenic cycle older than the deposition of the greenstones should be intrinsic features of Bell's "early Precambrian Pikwitonei Province". However, no compelling evidence was found during recent investigations for a pre-greenstone orogenic cycle. It is concluded, therefore, that the basement hypothesis is unfounded. This study indicates that the Pikwitonei granulite complex represents a more highly metamorphosed segment of the Superior Province, separated from the greenschist-amphibolite facies greenstone belt-gneiss terrane by an orthopyroxene isograd and not by an unconformity. Consequently, the granulite facies complex will be referred to in this report as the "Pikwitonei Granulite Domain" and is considered to be an integral part of the Superior Province.

ACKNOWLEDGEMENTS

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REGIONAL AND GEOLOGICAL SETTING

The Pikwitonei Granulite Domain separates the greenstone belt-tonalite gneiss complex of the northwestern Superior Province from the Thompson Belt and the Churchill Province (Fig. 1). The domain is exposed over a length of 200 km, and in the Split Lake region it reaches a maximum width of 75 km.

Bell (1971) has argued that the Pikwitonei Granulite Domain and the Superior Province are structurally unconformable, because of the apparent discordancy between the northeast-trending boundary of the Pikwitonei Granulite Domain and the east-trending structures of the Superior Province. However, recent mapping has demonstrated that the internal structures of the Pikwitonei domain trend easterly and are parallel and coeval with the Kenoran structures of the northwestern Superior Province. The apparent discordancy between the Superior Province and the Pikwitonei Granulite Domain results from the obliquity of the trace of the orthopyroxene isograd with respect to the east-trending Kenoran structural grain.

The Pikwitonei Granulite Domain contains areas of amphibolite facies rocks. They represent either Pikwitonei gneisses that have escaped the granulite facies metamorphism, or granulites that were retrogressed during late-Kenoran and late-Hudsonian events. The resultant distribution of granulite facies and amphibolite facies rocks is irregular and further complicated by late-Kenoran and Hudsonian fault movements.

The Pikwitonei gneisses are migmatites comprising two groups of compositionally contrasting rocks: an intermediate to felsic group of enderbites, opdalites, minor leuco-norites and charnockites, derived gneisses and amphibolite facies equivalents; and a group of mafic granulites, metagabbros, metapyroxenites and amphibolites. In the area between Cross Lake and Sipiwesk Lake, mafic granulites of the Pikwitonei Granulite Domain have been traced into mafic metamorphites of volcanic and subvolcanic origin. Similarly, enderbites and related felsic granulites have been traced

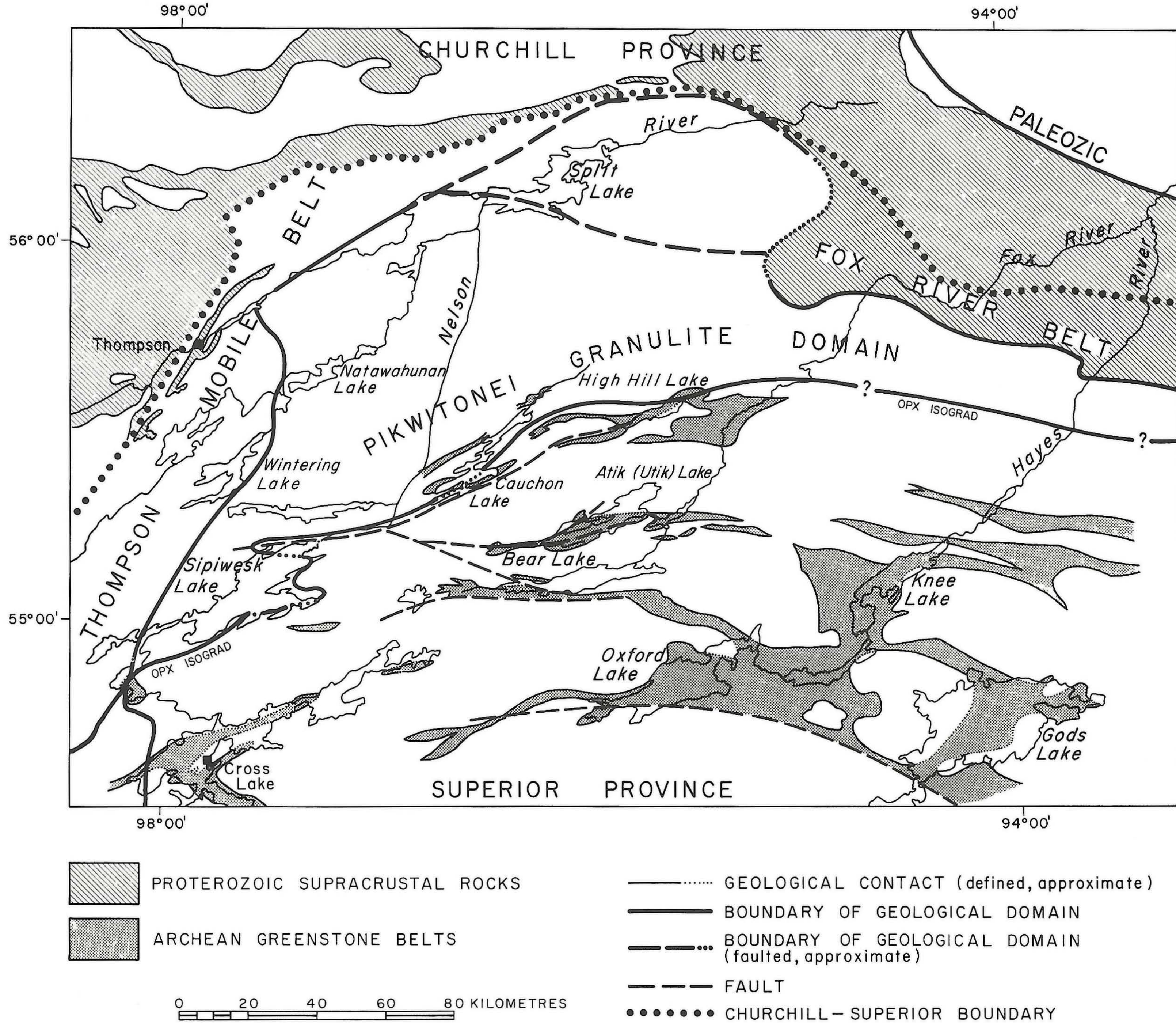

FIGURE 1: Major geological units of the Superior-Churchill Provinces boundary zone in central Manitoba. Simplified after Geological Map of Manitoba (Manitoba Mineral Resources Division, 1979).

into metatonalites and metagranodiorites (Rousell, 1965; Hubregtse, 1978 and 1979). Thus, the compositional dichotomy of the Pikwitonei Granulite Domain reflects to a large extent the two major compositional groups of the lower grade greenstone belt-tonalite gneiss terrane.

The Pikwitonei Granulite Domain differs from the two major metasedimentary gneiss belts of the southern Superior Province, the English River Subprovince (Breaks *et al.*, 1978) and the Quetico Belt (Goodwin, 1972), in that it contains a lower proportion of supracrustal rocks. Metasediments abound in the English River and Quetico gneiss belts, but metavolcanic rocks are scarce. Recently, however, Urquhart and West (1979) described granulites from the Lac Seul region which are identical to those of the Pikwitonei Granulite Domain, suggesting some similarities between the English River belt and the Pikwitonei Granulite Domain. The Lac Seul rocks include metamorphosed iron formations and mafic granulites similar to those that are interpreted as metabasalts in the Pikwitonei Granulite Domain. The authors state that the granulite facies iron formation looks exactly like those found in lower-grade greenstone belts. The precursors of the metasedimentary gneiss belts are envisaged as major troughs in which sedimentation took place penecontemporaneously with volcanism in the adjacent greenstone belt terranes (Goodwin, 1972; Breaks *et al.* 1978). By way of contrast the Pikwitonei Granulite Domain represents a high-grade, and perhaps deeper level of a Superior-type volcanic belt-tonalite gneiss system. In this respect the Pikwitonei Granulite Domain may resemble the Berens Batholithic Belt (Ermanovics and Davison, 1976), which is also considered to constitute a deeper and remobilized part of Superior-type crust. The Berens Batholithic Belt, situated south of the greenstone belt-gneiss terrane of the northwestern Superior Province, is mainly underlain by migmatite gneiss and gneissic and massive granodiorite, and its supracrustal component amounts to only 3% (Ermanovics and Davison, 1976).

East-trending Kenoran structures (D_1 and D_2) of the Pikwitonei Granulite Domain are overprinted and truncated to the northwest by later, possibly Hudsonian, northeast-trending structures (D_3) of the Thompson belt (Fig. 2). A preliminary Rb/Sr whole-rock isochron age of 1720 Ma (±140 Ma), which may represent the age of overprinting, was recently determined for metasomatized and remetamorphosed Archean granulites of the Thompson belt (Charbonneau, pers. comm.). The Hudsonian orogenic phase was predated by the intrusion of the Molson dyke swarm (Scoates and Macek, 1978), since the Molson dykes become increasingly metamorphosed and deformed (towards the zone of overprint) with attendant folding, transposition and re-orientation of both the dykes and the Kenoran structures. The process is similar to that described by Escher *et al.* (1975) for the deformation of the Aphebian mafic Kangâmiut dykes (Kalsbeek *et al.*, 1978) at the margin of the Nagssugtoqidian Mobile Belt in Greenland. The Thompson belt of reworked Archean granulites exhibits granitization, metasomatism, medium-grade metamorphism, intricate flow-folding and intense transposition, flattening and shearing of the older Kenoran structures (Hubregtse, 1978). These features are characteristic of mobile belts that have been described elsewhere by Anhaeusser *et al.*, (1969); Bridgwater *et al.*, (1973); Mendelsohn (1973), and Sutton (1976).

The reworked Pikwitonei granulites have been referred to as the Thompson Nickel Belt (Coats *et al.*, 1972) or the Wabowden subprovince of the Churchill Province (Bell, 1971). However, "Thompson Mobile Belt" is preferred by the present author. It is proposed that this name be adopted because the characteristic features of this belt are due to tectonic and metamorphic activity, and as such this belt closely resembles mobile belts described elsewhere. The main concentration of nickel deposits is restricted to a narrow northeast-trending zone along the northwest flanks of the "Thompson Mobile Belt". The nickel deposits cannot therefore be considered typical for the entire mobile belt nor even the Churchill-Superior boundary, as no occurrences have as yet been defined in the immediately contiguous east-trending segment of the boundary in the Split Lake and Fox River region.

The peak Hudsonian metamorphic and deformational events in the Churchill Province (McRitchie *et al.*, 1973; Bailes, 1975) do not appear to have affected the adjoining Pikwitonei Granulite Domain, whereas the later D_3-event affected both the Churchill Province and the Pikwitonei Granulite Domain of the Superior Province. Thus the D_3-event appears to be related to a separate younger orogenic phase[1], that may have been restricted to the contact between the two structural provinces. Therefore, the "Thompson Mobile Belt" should also encompass the Aphebian rocks overprinted by D_3 west of the Churchill-Superior boundary (McRitchie *et al.*, 1973; Bailes, 1975).

A review of the geochronological evidence supporting a late-Aphebian age for the orogenic event that led to the formation of the "Thompson Mobile Belt" has been presented by Weber and Scoates (1978).

DISCUSSION OF PREVIOUS WORK

The suggestion by Bell (1971) that the Pikwitonei granulite facies complex formed the basement for the northwestern Superior Province has been used as evidence for the existence of an early-Archean basement (older than 3 Ga) and as proof for a sialic composition of pre-greenstone belt crust (Cranstone and Turek, 1976; Ermanovics and Davison, 1976; Baragar and McGlynn, 1977; Goodwin, 1977; Young, 1978). However, Bell's (1971) "older basement" hypothesis has not been supported by isotopic ages. The Pikwitonei granulites were strictly

"thought to be the oldest rocks" (Bell, 1971, p. 12)

in the northwestern Superior Province. U/Pb isotopic zircon ages of older than 2.9 Ga, that were obtained from tonalite gneisses of the Superior Province in northwestern Ontario and central eastern Manitoba (Krogh *et al.*, 1974; Krogh *et al.*, 1975; Krogh *et al.*, 1976) appeared to support Bell's hypothesis. However, these are probably emplacement ages (Krogh *et al.*, 1976) and do not necessarily indicate pre-Kenoran[1] orogenic activity. Thus, Bell's hypothesis is based upon two assumptions: (1) that a local unconformity in the Cross Lake Greenstone Belt is a fundamental unconformity between the Superior Province and the "Pikwitonei Province"; and (2) that the granulites are older than 3 Ga (Bell, 1971, p. 33). The validity of Bell's assumptions is discussed below.

The Cross Lake unconformity and the Pikwitonei Granulite Domain — Superior Province relationship

Horwood (1935 and 1936) speculated that the widely exposed tonalite gneisses of the Cross Lake area formed the basement for the volcanosedimentary belt at Cross Lake, but he did not observe an unconformity. Rousell (1965) challenged Horwood's interpretation because he found an intrusive relationship between the tonalite gneisses and the supracrustal rocks. However, Rousell (1965) did report an unconformity between a small body of foliated biotite granodiorite and overlying metabasalts and metasediments in the Cross Lake area (Fig. 2), and he interpreted the biotite granodiorite

[1] Pre-Kenoran is herein understood as an orogeny older than the deposition of the Superior Province greenstone belts

[1] The age of the formation of the "Thompson Mobile Belt" is post-Hudsonian according to Stockwell's (1973) time classification. However, whether or not the formation of the "Thompson Mobile Belt" at about 1720 Ma ago should be part of the Hudsonian orogeny is beyond the scope of this paper. The D_3-event will be referred to as late-Hudsonian.

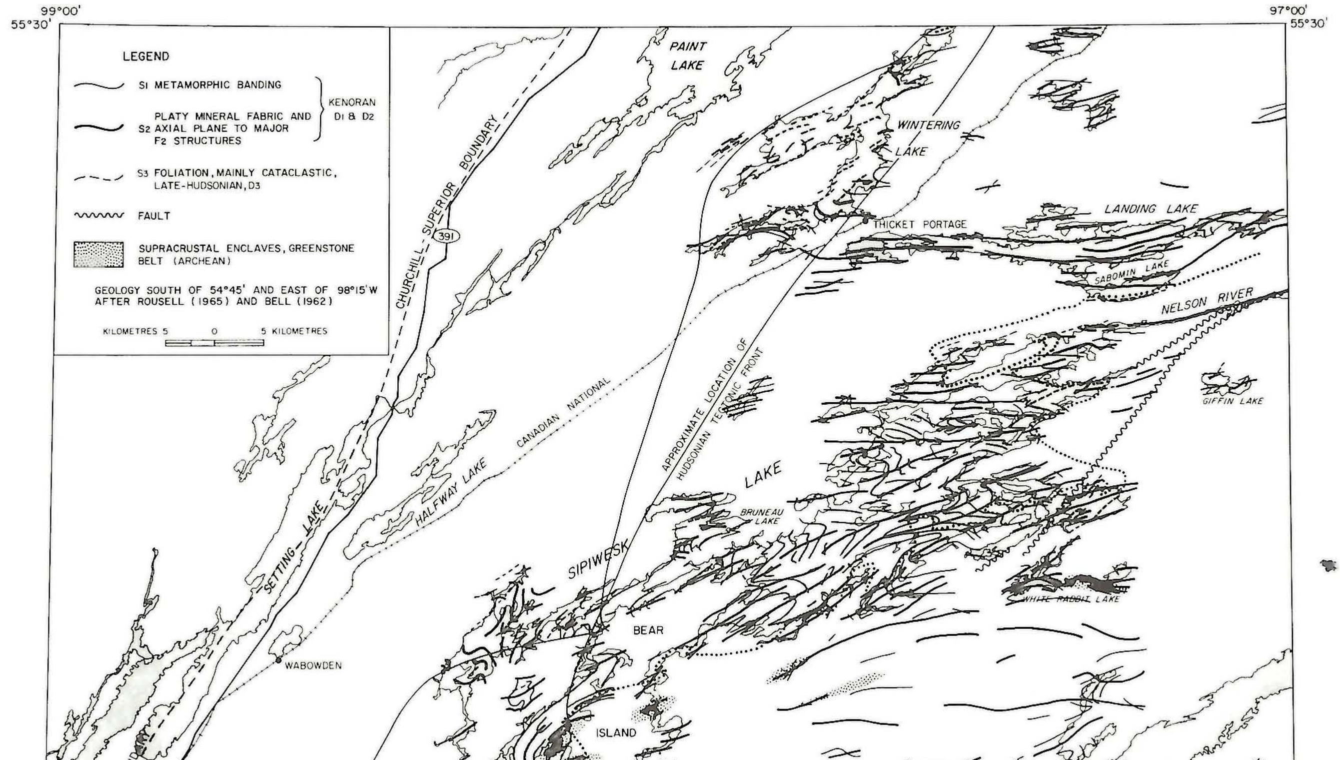

FIGURE 2: Structural map of southern Pikwitonei-Cross Lake area. Churchill-Superior boundary after Geological Map of Manitoba (Manitoba Mineral Resources Division, 1979).

to be a basement for the supracrustal rocks. Subsequently, Bell (1971) reintroduced Horwood's basement hypothesis, presumed a pre-Kenoran age for the biotite granodiorite underlying the local unconformity at Cross Lake and correlated the biotite granodiorite with the granulites of the Pikwitonei region. He also assumed an Archean age for the Cross Lake Greenstone Belt. In order to accomodate the interpretation, that the Pikwitonei granulites were part of an early Archean basement, Bell had to postulate a regional unconformity between the amphibolite facies gneiss terrane of the Cross Lake belt and the granulites. Accordingly, he suggested that the southeastern boundary of the granulite complex might represent a

> *"metamorphosed unconformity . . . , . . . approximately marked by the orthopyroxene isograd"* (Bell, 1971, p. 16).

He further stated that

> *"the magnitude of the stratigraphic break between the basement complex gneiss and the apparently overlying "type", Archean supracrustal rocks of the Superior Province suggest that the former can eventually be assigned to an early era of the Archean or . . . an eon that predates the Archean"* (Bell, 1971, p. 12).

One of the objectives of this paper is to show that neither stratigraphic nor structural breaks exist along the trace of the unconformity proposed by Bell (1971, Fig. 1).

According to Bell's (1971) hypothesis, "Superior-type" greenstone belt rocks should not be found in the Pikwitonei Granulite Domain. However, within greenstone belt-type rocks the transition from amphibolite facies to granulite facies mineral assemblages is locally very well exposed in several localities at Duck Lake, near Bear Island, at White Rabbit Lake and at Cauchon Lake over a distance of 125 km along the overprinting orthopyroxene isograd (Figs. 1 and 2) (Weber, 1976; Hubregtse, 1978). A similar transition was already reported in 1965 by Rousell within supracrustal enclaves just north of the Cross Lake Greenstone Belt, of which the western arm is overprinted by granulite facies metamorphism (Hubregtse, 1979).

The biotite granodiorite underlying the local unconformity at Cross Lake is not in the granulite facies nor are the clasts of the overlying conglomerate. A close inspection of this conglomerate at Cross Lake reveals a high proportion of mafic and porphyritic plutonic clasts in the predominantly biotite granodiorite-bearing clast population (Fig. 3). Thus, the conglomerate is not solely derived from biotite granodiorite and tonalite, nor does it contain clasts that could be derived from Pikwitonei granulites. The conglomerate most closely resembles an intra-greenstone belt conglomerate such as those described in the Oxford Lake Group (Hubregtse, in prep.) and the Island Lake Series (Godard, 1966). The immaturity of the Cross Lake conglomerate, which does not contain a high proportion of "abrasion resistors", such as quartz and chert, is more consistent with a local greenstone belt origin than it is with Bell's (1971) interpretation of it as a conglomerate marking a 300 Ma stratigraphic break. Thus, this author views the conglomerate at Cross Lake as an intra-greenstone belt conglomerate without any regional significance.

FIGURE 3: Detail of the conglomerate at the north shore of Cross Island, Cross Lake.

Another problem with Bell's (1971) hypothesis is that his interpreted unconformity is nearly coincident with the orthopyroxene isograd of the assumed pre-Kenoran basement complex. Since this would require that erosion consistently terminated at the depth of the orthopyroxene isograd of the supposedly pre-Kenoran basement complex over a length of approximately 200 km, this interpretation seems highly unlikely. Compelling evidence for the existence of a basement-cover relationship at Cross Lake has not been presented by Rousell (1965) nor Bell (1971). Bell (1971) described the metasediments and conformable gabbroic anorthosite sills of the Cross Lake Greenstone Belt as having

> *"been deformed into two open folds that plunge east at 40 and 65 degrees, respectively . . . These stratiform rocks lie with great structural discordance (90 degrees) on an old gneissic terrane that strikes east and dips vertically"* (Bell, 1971, p. 15).

Ermanovics and Davison (1976) concurred with Bell's claim that the observed structural discordance is proof that the biotite granodiorite formed a basement for the greenstone belt at Cross Lake. However, none of the authors explained whether the structural element in the underlying biotite granodiorite gneiss is older than the deposition of the greenstones, or simply an axial planar foliation formed during the folding of the overlying greenstone belt. The latter seems more likely since the structural grain in both the gneiss and the supracrustal rocks trends east.

Age of the granulites

Detailed mapping of lithologies, structures, and metamorphic facies (Hubregtse, 1977, 1978 and 1979; Weber, 1976, 1977 and 1978) has showed that the rocks of the Pikwitonei region are continuous with and part of the Superior Province, and that there is no evidence for an orogeny older than the Kenoran. Weber and Scoates (1978) concluded from published isotopic data (Cranstone and Turek, 1976) that the age of a first phase of granulite facies metamorphism is 2760 Ma (+135 Ma). A preliminary Rb/Sr rock isochron age of 2490 Ma (+50 Ma) was recently determined for rocks that intruded during a second phase of Kenoran granulite metamorphism (Charbonneau, pers. comm.). No isotopic ages indicating an event older than 3 Ga have been recorded in the Pikwitonei Granulite Domain (Weber and Scoates, 1978). Ages greater than 3 Ga may well be determined eventually. However, the detection of such ages does not necessarily imply that the Pikwitonei Granulite Domain was affected by an older, pre-Kenoran orogeny.

Furthermore, the 2712 ±5 Ma U/Pb zircon age (Ermanovics and Wanless, in prep.) reported for the "basement granodiorite" at Cross Lake, is similar to ages obtained from supracrustal rocks elsewhere in the northwestern Superior Province, e.g. a 2.7 Ga U/Pb zircon age for dacites in the Knee Lake are (Catanzaro, unpublished) and a 2.7 Ga Rb/Sr whole rock isochron age for mafic volcanics of the Oxford Lake Greenstone Belt (Brooks, pers. comm.).

The trace of Bell's (1971) proposed unconformity (i.e. the orthopyroxene isograd) has been field-checked in several localities and no structural breaks were observed. Moreover, the orthopyroxene isograd transects the supracrustal rocks of the Cross Lake Greenstone Belt (Hubregtse, 1979). There is, therefore, little reason to assume that the granulites of the Pikwitonei region and the granulite facies metamorphism are older than the Archean rocks of the Cross Lake area and the Kenoran orogeny, respectively.

TABLE 1

ORDER OF EVENTS

	"THOMPSON MOBILE BELT" — WINTERING LAKE — WESTERN SIPIWESK LAKE, DUCK LAKE — MINAGO RIVER		PIKWITONEI GRANULITE DOMAIN — LANDING LAKE — EASTERN AND CENTRAL SIPIWESK LAKE — BEAR ISLAND — BULGER LAKE — CROSS LAKE	Metamorphism		Orogeny
	— emplacement of granite and pegmatite	LATE-HUDSONIAN TECTONIC FRONT				LATE-HUDSONIAN OROGENY
	— formation of rare pseudotachylyte		— formation of pseudotachylyte			
D_{3B}	— renewed shearing within S_2-tectonic zones		— northeast-trending faults and mylonites			
	— greenish-grey lamprophyre					
M_3 / D_{3A}	— intense shearing and (blasto-) mylonitization formation of well-layered gneisses (S_3 — tectonites), profound reworking of Archean gneisses		— reactivation of D_2-shear belts, sporadic deformation of Molson dykes; weak metamorphism noticeable in Molson dykes	M_3	mainly amphibolite facies metamorphism in the Wintering and western Sipiwesk Lakes area, sporadic greenschist facies metamorphism east of the tectonic front	
M_3	— formation of M_3-migmatites					
M_3	— metasomatism of Archean gneisses					
	— pegmatite, tonalite and granodiorite					
	— emplacement of Molson diabase swarm					
	local anatexis of older migmatites					
	— north-northwest-trending mylonites					KENORAN OROGENY
D_{2B}	— formation of east-northeast-trending late-D_2 shear belts, augen gneisses and mylonites, attenuation of S_2-fabric					
	— granitization and recrystallization of migmatites between Sipiwesk Lake and Cross Lake			M_2	(hornblende) granulite facies and amphibolite facies metamorphism	
	— growth of post-S_2 garnet and local retrogression			M_2		
D_{2A}	— formation of planar and planolinear quartz fabric (S_2)			M_2		
	— formation of M_2-migmatites			M_2		
	— intrusion of quartz-monzonite, pegmatite, granite, minor tonalite and monzo-diorite			M_2		
	— intrusion of (leuco-)gabbro, leuco-enderbite, opdalite dykes and sills (central Sipiwesk Lake)			M_2		
	— derivation of quartz-feldspar (-orthopyroxene/hornblende) mobilizate from pre-M_1 migmatites			M_2		
	— intrusion of hornblendite dykes			M_2		
D_{1B}	— local isoclinal folding of S_1			M_1	amphibolite facies and hornblende granulite facies metamorphism, lower grade metamorphism in the Cross Lake area	
D_{1A}	— formation of metamorphic banding S_1			M_1		
	— derivation of K-feldspar-rich felsic mobilizate			M_1		
	— plagioclase-phyric mafic dykes (Bulger Lake dykes)					
	— formation of pre-M_1 migmatites					
	— intrusion of tonalite, granodiorite and minor quartz diorite (enderbite ?)					
	— emplacement of layered gabbro-pyroxenite (northwestern part of map area), minor peridotite					
	— intrusion of hypabyssal plagioclase-phyric gabbro and anorthosite in the greenstones					
	— deposition of greenstones (massive and pillowed basalts, sediments, iron formations, dacites and porphyries (southern part of map area))					
	?					

GEOLOGICAL HISTORY AND NATURE OF THE MIGMATITE GNEISSES OF THE PIKWITONEI AND CROSS LAKE AREAS

The Archean geological history of the Pikwitonei region and the Cross Lake area, based on data gathered during detailed geological mapping since 1975, is summarized in Table 1.

Pre-M_1 Lithologies; First Kenoran orogenic event (D_1-M_1)

Supracrustal rocks of typical Superior Province greenstone belts have been traced across the "orthopyroxene-in" isograd into the Pikwitonei Granulite Domain. The granulite facies lithologies are, therefore, interpreted as more highly metamorphosed equivalents of those found in the adjacent greenstone belt-tonalite gneiss terrane. Pillows, indicating a supracrustal origin, are locally well preserved in the mafic granulites, particularly those close to the orthopyroxene isograd (Weber, 1976; Hubregtse, 1978). Elsewhere, metagabbro-pyroxenite bodies with a primary, rhythmic, igneous layering have been documented at Wintering Lake (Fig. 4) (Hubregtse, 1975). Enclaves of well-preserved supracrustal rocks, including metabasalts, occur only in the southeastern part of the southern Pikwitonei Granulite Domain, whereas the deeper-seated layered metagabbro-pyroxenites occur farther to the northwest (away from the Superior greenstone belts) and in an area of generally higher metamorphic grade. The layered metagabbro-pyroxenites may be deep-seated equivalents of the metabasalts. Comparable gabbros and pyroxenites have not been observed in the low- to medium-grade greenstone belts of the northwestern Superior Province.

The supracrustal rocks that occur near, or straddle the orthopyroxene isograd (Fig. 2), are similar to those documented in typical Superior Province greenstone belts such as the Oxford Lake belt (Hubregtse, 1973 and 1976), Atik (Utik) and Bear Lake belts (Weber, 1974), the High Hill belt (Weber, 1975) and the Cross Lake belt (Rousell, 1965) (Fig. 1). Typical greenstone belt lithologies in granulite facies are pillowed metavolcanics, metamorphosed massive amygdaloidal volcanics, probable dacites and porphyries, arenaceous and argillaceous sediments, oxide and sulphide iron formations. calc-silicate gneisses, fragmental pyroclastic deposits and plagioclase-phyric gabbroic sills (Fig. 5). Marble is rare, and generally occurs in association with strongly assimilated and metasomatized supracrustal rafts, suggesting a metamorphic rather than sedimentary origin. The greenstones are locally strongly affected by deformation and recrystallization in the supracrustal enclaves. All stages are exhibited in the conversion from pillowed metabasalts and plagioclase-phyric anorthositic metagabbro to banded amphibolite and mafic granulite (Fig. 6).

FIGURE 4: Metagabbro with rhythmic primary igneous layering at Wintering Lake. Width of outcrop approximately 1.6 m.

The magnetite iron formations are usually the only supracrustal rocks that retain their identity in the granulite facies. They occur abundantly in the Natawahunan Lake area, associated with ultramafic and mafic granulites (Weber, 1978). Similar lithological associations were identified in the medium-to low-grade Atik (Utik) and High Hill greenstone belts southeast of the orthopyroxene isograd (Fig. 1) (Weber, 1974 and 1975).

The supracrustal belts, enclaves and layered gabbro-pyroxenite bodies were extensively invaded and partly assimilated by tonalite, quartz diorite and granodiorite. The process resulted in the formation of a migmatite complex. Rousell (1965) and Hubregtse (in prep.) report similar migmatites along the margins of the greenstone belts at Cross Lake and Oxford Lake, respectively. Plagioclase-phyric mafic dykes were emplaced into the migmatites prior to the onset of the first phase of deformation D_1 and metamorphism M_1. D_1 resulted in the formation of a well-defined metamorphic layering S_1, which generally exhibits northwest trends in domains of low-D_2 strain within the migmatite complex (Fig. 2). The physical conditions during M_1 locally reached hornblende-granulite grade in the Pikwitonei Granulite Domain and lower grades in the Cross Lake area farther to the south. Mobilization during M_1 is largely restricted to the segregation of leucocratic quartzofeldspathic mobilizates from the migmatites.

Second Kenoran orogenic event (D_2-M_2)

The second Kenoran orogenic event (D_2-M_2) is marked by extensive reactivation of S_1-migmatite gneisses. The M_2-event reached granulite grade in the Pikwitonei Granulite Domain and lower grades in the Cross Lake area. The boundary between the Pikwitonei Granulite Domain and the amphibolite facies rocks of the Cross Lake area is herein defined as the southeasternmost occurrence of orthopyroxene rather than a true metamorphic isograd. This is necessary because of the overlap between the two granulite facies events, and further complications resulting from subsequent retrograde metamorphic events. Typical granulite facies mineral assemblages formed during M_2 are:

- orthopyroxene + plagioclase + quartz (± hornblende ± clinopyroxene ± biotite) in enderbites, mafic granulites, leuco-norite, mafic metavolcanic rocks and layered metagabbros;
- orthopyroxene + clinopyroxene (± plagioclase ± hornblende ± biotite) in metapyroxenites; and
- sillimanite + potash feldspar + plagioclase + quartz + biotite in metasedimentary gneisses.

Garnet, sillimanite and cordierite may occur locally in felsic granulites. In the granulites of mafic and intermediate composition garnet developed at the expense of pyroxenes and plagioclase as a

FIGURE 5a: Relict pillow selvages preserved in mafic granulite, situated near the orthopyroxene isograd, southwestern Sipiwesk Lake. The light-coloured seams and patches of orthopyroxene-quartz-plagioclase segregations, in the lower left, resulted from incipient mobilization. Width of outcrop approximately 2.4 m.

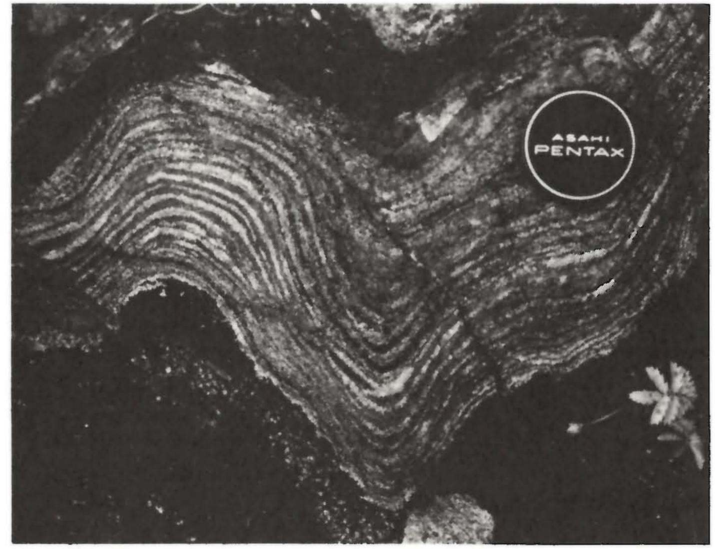

FIGURE 5b: Oxide iron formation near the orthopyroxene isograd, Nelson River south of Sipiwesk Lake.

FIGURE 5c: Fragmental deposit. Upper amphibolite facies, 4 km south of orthopyroxene isograd, between Cross Lake and Sipiwesk Lake. Length of bar is 16 cm.

FIGURE 5d: Plagioclase-phyric anorthositic gabbro, near orthopyroxene isograd, Nelson River south of Sipiwesk Lake.

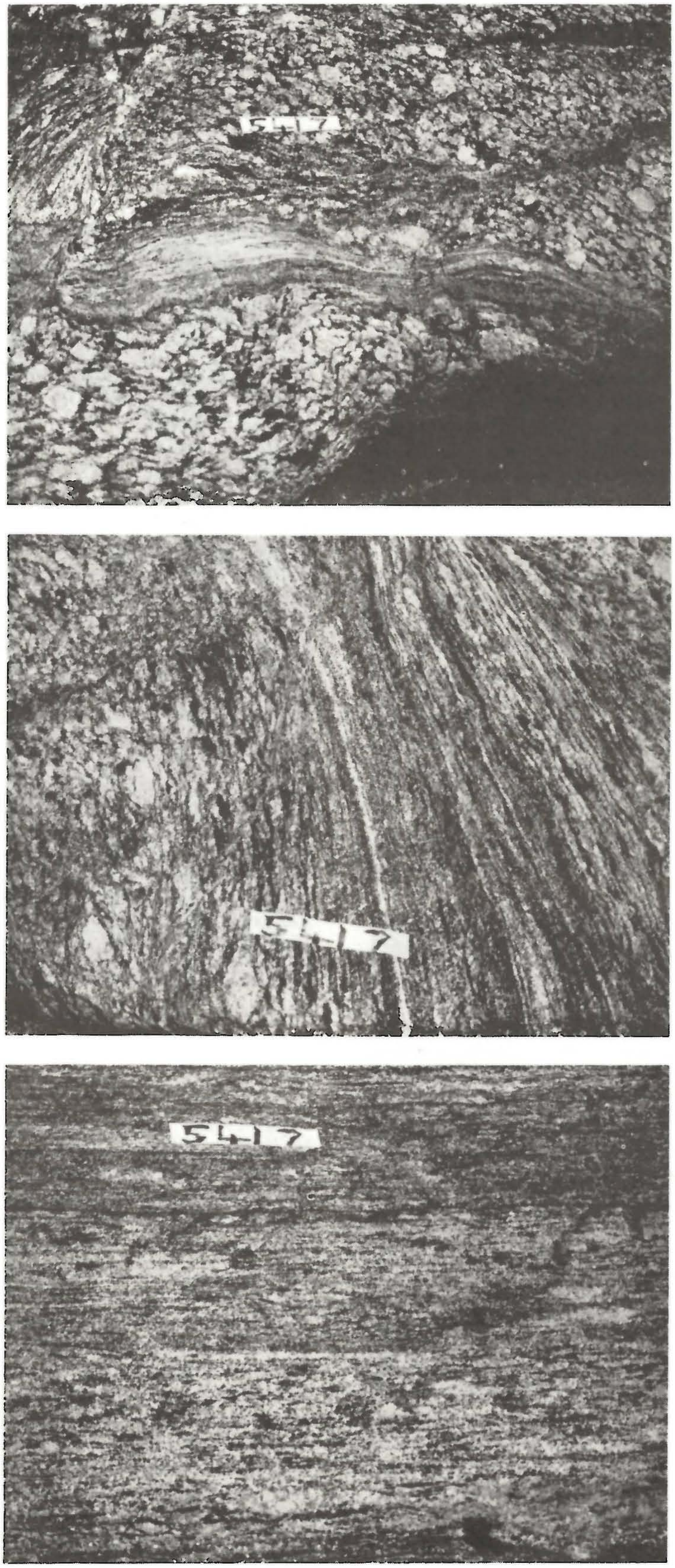

FIGURE 6: ***Progressive*** *conversion of gabbroic anorthosite into plagioclase-rich amphibolite by increase of D_2 strain, Duck Lake. Width of tape is 2.5 cm.*

retrograde late- to post-tectonic M_2-phase, and may sporadically exhibit corona textures.

The second phase of metamorphism M_2 is marked by the derivation of syn-orogenic mobilizates (plagioclase + quartz ± hornblende) from the older metagabbros, enderbites and tonalite gneisses and mafic metavolcanic rocks (Fig. 7). The mobilizates include enderbite, tonalite and quartz diorite. Minor anorthositic segregations were frequently noticed in mafic granulites. The mobilizates occur throughout the Pikwitonei Granulite Domain and adjacent amphibolite facies terrane of the Cross Lake area. They are the oldest members of a variety of suites of intrusive and mobilizate rocks, that were emplaced 2490 ± Ma ago (R. Charbonneau, pers. Comm.) during M_2, but prior to D_2, the second phase of deformation.

The widespread mobilization of the older migmatites was followed by emplacement of a suite of commonly porphyritic enderbite and opdalite and locally anorthositic leuco-quartz norite. The rocks of this suite are devoid of hydrous phases. They occur at central Sipiwesk Lake in an oblong zone (5 x 15 km) in which the M_2-metamorphism reached extreme conditions. The scarcity of hornblende in the enclosing pre-M_1 migmatites and the presence of orthopyroxene-sillimanite and sapphirine-bearing rocks indicates that the M_2-metamorphism culminated in this area (Hubregtse, 1978).

Sapphirine occurs in layers of variable composition. Ultra-basic layers contain sapphirine, enstatite, spinel, corundum and phlogopite. The intermediate compositions are characterized by sapphirine, enstatite, cordierite, sillimanite and plagioclase. Garnet is restricted to intermediate compositions and is likely a retrograde phase. The sapphirine-bearing rocks are directly associated with more acidic gneisses which contain co-existing sillimanite + orthopyroxene + quartz ± phlogopite. Acidic orthopyroxene-sillimanite gneisses are also exposed at Black Duck Lake (Fig. 2), southwest of the Cross Lake Greenstone Belt (Hubregtse, 1979). The mineral assemblages indicate pressures of 10 to 11 kb and temperatures of 900 to 1000°C, according to Hensen and Green (1973). The granulites belong to the intermediate pressure group (Ringwood and Green, 1967).

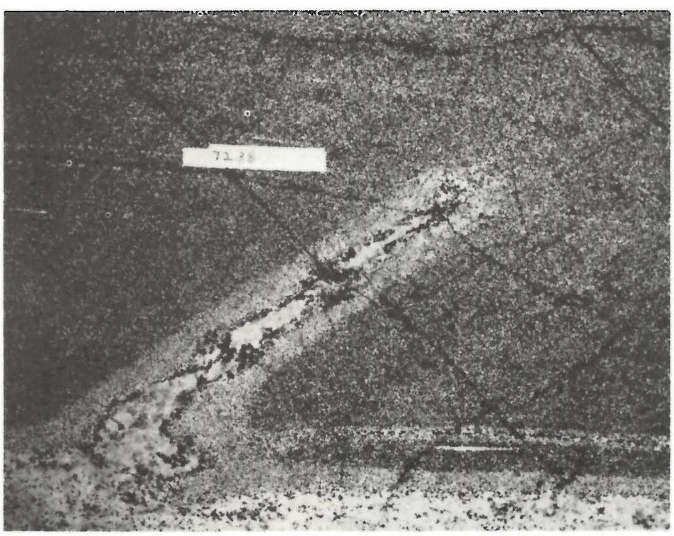

FIGURE 7: Formation of syn-M_2 orthopyroxene-quartz-plagioclase mobilizate in mafic hornblende two-pyroxene granulite (M_1) with faint S_1-banding parallel to white bar. Mobilizate seams formed parallel to S_1 and S_2. S_2-fabric is not well developed. Bleached margins of the hornblende two-pyroxene granulite resulted from recrystallization and breakdown of hornblende and clinopyroxene during M_2. Width of the area shown is 75 cm.

The early syn-M_2 mobilizates and leuco-quartz norite suite are postdated, prior to the second phase of deformation, by the emplacement of syn-M_2 quartz monzonite, pegmatite and granite and their granulite facies counterparts. This D_2-tectonic event resulted in the isoclinal folding of S_1 and development of the plano-linear S_2-fabric in the granulites. A typical S_1-S_2 relationship is shown in Figure 8 and the regional trends of S_1 and S_2 are depicted in Figure 2.

FIGURE 8: Layered granulite showing S_1-S_2 relationship. S_2 parallel marker pen (centre). Note strong transposition of left-hand side.

Extensive late-M_2 granitization of the amphibolite facies migmatite gneisses, situated between Sipiwesk Lake and Cross Lake, occurred generally southeast of the orthopyroxene isograd. Widespread recrystallization and introduction of pegmatitic and granitic phases has locally resulted in the complete obliteration of older D_2 and D_1 structural elements, and the assimilation of pre-M_1 mafic components of the migmatite gneisses. Faint, slightly more mafic schlieren outline the older structures in the resultant featureless, weakly foliated granodiorite and granite gneisses. The granitization is thought to be related to a deeper crustal "dry"-M_2 granulite facies metamorphism that effected the Pikwitonei domain at Sipiwesk Lake, and resulted in the extraction of volatile and potassium-rich components. Subsequent transfer of these components towards higher crustal levels, which are now exposed between Sipiwesk Lake and Cross Lake, led to the formation of a generally "dry" and potassium-depleted deeper crustal granulite facies complex overlain by an amphibolite facies complex, enriched in volatile and potassium-rich granitic and pegmatitic components (Hubregtse, 1978). A similar process has been described by Collerson and Fryer (1978) in their model for the development of early Archean crust.

Correlation of tectonometamorphic events

The metamorphic banding S_1 and the plano-linear fabric S_2 can be traced from the Pikwitonei Granulite Domain through the amphibolite facies migmatite complex north of Cross Lake, into the Cross Lake Greenstone Belt proper (Fig. 2). There is no sudden change in the geometry and attitude of folds at the orthopyroxene isograd to indicate an unconformable relationship as proposed by Bell (1971). Linear structures L_2 within the southern Pikwitonei Granulite Domain strike parallel to similar linear structures mapped by Rousell (1965) within and north of the Cross Lake Greenstone Belt. Rousell shows that the lineations are parallel to and coeval with the axes of the major structures of the Cross Lake Greenstone Belt, which are the enveloping surfaces of a folded older schistosity S_1.

Two major metamorphic and tectonic events, however, were recognized in the Oxford Lake Greenstone Belt (Hubregtse, in prep.) which is situated 135 km east of Cross Lake (Fig. 1). The first orogenic event in the Oxford Lake area postdated the deposition of the older volcanic Hayes River Group. The two orogenic events are separated by the deposition of the younger volcano-sedimentary Oxford Lake Group.

Preliminary isotopic data indicate a Kenoran age for the greenstones of the Oxford Lake belt. A U/Pb age of 2.7 Ga (Catanzaro, unpublished) was determined for zircons from a dacite of the volcanic Hayes River Group, and a Rb/Sr whole rock age of 2.7 Ga was obtained for a lower volcanic member of the Oxford Lake Group (C. Brooks, pers. comm.). Cheung (1978) reports a 2455 Ma (±37 Ma) whole rock Rb/Sr age for a late-tectonic granite that intruded the Oxford Lake Group metasediments (H.P. Gilbert, pers. comm.) during the second orogenic event that affected the Oxford Lake area. Cheung's data can be correlated with the 2490 Ma (±50 Ma) date (R. Charbonneau, pers. comm.) for the second orogenic event in the Sipiwesk Lake area. These dates, in conjunction with the 2712 ± 5 Ma U/Pb zircon date for the biotite granodiorite at Cross Lake (Ermanovics and Wanless, in prep.) indicate a Kenoran age for the tectonometamorphic events in the Oxford Lake area and the Cross Lake-Pikwitonei region.

Anorthosites; Remobilization of the Pikwitonei gneisses

Various plagioclase-rich rocks are locally abundant in the high-grade Pikwitonei region and the lower-grade Cross Lake area. Several authors have indicated that layered and/or unlayered anorthosite-gabbro complexes are an intrinsic feature of high-grade gneiss terranes (Sutton, 1976; Windley, 1976; Shackleton, 1976). Examples of these complexes have been described from the Fiskenaesset region in west Greenland (Bridgwater *et al.*, 1974; Meyers, 1976), where anorthosite complexes are found,

a) intruded into basic volcanics and subsequently engulfed by tonalite and granodiorite; and also
b) as rafts in younger granitic rocks.

In both cases, Windley (1976) interpreted the layered complexes as refractory residues of a basaltic-andesitic magma parental to the tonalite-granodiorite gneiss. He suggested that the layered complexes were intruded by their own fractionated granitic suite.

Four types of anorthosites, anorthosite-like rocks and anorthositic gabbros have been recognized in the Pikwitonei Granulite Domain and the adjacent Cross Lake Greenstone Belt-gneiss terrane of which some occur in settings similar to those described from Fiskenaesset. The main features of the plagioclase-rich rocks and their mutual relationships are summarized below:

I. Gabbro-pyroxenite complexes display two types of compositional layering. There is a large-scale repetition of gabbro layers, 15 cm to over 4 m thick, and pyroxenite horizons, varying in width between 3 and 60 cm. A small scale repetitious layering, varying in width between 3 and 15 cm, resulted from plagioclase enrichment, particularly within the gabbroic layers, due to gravity induced differential settling. Although these anorthosite layers generally have a limited width, much wider zones of plagioclase-enriched gabbro (anorthositic gabbro) have also been documented. The layered sequences were engulfed and intruded by tonalite and/or enderbite prior to the first phase of granulite facies metamorphism M_1 (Hubregtse, 1977). Layered gabbros of this type have not been found within the supracrustal sequence of the northwestern Superior Province.

II. Sheets of plagioclase-phyric rocks form a suite ranging in composition from gabbro to anorthosite (Fig. 5d) with conspicuous cumulus textures. These intrusions were emplaced into the supracrustal rocks of the northwestern Superior Province, including those supracrustals that occur within the granulite facies complex of the Pikwitonei region (Hubregtse, 1978). Coarse varieties of these rocks, with plagioclase crystals up to 25 cm across, occur abundantly in the Cross Lake Greenstone Belt (Rousell, 1965; Bell, 1971; Ermanovics and Davison, 1976). They occur also as intrusive sheets in the Oxford Lake Greenstone Belt, where textures indicate an originally shallow emplacement for the anorthositic gabbros (Hubregtse, in prep.). The igneous layering is conformable with the bedding of the surrounding pillow basalts. Moreover, the anorthosites and gabbros have been found associated with compositionally and texturally similar plagioclase-phyric basaltic flows, that occur repeatedly at intermediate stratigraphic positions between mafic tholeiitic and felsic calc-alkaline lavas, within volcanic cycles of the Knee Lake and Oxford Lake Greenstone Belts (Green, 1975; Hubregtse, 1976). Rocks of this nature have not been found associated with Type I in the infracrustal granulite domain of the western Pikwitonei region. The anorthositic gabbros were intruded by tonalite and/or enderbite prior to the first phase of Kenoran metamorphism.

III. Gneissic anorthosite occurs sporadically as layers in the granulite facies complex. Some have been found to be spatially associated with granulite facies supracrustal rocks (Weber, 1976). These anorthosites display a well-developed metamorphic banding and are distinct in that they have the highest plagioclase content. Relict cumulus textures are common in little-deformed domains. Plagioclase crystals range from 0.5 to 10 cm. Large crystals are usually internally recrystallized into mosaics of grains of 2 to 5 mm. Sporadic compositional variations to leuco-gabbro and pyroxene amphibolite have been documented (Weber, 1976). The relationship of the gneissic anorthosite with the older types of anorthosite and the enclosing granulites is uncertain. They were emplaced and subsequently engulfed by enderbite prior to M_1. The relict cumulus textures of the gneissic anorthosite resemble Type II and there is some field evidence at Sipiwesk Lake that both may be related.

IV. Plagioclase-phyric gabbroic dykes are locally abundant in southeastern Sipiwesk Lake. The dykes have been metamorphosed to granulite grade and some have an anorthositic gabbroic composition. Their direct relationship with the other types of anorthosite is not known. However, the dykes are younger, since they cut the tonalites and enderbites that are found as intrusions in anorthosites of Types I, II and III. They were also emplaced prior to M_1. Tectonized variations appear as "anorthosite-like" layers in the enderbite gneisses.

Pre-M_1 Types I, II, and III may be related. Type III may be a more highly fractionated, deeper-seated variety of Type II. It is also possible that Types I and II belonged to one larger differentiated mafic-ultramafic-anorthositic complex, before it was fragmented by tectonization and tonalite-enderbite intrusion. Type IV is definitely younger than Types I, II and III as it intrudes the tonalite-enderbite.

Evidence could not be found on the outcrop for a fractionation process in which the anorthositic complexes may have formed the refractory residue of a basaltic-andesitic magma, parental to the enclosing pre-M_1 tonalite-granodiorite suite (Windley, 1976). Moreover, the field relationships provide no evidence directly supporting a genetic relationship between the anorthosites and pre-M_1 tonalite-quartz diorite and enderbite gneisses, as experimentally proven by Green (1969). Contacts between the two rock types are intrusive and are not diagnostic for such a differentiation process. However, widespread generation particularly of enderbitic and tonalitic melts, resulted from mobilization of pre-M_1 gneisses during the second Kenoran metamorphic event (M_2) in the Pikwitonei Granulite Domain. The quantity and the composition of the syn-orogenic (M_2) mobilizates depended on the composition of the pre-M_1 source rocks. The syn-orogenic (M_2) rocks comprise variable proportions of plagioclase (antiperthite to mesoperthite), quartz, orthopyroxene, hornblende, (depending on the P_{H_2O}) and sporadic clinopyroxene. Pre-M_1 rocks of intermediate composition, such as tonalite-enderbite and granodiorite-opdalite, were most suitable for generation of large amounts of M_2-mobilizates of intermediate compositions and underlie areas up to 10 km^2. However, there is no field evidence to suggest that the pre-M_1 anorthosite bodies were responsible for the formation of large quantities of syn-orogenic (M_2) tonalitic-quartz dioritic and enderbitic mobilizates. Our preliminary conclusion is that the anorthositic complexes are related to the development of the greenstone belts, rather than being closely associated with the derivation of the pre-M_1 tonalite-enderbite suite.

Orthopyroxenite M_2-mobilizate seams were observed in mafic-ultramafic granulites. Patchy segregations and veins of anorthosite and leuco-norite are common in mafic granulites throughout the southern part of the Pikwitonei region (Fig. 2) and were also noticed earlier in the northern part (Corkery and Hubregtse, 1975; W. Weber, pers. comm.). Evidence for the formation of anorthositic melts was recently also presented by Wiebe (1979) from the Nain Complex (Labrador).

DISCUSSION

Relationships between high-grade and low-grade regions; Tectonic environment of the granulites

Glikson and Lambert (1976) and Shackleton (1976) have presented similar models pertaining to the relations between high-grade gneiss terranes and low-grade greenstone belt-gneiss systems in Archean terranes. They recognize three possible relationships:

1. Lateral variations in metamorphic grade at the same general crustal level (Glikson and Lambert); the granulites are younger than the adjacent low-grade greenstone belts (Shackleton).
2. Basement-cover relations between the high-grade suite and the volcanosedimentary succession of the greenstone belts (Glikson and Lambert); the granulites are older, upfolded elements in a younger orogenic belt (Shackleton).
3. Coeval syntectonic relations between the granite-greenstone suite and infracrustal high-grade equivalents (Glikson and Lambert); the granulite terranes are deeper levels of orogenic domains, in which high-grade greenstones occur, that are either of the same age or older than the adjacent greenstone belts (Shackleton).

Glikson and Lambert (1976) argued that the high-grade granulite suite of the Wheat Belt can be correlated with concealed infracrustal roots of the low-grade Kalgoorlie greenstone belt system within the Archean Yilgarn craton (southwestern Australia). The authors concluded that the relations within the Yilgarn craton can be explained by Model 3 only. Shackleton (1976) favoured his third model for the age relationships in the Mysore region (southern India), and the Limpopo belt and adjacent Kaapvaal and Rhodesian cratons, mainly on the basis of metamorphic and structural continuity between the high-grade and low-grade regions and the recognition of similar supracrustal rocks in both the high-grade and low-grade regions. Tarney *et al.*, (1976) proposed that the Cretaceous marginal basin of the southern Andes is a late-Phanerozoic analogue of the Archean greenstone belts, and they suggested that tonalite belts and greenstone belts evolved during the Archean from parallel arcs and marginal back-arc basin, respectively. Windley (1976) stressed that in this model the high-grade gneiss terranes and the low-grade greenstone belts developed coevally and laterally. The granulite facies metamorphism is thought to be a direct result of the supposedly high heat flow in the area.

The Pikwitonei Granulite Domain — Cross lake Greenstone Belt relationships fit a combination of Models 1 and 3 (Glikson and Lambert, 1976). Shackleton's (1976) third model is also applicable to the Pikwitonei granulites, with the restriction that the greenstones of the high-grade and low-grade terranes belong to the same age group. It has been demonstrated that supracrustal rocks of the "typical" Superior-type occur throughout a terrane that is metamorphically zoned from greenschist through amphibolite to granulite facies (Model 1). There is, however, a change from a supracrustal domain to an infracrustal domain within the granulite facies zone towards the western margin of the Pikwitonei region (Model 3). Thus, the Pikwitonei granulite — Cross Lake Greenstone Belt relationship definitively does not fit Model 2.

As for the nature of the Archean crust, it has been argued by Sutton (1976) and Windley (1976), amongst others, that on a global scale, different types of crust have evolved in areas that subsequently became low-grade and high-grade terranes:

- Greenstone belt-tonalite systems became low to medium metamorphic grade gneiss terranes;
- Basic-ultrabasic hypabyssal and volcanic successions with shallow-water shelf-type associations of orthoquartzites, limestone and shale coincide in general with high to medium metamorphic grade gneiss terranes.

This broad two-fold division of Archean crust applies reasonably well to the northwestern Superior Province. Layered gabbro sequences and mafic volcanics abound in the Pikwitonei region, but the granulite rock assemblage differs from Sutton's (1976) high-grade crust in that a shallow-water shelf-type sedimentary association has not been recognized. Marble (limestone?) occurs only rarely, and may be a product of metamorphic and metasomatic differentiation. Metamorphosed magnetite iron formations, associated with mafic granulites are the only recognizable sediments. Walker (1978) pointed out that oxide facies iron formations are not necessarily evidence for a shelf-type depositional environment and that their presence may, on the contrary, indicate the deepest part of the basin. On the other hand, shallow-water indicators are numerous in the greenstone belts of the low-grade terrane, e.g. the Oxford Lake belt (Hubregtse, in prep.), and the Cross Lake belt (Rousell, 1965): cross-bedded sediments of arkosic nature and conglomerates, water-reworked coarse fragmental volcanic rocks directly overlying their source, and local unconformities. The scarcity of iron formations in the Oxford Lake belt (Hubregtse, in prep.) as compared to the greater abundance in the more northerly situated greenstone belts and the Pikwitonei region (Weber, 1974, 1975, 1977, 1978), is striking. The supracrustal rocks of the high-grade gneiss terrane of the Pikwitonei region do not seem to belong to a shallow-water shelf-type association, but are interpreted as a more distal section of the volcanosedimentary pile deposited in a deeper part of the pre-Kenoran basin of the northwestern Superior Province. Supracrustal rocks deposited in the generally shallower part of the pre-Kenoran basin, are presently underlying the low-grade greenstone belt terrane.

It is still not clear whether there is a causal relationship between the supposedly distal nature of the northwestern segment of the pre-Kenoran depository and the subsequent granulite facies metamorphism of the first phase (D_1-M_1) of the Kenoran orogeny. Higher heat-flow in this "more oceanic" environment may have been an important factor. However, the granulite facies metamorphism culminated during D_2-M_2 in what was probably a continental tectonic environment, since the preceding D_1-M_1 event led to the cratonization of the precursor of the northwestern segment of the Superior Province. Evidence for Kenoran rifting was found in the Oxford Lake area where events are separated by the deposition of the volcanosedimentary Oxford Lake Group (Hubregtse, in prep.). The base of the Oxford Lake Group comprises shoshonitic volcanics, which characteristically occur within continental regions and along continental margins (Joplin, 1968). The shoshonites of the Oxford Lake area are interpreted to be related to the formation of at least part of the Oxford Lake Group depository by rifting of the newly created continental-type crust (Hubregtse, 1976 and 1978). There is no direct evidence that rifting occurred during the Kenoran orogeny in the Pikwitonei Granulite Domain. However, if high-grade charnockite terranes correspond with regions of crustal thickening (Martignole, 1979), and represent zones of continental collision (Dewey and Burke, 1973), an event of continental break-up and drift may have occurred in the Pikwitonei Granulite Domain prior to a collision, that may have taken place during the second Kenoran orogenic phase D_2-M_2. Such an event could be correlated with the pre-M_2 rifting process that occurred in the Oxford Lake area. There is no evidence that supracrustal rocks were deposited in the Pikwitonei region between D_1-M_1, which suggests that the presently exposed levels of the Pikwitonei Granulite Domain were not exhumed during the interval between the D_1-M_1 and D_2-M_2 events.

The pre-D_2 position of the edge of the northwestern Superior Province is not known. It may have been located west of the "Thompson Mobile Belt", since the northwestern Superior Province boundary was shaped during a late stage (D_3-M_3) of the Hudsonian orogeny, when the Superior Province and the younger Churchill Province were joined along the "Thompson Mobile Belt" (Gibb, 1975).

The Pikwitonei Granulite Domain — "Thompson Mobile Belt" relationship corroborates Sutton's (1976) conclusion that late-Archean areas of high-grade metamorphism became the site of many of the later Precambrian mobile belts.

The presently exposed metamorphic zonation reflects the depths reached by the northwestern segment of the Superior Province by subsidence during D_2-M_2. The exposure of the granulites, including the sillimanite-orthopyroxene-quartz gneisses, implies an additional post-D_2 rebound of 18 km or perhaps as much as 25 km, with respect to the uplift of the greenschist facies-amphibolite facies greenstone belts situated farther to the east. The subsequently eroded rocks that covered the granulites may have been low-grade greenstones of the typical Superior-type. Since the presently exposed lateral transition between the high-grade Pikwitonei granulites and the low-grade greenstones and gneisses is gradational, the original vertical transition may well have been the same.

Comments on the late-Archean and Aphebian history of the western edge of the Superior Province

Late-Kenoran amphibolite facies shear belts, that transect the Pikwitonei Granulite Domain indicate, at least partial, late-Kenoran rebound of the deeply buried granulites to higher crustal levels. The late-Kenoran shear belts strike east to east-northeast, a trend that appears to have been governed by the early-Kenoran structural grain. Subsequent, epeirogenetic uplift of the Pikwitonei region may have taken place during the interval between the Kenoran and late-Hudsonian orogenic events. In the northwestern Superior Province this interval was marked by the emplacement of the northeasterly-trending dilatation Molson dyke swarm (Scoates and Macek, 1978). The Molson dykes may have intruded zones of weakness, formed during the process of isostatic adjustment associated with the 18 to 25 km rebound of the Archean granulites, relative to the much smaller uplift of the low-grade Archean greenstone belts. Alternatively, the Molson dykes may have intruded during rifting and continental break-up of the Superior Province crust, as discussed above. In this respect, it is important to obtain an isotopic age for the Molson dykes, since such a rifting process may have occurred more than once during the Aphebian, and the intrusion of the Molson dykes may have been related to the rifting of the Archean crust, that led to the formation of an Aphebian basin. Alternatively, the emplacement of the Molson dykes may have been related to the formation of the depository of the Proterozoic Ospwagan Group supracrustal rocks (Scoates *et al.*, 1977), which occur in a linear zone in the western segment of the "Thompson Mobile Belt". The age relationships between the Ospwagan Group and the surrounding Proterozoic and Archean crustal segments are under investigation (Weber and Scoates, 1978).

Scoates and Macek (1978) assumed that the Molson dyke swarm represented a major period of Aphebian continental volcanism and magmatism, which led to increased strain in the crust with subsequent release and the development of fractures along which the dykes intruded.

The southeastern zone of the Pikwitonei Granulite Domain and the greenstone belts of the northwestern Superior Province escaped the main effects of the Hudsonian orogeny (Fig. 2). The western margin of the Pikwitonei Granulite Domain, however, was overprinted by late-Hudsonian metasomatism and amphibolite facies metamorphism 1720 Ma (± 140 Ma) ago (Charbonneau, pers. comm.). The accompanying late-Hudsonian deformation was responsible for the formation of the "Thompson Mobile Belt" (Fig. 1), in which Molson dykes were tectonized and metamorphosed and late-Kenoran shear belts were reactivated. This suggests that the Archean granulites presently underlying the western Pikwitonei region, were moved during or prior to the Hudsonian orogeny to a higher crustal level where amphibolite facies conditions prevailed.

The Molson dyke swarm has not been identified in the adjacent Churchill Province, which may suggest a minimum age of about 2.0 Ga for the Molson dykes. Alternatively, their absence in the Churchill Province may be explained by assuming that this segment of the Churchill Province was situated beyond the realm of the Molson dyke swarm, before the Churchill and Superior Provinces were joined along the "Thompson Mobile Belt" (Scoates, pers. comm.)

The roughly parallel trends of the Molson dykes, the trace of the southern part of the orthopyroxene isograd, and the late-Hudsonian "Thompson Mobile Belt" strongly suggest that, at the time of emplacement of the dykes, the axis of the tectonic process (whether isostatic rebound or continental rifting) was parallel to that which later became the "Thompson Mobile Belt". Consequently, it seems possible that a precursor of the late-Hudsonian "Thompson Mobile Belt" may have been active during early-or perhaps pre-Hudsonian time.

CONCLUSIONS

The Pikwitonei Granulite Domain did not form a basement for the Archean greenstone belts of the northwestern Superior Province (Fig. 1). On the contrary, the Pikwitonei Granulite Domain and the northwestern Superior Province are structurally continuous and are overprinted by progressive metamorphism that resulted in the formation of the granulites in the Pikwitonei region and lower-grade metamorphites in the adjoining Superior Province (Fig. 2). The two domains are separated by an orthopyroxene isograd and not by an unconformity. Superior-type supracrustal rocks (Fig. 5) occur on both sides of the orthopyroxene isograd. Their deposition predated the progressive metamorphism. Consequently the Pikwitonei granulites are interpreted as deep-seated more thoroughly metamorphosed equivalents of the lower grade greenstone-granite gneiss complexes typical of the Superior Province to the east and southeast. The present crustal setting of the granulites indicates substantial and preferred uplift of the crust along the margin of the northwestern Superior Province.

The supracrustal rocks of the northwestern Superior Province and their granulite facies equivalents are the oldest rocks recognized in the field. A basement for the pre-Kenoran volcanosedimentary rocks has yet to be identified.

Various types of anorthosites and anorthosite-like rocks occur in the Pikwitonei Granulite Domain and the adjacent Cross Lake Greenstone Belt-gneiss terrane. A genetic link with the younger tonalitic and enderbitic gneisses could not be established in the field. Relative age relationships indicate that some of the plagioclase-rich rocks and the supracrustals are of the same age.

Radiometric dates ranging from 2.7 to 2.8 Ga have been obtained for supracrustal and early intrusive rocks of the northwestern Superior Province. Therefore, the formation of the Pikwitonei M_1-granulites must be Kenoran. A late-Kenoran Rb/Sr whole rock ischron age of 2490 Ma (± 50 Ma) was recently determined for syn-orogenic M_2-mobilizates (Charbonneau, pers. comm.). The M_2-granulites belong to the intermediate-pressure group and the presence of rare sapphirine-bearing and orthopyroxene-sillimanite-quartz-bearing gneisses indicate that the physical conditions culminated around 10 — 11 kbar and 900 — 1000°C. The M_1-granulites were extensively reactivated during the M_2-event.

The Pikwitonei Granulite Domain was tectonically active throughout late-Archean and Aphebian times. Late-Kenoran and Hudsonian processes of continental rifting and collision may have occurred. The side-by-side position of the Pikwitonei Granulite Domain and the younger Proterozoic "Thompson Mobile Belt" lends support to Sutton's (1976) claim that the Archean high-grade terranes became the site of many of the later Precambrian mobile belts.

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