

Geology of the Burbidge Lake–Northern Upper Foster Lake Area, Eastern Wollaston Domain (NTS 74A-14)

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Tran, H.T. and Yeo, G.M. (1997): Geology of the Burbidge Lake–northern Upper Foster Lake area, eastern Wollaston Domain (NTS 74A-14); in Summary of Investigations 1997, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 97-4.

The map area lies in the eastern part of the Wollaston Domain southeast of the Athabasca Basin (Figure 1), about 140 km to the northwest of Missinipe. It includes the southeast quadrant of the Highrock Lake–Key Lake 1:100 000 scale map of Ray (1977), and the 1:40 000 scale Karin Lake map sheet of Thomas (1979). The 1:250 000 scale bedrock geology (Ray, 1983) and metallogenic (Scott, 1986) compilation maps of the Foster Lake area (NTS 74A) also encompass the map area.

This report is based on 1:20 000 scale mapping of more than 300 km² extending from Burbidge Lake to northern Upper Foster Lake. This was the first year of a multi-year project designed to examine the lithostratigraphy and structural geology of the central Wollaston Domain.

1. General Geology

The Burbidge Lake–northern Upper Foster Lake map area is underlain by generally northeast-trending belts of mainly siliciclastic to calc-silicate metasediments, overlying remobilized felsic gneiss basement, and intruded by minor granitic plutons (Figure 2). Five distinctive lithological assemblages are recognized: the Karin Lake basement complex, the basal assemblage, the transitional assemblage, the upper assemblage, and a late intrusive assemblage. The Karin Lake basement complex comprises variable granitic to tonalitic felsic gneisses of probable Archean age. The basal assemblage comprises mostly thin-bedded garnet-cordierite-sillimanite-bearing psammite to pelitic sediments. The transitional assemblage includes two heterogeneous packages containing various proportions

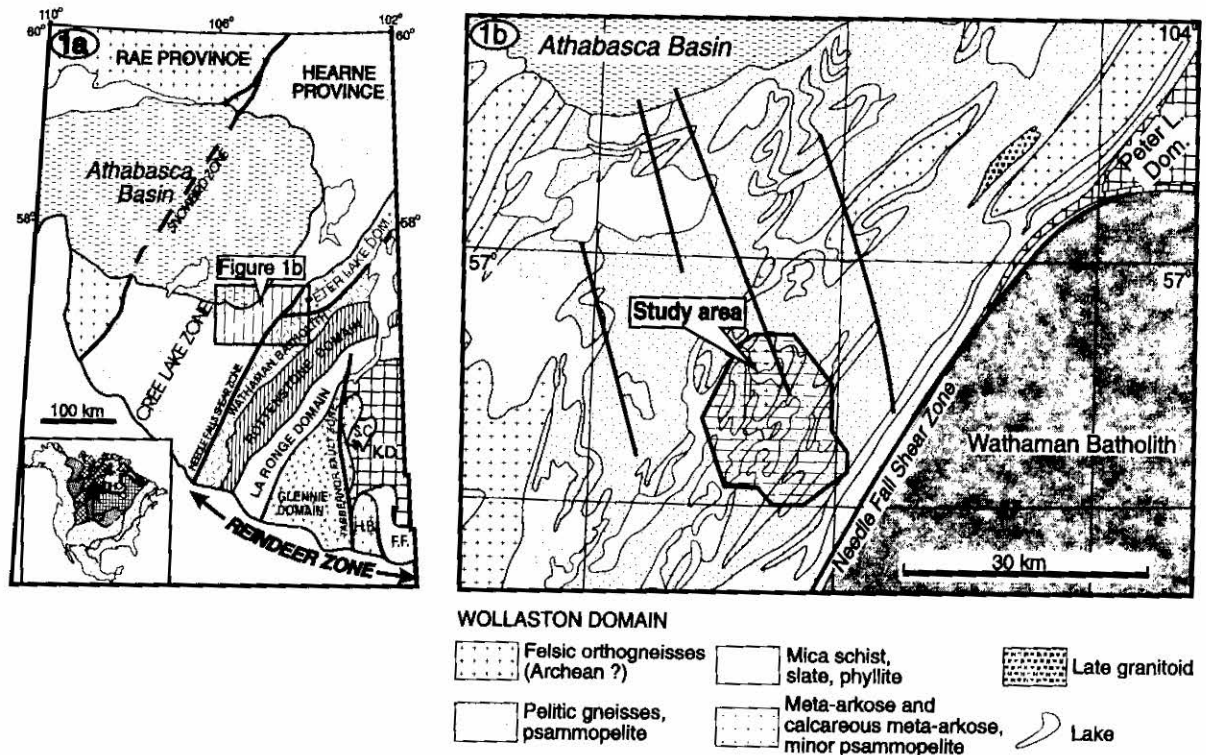


Figure 1 - a) Location of the Burbidge Lake–Upper Foster Lake area in Wollaston Domain. b) Generalized geology of the region surrounding the study area. FF=Flin Flon Domain, HB=Hudson Lake Block, KD=Kisseynew Domain, and SC=Scimitar Complex.

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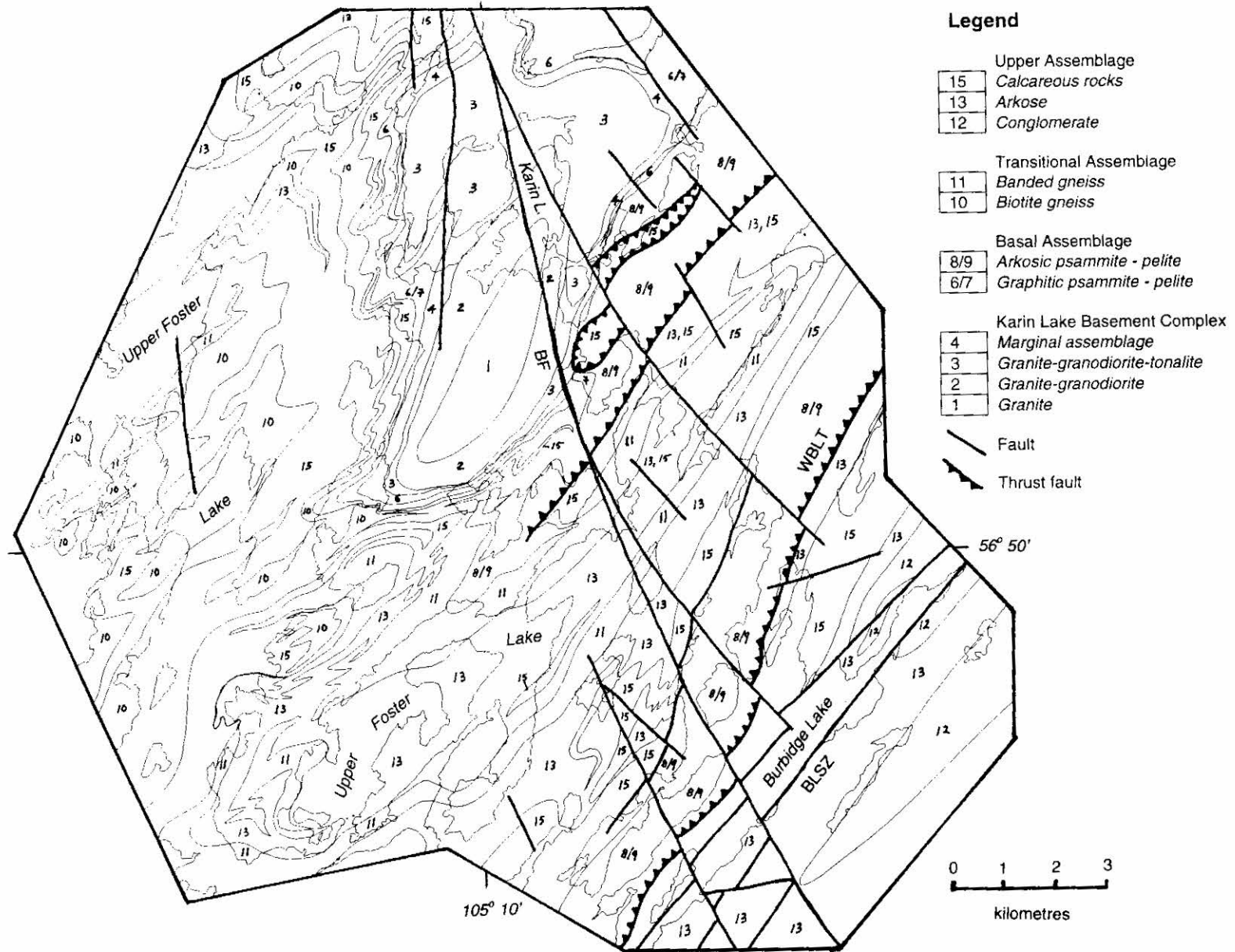


Figure 2 - Geological sketch map of the Burbidge Lake–Upper Foster Lake area. WBLT=West Burbidge Lake Thrust; BLSZ=Burbidge Lake Shear Zone; BF=Burr Fault.

of psammitic, arkosic and calc-silicate-bearing sediments. The upper assemblage is a thick package of conglomerate, arkose, marble, and calc-silicate rocks. Late intrusive rocks form small post-tectonic mafic to felsic bodies. The metasedimentary rocks can be interpreted as the products of post-rift subsidence and transgression (basal assemblage), delta progradation (transitional assemblage and upper assemblage arkose and marble), late-stage rifting (upper assemblage conglomerate and arkose), and renewed subsidence and marginal marine sedimentation (upper assemblage calc-silicates).

Four main phases of deformation were distinguished: D₁ resulted in development of isoclinal folds (F₁) and regional axial planar foliation (S₁) of variable intensity. D₂ produced doubly plunging northeast-southwest trending upright folds (F₂) with a weak steeply dipping to sub-vertical axial planar foliation (S₂). Late D₂ eastward directed reverse/thrust faulting explains the abrupt change in metamorphic grade and lithologies in the eastern part of the area. The D₃ deformation gave rise to open, upright, northwest-trending folds and crenulations (F₃), and the D₄ event to steeply dipping to

subvertical sinistral faults (e.g. the Burr Fault System).

Metamorphic grade increases westward from lower amphibolite to granulite facies. Two generations of mineral growth were distinguished, broadly coeval with the first two main deformation events. Metamorphic mineral paragenesis documents relatively high T/low P metamorphic conditions.

2. Rock Descriptions

The lithostratigraphic units described below are compared to map units of previous workers in Table 1.

a) Karin Lake Basement Complex

The Karin Lake inlier (Ray, 1977) is an elongate, heart-shaped, northeast-trending basement complex of about 33 km² exposed in the northwest part of the area (Figure 2). Its age is unknown, but the Johnson River Granite, a basement inlier 30 km to the northeast, has a U-Pb (zircon) age of ca. 2.5 Ga (Ray and Wanless, 1980). Hence an Archean age is likely, at least for the

Table 1 - Formations and comparison with previous map units.

This Report	Delaney <i>et al.</i> (1995)	Thomas (1979)	Ray (1979)
17. Dolomitic marble		3a. Calc-silicate and 3c. amphibolite	6. Calcareous meta-arkose
16. Calc-silicate rock			
15. Calc-silicate-bearing arkose	Formation rc (arkose/ calc-silicate)	4b. Meta-arkose (<5% gt±co±bt±hb±di)	5. Arkose
14. Muscovite schist	Formations r2 and r3 and Rafuse Lake Formation (arkose/wacke)		
13. Arkose	Janice Lake Formation (conglomerate and sandstone)	4a. Meta-arkose (5-10% gt±co±bt±hb±di)	4c. Pelitic and semipelitic schists and gneisses interlayered with meta- arkoses
12. Conglomerate and pebbly arkose			
11. Banded quartzofeldspathic to arkosic gneiss		2d. Cordierite-garnet- sillimanite gneiss 2c. Pelitic and semipelitic gneiss	4d. Graphite-bearing pelites and semipelites 4a & 4b. Pelitic and semipelitic schists and gneisses interlayered with amphibolite or quartzite
10. Psammopelitic biotite gneiss			
9. Arkosic pelite	Formation np (psammopelitic gneiss)	2a. Highly migmatized and pegmatitic rock 1b. "Marginal" granite and pegmatite	2. Biotite granite gneiss and biotite-hornblende granite gneiss
8. Arkosic psammite to psammopelite			
7. Graphitic pelite		1a. "Central" homogeneous biotite granite	
6. Graphitic psammite to psammopelite			
4. Marginal rocks (inc. amphiboite, quartzite, psammite, etc.)			
3. White granite to granodiorite-tonalite			
2. Foliated granite to granodiorite			
1. Granitic rocks			

core of the inlier. This complex can be divided into five different lithological units.

Unit 1: Granitic Rocks

The southwestern part of the Karin Lake inlier (Figure 2; map separate) is cored by pink to bright red, medium- to coarse-grained, massive to weakly foliated syenogranite to granite. This unit is relatively homogeneous, with biotite (<10%), K-feldspar (<60%) locally as 2 cm long lensoid crystals, plagioclase (15 to 30%), quartz (15 to 30%), and magnetite (<2%). Other minerals including hornblende, and possible clinopyroxene (?) are locally observed. This unit appears to be gradational into rocks of Unit 2.

Unit 2: Granite to Granodiorite

Surrounding the granite core of the inlier is a zone of light pink to brown, medium- to very coarse-grained, strongly foliated granite to granodiorite, and locally tonalite. Major mineral components are biotite (10 to 20%), K-feldspar (20 to 50%), plagioclase (20 to 30%), and quartz (20 to 30%). K-feldspar occurs as porphyroblasts up to 2 cm in maximum dimension. Biotite is typically oriented in the plane of the S_1 foliation and gives this rock a well-developed foliation. Accessory minerals (<2%) include magnetite and hornblende. Near its outer margin, a zone of up to several tens of metres of yellow-white granite to granodiorite with relatively high radioactivity is gradational into the typical pink variety. Ray (1977) and others have interpreted this 'white zone', which also characterizes the margins of other inliers in the Wollaston Domain, as a paleoweathering feature. In the western part of the inlier, the contact of this unit with Unit 3 is abrupt, and appears to be intrusive. Inclusions of Unit 2, generally with clean sharp contacts, are common in Unit 3.

Unit 3: White Granite to Granodiorite-tonalite

Rocks of this unit dominate most of the northern part and envelope the southern part of the Karin Lake inlier. They are typically light grey to white, medium grained, and massive to weakly foliated with some large crystals of white feldspar, and also comprise plagioclase (<60%), lesser amounts of K-feldspar and quartz, biotite (<5%), and magnetite (<5%). Metasedimentary xenoliths of amphibolite and cordierite-bearing biotite schlieren are locally present, as are pink, undeformed granite pegmatite sheets with transitional contacts. The pegmatites are interpreted as anatectic melts produced by late, high-grade metamorphism.

Unit 4: Marginal Assemblage

A heterogenous package of rocks, transitional between the inlier and supracrustals, comprise the marginal assemblage. Rocks include dismembered, foliated to mylonitic and sheared granodiorite and tonalite, abundant late aplite and granite pegmatite, and

unmappable xenoliths of amphibolite, quartzite, arkose, and sillimanite-garnet-bearing psammopelite. The granodiorite-tonalite components of this unit resemble Units 2 and 3, save that they are locally very strongly foliated to mylonitized. Aplite to pegmatite bodies range from less than 50 cm to several metres in width and typically crosscut early foliation, but locally have a weak later foliation. They intrude both sedimentary rocks (e.g. Unit 6) and granodiorite-tonalite (Unit 3), obscuring the contact between these units. Sedimentary xenoliths occur as lenses or boudins up to several metres across in both granodiorite-tonalite and pegmatite. Their compositions are partly similar to those of the basal sequence surrounding the inlier.

Unit 5: Amphibolite

Dark to light green, fine- to medium-grained, weakly to strongly foliated amphibolite, is found as elongate bodies of less than 10 m width, mostly in Units 2, 3, and 4. They comprise hornblende (40 to 70%), plagioclase (30 to 40%), and quartz (<10%). Hypersthene, clinopyroxene, and biotite are present as accessory minerals. At least two generations of amphibolite can be distinguished. Early foliated amphibolite occurs as xenoliths and lenses from less than 20 cm to 10 m in granitoids of Units 2, 3 and 4, whereas late, weakly or undeformed amphibolite occurs as sheets up to 2 m wide, generally oriented parallel to the main foliation.

b) Basal Assemblage

A relatively aluminous siliciclastic sequence lies adjacent to the basement complex, but is better developed along its eastern margin. This assemblage is divided into four mappable units.

Unit 6: Graphitic Psammite to Psammopelite

The lowest unit, comprising grey to rusty, fine- to coarse-grained, thin layered, graphite- and garnet-bearing psammite to psammopelite interlayered with thin bands of quartzite, and/or cordierite-sillimanite-bearing pelite, immediately overlies the basement complex. Psammitic layers, which range from less than 10 cm to several metres in thickness, contain garnet (5 to 20%) possibly of two generations, biotite (10 to 15%), and minor graphite (<5%). Interlayers of pelite, locally up to 40 percent of the outcrop, are up to 20 cm thick, and contain abundant sillimanite and/or cordierite, graphite, and subordinate garnet. Quartzite-rich layers, from less than 10 cm to 50 cm in thickness, occur locally. Rocks of Unit 6 are highly strained, well foliated to mylonitic, generally dismembered, and form discontinuous boudins of several centimetres to tens of metres. This unit is transitional into graphitic pelite (Unit 7).

Unit 7: Graphitic Pelite

Grey to rusty, coarse-grained pelitic rocks containing cordierite, sillimanite, graphite, and locally

orthopyroxene (?) interlayered with thin bands of psammopelite, psammite, and quartzite, overly the graphitic psammite to psammopelite (Unit 6), except around the southern part of the Karin Lake inlier where they directly overly the basement marginal assemblage (Unit 4). They are generally thin layered, strongly foliated, and migmatitic. In more pelitic varieties, up to 30% cordierite occurs as small, brown poikiloblastic grains and as at least two generations of coarse, purple coloured grains. Other minerals include sillimanite (5 to 10%), graphite (1 to 5%), garnet (<3%), and magnetite (<1%). At several localities west of the Karin Lake inlier, traces of a green mineral (hypersthene?) are found associated with anatectic melt. Hypersthene has also been reported in basal Wollaston pelitic rocks overlying the Pederson Lake Granite southwest of this area (Ray, 1981). Psammitic and quartzitic layers, which represent from 30 to 40 percent of this unit, are similar in character to those of Unit 6. Migmatitic neosome, including both melanosome and leucosome, is widespread and locally comprises up to 60 percent of the outcrop. Rocks of this unit appear to be transitional into Units 6, 8, and 9, and locally into Unit 15.

Unit 8: Arkosic Psammite to Psammopelite

This unit is characterized by light grey to pinkish, medium- to coarse-grained, arkosic psammite to psammopelite, with subordinate quartzite and arkosic pelite layers. It is widespread to the east, but is absent to the west of Karin Lake inlier. The psammite is generally homogeneous, and consists mostly of quartz (50 to 60%), K-feldspar (<50%), and biotite (<10%). Garnet and graphite are absent. In more psammopelitic layers, up to 3 cm long, augen-like K-feldspar lenses comprise up to 20 percent of the rock. These lenses generally contain cordierite (<5%) and fibrolitic sillimanite and have biotite selvages, suggesting that cordierite may have been formed by the breakdown of sillimanite and biotite. Two generations of such 'augen' are found, respectively oriented in S_1 and S_2 . East of the Karin Lake inlier a 3 to 20 m thick layer of coarse-grained, massive to weakly foliated, amphibole-diopside-bearing quartzite contains abundant, 5 to 10 cm long quartzite aggregates, which resemble clasts. The 'clasts', however, are oriented with their long axes parallel to S_2 , their composition is the same as that of the matrix, and the clast/matrix contacts appear to be gradational. These relationships suggest that this rock is a pseudo-conglomerate and the 'clasts' are either dismembered quartzite layers or products of metamorphism. Contacts between the arkosic psammite and psammopelite and Units 7 and 9 are transitional.

Unit 9: Arkosic Pelite

Arkosic pelite is typically pinkish grey and coarse to very coarse grained, with abundant K-feldspar knots, cordierite, sillimanite, and migmatitic neosome. It includes unmappable quartzitic to psammitic layers, similar to those of Unit 8, which locally account for up to 40 percent of the outcrop. Like Unit 8, this unit occurs east of the Karin Lake inlier, but not to the west.

Several generations of cordierite, locally comprise up to 20 percent of the rock, and sillimanite (<5%) generally occurs as xenoblasts associated with cordierite- and K-feldspar-bearing migmatitic neosome. Towards Burbidge Lake, pelitic rocks of this unit differ by containing up to 20 percent sillimanite, as faserkiesel up to 3 cm long of at least two generations. K-feldspar generally comprises up to 40 percent of the rock, and biotite is less than 5 to 10 percent. Garnet and graphite are absent in this unit.

c) Transitional Assemblage

These rocks contain a mixture of lithologies typical of units above and below them. They generally comprise thin, alternating layers of quartzite, sillimanite-bearing psammopelite, psammite, arkose and calc-silicate bearing arkose. They can be grouped into two mappable units.

Unit 10: Psammopelitic Biotite Gneiss

Biotite gneiss is grey to rusty, fine to medium grained, strongly foliated and interlayered with less than 10 cm thick beds of calc-silicate, arkosic and/or quartzofeldspathic gneiss, and subordinate sillimanite-bearing psammopelite. It is extensive to the south and west of the Karin Lake inlier but absent to the east. Biotite gneiss forms layers from less than 20 cm to several metres in width, with 10 to 20 percent biotite, and variable amounts of magnetite and spinel. Magnetite occurs as subidioblastic porphyroblasts up to 1 cm across, and is commonly rimmed by quartz and feldspar aggregates. Its content varies from layer to layer, and in some layers reaches 30 percent, almost iron formation. More typically, magnetite content is less than 5 percent and spinel is subordinate. Calc-silicate layers, from 1 to 20 cm thick, containing up to 15 percent diopside and amphibole, are locally common, but generally concentrated near the boundary between this unit and Unit 15, which locally appears transitional.

Unit 11: Banded Quartzofeldspathic to Arkosic Gneiss

A heterogenous sequence of light grey to rust-coloured, fine- to medium-grained, interlayered, thin to thick bedded (5 cm to 1 m), quartzitic, quartzofeldspathic, arkosic, psammopelitic, and minor calc-silicate bearing arkosic gneisses, forms a mappable unit, mainly to the south and southeast of the Karin Lake inlier. In the quartzofeldspathic to psammopelitic layers, which predominate, biotite ranges from less than 7 to 12 percent, and magnetite from trace to several percent. Locally, cross-bedding and bedding lamination, defined by concentrations of black, fine-grained opaque minerals, presumably ilmenite/magnetite, along the lamination planes, are preserved. This unit appears gradational into massive arkose (Unit 13), arkosic pelites and psammites (Units 8 and 9) and calc-silicate bearing arkose (Unit 15).

d) Upper Assemblage

Unit 12: Conglomerate/Pebbly Arkose

This unit comprises light grey to pink on fresh surfaces, and orange light grey or white weathering, massive to weakly foliated conglomerate and pebbly arkose north and east of Burbidge Lake. Conglomerate layers are up to hundreds of metres thick. Clasts are commonly rounded, weakly flattened, and oriented along the S_1 foliation. Their composition is locally variable. Granodiorite and quartz clasts, up to 10 cm long, in a fine- to medium-grained arkosic matrix are common north of Burbidge Lake, but east of this lake, fine-grained quartzite, granodiorite, and rare amphibolite (?) pebbles and cobbles up to 25 cm long predominate, also in an arkosic matrix. The ratio of clasts to matrix ranges from less than 20 to 70 percent. The conglomerates extend northeast of Burbidge Lake and are correlative with the Janice Lake Formation (Delaney *et al.*, 1995) which consists mostly of angular arkose clasts. Possibly the arkosic matrix farther south is a pseudomatrix comprising partly arkosic clasts destroyed by metamorphism. The base of this unit was not observed, but the abundance of metasedimentary clasts suggests that it overlies a thick metasedimentary succession.

Unit 13: Arkose

Arkose is predominantly pink on fresh surfaces and orange, light grey, or pink weathered, fine to coarse grained, and massive to thick bedded, with thin quartzofeldspathic or muscovite-, biotite- or sillimanite-bearing psammopelitic interlayers. Most commonly it is homogeneous and medium grained, with up to 30 percent K-feldspar and less than 7 percent biotite (in high-grade parts) and muscovite (in low-grade parts), and trace magnetite. Arkose is extensive south and east of the Karin Lake inlier, but uncommon in the southwest of the map area. West of Burbidge Lake it locally contains up to 1 percent of sillimanite faserkiesel up to 2 cm long, oriented in S_2 , and subidioblastic K-feldspar prophyroblasts up to 2 cm across, whereas east of that lake, there are muscovite-bearing psammopelite layers, ranging from several centimetres to less than 1 m in thickness. Also in the west, the arkose unit includes quartzofeldspathic members of Unit 11 and is generally gradational into it.

Unit 14: Muscovite Schist

Fine- to medium-grained, light-grey, strongly foliated muscovite schist, with thin psammitic or arkosic layers forms a mappable unit east of Burbidge Lake. It contains up to 15 percent muscovite and several percent biotite.

Unit 15: Calc-silicate-bearing Arkose

This unit is the most widespread sequence found in the study area. It comprises thin layered, pinkish, white,

and light green calc-silicate and arkose, and massive, light green calc-silicate-bearing psammite and arkose. These rocks contain up to 15 percent calc-silicate minerals, mostly amphibole (tremolite/actinolite and hornblende) and pyroxene (diopside), and several percent biotite. In thick massive layers, amphibole and pyroxene are commonly concentrated along late fractures as pods and swaths up to 20 cm wide, oriented both randomly and parallel to tectonic foliations. These members also contain abundant bodies of scapolite- and diopside-bearing albite similar to Unit 19. At the south end of the Karin Lake inlier an unmappable conglomerate or pseudoconglomerate very similar to that described in Unit 8 is found.

Unit 15 structurally or stratigraphically interfingers with most other units, but as it contacts so many other units it most likely lies on them with angular unconformity (Figure 3), an interpretation indicated by truncation of contacts of underlying units against Unit 15, particularly west of the Karin Lake inlier (Figure 2).

Unit 16: Calc-silicate Rock

Green, coarse-grained, massive to weakly foliated calc-silicate rock containing from 15 to 80 percent calc-silicate minerals, locally forms a thin mappable unit, commonly within rocks of Unit 15. These rocks contain diopside (15 to 70%), hornblende (5 to 20%), tremolite/actinolite (1 to 5%), and a trace of calcite and apatite. This unit also includes unmappable marble layers similar to Unit 17 and small bodies of Unit 19 plagioclase.

Unit 17: Dolomitic Marble

A mappable lens of light-grey, pinkish to rusty, coarse-grained, weakly foliated dolomitic marble, interlayered with quartzitic and calc-silicate members, crops out on the eastern shore of Upper Foster Lake, and several unmappable layers occur in calc-silicate rocks of Unit 16. Mineral composition is dolomite (<60%), calcite (20%), tremolite/actinolite (<5%), and trace vesuvianite, phlogopite, and scapolite.

e) Intrusive Rocks

Unit 18: Gabbro/Amphibolite

Dark green, medium- to coarse-grained, massive gabbro is exposed on two small islands west of Miller Island and another outcrop is found on the peninsula southeast of Craig Bay. Both outcrop areas have medium-grained, massive to foliated amphibolite at their margins and coarse-grained gabbro in their cores. They contain up to 60 percent hornblende crystals up to 2 cm across.

Other unmappable, dark green, fine- to medium-grained sheets of mafic composition, presumably intrusive, are locally found in rocks of Unit 6 and 10 northwest of the Karin Lake inlier.

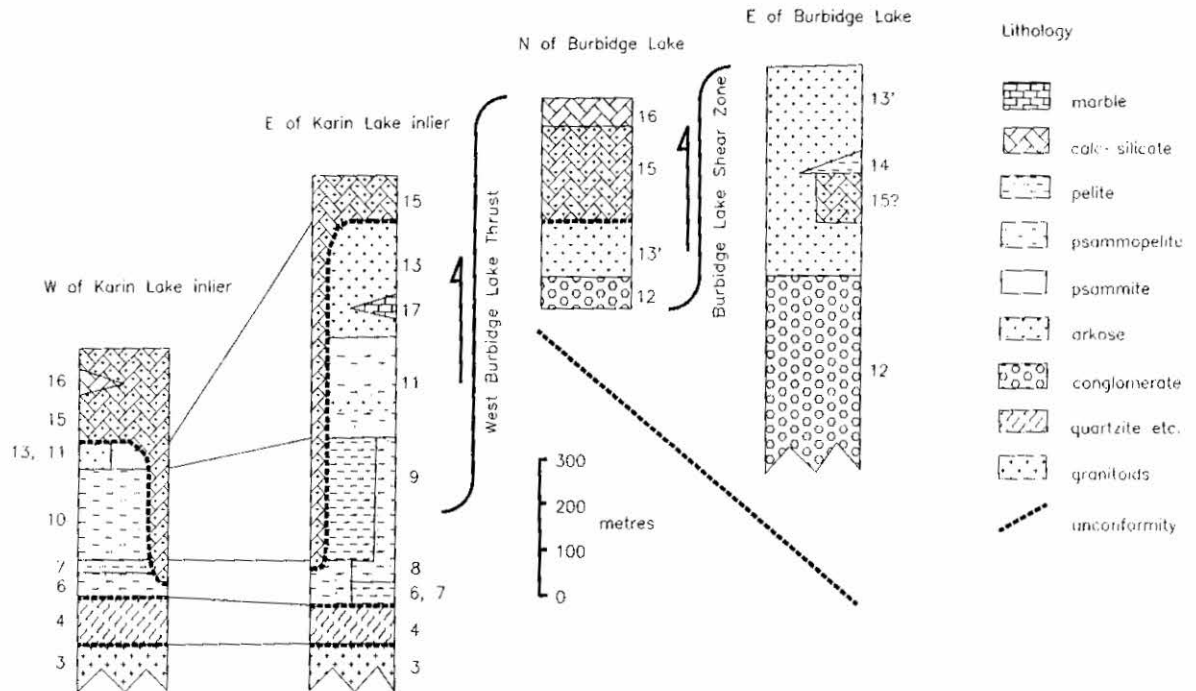


Figure 3 - Schematic cross-section of the stratigraphic succession (from left to right): west of the Karin Lake inlier, east of the Karin Lake inlier, north of Burbidge Lake, and east of Burbidge Lake. Because of the variable response of different lithologies to the style and degree of deformation, thicknesses shown here are only nominal values, based on typical thickness in fold limbs.

Unit 19: Plagioclaseite

Pinkish to light green, medium-grained to pegmatitic, massive to weakly foliated plagioclaseite containing amphibole (5 to 15%), diopside (5 to 15%), and up to 10 percent scapolite, forms locally mappable bodies, but more commonly occurs as unmappable bodies associated with and presumably derived from calc-silicate rocks of Unit 15 or 16. Xenoliths or boudins of calc-silicate rocks, ranging from several centimetres to several metres in size, are abundant in this unit. Contacts with the metasediments are commonly irregular, and both sharp and gradational. This rock may be the product of sodium metasomatism of calc-silicate rocks which possibly had an evaporite-rich protolith, as suggested for the origin of plagioclaseites elsewhere in the Wollaston Domain (Appleyard, 1984; Weber *et al.*, 1975).

Unit 20: Peraluminous Granite and Granite Pegmatite

White to pink, medium- to very coarse-grained, massive to weakly foliated, granite pegmatite and granite, locally containing up to 10 percent cordierite and sillimanite and up to 30% sedimentary xenoliths, is widespread in the study area and locally forms mappable bodies. It typically occurs as semiconcordant sheets and stringers ranging from less than 50 cm to hundreds of metres long. These crosscut sedimentary bedding and S_1 , but are deformed by D_2 . These rocks probably formed by in-situ melting of the host rocks.

Unit 21: Post-tectonic Pegmatite

Massive pink granite pegmatite, as sheets and irregular masses up to hundreds of metres wide, crosscuts all planar fabrics, and occurs throughout the study area. It consists mostly of K-feldspar, quartz (<10%), and biotite and/or muscovite (<2%).

3. Structural Geology

Four deformational events (D_1 - D_4), including three phases of penetrative deformation and at least one episode of later faulting, have been recognized in the study area.

a) First Phase (D_1) Structures

The earliest D_1 structure is a penetrative well-developed regional foliation (S_1), mostly transposed compositional layering, and coeval isoclinal folds. In nearly all the metasedimentary rocks, S_1 is paralleled by transposed primary layering (S_0), where present. The exception is the low strain part of the area east of Burbidge Lake where S_1 foliation locally crosscuts S_0 at low angles. S_1 includes preferred crystallographic and/or dimensional orientations of most minerals and orientation of maximum and intermediate dimensional axes of grain aggregates, rock fragments and/or pebbles as well as gneissic layering, concordant medium- to coarse-grained plagioclase-quartz-bearing veins and segregations, muscovite-, hornblende-, and/or biotite-rich layers, and early anatectic neosomal veins. Early

metamorphic minerals such as muscovite, biotite, sillimanite, K-feldspar, cordierite, and amphibole were partly formed and/or deformed during development of S_1 which clearly links the D_1 deformation event with broadly coeval high-grade metamorphism.

S_1 foliation is weakly to strongly developed within the granitoid basement complex of the Karin Lake inlier. Its trend is concordant with the regional S_1 foliation pattern found in the supracrustal cover rocks. Abundant mesoscopic F_1 isoclinal folds, formed by granodiorite-tonalite sheets, are found in rocks of Units 3 and 4. No evidence of an earlier fabric was observed in the basement.

The S_0/S_1 foliation is generally steeply dipping and trends northeast except where it wraps around the hinges of large scale F_2 and F_3 folds (see map separate). It is apparently axial planar to numerous isoclinal fold closures. Except Units 19, 20, and 21, which are unaffected by this deformation event, all rocks in the study area are typically moderately to highly strained and are locally isoclinally folded, with consequent lithological repetition. The most pronounced and best defined major F_1 folds occur in the west-central part of the area, mainly around the Karin Lake inlier (Figure 2). The Karin Lake inlier is also interpreted as a D_1 anticlinorium refolded by D_2 (Figure 2).

The S_1 foliation (and apparently coeval migmatization) tends to increase in intensity and becomes protomylonitic to mylonitic in character toward the Karin Lake inlier. Early pegmatites and other intrusive sheets as well as supracrustal rocks are highly flattened and boudinaged and become thin concordant bands or discontinuous boudins. Mesoscopic scale shear sense indicators are locally observed, including back-rotated layers and swells, rotated boudins, and asymmetric small-scale folds (Hanmer and Passchier, 1991). At several localities near the contact of the Karin Lake inlier with supracrustal rocks, highly strained granitoids of Unit 4 with strongly-developed C-S fabric (Berthé *et al.*, 1979) were locally observed.

An early mineral lineation (L_1) associated with the first foliation is locally well developed. It is defined mainly by mineral aggregate elongation, quartz rodding, clast and pebble extension. Later fold events have caused reorientation of this lineation and interpretation of the original plunge direction is generally problematic.

Isoclinal F_1 minor folds are locally observed (Figure 4). They are completely isoclinal and generally have class 2 similar fold geometry (Ramsay, 1962). They are overprinted by later structures, especially F_2 folds, forming typical type 3 fold interference patterns (Figure 5; Ramsay, 1962, 1967). F_1 fold closures may be more common but are largely unrecognizable due to transposition of layering (S_0).

b) Second Phase (D_2) Structures

The S_0/S_1 planar fabric elements are deformed by a second deformation event (D_2) and refolded by open to tight, major and minor folds (F_2), generally resulting in

the formation of type 3 coaxial fold interference patterns (Ramsay, 1962, 1967; Ramsay and Huber, 1987). F_2 minor folds were also seen to refold early boudinaged veins transposed into the S_1 fabric.

Minor F_2 folds of variable wavelength, are the most common fold structures in the study area, especially in the pelitic metasediments. They are open to tight (e.g. Ramsay, 1967) and, though somewhat variable in detail, generally exhibit a near-similar fold profile geometry (Ramsay, 1962; 1967; Ramsay and Huber, 1987) characteristic of highly flattened flexural folds. Axial surfaces of F_2 folds are dominantly northeast-trending, subvertical to steeply northwest-dipping (Figures 2 and 6). Fold axes plunge moderately to very steeply either to the northeast or southwest (Figures 2 and 6).

F_2 minor folds are commonly accompanied by a locally well-developed axial planar cleavage or schistosity (S_2). This is generally best developed in the hinge zones of F_2 minor folds and is most commonly a strain-slip schistosity. Where the F_2 folds are very tight or isoclinal, the S_2 foliation is more strongly developed,

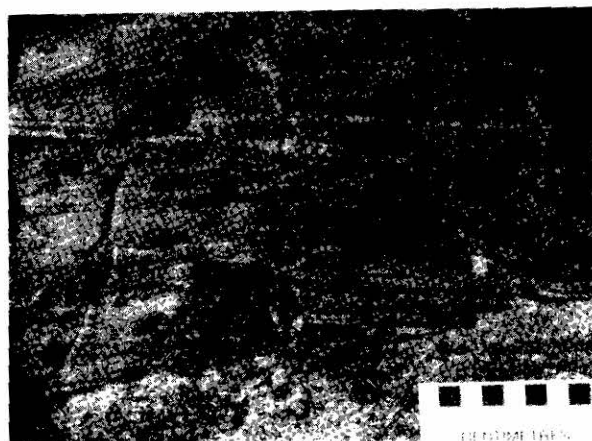


Figure 4 - F_1 isoclinal folds in psammite interlayered with very thin layers of pelite west of Burbidge Lake.

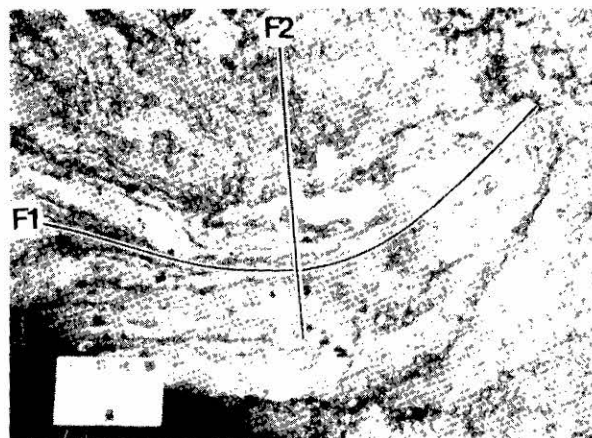


Figure 5 - F_1 and F_2 folds producing a type 3 fold interference pattern in rocks west of the Karin Lake inlier. Note cordierite knot oriented parallel to the F_1 fold axial plane.

the S_1 foliation is mostly transposed and distinction of S_1 and S_2 becomes problematic. The S_2 penetrative fabric is marked by a preferred crystallographic and/or dimensional orientation of muscovite, biotite, fibrous sillimanite, flattened sillimanite faserkiesel (Figure 7), cordierite and K-feldspar lenses, and concordant late melt sweats and 'granite' veins.

Major F_2 folds are the dominant large-scale structures in the area (Figure 2). East of Burbidge Lake, major F_2 folding is illustrated by a large antiform cored by conglomerate and pebbly arkose. Another antiform along the western margin of Burbidge Lake (also recognized by Ray, 1977), cored by arkosic psammite to pelitic rocks (Units 8 and 9), is interpreted as a late D_2 wedge structure in which lower stratigraphic

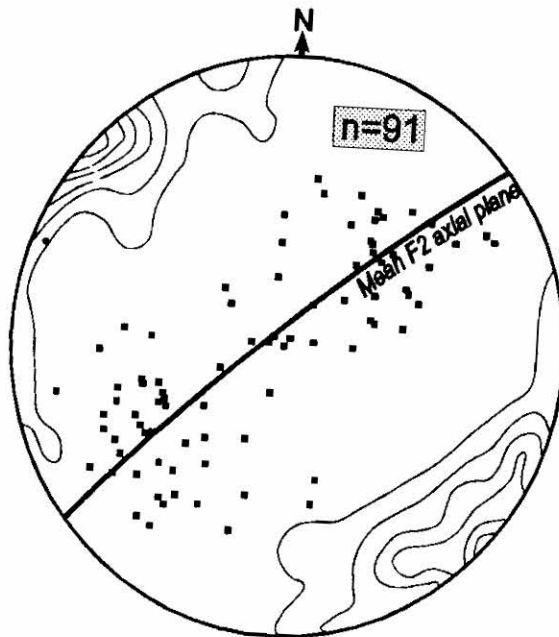


Figure 6 - Lower hemisphere equal area stereographic projection of axial planes (contours) and fold axes (squares) of F_2 minor folds. The base of the contour is 1 percent and the contour interval is 2 percent.

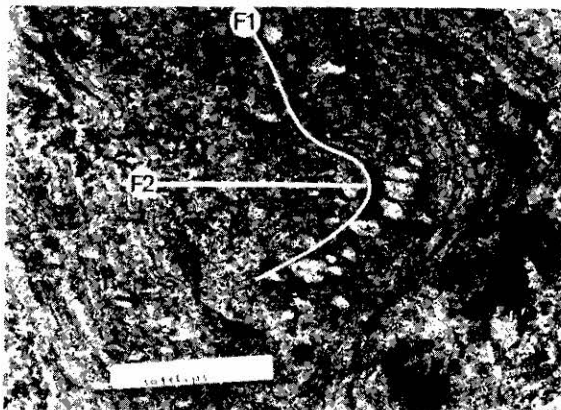


Figure 7 - F_2 folds with axial planar sillimanite faserkiesel west of Burbidge Lake.

sequences were thrust over the upper stratigraphic sequences. This structure is separated from the Karin Lake inlier (Ray, 1977) by a large, continuous synform, here termed the Miller Lake-Rupert Lake syncline (Figure 2). The Karin Lake dome (Figure 2) is the main F_2 anticlinorium structure in the study area. It is cored by Archean granitic basement which was previously folded by F_1 . D_2 deformation overprinted this F_1 structure, forming a series of doubly plunging northeast-southwest-trending, subvertical to overturned F_2 folds with axial planes dipping steeply southeasterly.

c) Late D_2 Reverse Faulting

A number of northeast-trending, brittle or locally brittle-ductile, steeply to gently northwest-dipping reverse faults are found east of the Karin Lake inlier. They are defined by cataclastic zones, ranging from less than 20 cm to several metres wide, abrupt disappearance of some lithological units, truncation of foliation trends, marked air photo lineaments, abrupt change in magnetic signature, topographic trends and mesoscopic kinematic indicators such as shear indicators, slickensides, or fault gouge. Metamorphic mineral assemblages dominated by muscovite and/or sericite in such zones are clearly retrograde. They generally mark the boundaries between predominantly pelitic rocks of the basal assemblage and meta-arkoses of the upper assemblage. The best developed of these thrusts, here called the West Burbidge Lake Thrust, runs northeastward through the western part of Burbidge Lake. In addition to an abrupt change in lithology it is well-defined by a sharp boundary between belts of very high- and very low-magnetic signature (Geological Survey of Canada, 1965). Numerous small-scale brittle to brittle-ductile reverse faults and extensive shallow- to steep-dipping slickensides are associated with this fault. F_2 folds adjacent to the fault are generally overturned and/or recumbent (Figure 8) with axial planes dipping very gently to the west. Limbs of such folds are generally sheared indicating reverse, west-side-up southeastward transport, suggesting that such faults postdate F_2 folds. This reversal movement brings upper amphibolite facies rocks of the lower stratigraphic sequence, the sillimanite-cordierite-bearing psammopelitic assemblages (Units 8 and 9) in the west, up over lower amphibolite grade, muscovite-bearing assemblages of the upper stratigraphic sequence in the east. These features suggest that reverse faults in this area may have been formed during a late stage of D_2 deformation when the area underwent maximum northwest-southeast-directed subhorizontal shortening. Further compression may have led to extrusion and wedging of part of the lower crust to higher levels, a mechanism similar to that proposed for the deformation of the western Swiss-Italian Alps (e.g. Escher and Beaumont, 1997).

Burbidge Lake Shear Zone

A brittle-ductile fault, the Burbidge Lake Shear Zone (Delaney *et al.*, 1995), trends northeastward along the eastern shore of the Burbidge Lake, into the adjacent

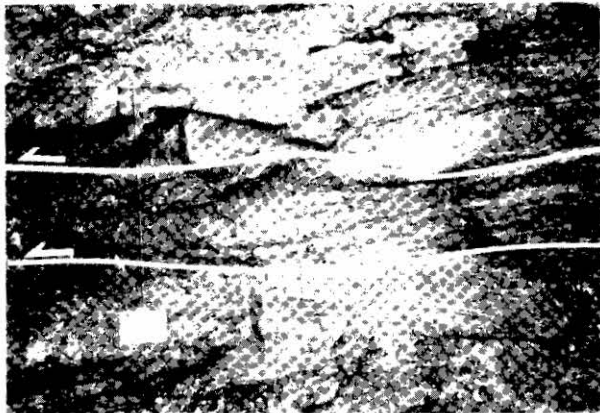


Figure 8 - Small-scale thrust faults and F_2 recumbent folds in arkosic pelite on an island in Burbidge Lake.

Janice Lake map area (Delaney *et al.*, 1995). The fault is represented by a relatively high-strain zone up to several tens of metres wide, consisting of small-scale protomylonitic to mylonitic zones. In such zones, rocks are highly dismembered and/or boudinaged. Some presumed pebble clasts of Unit 12 were flattened from 5:1 to 10:1 ratios. Locally, sigmoidal tension gashes (Ramsay and Graham, 1970) and small-scale asymmetric folds found in this zone indicate a dextral shear sense. C-S fabrics (Berthé *et al.*, 1979) were also found but in very narrow zones, generally less than 5 to 10 cm. Shear foliation is generally subvertical and imprinted by a prominent, pervasive slickenside lineation. In contrast to the horizontal shear sense described above, the slickenside lineation is down dip and steeply west-northwest plunging (see also Delaney, *et al.*, 1995). This suggests that at least two generations of movement occurred. Due to poor exposure of this fault zone in the study area, the regional scale effect of this fault is not clear, but the degree of deformation and field relations suggest that movement in the brittle-ductile environment may be insignificant.

d) Third Phase (D_3) Structures

D_3 structures are much less significant than those of D_2 age and are mainly observed in the area southwest of Karin Lake inlier (Figure 2). F_3 minor folds have subvertical, northwest-trending axial surfaces (Figures 2 and 9). In places, F_3 folds are superimposed on F_2 to form both type 2 (Figure 10) and type 3 fold interference patterns (Ramsay, 1967). F_3 folds are locally discontinuous and have larger wave length and amplitude compared to F_2 folds. Many of the F_3 folds show a kink-style which indicates deformation under brittle-ductile conditions. Late D_2 cordierite-bearing anatectic granitic veins, typically oriented in the F_2 axial plane, are locally refolded by the F_3 minor folds. Several very open, major, D_3 fold sets, with very long wave-length limbs, and generally subvertical axial planes and steeply plunging axes were defined, these are best developed in the southwestern part of the area, especially west of Miller Island (Figure 2).

e) Fourth Phase (D_4) Deformation

All structures described above are cut by a number of generally subvertical, mostly northwest-trending brittle faults, which form part of the Burr Fault System (e.g. Ray, 1977; or Karin Lake Fault System of Thomas, 1979).

The main Burr Fault and its splays (Figure 2) are marked by northwest-trending topographic lineaments extending throughout the study area. They are defined by: 1) cataclastic zones up to 10 m wide in which brittle silicified fault breccia is cemented by milky quartz; 2) zones of hematization up to several metres wide; 3) locally well-developed slickensides; and 4) disruption

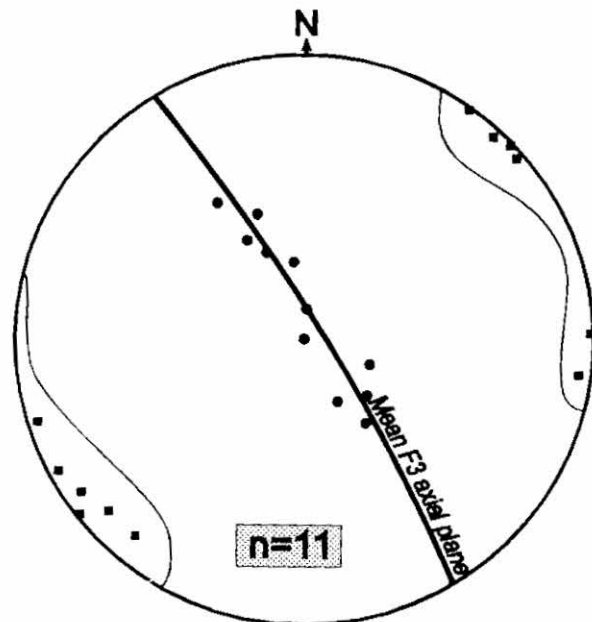


Figure 9 - Lower hemisphere equal area stereographic projection of poles to axial planes (squares) and fold axes (circles) of F_3 minor folds.

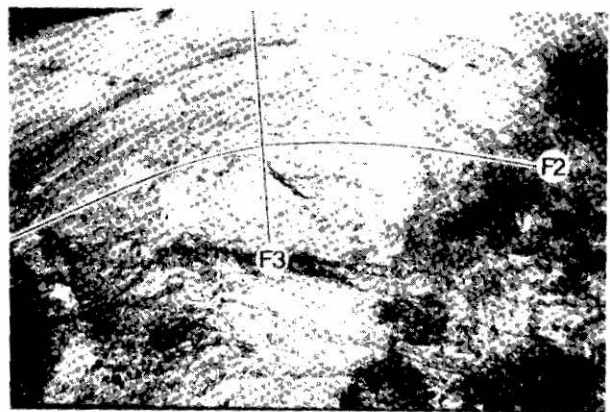


Figure 10 - F_2 and F_3 folds forming a typical type 2 fold interference pattern in rocks southwest of the Karin Lake inlier.

of different lithological units. Fault offset of some F_3 folds shows that fault movement postdated the D_3 event. Kinematic indicators including slickensides, slickenlines, offset layering, and fault gouge show a generally oblique sinistral movement. Although Sibbald *et al.* (1976) estimated 250 m of offset on the Burr Fault southeast of Burbidge Lake, the magnitude of displacement along the faults of this system is uncertain elsewhere. Ray (1977) demonstrated that movement along these faults post-dates the deposition of Athabasca Group farther northwest of the study area.

4. Metamorphism

Field observations show that the study area has a complex metamorphic history and all rocks except late granitic dikes and sills are metamorphosed. In aluminous metasedimentary rocks, metamorphic mineral assemblages include muscovite, biotite, sillimanite, cordierite, garnet, K-feldspar, magnetite, spinel, and hypersthene (?). Anatectic melt neosome is also present. No kyanite or staurolite were found. Andalusite occurs locally as probable pseudomorphs after cordierite. In calc-silicate-bearing rocks, metamorphic assemblages are dominated by tremolite/actinolite, diopside, hornblende, calcite, dolomite, and scapolite. In the following discussion, metamorphic relations will be based on the metamorphic assemblages found in aluminous psammopelitic to pelitic rocks because they generally display diagnostic metamorphic assemblages which allow a more complete documentation of metamorphic conditions in the study area.

a) Spatial Variations in Metamorphism

There is a marked variation in metamorphic grade across the area. At least two periods of mineral growth and recrystallization are recognized.

First Generation Mineral Growth

The first generation prograde metamorphic minerals probably formed prior to the peak of first episode (D_1) deformation and outlasted it. This is indicated by the preferred orientation of most metamorphic minerals such as muscovite, biotite, sillimanite, and cordierite within the S_1 fabrics. They are partly deformed by D_1 and commonly deflect the S_1 foliation.

Sillimanite is common in pelitic rocks immediately west of the Burbidge Lake Thrust. It increases in abundance towards the central part of the area, but becomes less abundant farther west. First generation fibrous sillimanite crystals commonly form lensoid 'faserkiesel' ranging from less than 1 to 5 cm in maximum dimension. The sillimanite lenses are generally flattened parallel to S_1 and elongated in L_1 . Some are even folded by intrafolial F_1 microfolds. Typically they are refolded by F_2 microfolds and crenulations, and rotated to lie in the S_2 foliation. These relationships indicate that sillimanite grew during D_1 . It

is commonly replaced by K-feldspar and cordierite (Figure 11).

Cordierite occurs in association with sillimanite locally in the central part of the area, but is the most prominent metamorphic mineral in the west. Several generations of growth are recognized. First generation cordierite occurs as flattened, dark-brown, poikiloblastic porphyroblasts oriented in S_1 , partially or wholly replacing fibrous sillimanite faserkiesel. It generally includes remnants of fibrolitic sillimanite, biotite, and quartz, implying that cordierite may have been formed by the breakdown of these minerals.

Early, probably syn- D_1 garnet occurs as relatively idioblastic porphyroblasts, generally less than 1 cm across, which are common in psammitic and psammopelitic rocks of Units 6 and 7, but are uncommon in pelitic components of these units. They are commonly deformed, locally forming fine-grained aggregates elongated in the S_1 foliation.

First generation metamorphic K-feldspar appears to have formed concurrently with first appearance of migmatic neosome and is generally accompanied by cordierite in pelitic rocks (Figure 11). It occurs as up to 2 cm lensoid poikiloblastic porphyroblasts with sillimanite (mostly fibrolitic), biotite and quartz inclusions, which mimic S_1 foliation but are strongly deformed by D_2 . K-feldspar also occurs as large aggregates in anatectic leucosome.

Early migmatitic neosome is widespread in pelitic rocks west of Burbidge Lake as small patchy sweats, pods and sheets, up to several metres wide, but generally less than 0.2 m. It locally comprises up to 70 percent of the rock volume, may be either concordant or discordant to the main S_1 foliation, is commonly boudinaged, is rotated sub-parallel to the S_1 fabric, is refolded by second generation folds, and commonly contains some sillimanite and cordierite.

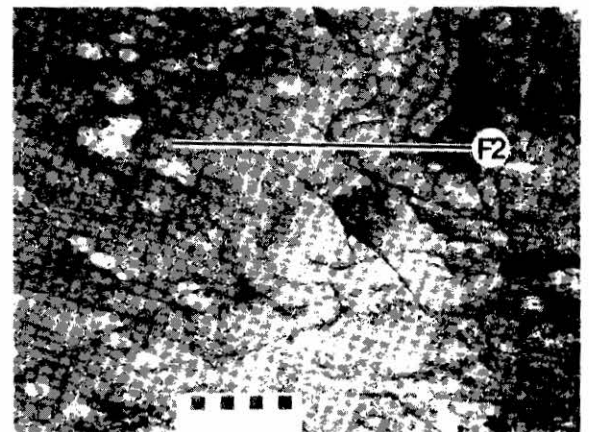


Figure 11 - Cordierite-bearing K-feldspathic lenses folded by F_2 folds east of Karin Lake inlier.

Second Generation Mineral Growth

The second generation of metamorphic minerals was formed broadly coeval with and outlasted the D₂ deformation. It extensively overprinted earlier metamorphic features.

West of Burbidge Lake in the central part of the map area, second generation sillimanite generally occurs as lensoid faserkiesel up to 3 cm long, oriented parallel to L₂ and flattened in S₂ (Figure 7).

In the west, other second generation minerals are garnet, cordierite, K-feldspar, and locally hypersthene. Cordierite occurs both as: i) purple, translucent subidioblastic to lensoid porphyroblasts up to 2 cm, either rimmed or cored by K-feldspar and dimensionally oriented in S₂ and ii) as unoriented large porphyroblastic aggregates up to 5 cm long in quartz-K-feldspar-plagioclase leucosomal segregation pods and veins.

Second generation garnet occurs as poikiloblastic grains less than one to several centimetres in diameter, commonly with quartz, biotite, and sillimanite inclusions, and associated with K-feldspar and cordierite. These features suggest that the garnet may have formed by the breakdown of sillimanite and biotite. It overprints D₂ fabrics, clearly indicating late to post D₂ growth.

Second generation K-feldspar, occurring as undeformed lensoid porphyroblasts up to several centimetres in diameter, is oriented parallel to the S₂ fabric, particularly in the hinge zone of F₂ folds (Figure 12). Such porphyroblasts, which locally comprise up to 30 percent of the rock volume, are generally either cored or rimmed by cordierite aggregates, like the first generation K-feldspar.

Hypersthene is tentatively identified in trace amounts in late undeformed neosome containing sillimanite, cordierite, and garnet. This suggests that hypersthene may have been formed by the breakdown of these minerals in a very high-temperature regime.

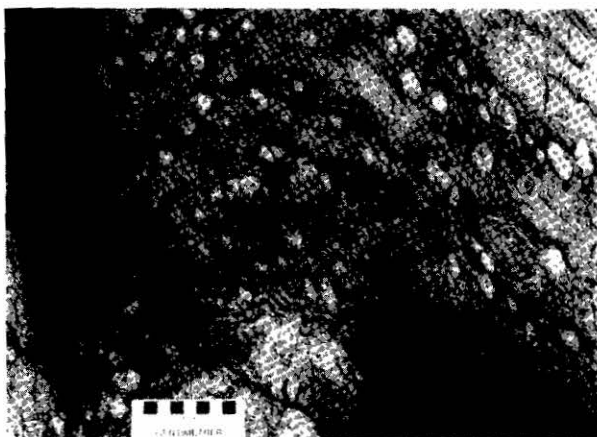


Figure 12 - K-feldspar lenses axial planar to F₂ folds east of Karin Lake inlier.

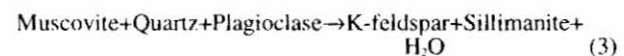
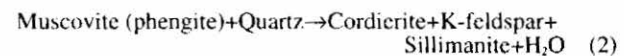
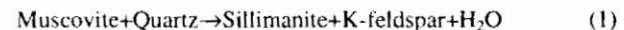
Second generation anatectic leucosome comprises weakly to undeformed, melt pods, veins and dikes, up to several metres wide, either axial planar to the F₂ folds or randomly crosscutting all earlier structures, and is locally weakly deformed by D₃. Their morphological and textural characteristics indicate that they formed during late stages of or after D₂, but predated D₃ deformation.

At several localities, cordierite is partly replaced by grey poikiloblastic aggregates up to 2 cm across, some of which resemble chialstolite. These may be decompression pseudomorphs of cordierite formed during retrograde metamorphism.

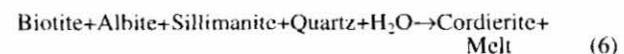
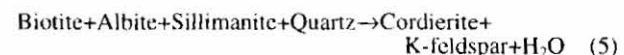
b) Physical Conditions of Metamorphism

Variations in metamorphic mineral assemblages in the pelitic rocks clearly record a westward increase in metamorphic grade toward the Karin Lake inlier from lower amphibolite to granulite facies. East of the Burbidge Lake Shear Zone, aluminous wackes (Unit 14) and some of the arkosic arenites (Unit 13) contain abundant muscovite and minor biotite.

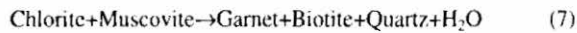
Muscovite abruptly disappears and is replaced by upper amphibolite facies assemblages including sillimanite, cordierite, K-feldspar, and extensive anatectic melt west of the Burbidge Lake Thrust. Several reactions involving the disappearance of muscovite, appearance of the second sillimanite isograd, and generation of a melt might be applicable to this situation. Since both sillimanite and cordierite occur with the melt component, such melt may have formed via reaction 1 (Evans, 1965), or 2 with the presence of phengite (e.g. Thompson, 1982) or, given the presence of plagioclase in pelitic rocks, reaction 3 (Evans and Guidotti, 1966).



Farther west, near the Karin Lake inlier, metamorphic conditions change to higher grade, represented by decreased sillimanite and increased cordierite, K-feldspar, and anatectic melt. It is likely that the changes in mineral composition in this part of the area were caused by reactions 4 (Holdaway and Lee, 1977), 5, and 6 (Wickham, 1987).



The first generation garnet, found in rocks of Units 6 and 7, however, may have been formed at lower metamorphic conditions via reaction 7 (Hsu, 1968).

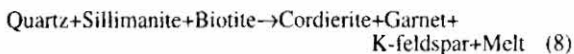


Reaction 7 takes place at low grade metamorphic conditions (i.e. ~500°C, Bucher and Frey, 1994), suggesting that the first generation garnet may have grown during the earliest stage of metamorphism.

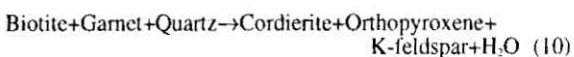
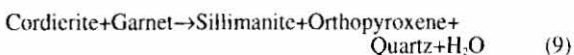
Reactions 1 to 7 are responsible for the widespread first generation metamorphic mineral growth. They reflect a change from lower amphibolite facies in the east to upper amphibolite facies in the west, during the early stages of metamorphism, possibly coeval with D₁ deformation. The abrupt change in metamorphic grade in the Burbidge Lake area, however, reflects movement on the thrust which transported lower stratigraphic level rocks of higher metamorphic grade (Units 8 and 9), over the stratigraphically higher, but lower grade ones (Figure 3).

Changing metamorphic conditions after D₁ deformation led to the formation of a second generation metamorphic mineral assemblage. In the east, this is represented by the growth of second generation sillimanite-cordierite and K-feldspar, possibly via reactions 1 to 6.

Further increase in metamorphic conditions during the D₂ deformation event, led to the production of a second generation, peak garnet-cordierite-K-feldspar-bearing assemblage and abundant cordierite-bearing leucosome, representing the transition from upper amphibolite to granulite facies (Bucher and Frey, 1994) in the west. This assemblage may have formed by reaction 8 (Grant, 1985).

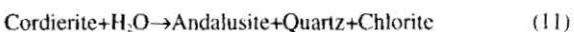


Orthopyroxene, tentatively identified in the pelitic rocks of Unit 7, may have formed by the breakdown of cordierite and garnet via reactions 9 and 10 (Grant, 1985).



Reactions 9 and 10 mark the highest grade metamorphic conditions the area attained during or after late D₂ deformation.

Finally, with a drop in temperature and introduction of hydrous fluids, cordierite may have decomposed to andalusite via reaction 11 (Seifert and Schreyer, 1970).



5. Economic Geology

Exploration in the Wollaston Domain has been mainly directed towards uranium and base metals. A number of uranium showings were found in the Foster Lakes area in the early 1950s, of which the most notable is the

Burr prospect southeast of Burbidge Lake (Sibbald *et al.*, 1976). More were found in the late 1960s around the margin of the Karin Lake inlier. Features of these showings are summarized by Scott (1986) and described in more detail by Ray (1977) and Thomas (1979).

No significant base metal showings occur within the map area, but copper occurrences hosted in the Janice Lake and Rafuse Lake formations are found northeast of Burbidge Lake. Features of these are summarized by Scott (1986) and described in more detail by Coombe (1994) and Delaney *et al.* (1995).

Several new occurrences of radioactivity, malachite, and sulphides, were identified during this mapping program (Figure 2 and map separate). Radioactivity anomalies in late pegmatite bodies that contain up to 50 percent smoky quartz, were found in Unit 4 of the basement complex, but no significant radioactivity anomalies were found in the graphitic basal metasediment sequence. Up to 1 percent malachite was identified at several places in Units 6 and 16. Pyrite/pyrrhotite is also present as trace minerals locally in quartzofeldspathic gneisses of Unit 11.

6. Discussion and Conclusions

a) Stratigraphy

Coombe (1979), Ray and Wanless (1980), Sibbald (1983), and others have interpreted the Wollaston Group as a sequence of rift and post-rift passive margin sediments accumulated on the western margin of the Rae-Hearne craton. Although scarcity of sedimentary structures constrains detailed interpretation, vertical and lateral variations in composition and layering suggest broad depositional conditions consistent with pre-rift and post-rift tectonic settings.

Except for xenoliths of aluminous pelite, the remnants of metasediments preserved in or at the margins of the Karin Lake inlier have sandstone protoliths. Quartzite preserved at the outer margin of Unit 4, suggests a stable platform setting prior to the onset of rifting. While the stratigraphic contact between Unit 4 and the underlying granitoids was probably a nonconformity (Ray, 1977), high strain at the margin of the Karin Lake inlier (discussed below) has eliminated any direct evidence of this. The compositional variability and contrast with overlying metasediments suggest that a second unconformity, possibly a break-up unconformity, separates Unit 4 from the overlying supracrustal succession.

Overall, the supracrustal rocks (Units 6 to 17) show an upward increase in grain size, compositional maturity, and bed thickness, indicative of relative sea-level fall. This is consistent with rapid post-rift subsidence accompanied by progradation of sediment. Lamination and/or thin (3-10 cm) bedding, continuous on an outcrop scale in many of the units, shows that most of the sediments were deposited below wave base. Scarcity of graded bedding or any other features of

turbidites precludes a deep water submarine fan setting, however. Hence the bulk of the sediments accumulated in a sublittoral or shallow shelf setting.

The basal pelitic units (6 and 7) are graphite-rich, in contrast with overlying pelitic sediments. Organic-rich shallow marine muds are typical of conditions in which the oceanic oxygen minimum zone extends onto the shelf (Jenkyns, 1986). Such conditions occur during periods of restricted ocean circulation and rapid transgression characteristic of early rift ocean margins (e.g. Arthur and Schlanger, 1979). The delta-basin facies of the Devonian Catskill Delta (Ettensohn, 1985) provides a good analog for these sediments.

Aluminous minerals (cordierite and sillimanite) become more prominent upwards and eastward in the basal sequence (e.g. Units 8 and 9). This must reflect increased protolith clay content, and likely indicates continued relative sea-level rise. Units 7 and 8 are also more pelitic than overlying and underlying strata. The upward decline in organic content, however, suggests a fall in the oxygen minimum level and stronger ocean circulation. This is consistent with a widening ocean at this time.

The proportion of pelitic sediment declines upward in the upper part of the basal sequence and the transitional sequence (e.g. Units 7 and 10 west of the inlier and Units 8 and 9 east of the inlier). This suggests relative sea-level fall, most likely a function of increased sediment progradation from the west. Upward increase in proportion of sandy sediment suggests a transition to a marginal marine environment, such as a delta or siliciclastic shoreline (e.g. Surlyk *et al.*, 1981). The unusual association of a thin carbonate (Unit 17) interbedded with the thick bedded to massive arkose (Unit 13) is an important clue, as it indicates a temporary cut-off of sand supply, which allowed limestone to precipitate. This most likely represents an abandonment facies in a delta (e.g. Elliott, 1986). In a delta model, the aluminous pelites (Units 7 to 9) could represent pro-delta deposits, while the interbedded sands and muds of Unit 11 represent delta-front deposits. The thick-bedded arkoses of Unit 13 may be channel mouth bars or reworked shoreface sands. The Unit 17 marble, interpreted as a delta-abandonment limestone, formed when sediment supply was cut off as that part of the delta built up too high. It may have been a stromatolitic limestone.

The ferruginous wackes of Unit 10, west of the Karin Lake inlier, are stratigraphically correlative with arkosic sandstones, wackes, and mudstones of Units 8 and 9 east of the inlier. Unit 10 contrasts with these and other units in its poor sorting and weakly developed bedding. This suggests rapid deposition in a sheltered setting, perhaps an interdistributary bay complex (e.g. Coleman and Prior, 1982) or an estuary adjacent to the delta (e.g. Roy *et al.*, 1980 in Galloway and Hobday, 1983).

The thick Janice Lake conglomerates and associated sediments (Unit 12) have a strike length of at least 35 km subparallel to the Needle Falls Shear Zone. They

are interpreted to be alluvial fan deposits (fanglomerate) and derived braided river deposits shed towards the southeast (Delaney *et al.*, 1995). The abundance of arkosic clasts indicates that they postdate deposition of arkose to the west (e.g. Unit 13). They provide strong evidence for renewed rifting (Delaney *et al.*, 1996). Over much of Wollaston Domain this must have been a period of uplift and non-deposition (Delaney *et al.*, 1995). Weber *et al.* (1975) document a possibly correlative event with deposition of conglomerates and arkoses in the northeastern Manitoba extension of the Wollaston Domain. There, however, the coarse clastics overlie calc-silicates, whereas in this area the stratigraphic order is reversed.

Controversial monomictic quartz pebble conglomerates (?) found locally in Units 13 and 8 west of Burbidge Lake may be channel deposits related to deltaic sedimentation, and are not correlative with the Janice Lake conglomerates.

The arkosic sediments overlying the Janice Lake Formation (Unit 13 in Figure 3) belong to the Rafuse Lake Formation and younger formations (Delaney *et al.*, 1995). Although they are lithologically indistinguishable from Unit 13 arkose to the west, they are probably younger.

The calc-silicate-bearing arkose, Unit 15, is notable as the most widespread unit in the map area and because it appears to overlie or structurally interfinger with nearly all of the other sedimentary units. As noted earlier, its base is probably an angular unconformity, correlative with the period of rifting and deposition of the Janice Lake sediments. This cuts down to progressively lower stratigraphic levels towards the Karin Lake inlier (Figure 2 and 3), suggesting that the latter was a structural high in Janice Lake time. Facies changes among supracrustal units (particularly Units 8, 9, and 10) surrounding the inlier suggest it was a topographic high even earlier. The thin to medium interlayered arkose and calc-silicates most typical of Unit 15 may represent sabkha deposits (e.g. Schreiber, 1986) or alternating deltaic or siliciclastic shoreline, shoreface sands and offshore carbonates similar to the early Carboniferous Yoredale Series of northern England (e.g. Leeder and Strudwick, 1987 in Tucker and Wright, 1990).

b) Structural Geology

Four deformation events are recognized. The first deformation (D_1) involved isoclinal recumbent folding and development of a regional foliation. A relatively high-strain zone with pronounced kinematic indicators was developed at a deep crustal level at the contact between the cover rocks and Archean (?) basement. Layered supracrustal rocks and early intrusive sheets at or near the contact were deformed into overturned isoclinal folds. This suggests that the basement/cover contact is tectonically modified and perhaps not a simple unconformity as previously suggested (Ray, 1977; Thomas, 1979). This deformation event may have been produced by tectonic transport and crustal imbrication, resulting in moderate crustal thickening

which led to the formation of first generation metamorphic assemblages. The F_2 folds, which formed during the second deformation event (D_2), reflect subhorizontal shortening and are thought to be related to a major northwestward shortening caused by northwest-southeast directed convergence and collision of major tectonic blocks. Doubly plunging, northeast-southwest trending, subvertical axial planar F_2 folds define the structural grain of the area. Refolding of the first generation structures generally produced type 3 fold interference patterns. D_2 deformation was accompanied by a second generation of metamorphic mineral growth. The D_3 event, involving northwest-trending, upright folding, locally produced complex fold interference but was relatively weak and had little effect on regional structural trends. This deformation event probably occurred during a period of regional cooling, and related metamorphism is insignificant, involving minor retrogression and alteration. Late brittle-ductile D_4 faulting appears to postdate all fold-forming events. It may be related to disruption of the accreted terrain collage of the Reindeer Zone during terminal post-collisional stages of deformation.

The structural and tectonic development of Wollaston Domain has been discussed by a number of workers including Lewry and Sibbald (1977, 1980) and Ray (1977). These authors suggested that the first deformation event (D_1) which produced regional gneissic and schistose fabrics in the Wollaston Domain, is associated with the development of subvertically inclined, and possibly elongate, mantled basement gneiss domes, interpreted by Lewry and Sibbald (1980) to have been caused by upward migration of a 'migmatite front' on the basis of the absence of coeval D_1 folding and lack of evidence for major stratigraphic repetition by D_1 structures (Lewry and Sibbald, 1980). Such domes developed in the Archean basement in response to gravitational instability resulting from the heating and thermal expansion accompanying the D_1 event. The basement domes moved upwards without penetrating or seriously disrupting the overlying cover rocks so that the stratigraphic relationships are essentially preserved, and the S_1 foliation is weak in the gneiss dome cores and in the upper part of the Wollaston succession but it is intensely developed along and parallel to the basement cover contact.

Such a model alone cannot explain the development of D_1 structures in the study area.

- 1) There is a systematic development of penetrative S_1 foliation throughout the study area; not restricted to the basement/cover contacts.
- 2) Although heavily disturbed by later deformation and high-grade metamorphic overprinting, F_1 isoclinal folding is widespread and recognizable throughout the study area, both on a mesoscopic and macroscopic scale, giving rise to lithological repetition.
- 3) Superimposition of F_2 on F_1 folds produced typical type 3 'convergence divergence' interference patterns (Ramsay, 1962; Ramsay and Huber, 1987). Such patterns are produced only by a

mechanism in which tight to isoclinal recumbent first generation folds are refolded by new structures with steeply inclined axial surfaces, fold axes parallel or subparallel to those of the first phase structures, and the differential movement direction of the second phase folds lies at a high angle to the first fold axial surfaces (Ramsay, 1962; 1967; Ramsay and Huber, 1987). Thus the F_1 folds must have been produced by significant tectonic transport and imbrication in a relatively ductile environment, a mechanism in sharp contrast with the 'migmatite front' migration scheme described above. The relationship between the F_1 and F_2 folds found in this study is also in contrast with that described by Ray (1977) and Lewry and Sibbald (1980) who argued that D_2 deformation and resultant F_2 folding involved compression and modified pre-existing D_1 domes into flattened or complex domes or into major non-cylindrical upright folds.

- 4) The contact between Archean basement and cover rocks is represented by a relatively high-strain zone. A number of strain indicators indicate that there was movement and perhaps significant displacement of the cover rocks relative to the basement (i.e. the supracrustal rocks are allochthonous). Thus the high-strain regime at the contact can be interpreted to be the result of detachment and tectonic transport of the cover rocks (e.g. a décollement zone).

c) P-T Conditions of Metamorphism

The relationships between metamorphic assemblages discussed above clearly indicate two generations of metamorphic mineral growth, possible coeval with the two main deformation events. The first metamorphic assemblages, representing lower to upper amphibolite facies, formed during D_1 deformation. Metamorphic conditions, however, reached their peak during late stages of, or after D_2 deformation.

Figure 13 summarizes P-T grids of metamorphic reactions in pelitic rocks based on the field relations discussed above, and shows a proposed P-T trajectory for metamorphism in the study area.

Reaction 1 intersects the water-saturated solidus curve at 4 kbar and 680°C (point A, Figure 13; Bucher and Frey, 1994). At pressures above that intersection, muscovite disappears by partial melting. At pressures below this point, muscovite disappears by reaction 1 (Bucher and Frey, 1994). Thus the temperature at this intersection point marks the highest possible temperature for stable muscovite+quartz assemblages. This marks the maximum metamorphic grade in the area east of Burbidge Lake. A rise in P-T conditions above this limit probably produced extensive early migmatitic leucosomes in the pelitic rocks farther west.

The highest P-T conditions during metamorphism in the map area must have reached those required for reactions 8 and 9 in which garnet-cordierite-K-feldspar-hypersthene assemblages formed. These reactions intersect at a P-T invariant point (Point B in Figure 13)

with estimated P-T conditions of about 5 kbar and 750°C (Grant, 1985; Bucher and Frey, 1994). However, the stable coexistence of garnet and cordierite with hypersthene, and the small quantity of hypersthene generated, indicates that maximum temperature did not exceed this invariant point. Thus the maximum thermal peak is estimated to have been 750°C. This represents temperature conditions during or after peak D₂ deformation since the second garnet-cordierite-K-feldspar-hypersthene-melt assemblages were not formed until the late stages of D₂. Temperature during the first episode of mineral growth, and D₁ deformation, must have been well below this temperature range (i.e. lower than 725°C, Grant, 1985).

The maximum pressure conditions during metamorphism in the map area can be estimated on the basis of the complete absence of kyanite and the abundance of cordierite. Pressure conditions governing formation of cordierite are, however, largely dependent on magnesium to iron ratios. Hess (1969) showed that garnet+cordierite+biotite (+sillimanite) assemblages generally indicate P-T metamorphic conditions ranging from less than 1.5 kbar at 500°C to 4.5 kbar at 800°C or more. Pelitic rocks in the study area, which contain garnet-sillimanite-cordierite assemblages, may belong to this category. Assuming that the pelitic rocks have 'normal' low Mg/Fe ratios, maximum pressure conditions during metamorphism in this area would have been about 5 kbar.

In conclusion, given the mineral reactions proposed above, peak metamorphic temperatures ranging from less than 680°C in the east to 750°C in the west at a maximum pressure of 5 kbar are suggested for peak metamorphic conditions in the study area, coeval with or after D₂ deformation. This P-T range indicates a maximum average geothermal gradient of 50 to 60°C/km⁻¹ at the metamorphic peak prior to uplift and erosion. Such a high thermal gradient, together with the complete absence of kyanite, indicates a high T/low P metamorphic regime and belongs to andalusite-sillimanite facies series metamorphism (Miyashiro, 1973) or Abukuma facies series (Winkler, 1967) as suggested by Lewry and Sibbald (1977) and Ray (1977). The presence of the cordierite-garnet-K-feldspar-melt assemblage with an estimated maximum pressure of about 5 kbar provides an upper limit on crustal thickness/erosion. An erosional depth of 15 to 18 km is estimated for the western part of the area.

7. Acknowledgments

The principal author (H. Tran) gratefully acknowledges support for this project from Cameco Corporation, Cogema Resources Inc., PNC Exploration (Canada) Co. Ltd., and Uranerz Exploration and Mining Limited. Christian Miller, Naomi Wiebe, Colin Lewry, Raza Hasanie, Alex MacNeil, and Josh McGowan were cheerful and willing field assistants. Tom Sibbald, John Lewry, and Gary Delaney provided valuable

discussions in the field. We also thank Gary Thompson and the pilots and staff of Osprey Wings and Thompson's Upper Foster Lake fishing camp for their support.

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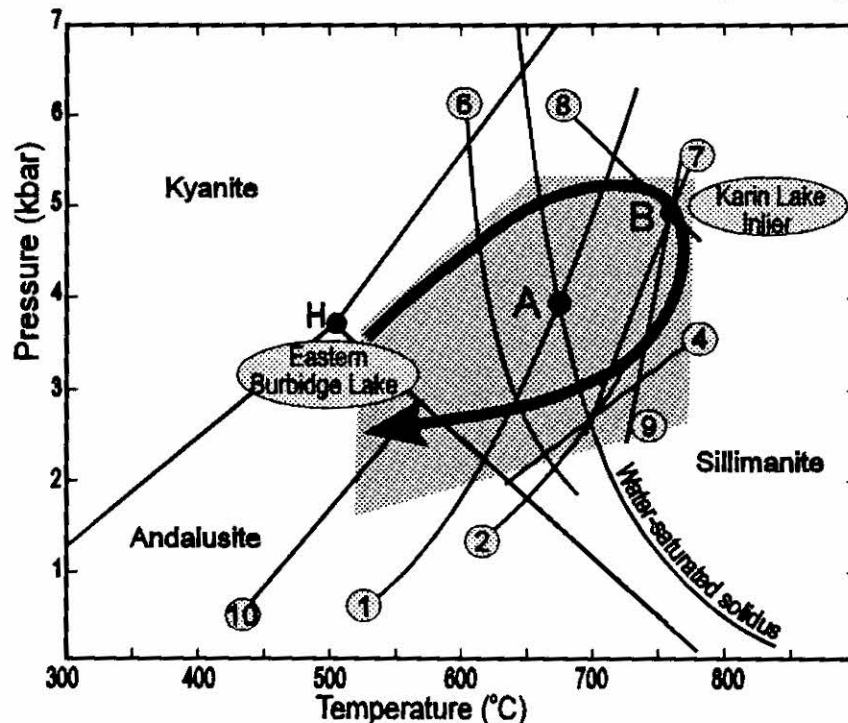


Figure 13 - P-T grid showing proposed metamorphic conditions in the Burbidge Lake–Upper Foster Lake area on the basis of metamorphic assemblages observed in the field. Arrow indicates P-T trajectory. The shaded area indicates suggested P-T conditions for the study area. The number of each invariant curve refers to a reaction in the text. H is Holdaway's (1971) triple point. The water-saturated solidus is after Bucher and Frey (1994).

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