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Evidence for magmatism of Elzevirian age in the Sharbot Lake domain, Central metasedimentary belt, Grenville Province, Ontario

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Abstract: Uranium-lead data from a granodioritic phase of the Pakenham intrusion impose important new constraints on the tectonic evolution of the Sharbot Lake domain, Central metasedimentary belt. The granodiorite yields a crystallization age of 1263 +4/-2 Ma, which expands the known age range for magmatism of Elzevirian age in this domain. The similarity in age and geochemical data of the Pakenham intrusion with 1280–1250 Ma calc-alkaline plutonic rocks in domains to the west suggests an early phase of arc building in the Sharbot Lake domain. Titanite from the granodiorite gives an age of 1113 ± 4 Ma. Together with petrographic observations, this age suggests that titanite formed in response to greenschist-facies overprinting metamorphism and (or) fluid infiltration.

Résumé : Les données U-Pb d'une phase granodioritique de l'intrusion de Pakenham imposent de nouvelles contraintes sur l'évolution tectonique du domaine de Sharbot Lake, dans la ceinture métasédimentaire centrale. La granodiorite fournit un âge de cristallisation de 1263 +4/-2 Ma, ce qui élargit l'intervalle d'âges connu pour le magmatisme elzevirien dans ce domaine. La concordance de l'âge et des données géochimiques de l'intrusion de Pakenham et de roches plutoniques calco-alcalines de 1280–1250 Ma dans des domaines plus à l'ouest laisse supposer l'existence d'une phase précoce d'édification d'arc dans le domaine de Sharbot Lake. De la titanite provenant de la granodiorite donne un âge de 1113 ± 4 Ma. Cet âge et les observations pétrographiques indiqueraient que la titanite s'est formée en réponse à la surimpression au faciès des schistes verts et (ou) à l'infiltration de fluides.

INTRODUCTION

This study examines aspects of the geological evolution of the Sharbot Lake domain and compares it with that of neighbouring domains and terranes in the Central metasedimentary belt of the Grenville Province in Ontario (Fig. 1). The Sharbot Lake domain is of interest because it lies between areas with drastically different geological histories. The Frontenac terrane to the southeast comprises mainly platformal siliciclastic sedimentary rocks and marble and underwent intense magmatic and high-grade metamorphic activity between 1190 and 1155 Ma, with subsequent plutonism at ca. 1075 Ma. In contrast, the Mazinaw domain to the west consists of marble and widespread 1280–1240 Ma volcanic and plutonic successions of arc affinity, and underwent polyphase deformation and metamorphism reaching amphibolite facies during the period 1100 to 1000 Ma. A limited amount of U-Pb data exists for the Sharbot Lake domain, focused mainly on addressing the younger history of the domain (e.g. Mezger et al., 1993; Corfu and Easton, 1997; Davidson and van Breemen, 2000a, b).

In this paper we report U-Pb zircon and titanite ages for a granodioritic phase of the Pakenham intrusion from the Carleton Place area in the northern Sharbot Lake domain (Fig. 1, 2). The new data expand the known age range for Elzevirian magmatism in this part of the Central metasedimentary belt, shed some light on the early tectonic evolution of the Sharbot Lake domain, and constrain the timing of overprinting metamorphism. For the purposes of this paper, the term 'Elzevirian' is used to refer to rocks and events within the range ca. 1.29–1.22 Ga (e.g. Moore and Thompson, 1980; Davidson, 1995; Carr et al., 2000).

GEOLOGICAL SETTING

The Central metasedimentary belt in Ontario can be subdivided into several domains and terranes on a lithotectonic basis (Fig. 1; e.g. Easton, 1992). A major distinction is made between a northern superterrane (Composite Arc Belt of Carr et al., 2000), composed of the Bancroft terrane and the Harvey-Cardiff, Belmont, Grimsthorpe, Mazinaw, and Sharbot Lake domains, and a southern superterrane, composed of the Frontenac terrane and the Adirondack Lowlands. The northern superterrane comprises metavolcanic and metasedimentary rocks and related plutonic suites formed largely between 1300 and 1230 Ma, except for a late clastic metasedimentary sequence, the Flinton Group of the Mazinaw domain, deposited after 1150 Ma (Sager-Kinsman and Parrish, 1993). The intensity and timing of metamorphism and deformation varies across the northern superterrane. The southern superterrane comprises platformal sedimentary rocks, lacks volcanic rocks, and was affected by plutonism and metamorphism in the period 1190–1155 Ma. A younger suite of 1090–1065 Ma plutonic rocks is present across the entire Central metasedimentary belt.

This study focuses on rocks located in the Carleton Place area in the northern Sharbot Lake domain (Fig. 2). This area was mapped at 1:50 000 scale by Reinhardt et al. (1973), with subsequent detailed studies by Easton and Hildebrand (1994), Easton (1995), Corfu and Easton (1997), and Buckley et al. (1997). As shown in Figure 2, the Carleton Place area contains rocks assigned to both the Sharbot Lake domain and the Frontenac terrane. Figure 2 also shows the new and previously published (Corfu and Easton, 1997) U-Pb ages from this area.

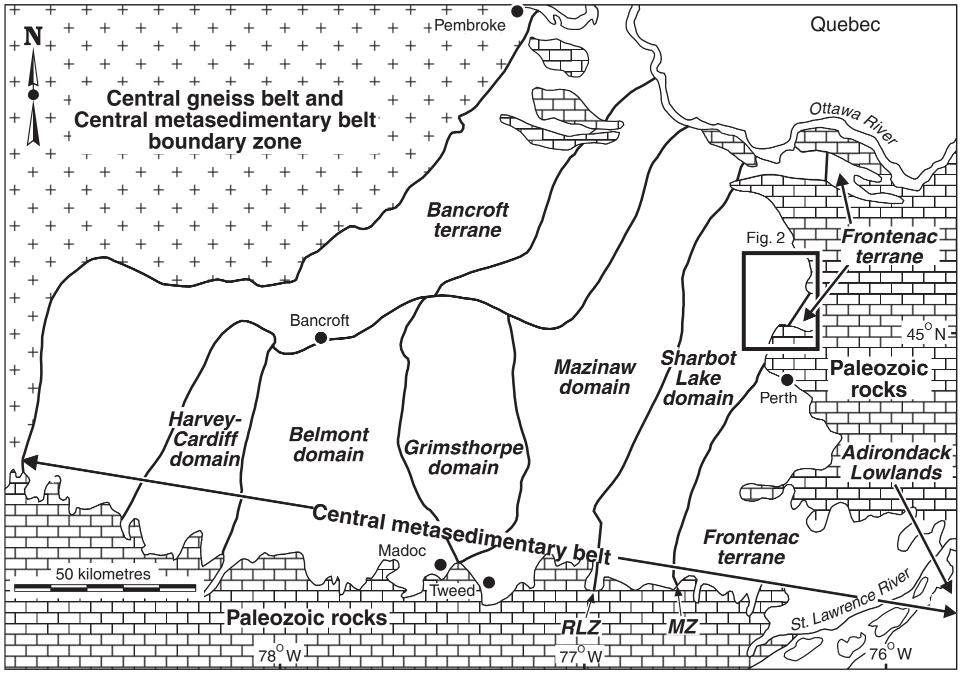

Figure 1. *Subdivision of the Central metasedimentary belt, Ontario (modified from Easton 1992, 1999). RLZ = Robertson Lake mylonite zone; MZ = Maberly shear zone.*

Sharbot Lake domain

The Sharbot Lake domain is bounded to the west by the Robertson Lake mylonite zone and to the east by the Maberly shear zone (Fig. 1). Within the Carleton Place area (Fig. 2), supracrustal rocks of the Sharbot Lake domain consist mainly of marble with subordinate mafic metavolcanic rocks and minor siliciclastic metasedimentary rocks, all cut by mafic to felsic plutons. There are also two areas of gneiss and associated metaplutonic rocks, the Pakenham and Wolf Grove structures.

Supracrustal rocks in the Carleton Place area are described in detail in Easton and Hildebrand (1994) and Easton and Davidson (1997). Geochemical data (e.g. Corfu and Easton, 1997) suggest that the mafic metavolcanic rocks formed in an oceanic environment, possibly as island-arc tholeiite. Amphibolite and gabbro sills present within marble are geochemically comparable to the mafic metavolcanic rocks (Corfu and Easton, 1997). The geochemical composition of marble from the northern Sharbot Lake domain indicates little input of detritus, either from volcanic or continental sources (Easton, 1995).

The Lavant gabbroic complex, which only partly underlies the Carleton Place area (Fig. 2), is a composite intrusion consisting of a voluminous mafic suite, dominated by medium-grained gabbro to diorite, and a granodiorite-monzogranite suite, which forms several small intrusive bodies and dykes cutting the gabbro. The intermediate to felsic phases occur mainly near the roof of the complex, and also intrude adjacent supracrustal rocks, including marble. Geochemical data point to a calc-alkalic affinity of the complex (Easton, 1988b; Corfu and Easton, 1997). Uranium-lead zircon data from a gabbro and monzogranite show that the mafic and felsic phases of the Lavant gabbroic complex are genetically related and that they were emplaced within a short time span, at about 1224 Ma (Corfu and Easton, 1997).

Polydeformed bodies of gneiss near Pakenham and Wolf Grove (Fig. 2) were included within the original outline of the Sharbot Lake domain (Moore, 1982), but the assignment of these rocks to the Sharbot Lake domain was questioned by Easton (1992) and Easton and Hildebrand (1994). The Pakenham gneiss consists of several sill-like appendages of younger, foliated, granitoid rocks (i.e. Pakenham intrusion) with intervening screens of marble and migmatitic gneiss (Reinhardt et al., 1973). Field relations suggest that leucosome formation in the migmatitic gneiss preceded

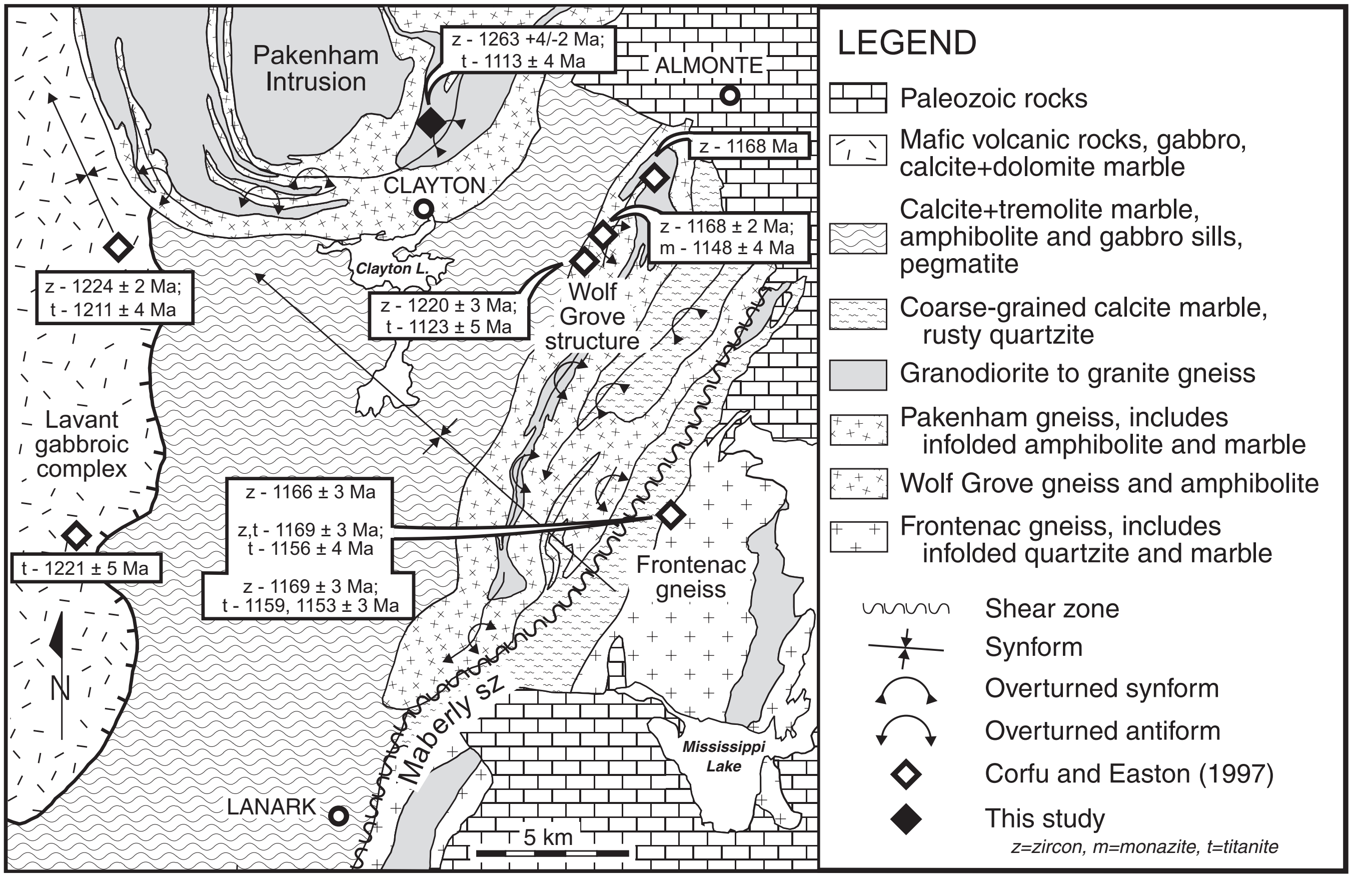

Figure 2. *Simplified geology of the Carleton Place area, northern Sharbot Lake domain, showing the location of the geochronology sample site as well as the location of U-Pb ages reported by Corfu and Easton (1997). Geology from Reinhardt et al. (1973), Easton (1988a), and Easton and Hildebrand (1994).*

emplacement of the Pakenham granitoid rocks. In plan view, the Pakenham gneiss forms a large, circular mass, but north of the map area foliation and layering dip easterly, indicating that the structure is inclined at depth.

The sample dated in this study is a medium-grained granodiorite collected from the southeastern part of the Pakenham intrusion (Fig. 2). Limited geochemical data from foliated granodioritic to monzogranitic rocks of the intrusion located 4 km north of the geochronology sample site (R.M. Easton, unpub. data, 1989) is consistent with assignment of some of the granitoid rocks to the 1280–1250 Ma Elzevir suite (based on the recently published U-Pb ages of 1267 ± 5 Ma for the Helena stock and 1250 +10/-5 Ma for the Cross Lake pluton (Corfu and Easton, 1995), the age range of the Elzevir suite (cf. Easton, 1992) should be expanded from 1280–1270 Ma ('late trondhjemite suite' of Lumbers et al., 1990) to 1280–1250 Ma), as implied by Lumbers et al. (1990, Fig. 1).

The Wolf Grove structure (Fig. 2) contains several types of gneiss, including mafic orthogneiss, migmatitic intermediate to felsic gneiss, and sillimanite- and orthopyroxene-bearing gneiss. An amphibolite associated with these gneiss units yielded a U-Pb zircon age of 1220 ± 3 Ma, which could date either magmatic crystallization of a gabbro protolith or metamorphic crystallization of the amphibolite, or both (Corfu and Easton, 1997). Gneissosity is cut by the foliated Wolf Grove granodiorite to granite, which gave a U-Pb zircon age of ca. 1168 Ma (Corfu and Easton, 1997); however, as discussed in Easton and Davidson (1997), this age could date regional metamorphism and not primary emplacement. Rocks from both the Wolf Grove and Pakenham structures record at least three folding episodes, an early, northeast-trending set of refolded folds (F_1 and F_2) and younger, northwest-trending cross folds (F_3) (Fig. 2; Easton and Hildebrand, 1994). In contrast, only F_3 cross folds have been observed in marble and in the Lavant gabbroic complex.

Metamorphism

Metamorphic grade in the Lavant gabbroic complex and adjacent marble (i.e. outside the Pakenham structure) ranges from greenschist to lower amphibolite facies (e.g. Ewert, 1977; Easton, 1992). In contrast, mineral assemblages in the Wolf Grove and Pakenham gneisses document conditions ranging from upper amphibolite to locally granulite facies. In addition, relict mineral assemblages in Wolf Grove migmatitic gneiss provide evidence for multiple or protracted high-grade metamorphism (Easton and Davidson, 1997). From these observations, Easton and Hildebrand (1994) and Corfu and Easton (1997) suggested that marble and gneiss from the Wolf Grove and Pakenham structures did not share common metamorphic histories. Consistent with this interpretation is the local preservation of primary sedimentary features in the carbonate rocks (e.g. Easton and Davidson, 1997), which strongly suggests that high-grade metamorphism could not have been regionally extensive in this part of the Sharbot Lake domain, even though some of the low-grade mineral assemblages in marble appear retrograde in origin (Skippen, 1997).

Currently, geochronological constraints on timing of metamorphism in the northern Sharbot Lake domain exist only for the Wolf Grove area and Lavant gabbroic complex. In the Wolf Grove structure, the main phase of high-grade metamorphism occurred at ca. 1168 Ma, the age of metamorphic zircon (Fig. 2; Corfu and Easton, 1997). Buckley et al. (1997) estimated P-T conditions of roughly 718°C and 7.2 kb. In contrast, in the western Carleton Place area, titanite extracted from the Lavant gabbroic complex yielded ages of 1221 ± 5 and 1211 ± 4 Ma, close to the emplacement age of the body (Corfu and Easton, 1997). Easton and Davidson (1997) suggested that the 1168 Ma high-grade metamorphism in the eastern part of the Carleton Place area overprints an older metamorphic assemblage now preserved only in the western part of the area.

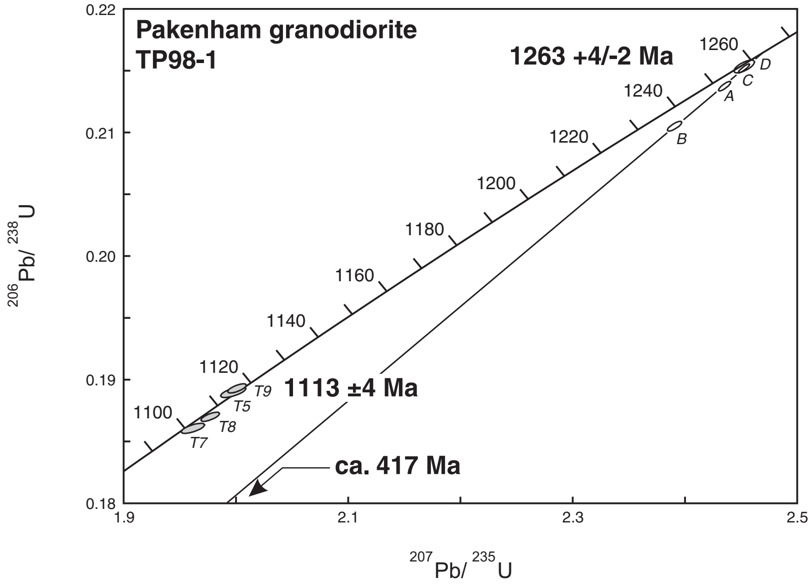

Figure 3.

Concordia diagram showing U-Pb isotopic data for zircon (open ellipses) and titanite (shaded ellipses) from a granodioritic phase of the Pakenham intrusion. Error ellipses are 2σ.

Table 1. Uranium-lead analytical data.

Fraction[a]	Wt.[b] (µg)	U (ppm)	Pb[c] (ppm)	Pb[d] (pg)	$^{206}\mathrm{Pb}/^{204}\mathrm{Pb}$[e]	$^{208}\mathrm{Pb}/^{206}\mathrm{Pb}$[f]	$^{206}\mathrm{Pb}/^{238}\mathrm{U}$[f]	$^{207}\mathrm{Pb}/^{235}\mathrm{U}$[f]	$^{207}\mathrm{Pb}/^{206}\mathrm{Pb}$[f]	$^{207}\mathrm{Pb}/^{206}\mathrm{Pb}$[g] age (Ma)	Disc.[h] %
TP98-1 Pakenham granodiorite (UTM Zone 18 395317 E, 5007049 N)											
A z,pb,eu,lp,m3° (6)	6	163	35	5	2450	0.083	0.2137 ± 0.09	2.435 ± 0.11	0.08263 ± 0.06	1261 ± 2	1.0
B z,pb,eu,sp,m3° (5)	5	149	31	7	1421	0.081	0.2105 ± 0.10	2.391 ± 0.13	0.08237 ± 0.08	1254 ± 3	2.0
C z,pb,eu,sp,m3° (5)	6	204	44	4	4288	0.089	0.2152 ± 0.08	2.453 ± 0.10	0.08266 ± 0.05	1261 ± 2	0.4
D z,pb,eu,sp,m1° (4)	4	103	22	6	884	0.082	0.2153 ± 0.12	2.453 ± 0.19	0.08261 ± 0.13	1260 ± 5	0.2
T5 t,py,an,fr,0.75A	143	96	21	294	567	0.232	0.1890 ± 0.11	1.998 ± 0.28	0.07666 ± 0.22	1112 ± 9	-0.4
T7 t,py,an,fr,0.75A	243	73	15	337	621	0.214	0.1861 ± 0.11	1.962 ± 0.27	0.07646 ± 0.21	1107 ± 8	0.7
T8 t,pb,an,fr,0.75A	257	86	18	319	823	0.241	0.1870 ± 0.10	1.977 ± 0.21	0.07668 ± 0.16	1113 ± 6	0.8
T9 t,mb,an,fr,0.75A	275	119	25	468	834	0.216	0.1892 ± 0.10	2.001 ± 0.21	0.07666 ± 0.16	1112 ± 6	-0.5

[a] mineral: z = zircon; t = titanite; grain characteristics: pb = pale brown; mb = medium brown; py = pale yellow; eu = euhedral; an = anhedral; lp = long prism; sp = short prism; fr = fragment; magnetic properties: m1° — magnetic at indicated side slope of Frantz; 0.75A — magnetic at given amperage (10° side slope). The number in parentheses following zircon descriptions is the number of grains analyzed.

[b] Error on weight = ±1 µg.

[c] Radiogenic Pb.

[d] Total common Pb in analysis corrected for fractionation and spike.

[e] Measured ratio corrected for spike and Pb fractionation of 0.09 ± 0.03%/AMU.

[f] Ratios corrected for spike, fractionation, blank and initial commom Pb (Stacey-Kramers model Pb composition equivalent to the Pb/ Pb age). Errors quoted are 1σ in %.

[g] Age error is ± 2σ in Ma.

[h] Discordance (along discordia to origin).

URANIUM-LEAD GEOCHRONOLOGY

Analytical methods

Zircon and titanite were separated by standard crushing, grinding, hydrodynamic, and heavy liquid techniques. Purification of the heavy mineral concentrates was carried out using a Frantz LB-1 isodynamic separator. All zircon fractions were air-abraded following the method of Krogh (1982). The analytical procedures for U-Pb analysis of zircon are summarized in Parrish et al. (1987), and those for titanite in Davis et al. (1997). Treatment of analytical errors follows that outlined by Roddick (1987), with regression analysis modified after York (1969). Analytical results are presented in Table 1 and displayed in the concordia diagram (Fig. 3), with errors reported at the 2σ level.

Results

The sampled granodiorite (TP98-1) contains a weak to moderate foliation principally defined by alternating quartz-feldspar-rich layers and biotite ± hornblende-rich layers. The rock is partly recrystallized and contains accessory zircon, allanite, Fe-Ti oxides, and apatite. It also shows signs of reaction textures including titanite rimming Fe-Ti oxides, epidote rimming allanite, sericite replacing feldspar, and chlorite replacing both hornblende and biotite.

Zircon recovered from the sample consists dominantly of clear, pale brown, short to elongate prisms with well developed crystal faces and rounded edges and terminations. Some grains are fractured and contain minor fluid inclusions. Core-overgrowth relationships were not observed. Analyses of four multigrain fractions yielded 0.2 to 2% discordant results (Fig. 3). Fraction D has the largest error ellipse due to a high relative proportion of common Pb (Table 1). All four analyses are collinear and regression of the data gave an upper intercept age of 1263 +4/-2 Ma, a lower intercept age of ca. 417 Ma, and a mean square of weighted deviates (MSWD) of 0.71 (Fig. 3). The upper intercept is interpreted as the crystallization age of the granodiorite.

Titanite occurs as brown to almost colourless anhedral fragments. The analysis of four multigrain fractions resulted in two nearly concordant data points (T5 and T9) and two slightly discordant data points (T7 and T8) (Table 1; Fig. 3). Model Th/U ratios for all four fractions range between 0.71 and 0.80, well below those expected for magmatic titanite, but typical of secondary titanite (e.g. Abraham et al., 1994). Fractions T5, T8, and T9 yielded a weighted average $^{207}\mathrm{Pb}/^{206}\mathrm{Pb}$ age of 1113 ± 4 Ma (MSWD = 0.01). A linear regression through all four analyses gave a similar upper intercept age of 1112 +10/-5 Ma (MSWD = 0.46; Fig. 3). On the basis of these results and the textural characteristics noted above, the 1113 ± 4 Ma age is taken to date growth of titanite rims on Fe-Ti oxides.

DISCUSSION AND CONCLUSIONS

Early tectonic evolution of the Sharbot Lake domain

Moore (1982) originally included granitoid rocks of the Pakenham intrusion in the Sharbot Lake domain, and Lumbers et al. (1990) later suggested that these rocks form part of the ca. 1280–1250 Ma Elzevir suite, as defined above, found throughout the western part of the northern superterrane. However, limited geochemical data (R.M. Easton, unpub. data, 1989) from the Pakenham intrusion show that only some of the granitoid rocks have chemical affinities with the Elzevir suite, whereas others have rare-earth-element patterns atypical of this suite. Combined with structural and metamorphic considerations, this led Easton (1992) and

Easton and Hildebrand (1994) to question the assignment of the Pakenham intrusion to the Sharbot Lake domain. The new U-Pb age determination reported here for a granodioritic phase of the Pakenham intrusion, 1263 +4/-2 Ma, not only supports linkage of the intrusion to the Sharbot Lake domain, but also expands the known age range for Elzevirian magmatism in this domain. Furthermore, together with the slightly younger, 1.25 Ga U-Pb age (Wallach, 1973) for a granodioritic component of the Hinchinbrooke pluton in the southern Sharbot Lake domain, the 1263 +4/-2 Ma age for the Pakenham intrusion provides firm evidence for the presence of Elzevir suite plutonic rocks in the domain. Previously observed geochemical differences between different phases of the Pakenham intrusion may reflect the presence of younger granitic rocks cutting the Elzevir suite granodiorites. These younger granitic rocks could be related to either the ca. 1224 Ma (Corfu and Easton, 1997) Lavant gabbroic complex or the 1180–1150 Ma Frontenac (*see* Davidson, 1996) or 1090–1065 Ma Skootamatta (*see* Easton, 1992) suites that occur elsewhere in the Sharbot Lake domain (Corfu and Easton, 1997; Davidson and van Breemen, 2000a, b).

The 1280–1250 Ma plutonic rocks (tonalite, trondhjemite, granodiorite) of the Elzevir suite are calc-alkaline and restricted to the northern superterrane (Lumbers et al., 1990; Easton, 1992). In the Harvey-Cardiff, Belmont, Grimsthorpe, and Mazinaw domains (Fig. 1), these plutonic rocks are closely associated with volcanic rocks ranging in composition from tholeiitic to calc-alkaline (e.g. Condie and Moore, 1977; Smith and Holm, 1990a; Harnois and Moore, 1991). The calc-alkaline plutonic rocks and associated volcanic successions have been interpreted to be either a fragment of an oceanic arc (e.g. Brown et al., 1975), representatives of a marginal basin developed on thinned continental crust (e.g. Smith and Holm, 1990b; Harnois and Moore, 1991), or a 'composite arc belt' consisting of primitive and more mature arcs, rifted arcs, and marginal basins (Easton, 1992; Carr et al., 2000). Within the Sharbot Lake domain, mafic volcanic rocks are clearly intruded by the ca. 1224 Ma calc-alkaline Lavant gabbroic complex, but the nature of their contacts with the Pakenham intrusion is unclear owing to deformation. The tholeiitic volcanic rocks of this domain are locally interbedded with, but mostly overlain by, carbonate rocks, suggesting that mafic volcanism took place, at least in part, in an active carbonate basin. Corfu and Easton (1997) suggested that the tectonic setting of this basalt-carbonate sequence was a rifted arc regime.

From these observations and U-Pb data, two possible scenarios can be envisaged for the tectonic evolution of the Sharbot Lake domain between about 1300 and 1220 Ma. In the first case, the related mafic volcanic and carbonate sequence could have been constructed on an Elzevir-type basement comprising the ca. 1263 Ma Pakenham intrusion. Subsequently, the supracrustal sequence was intruded by rocks of the Lavant gabbroic complex, which could have represented the subvolcanic magma chamber for the volcanic succession (Easton, 1988b). A similar geological setting has been proposed for both the Harvey-Cardiff and Belmont domains (e.g. Easton, 1992). An alternative interpretation is that the basalt-carbonate sequence was intruded by both the Pakenham intrusion and the younger Lavant gabbroic complex. In this case, it is not known whether calc-alkaline magmatism was continuous or episodic during the ca. 1263–1224 Ma interval. Within the Grimsthorpe domain, the ca. 1267 Ma (L. Heaman *in* Davidson et al., 1990) Elzevir tonalite intrudes two tholeiitic volcanic sequences (Easton and Ford, 1994); however, these early tholeiitic successions do not appear to be associated with carbonate and siliciclastic sedimentary rocks. Clearly, more data are required to distinguish between these two scenarios. However, the following observations strongly favour the first interpretation: 1) the contrasting structural-metamorphic histories documented for the Pakenham structure and carbonate rocks, and 2) the possibility that felsic components of the Lavant gabbroic complex were produced by partial melting of, or strongly contaminated by, sialic crust underlying the Sharbot Lake domain (Corfu and Easton, 1997).

Possible links between the Pakenham and Wolf Grove structures

Although lithologically and structurally similar to the Pakenham structure, the Wolf Grove structure to the southeast appears to contain rocks that are distinctly younger than the Pakenham intrusion (Fig. 2). The Wolf Grove structure is characterized by an amphibolite with a probable protolith age of ca. 1220 Ma, and by migmatitic gneiss and granite from which extracted zircon fractions gave an age of ca. 1168 Ma (Corfu and Easton, 1997). The significance of the 1168 Ma age for the Wolf Grove granite has been questioned by Easton and Davidson (1997). Zircon from this unit yielded discordant $^{207}Pb/^{206}Pb$ ages ranging from 1258 to 1166 Ma. The youngest ages were interpreted by Corfu and Easton (1997) to date emplacement of the granite at ca. 1168 Ma, whereas the older ages were interpreted as representing the ages of inherited Pb. In contrast, Easton and Davidson (1997) argued that the granite may be older and was affected by 1168 Ma metamorphism. The presence of zircon as old as ca. 1258 Ma in the Wolf Grove granite could suggest that this granite is similar in age to the 1263 +4/-2 Ma Pakenham intrusion. If correct, this correlation suggests that migmatization in the Wolf Grove structure occurred prior to ca. 1258 Ma. Also, this potential linkage leads to the question of why did the Pakenham intrusion apparently escape the main 1168 Ma metamorphism documented in the Wolf Grove structure. A possible explanation is that high-grade metamorphism at ca. 1168 Ma, which likely resulted from transport of the Frontenac terrane onto the Sharbot Lake domain (Easton and Davidson, 1997), only affected rocks in the immediate footwall of the Maberly shear zone. Further geochronological and petrographic work is needed to test these hypotheses.

Significance of the titanite age

Previously published monazite and titanite metamorphic ages for the Sharbot Lake domain are highly varied but generally fall in the ranges of ca. 1221–1211 Ma, ca. 1152–1143 Ma, and ca. 1123–1121 Ma (Mezger et al., 1993; Corfu and Easton, 1997). The oldest 1221–1211 Ma titanite ages are from pegmatitic gabbro of the Lavant gabbroic complex (Fig. 2), with the 1221 ± 5 Ma age interpreted as closely recording syn-Lavant contact metamorphism and the 1211 ± 4 Ma age as reflecting limited Pb loss related to 1168 Ma metamorphism in the adjacent Frontenac terrane (Corfu and Easton, 1997). In contrast, the post-ca. 1150 Ma ages are interpreted to date either localized, low-grade metamorphic and hydrothermal events or regional cooling (Mezger et al., 1993; Corfu and Easton, 1997). The 1113 ± 4 Ma titanite age from the Pakenham granodiorite roughly coincides with the youngest titanites (1123–1121 Ma). The following observations collectively suggest that the ca. 1123–1113 Ma titanite ages record greenschist-facies metamorphism and/or fluid infiltration as opposed to regional cooling: 1) titanite from this study preserves textural and isotopic evidence for a secondary origin by breakdown of Fe-Ti oxides; and 2) the Wolf Grove amphibolite, which contains the 1123 ± 5 Ma titanite (Fig. 2), shows evidence for a greenschist-facies overprint (Buckley et al. 1997, Table 21.1). Whether or not these results reflect an areally widespread event in the Sharbot Lake domain is unclear and would require detailed U-Pb and petrographic investigations. The relations, if any, between this event and thermotectonic processes occurring at a regional scale are also unknown as the 1123–1113 Ma ages cannot be linked to the timing of any major metamorphic or magmatic episodes within the northern superterrane. Finally, the possibility that this thermal-hydrothermal event represents a distal effect of ca. 1120 Ma Grenvillian tectonic activity in the Central metasedimentary belt of western Quebec (Friedman and Martignole, 1995) or in some parts of the Central Gneiss Belt (e.g. Culshaw et al., 1997) remains to be determined.

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