The Canadian Mineralogist
Vol. 38, pp. 435-442 (2000)

METAMORPHISM OF THE BURNTWOOD GROUP IN THE DUVAL LAKE AREA, MANITOBA, CANADA*

TRACEY JUNGWIRTH† and TERENCE M. GORDON§

Department of Geology and Geophysics, University of Calgary, Calgary, Alberta T2N 1N4, Canada

EDGAR FROESE

Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada

Abstract

The occurrence of porphyroblastic staurolite-bearing metagreywacke of the Burntwood Group between Duval Lake in northern Manitoba and the Saskatchewan–Manitoba border led previous investigators to suggest the presence of a metamorphic low in the Kisseynew gneiss belt. Thermobarometric measurements on quartz – plagioclase – sillimanite – garnet – biotite assemblages in the Duval Lake area and in the vicinity of Lobstick Narrows (Kisseynew Lake), near the boundary between the Kisseynew gneiss belt and the Flin Flon volcanic belt, gave values of 3000 ± 600 bars and 530° ± 27°C. These values are within measurement uncertainty and suggest a uniform metamorphic grade. We conclude that the occurrence of staurolite is controlled by bulk composition and that there is no metamorphic low at Duval Lake.

Keywords: staurolite, grade of metamorphism, Burntwood Group, Kisseynew gneiss belt, Duval Lake, Manitoba.

Sommaire

La présence de méta-grauwacke à porphyroblastes de staurolite du groupe de Burntwood entre la région du lac Duval, dans le nord du Manitoba, et la frontière entre le Saskatchewan et le Manitoba, a mené à la conclusion qu'il y a un minimum en intensité de métamorphisme dans la ceinture gneissique de Kisseynew. De nouvelles mesures thermobarométriques portant sur l'assemblage quartz – plagioclase – sillimanite – grenat – biotite dans la région du lac Duval et près de Lobstick Narrows (lac Kisseynew), près de la frontière entre la ceinture gneissique de Kisseynew et la ceinture volcanique de Flin Flon, a donné des valeurs de 3000 ± 600 bars et 530° ± 27°C. Cette évaluation concorde avec les mesures antécédentes, compte tenu de leur précision, et démontre un degré de métamorphisme uniforme. A notre avis, la présence de staurolite est régie par la composition globale des roches; il n'y aurait donc pas de minimum en intensité du métamorphisme dans la région du lac Duval.

Mots-clés: staurolite, degré de métamorphisme, ceinture gneissique de Kisseynew, Groupe de Burntwood, lac Duval, Manitoba.

Introduction

The Flin Flon volcanic belt is part of a Paleoproterozoic assemblage of low- to medium-grade metamorphosed volcanic and sedimentary rocks in northern Manitoba. It is bounded on the north by the Kisseynew gneiss belt. The boundary between the two belts is marked by changes in both lithology and metamorphic grade. In this study, we present new data on the nature of the metamorphic transition between the two belts.

Background Information

Figure 1 (modified from NATMAP Shield Margin Working Group 1998 by Froese 1997) shows the regional geology of the Kisseynew Lake area. Three main rock units are recognized, with ages taken from NATMAP Shield Margin Working Group (1998): the Amisk Group of mainly volcanic rocks (1.92–1.87 Ga), the Burntwood Group of greywacke (1.85–1.84 Ga), and the Missi Group of lithic arenite and conglomerate

---

* LITHOPROBE contribution number 977.

† *Present address*: Canadian Mustang Energy, Inc., 910 – 603-7th Avenue, S.W. Calgary, Alberta T2P 2T5, Canada.
§ *E-mail address*: tmg@geo.ucalgary.ca

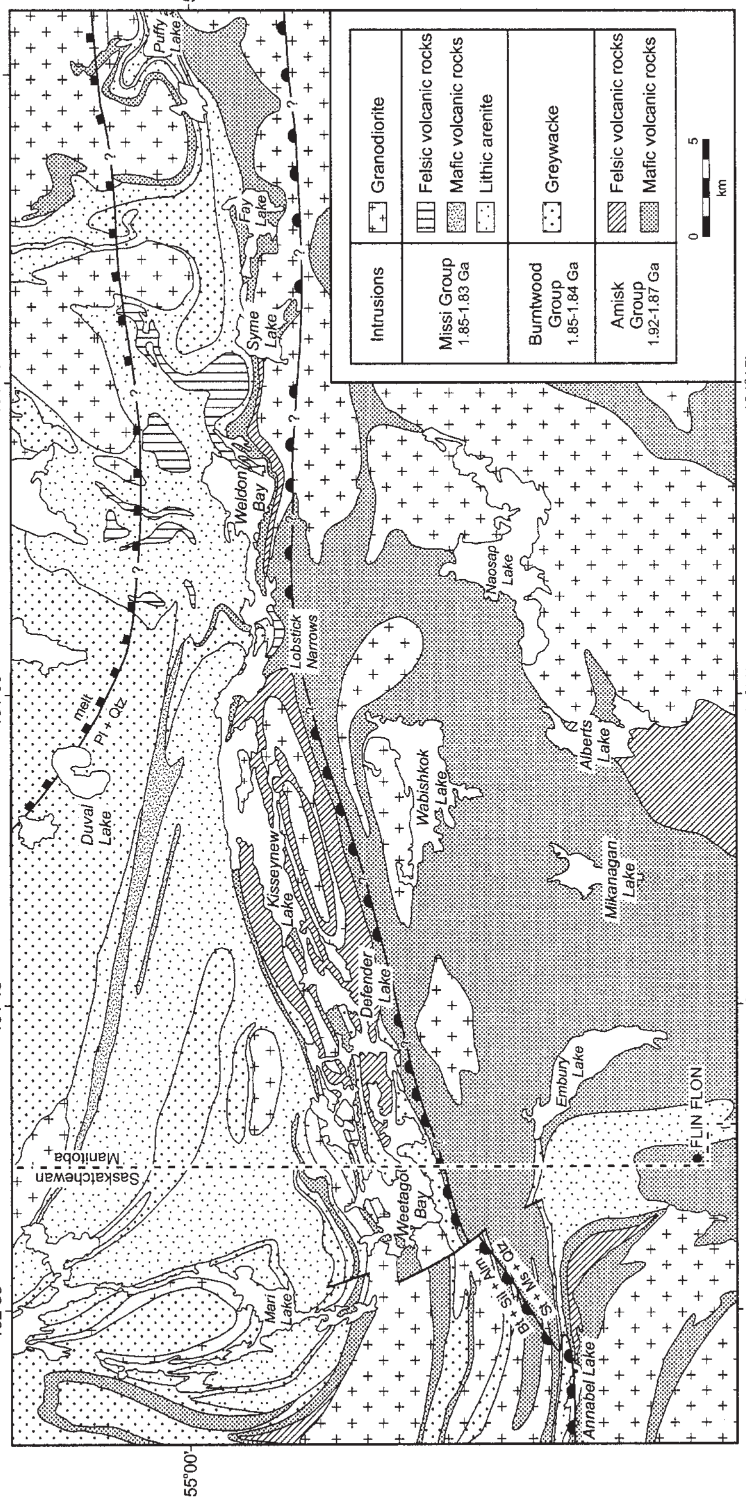

FIG. 1. Regional geology of the Kisseynew Lake area after Froese (1997). The study area shown in Figure 2 lies between Duval Lake and Kisseynew Lake in the north-central part of this map.

(1.85–1.83 Ga). In recent work (NATMAP Shield Margin Working Group 1998), the designation Amisk Group is not used, and there is no collective term for the rocks formed during the period 1.92–1.87 Ga. The rocks of all three groups were metamorphosed at 1.82–1.80 Ga.

Regionally, metamorphic grade increases toward the north, and garnet – cordierite – K-feldspar migmatites are characteristic of the central portion of the Kisseynew gneiss belt. Northwest of Flin Flon, Manitoba, Ashton *et al*. (1992) mapped the biotite – sillimanite – almandine isograd based on the reaction:

$$\text{staurolite + muscovite + quartz} \Leftrightarrow \text{biotite} + \text{sillimanite + almandine} + H_2O \qquad (1).$$

Its approximate position further east is shown in Figure 1, at a grade somewhat above the greenschist–amphibolite transition. At Duval Lake, a melt-in isograd has been recognized in rocks of the Burntwood Group (Jungwirth 1995).

In an area between the Saskatchewan border and the southern end of Duval Lake, underlain by rocks of the Burntwood Group, Pollock (1964) observed staurolite schist interlayered with the more common biotite–garnet schist. On the assumption that muscovite is present, an isograd based on reaction (1) is shown on the Metamorphic Map of the Canadian Shield (Fraser *et al.* 1978) around the occurrences of staurolite schist, in the form of an elongate metamorphic low. James (1983) reported staurolite without muscovite south of Duval Lake and terminated the eastern boundary of the isograd 2 km west of Duval Lake. Near Lobstick Narrows, Norman *et al*. (1995) noticed small resorbed grains of staurolite in biotite – garnet – sillimanite schist of the Burntwood Group. They interpreted this feature as indicating a grade of metamorphism higher than that corresponding to reaction (1). In their opinion, the staurolite schist at Duval Lake possibly indicated a lower metamorphic grade. If there is a metamorphic low at Duval Lake, there must be a reversal of metamorphic gradient such that the grade increases both to the north and south.

The presence of a metamorphic low would have important implications for the history and geometry of metamorphism and deformation in the area. However, new petrological and thermobarometric data show that, within measurement error, the rocks indicate a constant metamorphic grade in the area between Duval Lake and Lobstick Narrows. The occurrence of staurolite is probably controlled by bulk composition. No reversal of metamorphic gradient could be substantiated.

Geological Setting

A geological sketch-map of the study area is shown in Figure 2. Rocks of the Burntwood Group consist mainly of metamorphosed greywacke and have been subdivided into three map units: porphyroblastic metagreywacke, porphyroblast-free metagreywacke, and migmatite. The first two subdivisions correspond to the "Duval Lake Schists" of Pollock (1964), which Zwanzig & Schledewitz (1992) have assigned to the Burntwood Group. Because of the low percentage of white and dark micas (less than 35%) and the lack of gneissic banding, the metasedimentary rocks of the Burntwood Group are called metagreywacke and migmatite in this study.

The metagreywacke is a well-foliated quartz – plagioclase – biotite rock that may contain up to 30% staurolite ± garnet ± sillimanite porphyroblasts. Muscovite, where present, overgrows the foliation and generally occurs as large flakes that are easily identified on a weathered surface. Graphite is a characteristic accessory mineral. The observed mineral assemblages are listed in Table 1.

Porphyroblastic metagreywacke crops out south and west of Duval Lake. It is fine grained and grey on a fresh surface, and weathers a distinctive reddish brown. The most distinctive characteristic is the compositional layering defined by alternating layers of psammite and pelite. Individual layers vary from a few cm to about 30 cm in thickness. Staurolite and sillimanite are restricted to the more pelitic layers, whereas garnet is present in both pelitic and psammitic layers. Total porphyroblast content attains 30% by volume. Biotite and sillimanite define a foliation parallel to the compositional layers. Sillimanite occurs as 1 × 3 mm nodules of quartz and sillimanite or as 2 mm crystals. Staurolite occurs as anhedral, mm-scale porphyroblasts or as euhedral porphyroblasts up to 10 mm in length. Staurolite is commonly yellow on a weathered surface, though it may weather brownish black. Cruciform twins are rare. Muscovite porphyroblasts, oblique to the main foliation, occur locally and are considered to be retrograde.

Porphyroblast-free metagreywacke is exposed north of the porphyroblastic metagreywacke. It is medium to

TABLE 1. MINERAL ASSEMBLAGES OF THE BURNTWOOD GROUP, DUVAL LAKE AREA, MANITOBA

Unit	Pl	Qtz	Bt	St	Grt	Sil
Migmatite						
	×	×	×			×
Porphyroblast-free metagreywacke						
	×	×	×			
Porphyroblastic metagreywacke						
	×	×	×			×
	×	×	×		×	
	×	×	×		×	×
	×	×	×	× (A)	×	×
	×	×	×	× (E)	×	
	×	×	×	× (E)	×	×

A: anhedral crystal habit; E: subhedral to euhedral crystal habit.

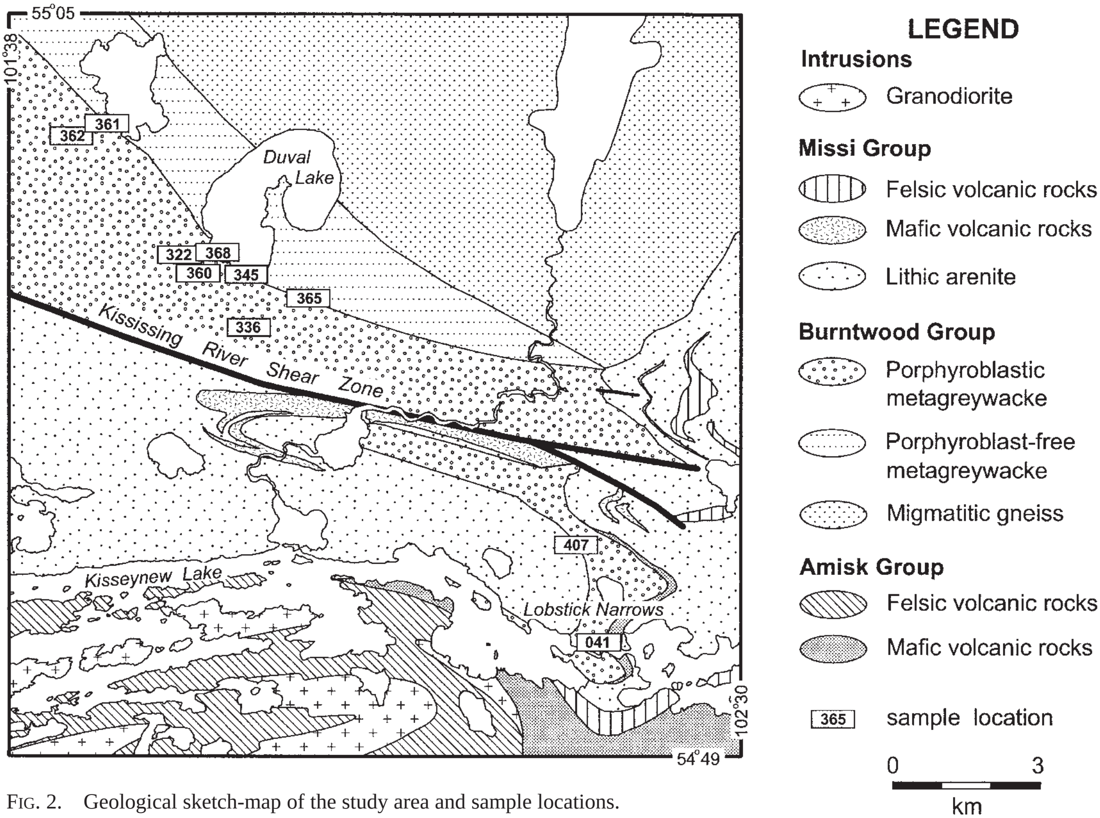

FIG. 2. Geological sketch-map of the study area and sample locations.

coarse grained, with one- to ten-cm layers defined by minor compositional variations. The metagreywackes contain aligned flakes of biotite in a quartz–plagioclase granoblastic matrix. No garnet, staurolite or sillimanite porphyroblasts occur. Biotite content varies between 10 and 20%. Trace amounts of secondary matrix and porphyroblastic muscovite also were observed.

Migmatitic gneiss underlies the northern part of the area. This rock type is characterized by alternating, irregular compositional layers of paleosome, melanosome and leucosome, varying from a few mm to a few cm in thickness. The paleosome is a medium-grained, grey quartz–plagioclase metagreywacke containing 15–20% aligned flakes of biotite. The melanosome is darker grey owing to a higher biotite content (25–35%). Melanosome with greater than 50% biotite occurs adjacent to leucosome layers and folded tonalitic veins. Leucosomes have a granoblastic quartz–plagioclase matrix with rare biotite and occur as isoclinally folded veins and as discontinuous layers. All layers contain up to 10% randomly oriented 2–3 mm flakes of muscovite. Sillimanite was observed in thin section within both paleosome and melanosome material.

PETROGRAPHY

Porphyroblastic metagreywacke is composed of a granoblastic matrix of quartz, twinned plagioclase and biotite. The plagioclase is typically altered to very fine-grained white mica.

Biotite is generally red-brown but locally green-brown and contains abundant inclusions of zircon. Biotite defines the main foliation and wraps around bundles of fibrolitic sillimanite, garnet and staurolite. The percentage of biotite depends on the type of compositional layer, and may amount to more than 15% of the pelite layers.

Garnet grains are subhedral to euhedral. Quartz and minor amounts of tourmaline, ilmenite and chlorite form oriented trails of inclusions oblique to the main foliation. Poikiloblastic euhedral grains of garnet occur with euhedral grains of staurolite, whereas subhedral grains of garnet with few inclusions are associated with anhedral grains of staurolite.

Staurolite is poikiloblastic with quartz and rare trails of ilmenite and tourmaline inclusions oblique to the external foliation. Grains vary from anhedral to euhedral in shape and have variable amounts of inclusions. The long axis of staurolite, in some cases, is oblique to the foliation. Locally, staurolite encloses euhedral poikiloblastic porphyroblasts of garnet.

Sillimanite occurs as ellipsoidal fibrolitic bundles or as needle-like crystals. The fibrolitic bundles are parallel to foliation. Sillimanite crystals are commonly intergrown with biotite and, therefore, mimic the foliation and appear to wrap around garnet and staurolite porphyroblasts.

Minor muscovite occurs as flakes considerably larger in size than the other minerals. The muscovite has a "wormy" appearance and encloses grains of quartz and, less commonly, biotite. These porphyroblasts are oblique to the foliation defined by biotite flakes and sillimanite bundles, and are interpreted as having developed after peak conditions of metamorphism.

Chlorite occurs as inclusions in garnet, growing on and cutting across biotite or, rarely, adjacent to garnet porphyroblasts. On the basis of these textures, chlorite and muscovite porphyroblasts are interpreted to have crystallized after development of the main foliation.

Tourmaline, ilmenite and apatite are accessory minerals in porphyritic metagreywacke. Color-zoned tourmaline is present in the matrix and locally occurs as inclusions in porphyroblasts.

Porphyroblast-free metagreywacke is characterized by red-brown biotite in a granoblastic matrix of quartz and plagioclase. No porphyroblasts of garnet, staurolite or sillimanite are present. Biotite is generally weakly aligned, although in one thin section biotite is randomly oriented. Plagioclase contains simple twins, and much of it is altered to white mica.

Migmatitic gneiss is characterized by anastomosing layers and lenses of paleosome, melanosome and leucosome. The leucosome is a tonalite with less than 2% red-brown biotite randomly to weakly oriented within a granoblastic matrix of quartz and twinned plagioclase. The paleosome contains red-brown aligned biotite, sillimanite, quartz and twinned plagioclase. Sillimanite occurs as lath-like crystals less than 0.1 mm in length and as fibrous aggregates. Both types of sillimanite are intergrown with biotite; hence, the orientation of biotite and sillimanite defines the foliation. Up to 3% porphyroblasts of muscovite cross-cut aligned biotite and biotite–sillimanite microfolds. Alteration of plagioclase to white mica is common. Opaque minerals are spatially associated with fibrous sillimanite.

Textures and their Interpretation

1. Where staurolite, garnet and sillimanite are in direct contact in the metagreywackes, there is no textural evidence (*e.g.*, reaction minerals) between grains that would indicate disequilibrium.

2. There is no evidence of relict or replacement textures in porphyroblasts in the metagreywackes or migmatites.

3. Garnet shows no evidence of multiphase growth or compositional zoning (see below).

4. Porphyroblast–matrix relationships indicate the porphyroblasts grew pre- to syn-development of the main foliation. Inclusion trails at an angle to the present foliation are indicative of a pre-existing fabric.

5. Muscovite appears to be entirely secondary and unrelated to the assemblage of primary minerals.

Mineral Chemistry

The ARL–SEMQ electron-microprobe facilities at the University of Calgary were used to analyze selected grains of garnet, biotite, plagioclase and staurolite in samples from the locations shown on Figure 2. All samples are from sillimanite-bearing porphyroblastic metagreywacke. Staurolite is absent in sample 361. Five samples (322, 336, 360, 362 and 365) are staurolite-rich metagreywackes with about 15 modal % euhedral staurolite. These samples represent the staurolite schist of Pollock (1964). Five samples (345, 361,368, 407 and 041) are from the more common biotite–garnet metagreywacke of the Burntwood Group. In some rocks, anhedral staurolite also is present in small amounts (about 5 modal %). In each polished section, the smallest area containing the appropriate minerals was selected. Cores and rims of minerals exhibiting solid solution were analyzed. The number of points per mineral grain was variable. The electron microprobe was operated at an accelerating voltage of 15 kV and a beam current of 15 nA. Data were reduced using the methods of Bence & Albee (1968).

Zoning is not pronounced in biotite, plagioclase and garnet. Core and rim FeO and MgO concentrations vary less than 1 wt.% in biotite. Core and rim FeO and MgO concentrations differ by 1–2 wt.% and 1 wt.%, respectively, in garnet. Although garnet in some samples contains up to 4.3% MnO, the majority of garnet grains analyzed have less than 1% MnO by weight. Plagioclase grains have less than 1 mol% variation in An content between core and rim. Rim analyses of plagioclase grains were difficult to obtain because of alteration. In such instances, compositions of the core were used in subsequent thermobarometric calculations.

Within each polished section, a subarea containing quartz, sillimanite, garnet, biotite and plagioclase in textural equilibrium was chosen for detailed analysis. Results of single spot-analyses from within 10 μm of the rims of adjacent homogeneous grains of garnet, biotite and plagioclase (Tables 2–4) were chosen for thermobarometric calculations. No *ex post facto* selection of analytical results was made on the basis of mineral chemistry or of P–T determinations. No compositional averaging was done.

Tables 2 to 4 contain compositional data (in wt.%) used in thermobarometry calculations. Site occupancies were computed with the CMP program supplied by Dr. R.G. Berman of the Geological Survey of Canada.

Table 5 contains compositional data on staurolite from the same samples; staurolite is absent in sample 361.

Thermobarometry

Whereas petrogenetic grids provide relative P–T conditions, specific P–T conditions can be estimated by thermobarometry. In this study, mineral compositions from metagreywackes of the Burntwood Group have been used with the computer program INVEQ to estimate conditions of metamorphism. Rocks including the assemblage garnet – biotite – sillimanite – plagioclase – quartz were analyzed.

INVEQ (INVerse chemical EQuilibrium problem) is a method of Gordon (1992) and Gordon *et al.* (1994) that determines a P–T estimate of a sample considered to retain equilibrium mineral compositions. This method takes advantage of the fact that the chemical potentials of all end-members should be related to the chemical potentials of a linearly independent subset at equilibrium. In this study, the estimated pressures and temperatures are identical to those that would be calculated from the equilibria among mineral end-members:

phlogopite + almandine = annite + phlogopite
3 anorthite = grossular + 2 sillimanite + quartz.

Thermodynamic properties of mineral end-members are taken from Berman (1988). The activity model for garnet is that of Berman (1990); for biotite, we used that of McMullin *et al.* (1991), and for plagioclase, that of Fuhrman & Lindsley (1988). The resulting pressure–temperature estimates are shown in Table 6.

The pressure estimates have a mean of 2800 bars and a range of 2430–3620 bars, and the temperature estimates have a mean of 523°C and a range of 503°–556°C. These values are within the range of analytical uncertainty (*e.g.*, Gordon *et al.* 1991). No spatial trend is apparent.

Summary of Results

In the study area, the muscovite in rocks of the Burntwood Group is regarded as retrograde, and porphyroblastic metagreywacke is characterized by the assemblage biotite – staurolite – sillimanite – garnet. According to the grid of D.M. Carmichael in Davidson

TABLE 2. ELECTRON-MICROPROBE DATA ON GARNET, PORPHYROBLASTIC METAGREYWACKE, DUVAL LAKE AREA, MANITOBA

Sample	322	336	345	360	361	362	365	368	407	041
SiO_2	36.67	36.63	35.98	37.04	37.43	37.39	37.92	37.20	37.14	36.42
Al_2O_3	21.06	21.44	20.17	21.25	20.66	21.24	21.39	20.87	21.24	20.59
FeO	37.37	37.35	33.88	38.04	35.30	36.67	37.32	35.75	36.73	34.19
MnO	1.81	1.07	4.31	1.25	3.94	0.99	0.65	3.78	0.94	2.17
MgO	2.55	2.45	2.13	2.43	2.10	3.37	3.18	2.18	2.89	2.41
CaO	1.43	1.45	1.13	1.52	1.39	1.29	1.46	1.09	1.75	1.91
Total	100.89	100.39	97.60	101.53	100.82	100.95	101.92	100.87	100.69	97.69

The compositions are reported in weight %.

TABLE 3. ELECTRON-MICROPROBE DATA ON BIOTITE, PORPHYROBLASTIC METAGREYWACKE, DUVAL LAKE AREA, MANITOBA

Sample	322	336	345	360	361	362	365	368	407	041
SiO_2	34.69	34.72	34.20	35.48	34.16	36.38	35.97	35.22	35.15	36.97
TiO_2	2.02	1.73	2.04	2.33	2.66	1.68	1.55	2.41	2.48	2.34
Al_2O_3	20.42	20.08	19.42	19.83	19.58	18.45	19.54	18.91	18.52	19.20
FeO	19.80	20.09	21.20	20.89	21.30	18.05	19.26	20.57	19.66	18.55
MnO	b.d.	0.03	b.d.	0.02	0.13	b.d.	0.02	0.05	b.d.	0.04
MgO	9.52	9.54	9.05	9.31	8.63	11.35	11.28	8.79	9.71	9.93
CaO	b.d.	0.02	0.04	b.d.	0.03	b.d.	b.d.	b.d.	0.05	0.02
Na_2O	0.22	0.24	0.22	0.19	0.12	0.25	0.25	0.18	0.23	0.25
K_2O	9.51	9.52	8.91	9.00	8.97	8.94	9.02	9.39	8.91	9.02
Total	96.18	95.97	95.08	97.05	95.58	95.10	96.89	95.52	94.71	96.32

The compositions are reported in weight %; b.d.: below detection limits.

TABLE 4. ELECTRON-MICROPROBE DATA ON PLAGIOCLASE, PORPHYROBLASTIC METAGREYWACKE, DUVAL LAKE AREA, MANITOBA

Sample	322	336	345	360	361	362	365	368	407	041
SiO_2	60.42	60.09	61.95	60.03	62.55	61.64	60.86	60.39	58.92	59.41
Al_2O_3	23.78	24.47	23.75	24.13	23.96	25.91	25.01	25.24	26.06	25.08
FeO	0.07	0.07	0.13	0.24	0.10	0.10	0.19	0.02	b.d.	0.07
CaO	5.53	5.48	4.09	6.23	5.36	4.50	6.24	4.41	7.67	6.91
Na_2O	8.27	8.19	8.74	8.00	8.68	8.71	7.95	8.85	7.44	8.07
K_2O	0.05	0.14	0.08	0.05	0.05	b.d.	0.06	0.05	0.07	0.09
Total	98.12	98.44	98.74	98.68	100.70	100.86	100.31	98.96	100.16	99.63

The compositions are reported in weight %; b.d.: below detection limits.

TABLE 5. ELECTRON-MICROPROBE DATA ON STAUROLITE, PORPHYROBLASTIC METAGREYWACKE, DUVAL LAKE AREA, MANITOBA

Sample	322	336	345	360	362	365	368	407	041
SiO_2	26.99	26.79	26.54	27.76	26.97	26.91	27.18	27.56	27.13
TiO_2	n.a.	n.a.	0.58	n.a.	n.a.	n.a.	n.a.	0.59	0.69
Al_2O_3	53.15	53.96	52.88	53.78	55.99	53.17	55.11	54.42	55.21
FeO	15.30	14.49	14.53	15.04	14.53	14.84	14.38	11.46	12.11
MnO	n.a.	n.a.	0.25	n.a.	n.a.	n.a.	n.a.	0.05	0.11
ZnO	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.28	2.07
MgO	1.71	1.56	1.53	1.13	1.64	1.73	1.38	1.37	1.29
CaO	b.d.	0.02	0.01	b.d.	b.d.	b.d.	b.d.	b.d.	0.02
Na_2O	b.d.	b.d.	0.02	b.d.	b.d.	b.d.	0.01	0.18	0.16
Total	97.15	96.82	96.34	97.71	99.13	96.65	98.06	97.91	98.79

The compositions are reported in weight %; b.d.: below detection limits; n.a.: no data available.

TABLE 6. PRESSURE – TEMPERATURE ESTIMATES, DUVAL LAKE AREA, MANITOBA

Sample	P	T	Sample	P	T
322	2539	515	362	3621	532
336	2703	516	365	2539	530
345	3237	527	368	2494	512
360	2429	521	407	2970	556
361	2858	524	041	3036	503

Pressure P in bars, temperature T in C.

et al. (1990), this assemblage is stable in the approximate temperature range of 570°–585°C, at 4 kbar. On the basis of this assemblage, metamorphic conditions are above those of reaction (1), and an isograd based on this reaction cannot be placed between Duval Lake and Lobstick Narrows. James (1983) retained this isograd 2 km west of Duval Lake, on the basis of four occurrences of staurolite plus muscovite as far as 10 km west of the isograd. In view of the common occurrence of retrograde muscovite in the study area, it seems probable that this isograd does not exist.

The occurrence of staurolite in some rocks of the porphyroblastic metagreywackes and the variation in modal amounts of staurolite are attributed to differences in bulk composition. The absence of garnet and sillimanite in the porphyroblast-free greywacke at Duval Lake indicates bulk compositions with less Fe and Al than the porphyroblastic greywackes.

Thermobarometric P–T estimates across the study area give 2300–3620 bars and 503°–556°C, indistinguishable within measurement error. In most samples, the analyzed biotite and garnet were in contact. For this reason, the indicated pressures and temperatures might be somewhat lower than peak conditions of metamorphism. Local variations in peak conditions of metamorphism cannot be ruled out, although these are not expected to be sufficiently large or systematic to generate the metamorphic low originally proposed on the Metamorphic Map of the Canadian Shield (Fraser *et al.* 1978). Therefore, we conclude that the metamorphic grade in the vicinity of Duval Lake is the same as that at Lobstick Narrows.

Acknowledgements

The results reported here form part of the M.Sc. thesis of the senior author (Jungwirth 1995). The field assistance of Erik Nickel, and discussions and field trips with Herman Zwanzig, Tony Norman and Kevin Ansdell were invaluable and are gratefully acknowledged. Special thanks go to John Machacek and Deb Glatiotis for instruction and assistance with instrumental analyses. Angela Kolisnik obtained some of the electron-microprobe analyses. The diagrams were drafted by D. Paul. The manuscript was improved by the helpful comments of referees Helen Lang and Tom Foster. The cost of the field work was funded in part by the Canada–Manitoba Agreement on Mineral Devlopment (1990–1995).

References

Ashton, K.E., Hunt, P.A. & Froese, E. (1992): Age constraints on the evolution of the Flin Flon volcanic belt and Kisseynew gneiss belt, Saskatchewan and Manitoba. *Geol. Surv. Can., Pap.* **91-2**, 55-69.

Bence, A.E. & Albee, A.L. (1968): Empirical correction factors for electron microanalysis of silicates and oxides. *J. Geol.* **76**, 382-403.

Berman, R.G. (1988): Internally-consistent thermodynamic data for minerals in the system Na_2O–K_2O–CaO–MgO–FeO–Fe_2O_3–Al_2O_3–SiO_2–TiO_2–H_2O–CO_2. *J. Petrol.* **29**, 445-522.

________ (1990): Mixing properties of Ca–Mg–Fe–Mn garnets. *Am. Mineral.* **75**, 328-344.

Davidson, A., Carmichael, D.M. & Pattison, D.R.M. (1990): Metamorphism and geodynamics of the southwestern Grenville Province, Ontario. *Field Trip Guidebook, Int. Geol. Correlation Program, Project*, 235-304.

Froese, E. (1997): Metamorphism in the Weldon Bay – Syme Lake area, Manitoba. *Geol. Surv. Can., Current Research* **1997-E**, 35-44.

Fraser, J.A., Heywood, W.W. & Mazurski, M.A. (1978): Metamorphic map of the Canadian Shield. *Geol. Surv. Can., Map* **1475A** (scale 1:3 500 000).

Fuhrman, M.L. & Lindsley, D.H. (1988): Ternary-feldspar modeling and thermometry. *Am. Mineral.* **73**, 201-216.

Gordon, T.M. (1992): Solution of the inverse geochemical problem using data for individual species. *Geochim. Cosmochim. Acta* **56**, 1793-1800.

________, Aranovich, L. Ya. & Fed'kin, V.V. (1994): Exploratory data analysis in thermobarometry: an example from the Kisseynew sedimentary gneiss belt, Manitoba, Canada. *Am. Mineral.* **79**, 972-982.

________, Ghent, E.D. & Stout, M.Z. (1991): Algebraic analysis of the biotite–sillimanite isograd in the File Lake area, Manitoba. *Can. Mineral.* **29**, 673-686.

James, D.T. (1983): *Origin and Metamorphism of the Kisseynew Gneisses, Kisseynew Lake – Cacholotte Lake Area, Manitoba.* M.Sc. thesis, Carleton Univ., Ottawa, Ontario.

Jungwirth, T. (1995): *Metamorphism in the Duval Lake Area, Kisseynew Gneiss Belt, Manitoba.* M.Sc. thesis, Univ. of Calgary, Calgary, Alberta.

McMullin, D.W.A., Berman R.G. & Greenwood, H.J. (1991): Calibration of the SGAM thermobarometer for pelitic rocks using data from phase equilibrium experiments and natural assemblages. *Can. Mineral.* **29**, 889-908.

NATMAP Shield Margin Working Group (1998): Geology, NATMAP Shield Margin Project Area (Flin Flon Belt), Manitoba – Saskatchewan. *Geol. Surv. Can., Map* **1968A** (scale 1:100 000).

Norman, A.R., Williams, P.F. & Ansdell, K.M. (1995): Early Proterozoic deformation along the southern margin of the Kisseynew gneiss belt, Trans-Hudson Orogen: a 30 Ma progressive deformation cycle. *Can. J. Earth Sci*. **32**, 875-894.

Pollock, G.D. (1964): Geology of the Duval Lake area, Athapapuskow Mining Division, Manitoba. *Manitoba Dep. of Mines and Natural Resources, Publ.* **61-6**.

Zwanzig, H. V. & Schledewitz, D.C.P. (1992): Geology of the Kississing–Batty lakes area: interim report. *Manitoba Energy and Mines, Geol. Services, Open File* **OF92-2**.

Received April 16, 1998, revised manuscript accepted December 9, 1999.