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Mid-Mesoproterozoic granitoid rocks in the North Bay area, Grenville Province, Ontario

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Abstract

Granite from the Powassan and Mulock batholiths, both lying within the parautochthonous part of the Central Gneiss Belt of the Grenville Province, have U-Pb zircon ages of 1270 ± 3 and ca. 1250 Ma, respectively. These and other coeval metaplutonic rocks in this belt have A-type affinity and thus contrast with coeval, predominantly calc-alkaline plutonic rocks in the Central Metasedimentary Belt some 200 km to the southeast. The difference in character may be accounted for by their relative positions with respect to the pre-Grenvillian margin of Laurentia. If true, this relationship supports the interpretation that subduction polarity in the Mesoproterozoic, preceding closure at 1.2 Ga, was toward the present-day northwest.

INTRODUCTION

This paper reports new ages for granitoid rocks in the northwestern part of the Grenville Province in Ontario, and compares these rocks with coeval plutonic rocks some 200 km to the southeast. The names used for lithotectonic divisions within this part of the province have been drawn from several

Résumé

Dans la partie parautochtone de la ceinture gneissique centrale de la Province de Grenville, les phases granitiques des batholites de Powassan et de Mulock ont été datées par la méthode U-Pb sur zircon à 1 270 ± 3 et 1 250 Ma respectivement. Ces granites et les autres roches plutoniques métamorphisées d'âge équivalent contenus dans cette ceinture présentent des affinités de type A et, par conséquent, ils se distinguent nettement des roches plutoniques à prédominance calco-alcaline d'âge équivalent présentes dans la ceinture métasédimentaire centrale, à quelque 200 km au sud-est. La différence observée dans le caractère de ces roches plutoniques pourrait s'expliquer par leur position relative à la marge antégrenvillienne de la Laurentie. Si tel est le cas, cette relation viendrait appuyer l'interprétation selon laquelle la subduction s'effectuait au Mésoprotérozoïque, avant la fermeture du bassin océanique à 1,2 Ga, en direction du nord-ouest actuel.

sources. Nomenclature has evolved and usage changed in the nearly thirty years since first proposed by Wynne-Edwards (1972). More recent schemes are generally complementary to the original one, but differ in subtle ways and are not strictly interchangeable. To aid the reader, therefore, the distinctions between the most widely used schemes are set out in **Table 1** and the main divisions are shown in the inset map of **Figure 1**.

In the Central Metasedimentary Belt of Ontario and southwestern Quebec, nearly all of the granitoid plutonic rocks that have been dated by the U-Pb zircon method belong to three mid- to late Mesoproterozoic suites: the Elzevir (1.27–1.23 Ga), Frontenac/Chevreuil (1.18–1.15 Ga), and Skootamatta/Kensington suites (1.09–1.06 Ga) (*see* Davidson and van Breemen, 2000). The predominantly calc-alkaline Elzevir suite and its intimately associated metavolcanic rocks together represent arc and back-arc magmatism and terrane amalgamation (Carr et al., 2000) that preceded basin closure at ca. 1.2 Ga (Hanmer and McEachern, 1992; McEachern and van Breemen, 1993; Wasteneys et al., 1999; Corriveau and van Breemen, 2000). The two younger suites have A-type character and, along with more voluminous anorthosite and granite magmatism (AMCG suites) farther east in the Grenville Province, accompanied the protracted Grenvillian orogeny (Shawinigan and Ottawan pulses of Rivers, 1997) in the late Mesoproterozoic. In contrast, most dated granitoid orthogneiss bodies in the Central Gneiss Belt to the northwest are early Mesoproterozoic (1.47–1.34 Ga; van Breemen et al., 1986; van Breemen and Davidson, 1990; Davidson and van Breemen, 1994; Corrigan et al., 1994; Bussy et al., 1995; Timmermann et al., 1997; Nadeau and van Breemen, 1998; McMullen et al., 1999), with older suites identified in the parautochthonous belt (Rivers et al., 1989; Fig. 1, inset) closer to the Grenville Front, namely late Paleoproterozoic (1.74–1.68 Ga; e.g. Davidson et al., 1992; Corrigan et al., 1994), earliest Paleoproterozoic (2.48–2.46 Ga; Corfu and Easton, 2000), and late Archean (2.7–2.6 Ga; e.g. Chen et al., 1995). A published exception to this is the Mulock batholith, situated near North Bay, Ontario (1244 +4/-3 Ma; Lumbers et al., 1991); in addition, L.M. Heaman (pers. comm., 1993) obtained a preliminary U-Pb zircon age of ca. 1.24 Ga for the West Bay batholith near Sturgeon Falls, and Baer (1980) reported an imprecise Rb-Sr whole-rock age of 1137 ± 173 Ma for the Timber Lake pluton, some 25 km east of the Mulock batholith (**Fig. 1**). In addition to granitoid rocks, mid-Mesoproterozoic gabbro and anorthosite were also emplaced in this region: Prevec (1992) reported a U-Pb zircon age of 1222 ± 2 Ma for recrystallized anorthositic gabbro of the Mercer pluton west of Lake Nipissing.

The occurrence of granitoid plutonic rocks near the Grenville Front having ages coeval with the Elzevir suite in the Central Metasedimentary Belt, even though removed from them by 150 to 250 km, raises the question of correlation of tectonic events, if not of the rocks themselves. Lumbers et al. (1991) showed convincingly that the 1244 Ma Mulock granite has A-type chemical affinity. Several other large masses of granitoid plutonic rock in the northwestern Grenville Province of Ontario, many of which have not been dated, would also seem to have A-type character (rich in alkali feldspars, pyroxene-bearing where not hydrated during metamorphism, association with syenitic, monzonitic, and anorthositic phases; Lumbers, 1971). However, other than those mentioned above, the metaplutonic rocks of this type that have been dated are early Mesoproterozoic (e.g. the 1457 +9/–6 Ma Britt pluton; van Breemen et al., 1986). Thus it cannot be predicted on the basis of geochemical affinity alone what age an undated plutonic rock unit in this region is likely to be.

A major tectonic boundary within the northwestern part of the Grenville Province separates that part of the province closest to the Grenville Front, in which rocks may be correlated with those in the Grenville foreland northwest of the front, from structurally overlying domains to the southeast, in which no such correlation can be made. This boundary is known as the allochthon boundary thrust (ABT; Rivers et al., 1989); its footwall is thus parautochthonous with respect to the older Shield provinces northwest of the Grenville Front, and its hanging wall is composed of allochthonous slices. In most of the structural province its position is faithfully reflected by a pronounced change in aeromagnetic signature (Rivers et al., 1989, **Fig. 2**; *also see* Lucas and St-Onge, 1998, Map C41547G), but its location in Ontario is not so clear and has been the subject of some debate. At first placed along the Parry Sound shear zone (Rivers et al., 1989), it is now considered to coincide with a more northerly shear zone, originally referred to as the Central Britt shear zone (e.g. Culshaw et al., 1994), but subsequently called the Shawanaga shear zone (Ketchum, 1994). This shear zone was shown to have a component of late Grenvillian extensional displacement by Ketchum (1994), and an earlier thrust-sense displacement history was argued by Culshaw et al. (1994). Remnants of eclogite lie within it (Davidson et al., 1982; Needham, 1992), and its hanging wall contains tectonic remnants of remarkably coarse-grained coronitic gabbro, dated at 1.15 Ma to 1.17 Ga (Heaman and LeCheminant, 1993; Davidson and van Breemen, 1988; van Breemen and Davidson, 1990). Coronitic gabbro of this type has not been recognized in the footwall of the Shawanaga shear zone, where fine-grained metadiabase dyke remnants, although coronitic, have a different whole-rock chemistry

(Ketchum and Davidson, 2000). Recognition at several widely separated locations to the northeast of the same spatial relationship between these three mafic rock types and highly strained rocks of the ABT allowed Ketchum and Davidson (2000) to trace this fundamental break across the Central Gneiss Belt in Ontario.

With respect to the identification of mid-Mesoproterozoic (1.35–1.2 Ga) granitoid plutonic rocks in the northwestern Grenville Province, all of the dated bodies mentioned above lie in the footwall of the ABT. The only metaplutonic rocks in the hanging wall with published ages younger than early Mesoproterozoic (<1.35 Ga), apart from the 1.17–1.15 Ga coronitic metagabbro already mentioned, are tonalitic orthogneiss from the interior of the Parry Sound allochthon (mid-Mesoproterozoic, 1314 +12/-9 Ma), and gneissic anorthosite within the Parry Sound shear zone (late Mesoproterozoic, 1163 ± 3 Ma) (Wodicka et al., 1996).

This study was undertaken in order to confirm the unpublished and corroborate the published mid-Mesoproterozoic ages of granitoid rocks in the northwestern Central Gneiss Belt. To this end, samples were collected from 1) the Powassan batholith south of North Bay, which is probably continuous with the west Bay batholith beneath Lake Nipissing, and 2) the Mulock batholith, from a different locality to the one reported in Lumbers et al. (1991). Sample locations are shown in **Figure 1**.

GEOLOGY AND GEOCHRONOLOGY

Two large plutons in the North Bay area are the Bonfield and Powassan batholiths (Fig. 1). Ketchum and Davidson (2000) located the ABT between the two in the area just east of Lake Nipissing, where it turns south and is steeply dipping. A preliminary zircon age of ca.1.5 Ga has been obtained for the Bonfield batholith (L.M. Heaman, pers. comm., 1993). Both batholiths are composed largely of metamorphosed quartz monzonitic rocks characterized by the presence of dark red garnet porphyroblasts set in a pink or cream matrix of fine-grained, recrystallized feldspar, usually with minor quartz, biotite, and amphibole. The rocks are commonly foliated and may be migmatitic. Other phases include medium- to fine-grained leucogranitic, syenitic, and darker dioritic orthogneiss. Very locally, the rocks are massive, coarse grained, non-migmatitic, and retain original igneous features such as rapakivi texture, and primary igneous minerals such as bright green clinopyroxene and large mesoperthite grains.

To ascertain whether these two batholiths are similar or different in age, a sample of fresh, massive, clinopyroxene-biotite perthite granite was collected for dating from a roadcut in the Powassan batholith (location shown in **Fig. 1**). Thin sections show coarse mesoperthite, unstrained quartz, and aggregates of randomly oriented red-brown biotite flakes surrounding cores of partly reacted green clinopyroxene. Clear, stubby zircon prisms are associated with the aggregates of mafic minerals, along with minor allanite and apatite. The zircon separate contained plentiful clean, well-formed, simple, doubly terminated prisms with length-to-breadth ratios ranging from 1:1 to 3:1, clearly of igneous origin. Seven fractions, based on variation in size and length, were picked for isotopic analysis. For analytical techniques, see Nadeau and van Breemen (2001). Six analyses are slightly discordant and have $^{207}Pb/^{206}Pb$ ages ranging from 1263.6 to 1268.1 Ma, whereas the seventh (fraction A) is concordant at 1269.1 Ma (**Table 2**). Regression of these data (**Fig. 2**, A) yielded an upper intercept of 1270 ± 3 Ma, taken as the age of igneous crystallization, and a lower intercept of 730 Ma.

In order to corroborate the age of 1244 Ma obtained previously for the Mulock batholith by Lumbers et al. (1991), a sample of relatively weakly foliated pink granite was collected for isotopic analysis from a railway cutting near its northeastern contact, a different site than that of the original sample. Most outcrops observed within the central and southern parts of this batholith are strongly foliated parallel to the northwest elongation of the pluton, and may be equally strongly lineated, with mineral aggregate streaks and the axes of cigar-shaped xenoliths plunging gently southeast. A thin section of the sample shows remnants of coarse sodic oligoclase and microcline perthite within a recrystallized matrix of albite, non-perthitic microcline, and mildly strained quartz. The mafic mineral component occurs as aggregates of amphibole with blue-green to buff pleochroism, greenish-brown to straw-coloured biotite in unstrained but oriented flakes, and granular titanite. As in the Powassan batholith sample, clear, well-formed zircon crystals, along with apatite and allanite, are intimately associated with the other mafic minerals and do not occur as isolated grains in the quartzofeldspathic matrix. The zircon separate was composed of grains very similar in character to those of the Powassan batholith sample. Four fractions were analyzed (**Table 1**); three are nearly concordant with $^{207}Pb/^{206}Pb$ ages ranging from 1233.1 to 1244.2 Ma, and the fourth (fraction A) is somewhat more discordant with a $^{207}Pb/^{206}Pb$ age of 1241.8 Ma — all appreciably younger than the $^{207}Pb/^{206}Pb$ ages of the Powassan fractions. The three most concordant points, however, define a discordia with an upper intercept age of 1258 ± 15 Ma and a lower intercept around 1044 Ma. The upper intercept age is within error of the previous age for the Mulock batholith, but also the age of the Powassan batholith sample. However, given the clustering of the most concordant data points from two separate samples from the Mulock Batholith, we interpret the emplacement age of this intrusion to be around 1250 Ma, with a lower limit of 1244 Ma and a maximum that is unlikely to exceed 1260 Ma.

DISCUSSION

The ages reported above place on a firmer footing the occurrence of significant mid-Mesoproterozoic plutonism in the parautochthonous belt of the Grenville Orogen in Ontario. The A-type nature of this plutonism, however, implies that it developed in a different crustal regime than that envisaged for the coeval, predominantly calc-alkaline plutonic rocks of the Composite Arc Belt in the Central Metasedimentary Belt. It is nonetheless plausible to suggest a relationship between the two whereby the mid-Mesoproterozoic plutonism in the Grenville parautochthon was a distal, intraplate manifestation of arc or back-arc magmatism along the margin of Laurentia at that time (before continental collision at ca. 1.2 Ga).

Several modelers (e.g. Rivers, 1997; Hanmer et al., 2000; Rivers and Corrigan, 2000) interpret the southeastern edge of Laurentia (present-day co-ordinates) during the early and middle Mesoproterozoic (1.5–1.2 Ga) to have been a convergent margin, and that the plutonic rocks (including anorthosite and related rocks) intruded during this period are manifestations of a long-lived continental magmatic arc. Development of marine volcanic suites and tonalite-granodiorite plutonic rocks at different times in different places in the southeastern Grenville Province is suggested to have been related to times when parts of the margin experienced retreating subduction, producing extensional back-arc/marginal basins (Rivers and Corrigan, 2000) and splitting of the magmatic arc (Hanmer et al., 2000). These models require subduction polarity to have been consistently toward pre-Grenvillian Laurentia. Other proposed models have called upon subduction of opposite polarity during this period (e.g. Windley, 1988; McLelland et al., 1996), requiring association of arc and back-arc basins to the advancing continental mass, in which case related continental-arc magmatism would have lain to the southeast. If there is indeed a tectonic relationship between marginal magmatism represented in the Composite Arc Belt and plutonism in the parautochthonous belt, then the former model is favoured.

Two further points are made. The first is that not all plutonic rocks of the Elzevir suite in the Composite Arc Belt are calc-alkaline. The Deloro stock, for example, dated at 1241 Ma (van Breemen and Davidson, 1988) is a high-level peralkaline ring complex with parts of its associated volcanic edifice preserved. Although classified as ‘anorogenic’ by Abdel-Rahman and Martin (1987, 1990), it lies within a few kilometres of coeval plutonic rocks that do not have this character, such as the 1242 Ma Cordova gabbro (tonalite sample; Davis and Bartlett, 1988) and the 1245 Ma Addington granite (muscovite-biotite leucogranite; van Breemen and Davidson, 1988), which are typical members of the Elzevir suite. Recognition that coeval hornblende-biotite tonalite and granodiorite (I-type), muscovite-bearing granite (S-type), and riebeckite granite and syenite (A-type) occur in close proximity within the Composite Arc Belt points suggests that this part of the Grenville Province could not have been in an anorogenic state at the time of magmatic activity. The occurrence of peralkaline rocks in an orogenic environment is not unknown, examples being the late Ordovician granites of the Topsails suite in the Appalachians of Newfoundland, interpreted to have formed by partial melting of underthrust Grenvillian basement during marginal-basin closure (Whalen et al., 1987), and the Miocene-to-Pleistocene Anahim volcanic belt in the Cordillera of central British Columbia, attributed to transverse passage of a hot spot beneath this active orogen (Bevier et al., 1979). Whether either of these explanations can be applied to the Composite Arc Belt has yet to be evaluated. An alternative, but perhaps less likely explanation is that there has been subsequent tectonic juxtaposition, as yet undocumented, of small slices of crust of widely differing character within the Composite Arc Belt. In any case, the presence of A-type granitoid rocks in the parautochthon does not necessarily imply lack of tectonism at the time of their emplacement in that region.

The second point is that, to date, no plutonic rocks of Elzevir suite age (1.27–1.23 Ga) have been identified in the allochthonous terranes that lie between the Composite Arc Belt and the parautochthonous part of the Central Gneiss Belt, although many bodies of plutonic rock in this region have yet to be dated. Future geochronology may prove their presence; if it does not, the lack of spatial continuity between those in the Composite Arc Belt and those in the parautochthon will have to be explained either on the grounds that they became separated during tectonic emplacement of the intervening allochthonous terranes of the Central Gneiss Belt, in the late Mesoproterozoic, or that the two are in fact unrelated.

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REFERENCES

Abdel-Rahman, A.M. and Martin, R.F.

1987: The Deloro anorogenic igneous complex, Madoc, Ontario. I. Geochemistry and feldspar mineralogy of the felsic plutonic rocks; Canadian Mineralogist, v. 25, p. 321–336.

1990: The Deloro anorogenic igneous complex, Madoc, Ontario. II. Evolution and post-eruptive metasomatism of the volcanic units; Canadian Mineralogist, v. 28, p. 267–285.

Baer, A.J.

1980: Foliated and recrystallized granites from the Timberlake pluton, Ontario; *in* Current Research, Part C; Geological Survey of Canada, Paper 80-1C, p. 201–205.

Bevier, M.L., Armstrong, R.L., and Souther, J.G.

1979: Miocene peralkaline volcanism in west-central British Columbia — its temporal and plate tectonics setting; Geology, v. 7, p. 389–392.

Brock, B.S. and Moore, J.M., Jr.

1983: Chronology, chemistry, and tectonics of igneous rocks in terranes of the Grenville Province, Canada; Geological Society of America, Abstracts with Programs, v. 15, p. 533.

Bussy, F., Krogh, T.E., Klemens, W.P., and Schwerdtner, W.M.

1995: Tectonic and metamorphic events in the westernmost Grenville Province, central Ontario: new results from high-precision U-Pb zircon geochronology; Canadian Journal of Earth Sciences, v. 32, p. 660–671.

Carr, S.D., Easton, R.M., Jamieson, R.A., and Culshaw, N.G.

2000: Geologic transect across the Grenville orogen of Ontario and New York; Canadian Journal of Earth Sciences, v. 37, p. 193–216.

Chen, Y.D., Krogh, T.E., and Lumbers, S.B.
1995: Neoarchean trondhjemitic and tonalitic orthogneiss identified within the northern Grenville Province in Ontario by precise U-Pb dating and petrologic studies; Precambrian Research, v. 72, p. 263–281.

Corfu, F. and Easton, R.M.
2000: U-Pb evidence for polymetamorphic history of Huronian rocks within the Grenville Front tectonic zone east of Sudbury, Ontario, Canada; Chemical Geology, v. 172, p. 149–171.

Corrigan, D., Culshaw, N.G., and Mortensen, J.K.
1994: Pre-Grenvillian evolution and Grenvillian overprinting of the parautochthonous belt in Key Harbour, Ontario: U–Pb and field constraints; Canadian Journal of Earth Sciences, v. 31, p. 583–596.

Corriveau, L. and van Breemen, O.
2000: Docking of the Central Metasedimentary Belt to Laurentia in geon 12: evidence from the 1.17–1.16 Ga Chevreuil intrusive suite and host gneisses, Quebec; Canadian Journal of Earth Sciences, v. 37, p. 253-269.

Culshaw, N.G., Davidson, A., and Nadeau, L.
1983: Structural subdivisions of the Grenville Province in the Parry Sound – Algonquin region, Ontario; *in* Current Research, Part B; Geological Survey of Canada, Paper 83-1B, p. 243–252.

Culshaw, N.G., Ketchum, J.W.F., Wodicka, N., and Wallace, P.
1994: Ductile extension following thrusting in the deep crust: evidence from the southern Britt domain, southwest Grenville Province, Georgian Bay, Ontario; Canadian Journal of Earth Sciences, v. 31, p. 160–175.

Davidson, A.
1986: New interpretations in the southwestern Grenville Province; *in* The Grenville Province, (ed.) J.M. Moore, A. Davidson, and A.J. Baer; Geological Association of Canada, Special Paper 31, p. 61–74.

Davidson, A. and Ketchum, J.W.F.
1993: Observations on the Maberly shear zone, a terrane boundary within the Central Metasedimentary Belt, Grenville Province, Ontario; *in* Current Research, Part C; Geological Survey of Canada, Paper 93-1C, p. 265–269.

Davidson, A. and van Breemen, O.
1988: Baddeleyite-zircon relationships in coronitic metagabbro, Grenville Province, Ontario: implications for geochronology; Contributions to Mineralogy and Petrology, v. 100, p. 291–299.
1994: U-Pb ages of granites near the Grenville Front, Ontario; *in* Radiogenic Age and Isotopic Studies: Report 8; Geological Survey of Canada, Current Research 1994-F, p. 107–114.
2000: Age and extent of the Frontenac plutonic suite in the Central Metasedimentary Belt, Grenville Province, southeastern Ontario; Radiogenic Age and Isotopic Studies: Report 13; Geological Survey of Canada, Current Research 2000-F4, 7 p. (online; http://www.nrcan.gc.ca/gsc/bookstore).

Davidson, A., Culshaw, N.G., and Nadeau, L.
1982: A tectonometamorphic framework for part of the Grenville Province, Parry Sound region, Ontario; *in* Current Research, Part A; Geological Survey of Canada, Paper 80-1A, p.175–190.

Davidson, A., van Breemen, O., and Sullivan, R.W.
1992: Circa. 1.75 Ga ages for plutonic rocks from the Southern Province and adjacent Grenville Province: what is the expression of the Penokean orogeny?; *in* Radiogenic Age and Isotopic Studies: Report 8; Geological Survey of Canada, Paper 92-2, p. 107–118.

Davis, D.W. and Bartlett, J.R.
1988: Geochronology of the Belmont Lake metavolcanic complex and implications for crustal development in the Central Metasedimentary Belt, Grenville Province, Ontario; Canadian Journal of Earth Sciences, v. 25, p. 1751–1759.

Derry, D.R.
1950: A tectonic map of Canada; Geological Association of Canada Proceedings, v. 3, p. 39–53.

Easton, R.M.
1992: The Grenville Province and the Proterozoic history of central and southern Ontario; *in* Geology of Ontario, (ed.) P.C. Thurston, H.R. Williams, R.H. Sutcliffe, and G.M. Stott; Ontario Geological Survey, Special Volume 4, pt. 2, p. 715–904.

Geraghty, E.P., Isachsen, Y.W., and Wright, S.F.
1981: Extent and character of the Carthage–Colton mylonite zone, northwest Adirondacks; NUC Regulatory Commission, Washington, Contract Report NUREG/CR-1865, 83 p.

Hanmer, S. and McEachern, S.
1992: Kinematical and rheological evolution of a crustal-scale ductile thrust zone, Central Metasedimentary Belt, Grenville orogen, Ontario; Canadian Journal of Earth Sciences, v. 29, p. 1779–1790.

Hanmer, S., Corrigan, D., Pehrsson, S., and Nadeau, L.
2000: SW Grenville Province, Canada: the case against post-1.4 Ga accretionary tectonics; Tectonophysics, v. 319, p. 33–51.

Heaman, L.M. and LeCheminant, A.N.
1993: Paragenesis and U–Pb systematics of baddeleyite (ZrO_2); Chemical Geology, v. 110, p. 95–126.

Ketchum, J.W.F.
1994: Extensional shear zones and lithotectonic domains in the southwest Grenville Orogen: structure, metamorphism, and U–Pb geochronology of the Central Gneiss Belt near Pointe-au-Baril, Ontario; Ph.D. thesis, Dalhousie University, Halifax, Nova Scotia, 341 p.

Ketchum, J.W.F. and Davidson, A.
2000: Crustal architecture and tectonic assembly of the Central Gneiss Belt, southwestern Grenville Province, Canada: a new interpretation; Canadian Journal of Earth Sciences, v. 37, p. 217–234.

Lucas, S.B. and St-Onge, M.R. (co-ordinators)
1998: Geology of the Precambrian Superior and Grenville provinces and Precambrian fossils in North America; Geological Survey of Canada, Geology of Canada, no. 7, 387 p. (*also* Geological Society of America, The Geology of North America, v. C-1, 387 p.).

Lumbers, S.B.
1971: Geology of the North Bay area, districts of Nipissing and Parry Sound; Ontario Department of Mines and Northern Affairs, Geological Report 94, 104 p.

Lumbers, S.B., Wu, T.-W., Heaman, L.M., Vertolli, V.M., and MacRae, N.D.
1991: Petrology and age of the A-type Mulock granite batholith, northern Grenville Province, Ontario; Precambrian Research, v. 53, p. 199–231.

McEachern, S.J. and van Breemen, O.
1993: Age of deformation within the Central Metasedimentary Belt boundary thrust zone, southwest Grenville Orogen: constraints on the collision of the Mid-Proterozoic Elzevir terrane; Canadian Journal of Earth Sciences, v. 30, p. 1155–1165.

McLelland, J., Daly, J.S., and McLelland, J.M.
1996: The Grenville Orogenic Cycle (ca. 1350–1000 Ma): an Adirondack perspective; Tectonophysics, v. 265, p. 1–28.

McMullen, S.M., Carr, S.D., and Easton, R.M.
1999: Tectonic evolution of the Bark Lake area, eastern Central Gneiss Belt, SW-Ontario Grenville: constraints from geology, geochemistry and U-Pb geochronology; Geological Association of Canada, Abstract Volume 24, p. 82.

Nadeau, L. and van Breemen, O.
1998: Plutonic ages and tectonic setting of the Algonquin and Muskoka allochthons, Central Gneiss Belt, Grenville Province, Ontario; Canadian Journal of Earth Sciences, v. 35, p. 1423–1438.
2001: U-Pb zircon age and regional setting of the Lapeyrère gabbronorite, Portneuf-Mauricie region, south-central Grenville Province, Quebec; Radiogenic Age and Isotopic Studies: Report 14; Geological Survey of Canada, Current Research 2001-F6.

Needham, T.W.
1992: The metamorphic evolution of the Frederick Inlet metagabbros, southwestern Grenville Province, Ontario; M.Sc. thesis, Queen's University, Kingston, Ontario.

Prevec, S.A.
1992: U-Pb age constraints on Early Proterozoic mafic magmatism from the southern Superior and western Grenville provinces, Ontario; *in* Radiogenic Age and Isotopic Studies: Report 6; Geological Survey of Canada, Paper 92-2, p. 97–106.

Rivers, T.
1997: Lithotectonic elements of the Grenville Province: review and tectonic implications; Precambrian Research, v. 86, p. 117–154.

Rivers, T. and Corrigan, D.
2000: Convergent margin on southeastern Laurentia during the Mesoproterozoic: tectonic implications; Canadian Journal of Earth Sciences, v. 37, p. 359–383.

Rivers, T., Martignole, J., Gower, C.F., and Davidson, A.
1989: New tectonic divisions of the Grenville Province, southeast Canadian Shield; Tectonics, v. 8, p. 63–84.

Timmermann, H., Parrish, R.R., Jamieson, R.A., and Culshaw, N.G.
1997: Time of metamorphism beneath the Central Metasedimentary Belt boundary thrust zone, Grenville Orogen, Ontario; Canadian Journal of Earth Sciences, v. 34, p. 1023–1029.

van Breemen, O. and Davidson, A.

1988: U-Pb zircon ages of granites and syenites in the Central Metasedimentary Belt, Grenville Province, Ontario; *in* Radiogenic Age and Isotopic Studies: Report 2; Geological Survey of Canada, Paper 88-2, p. 45–50.

1990: U-Pb zircon and baddeleyite ages from the Central Gneiss Belt, Ontario; *in* Radiogenic Age and Isotopic Studies: Report 3; Geological Survey of Canada, Paper 89-2, p. 85–92.

van Breemen, O., Davidson, A., Loveridge, W.D., and Sullivan, R.W.

1986: U-Pb zircon geochronology of Grenville tectonites, granulites and igneous precursors, Parry Sound, Ontario; *in* The Grenville Province, (ed.) J.M. Moore, A. Davidson, and A.J. Baer; Geological Association of Canada, Special Paper 31, p. 191–207.

Wasteneys, H., McLelland, J., and Lumbers, S.

1999: Precise zircon geochronology in the Adirondack Lowlands and implications for revising plate-tectonic models of the Central Metasedimentary Belt and Adirondack Mountains, Grenville Province, Ontario and New York; Canadian Journal of Earth Sciences, v. 36, p. 967–984.

Whalen, J.B., Currie, K.L., and Chappell, B.W.

1987: A-type granites: geochemical characteristics, discrimination and petrogenesis; Contributions to Mineralogy and Petrology, v. 95, p. 407–419.

Windley, B.F.

1988: Anorogenic magmatism and the Grenvillian Orogeny; Canadian Journal of Earth Sciences, v. 26, p. 479–489.

Wodicka, N., Parrish, R.R., and Jamieson, R.A.

1996: The Parry Sound domain: a far-travelled allochthon? New evidence from U-Pb zircon geochronology; Canadian Journal of Earth Sciences, v. 33, p. 1087–1104.

Wynne-Edwards, H.R.

1972: The Grenville Province; *in* Variations in Tectonic Styles in Canada, (ed.) R.A. Price and R.W.G. Douglas; Geological Association of Canada, Special Paper 11, p. 263–334.

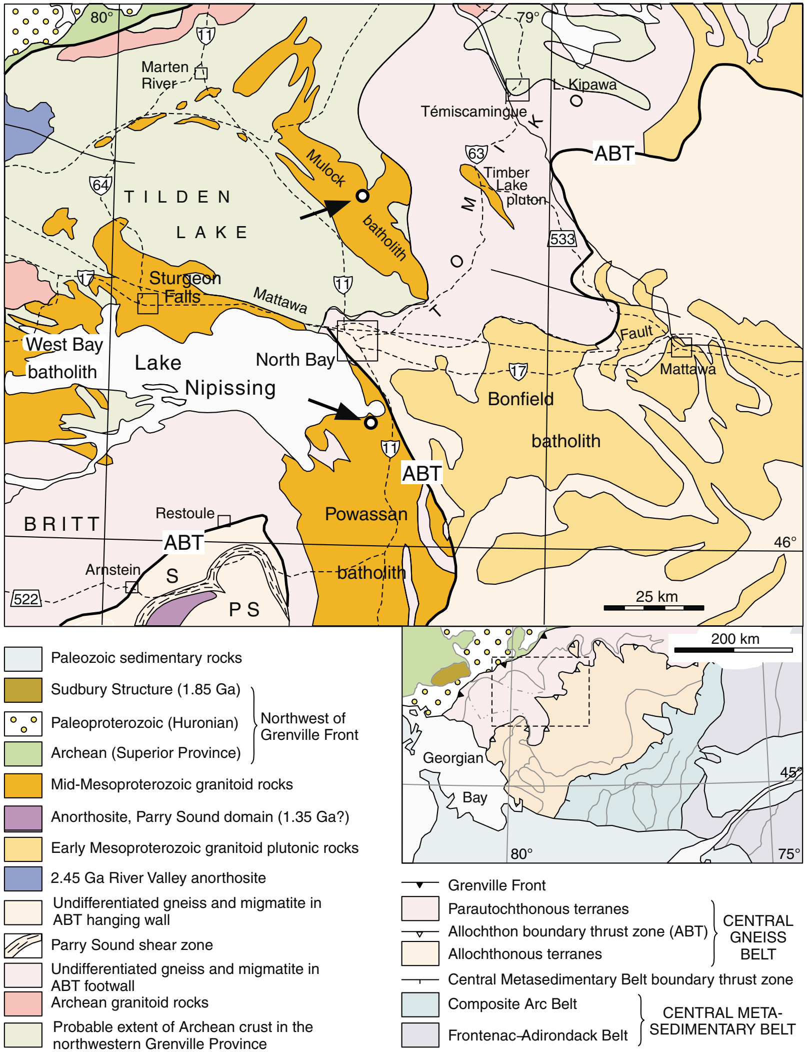

Figure 1. Geological and tectonic features of the northwestern part of the Grenville Province in the vicinity of North Bay, Ontario (*adapted from* Ketchum and Davidson, 2000, Fig. 5). Localities for the dated samples of the Powassan and Mulock batholiths are shown (arrows). S is Shawanaga domain, PS is Parry Sound domain, and ABT, the allochthon boundary thrust. The inset map shows the principal lithotectonic divisions in the southwest Grenville Province, and the location of the main figure.

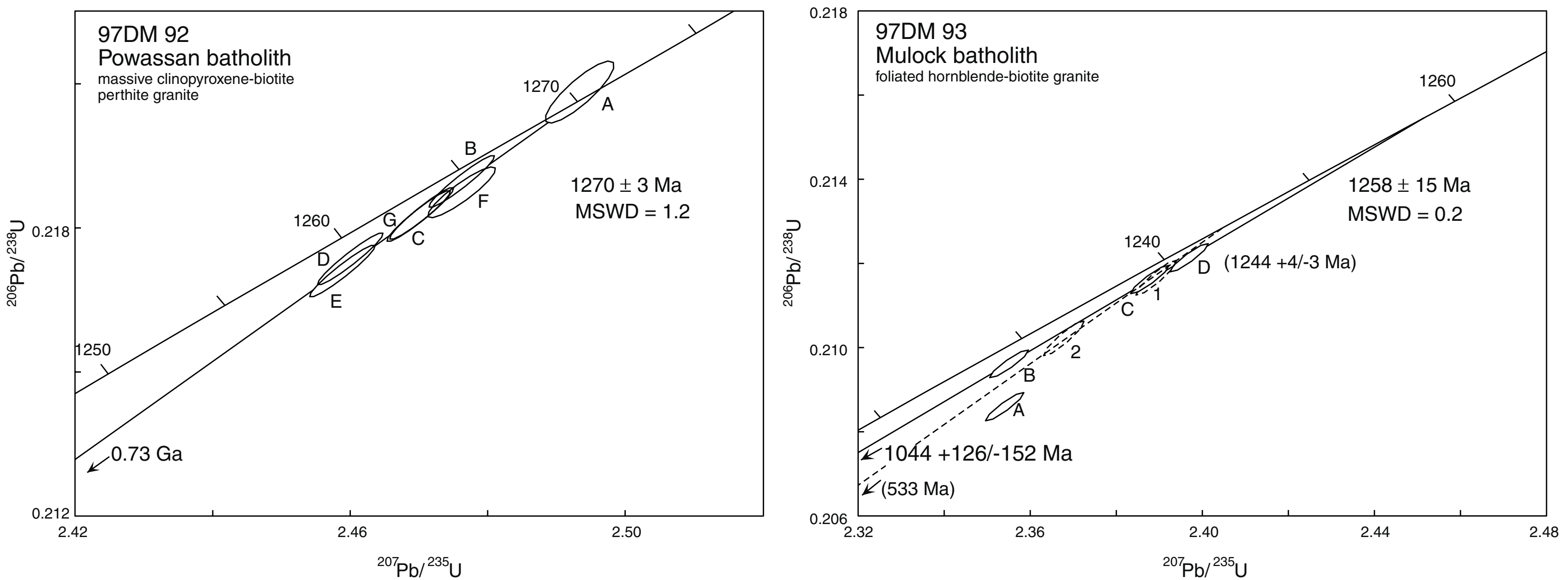

Figure 2. Uranium-lead concordia diagrams for granitoid rocks from the Powassan and Mulock batholiths in the Grenville parautochthonous belt. In the plot for the Mulock batholith, dashed concordia and data points 1 and 2, taken from Lumbers et al. (1991), are shown for comparison. From the combined data, the emplacement age for the Mulock batholith is interpreted to be ca. 1250 Ma.

Table 1. Nomenclature of lithotectonic divisions in the southwest Grenville Province.

Wynne-Edwards (1972)	Rivers et al. (1989)	Easton (1992)	Carr et al. (2000)
Grenville Foreland Belt	(autochthon)		Pre-Grenvillian Laurentia (margin)
Grenville Front (1)			
Grenville Front Tectonic Zone	parautochthonous belt		
	allochthon boundary thrust		
Central Gneiss Belt	polycyclic allochthonous belt		
	monocyclic belt boundary zone	*Central Metasedimentary Belt boundary zone (2)*	
Central Metasedimentary Belt	allochthonous monocyclic belt	Bancroft terrane (3) Elzevir terrane (3) Mazinaw terrane Sharbot Lake terrane (3)	Composite Arc Belt
		Maberly shear zone (4)	
		Frontenac terrane (3) Adirondack Lowlands terrane (5)	Frontenac–Adirondack Belt
Adirondak [sic] Highland line		*Carthage–Colton mylonite zone* (6)	
Central Granulite Terrain [sic]		Adirondack Highlands	

(1) Derry (1950). (2) Culshaw et al. (1983) [CMB boundary thrust zone of Hanmer and McEachern (1992)]. (3) Brock and Moore (1983). (4) Davidson and Ketchum (1993). (5) New York Lowlands terrane of Davidson (1986). (6) Geraghty et al. (1981).

Table 2. U-Pb isotopic data for zircon.

Fraction[1]	Weight[2] µg	U ppm	Pb[3] ppm	$^{206}Pb/^{204}Pb$ [4]	Pb[5] pg	^{208}Pb[6] %	$^{207}Pb/^{235}U$ [6]	$^{206}Pb/^{238}U$ [6]	$^{207}Pb/^{206}Pb$ [6]	$^{207}Pb/^{206}Pb$ [7]	Disc[8]
Powassan batholith (97DM 92; z5379) Zone 17 Easting 621150 Northing 5115475											
A, -149+105	0.065	137	31	17007	7	10.6	0.2179 ± 0.10	2.493 ± 0.10	0.08300 ± 0.05	1269.1 ± 2.1	-0.1
B, -149+105	0.045	139	31	25340	3	10.2	0.2166 ± 0.08	2.476 ± 0.10	0.08290 ± 0.03	1266.8 ± 1.1	0.2
C, -149+105	0.097	134	30	37256	5	10.0	0.2162 ± 0.08	2.470 ± 0.10	0.08287 ± 0.03	1266.2 ± 1.1	0.4
D, -149+105	0.153	108	24	24244	9	9.3	0.2156 ± 0.09	2.460 ± 0.10	0.08276 ± 0.03	1263.6 ± 1.1	0.4
E, -149+105	0.148	97	21	23586	8	8.4	0.2154 ± 0.08	2.459 ± 0.10	0.08279 ± 0.03	1264.3 ± 1.1	0.6
F, -149+105	0.059	87	19	4663	14	7.7	0.2165 ± 0.08	2.476 ± 0.10	0.08295 ± 0.04	1268.1 ± 1.7	0.4
G, -149+105	0.088	117	26	29264	5	8.0	0.2162 ± 0.08	2.470 ± 0.09	0.08287 ± 0.03	1266.2 ± 1.1	0.4
Mulock batholith (97DM 93; z5380) Zone 17 Easting 620925 Northing 5157075											
A, -149+105	0.060	74	18	12830	4	19.7	0.2086 ± 0.08	2.354 ± 0.10	0.08185 ± 0.03	1241.8 ± 1.2	1.8
B, -149+105	0.100	66	16	7281	12	19.5	0.2096 ± 0.08	2.355 ± 0.10	0.08148 ± 0.04	1233.1 ± 1.4	0.6
C, -105	0.059	65	16	7835	6	19.6	0.2116 ± 0.08	2.388 ± 0.10	0.08183 ± 0.03	1241.5 ± 1.3	0.4
D, -105+74	0.116	58	15	9490	9	21.8	0.2121 ± 0.08	2.397 ± 0.10	0.08195 ± 0.03	1244.2 ± 1.2	0.4

[1]Sizes in µm before abrasion; all fractions are non-magnetic at a side slope of -0.5° on a Frantz isodynamic magnetic separator operating at 1.8 amps; [2]error on weight = ±1 µg; [3]radiogenic Pb; [4]measured ratio corrected for spike and Pb fractionation of 0.09 ± 0.03 per cent per AMU; [5]total common Pb on analysis corrected for fractionation and spike; [6]corrected for blank Pb and U, common Pb, errors quoted are 1σ in per cent; [7]age errors quoted are 2σ in Ma; [8]discordance in per cent along a discordia to origin.