KECK GEOLOGY CONSORTIUM

PROCEEDINGS OF THE TWENTY-FIFTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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GEOCHEMISTRY AND GEOCHRONOLOGY OF THE CENTRAL METASEDIMENTARY BELT BOUNDARY THRUST ZONE THRUST SHEETS IN SOUTHERN ONTARIO, GRENVILLE PROVINCE

KENJO S. AGUSTSSON, California Polytechnic State University, San Luis Obispo
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INTRODUCTION

Studies of ancient continental collisions offer insight into the evolution of modern-day mountain belts such as the Himalaya. In particular, the now-exhumed cores of ancient orogens facilitate the investigation of lower crustal orogenic processes, and in some cases, including the Grenvillian Orogeny, the exhumed core may preserve crustal remnants that provide information regarding their pre-orogenic histories. In southern Ontario, the Grenville province consists of superterranes that have been amalgamated, metamorphosed, and plutonically emplaced along or on the Laurentian margin. Detailed investigations into these superterranes and associated subterranes provide clues into the reconstruction of the complex pre-orogenic history of the Grenville province and may assist the interpretation of analogous modern-day continental collisional orogens and the general evolution of continental collisions.

This paper contributes new data for metatonalitic thrust sheets of the pre-Grenvillian Laurentian margin in order to better constrain the timing of formation and the tectonic setting with respect to other terranes within the Grenville. Results show that these thrust sheets contain ca. 1330–1300 Ma calc-alkaline tonalites and amphibolites with synchronous tholeiitic amphibolites, which suggest an arc setting for plutonic emplacement followed by a backarc rifting episode.

GEOLOGIC HISTORY

Orogenic History

The Grenville consists of a series of different terranes that were juxtaposed during closure of an ocean basin leading up to and during the ultimate collision between Laurentia and Amazonia (McLelland et al., 2010). From northwest to southeast in southern Ontario, pre-Grenville terranes (older than ~1200 Ma) are found within the Central Gneiss Belt (CGB), Central Metasedimentary Belt boundary thrust zone (CMBbtz), Central Metasedimentary Belt (CMB), and the Frontenac–Adirondack Belt. The CGB consists of ca. 1900–1450 Ma Laurentian crust thought to have formed as an Andean-style continental margin (Carr et al., 2000). The CMB consists of early (1370–1350 Ma) and late (1280–1230Ma) intrusions throughout the CMB suggested to be resultant of Andean-style magmatism followed by backarc development (Lumbers et al., 1990; Hanmer et al., 2000; Davis and Bartlett, 1988; Corfu and Easton, 1995). Between the CGB and the CMB, the CMBbtz is a 30 km wide zone of pre-Grenvillian plutons enveloped by teconites and calcitic–dolomitic marbles. On the southeastern margin of the Grenville province, the Frontenac–Adirondack Belt is thought to extend to the Mount Holly suite in Vermont (Adirondack Highlands–Mount Holly Belt) and thought to represent a rifted continuation of the CMB (McLelland et al., 2010; Fig. 1A Peck et al., this volume). These terranes were emplaced and subsequently juxtaposed in a complex series of collisional events, which include the Elzevirian (ca. 1245–1225 Ma) arc-type orogeny, the Shawinigan (ca. 1190–1140 Ma) contractional orogeny, and the Grenville (1090–980 Ma) continental collisional orogeny (Rivers, 2008; Easton and Kamo, 2011; McLelland et al., 2010).

CMB and its link to the Adirondack–Mt. Holly Belt

The CMB consists of an important component in the link between the pre-Grenvillian Laurentian margin and the arcs that were subsequently amalgamated onto Laurentia during the Shawinigan orogeny. The CMB is divided into the following terranes and domains: the Elzevir terrane (including the Harvey-Cardiff, Belmont and Grimsthorpe domains); the Sharbot Lake and Mazinaw terranes (Easton, 1992); and the CMBbtz (Hanmer and McEachern, 1992). The CMB is characterized by metavolcanic and metasedimentary rocks, including abundant marble, intruded by plutonic rocks that include ca. 1.35–1.30 Ga tonalites in the western CMB, 1.25–1.22 Ga granitic to gabbroic plutons and 1.09–1.06 Ga late plutons across the southern CMB (Carr et al., 2000). The eastern CMB according to McLelland et al. (2010) includes the Frontenac–Adirondack Lowlands Belt corresponding to the original divisions proposed by Wynne-Edwards (1978). Tonalitic and trondhjemitic 1.4–1.3 Ga plutons of the Adirondack Highlands and Mount Holly suite are geochemically correlative with tonalitic intrusions of the Laurentian margin and the CMB farther east (Ratcliffe et al., 1991; McLelland et al., 2010).

Two end-member models are hypothesized for the formation of the CMB. Carr et al. (2000) suggest the CMB and the Frontenac–Adirondack Belt were formed allochthonously with respect to, and later amalgamated onto, the Laurentian margin. In contrast, McLelland et al. (2010) and Hanmer et al. (2000) suggest the CMB and Adirondack Highlands–Mount Holly Belt represent rifted fragments of the Laurentian margin that evolved as part of an arc–backarc basin prior to subsequent re-amalgamation with the Laurentian margin during the Shawinigan.

CMBbtz

The CMBbtz is central to our understanding of the evolution of the pre-Grenvillian Laurentian margin because its tonalitic thrust sheets may provide a potential link between similar rocks within the CGB, the CMB and the Adirondack Highlands–Mount Holly Belt. The CMBbtz is the boundary zone between the high-grade metamorphic gneisses of the CGB to the west and the Elzevir terrane (and the rest of the CMB), to the east. This paper follows the CMBbtz subdivisions proposed by Hanmer and McEachern (1992) where the CMBbtz encompasses the Redstone, Dysart and Glamorgan thrust sheets.

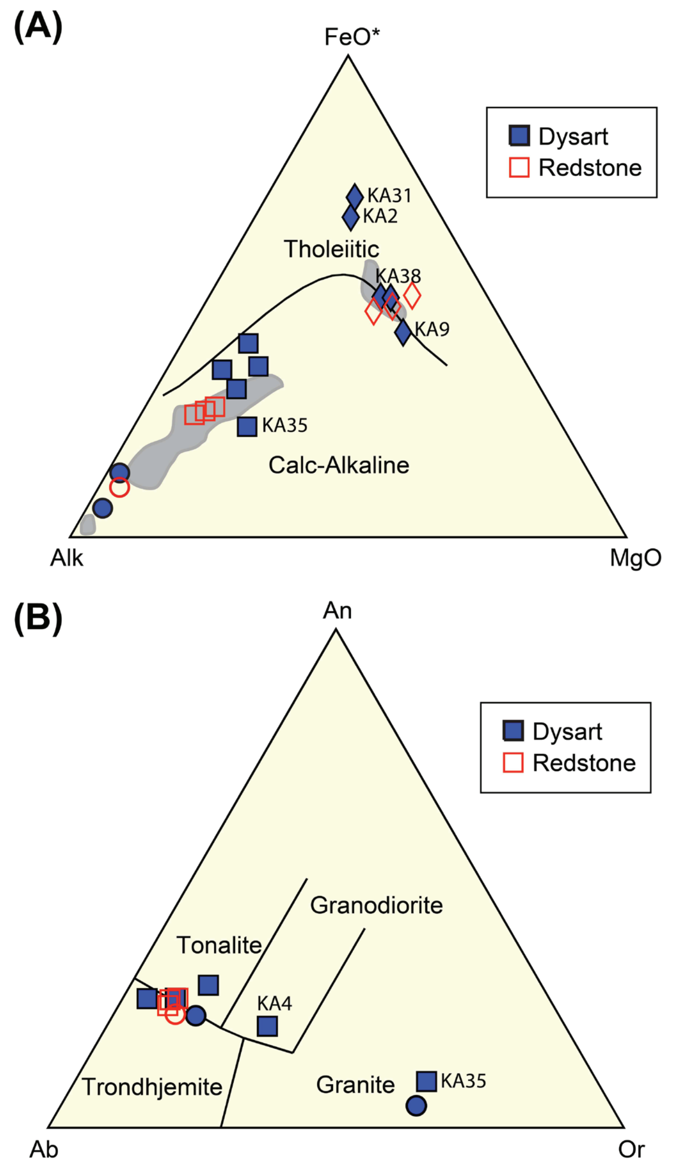

Figure 1. Blue solid shapes correspond to Dysart samples. Red open shapes correspond to Redstone samples. Diamonds are amphibolites, squares are tonalites/trondhjemites, and circles are granites and granodiorites. Sample identification numbers are shortened for clarity in all figures. Sample KA35 displays anomalous trends with the rest of the samples and is removed from the later figures. (A) AFM diagram showing all samples. FeO is the total iron in the sample recalculated as FeO. The gray field represents samples from the Mt. Holly suite, Vermont after Ratcliffe et al. (1991). The calc-alkaline division is after Irvine and Baragar (1971). (B) Ab–An–Or diagram with amphibolite samples excluded. Solid line divisions and fields after Barker (1979).*

The westernmost thrust sheet, the Redstone thrust sheet, is characterized by coarse-grained biotite–hornblende tonalitic orthogneiss with rare, relic strongly pleochroic metamorphic orthopyroxene (Hanmer, 1988). The Redstone thrust sheet is the only thrust sheet within the CMBbtz surrounded by tectonites and straight gneiss (Hanmer, 1988), leading some authors (e.g. Lumbers et al., 1990) to place the Redstone within the Algonquin terrane of the CGB, corresponding to the Laurentian margin. Conversely, the Dysart thrust sheet, which lies east of and structurally above the Redstone thrust sheet, is surrounded by marble tectonic mélange and is characterized by tonalitic orthogneiss with amphibolite sheets that are foliation parallel (Hanmer, 1988). Lumbers et al. (1990) categorized the Dysart thrust sheet as an early (1370–1350 Ma) low-Al2O3 type trondhjemite suite with hornblende as its major mafic component and with some metamorphic clinopyroxene, formed at the expense of hornblende. The Dysart trondhjemites are juxtaposed with the Glamorgan trondhjemites of the adjacent, structurally higher Glamorgan thrust sheet, which are younger (1280–1270 Ma) and geochemically different (high-Al2O3 type, Lumbers et al., 1990).

Based on these limited geochemical studies and unpublished geochronology (i.e. Hanmer, 1988; Lumbers 1990), the CMBbtz thrust sheets have been genetically linked to the intrusive rocks of the Adirondack–Mount Holly regions (McLelland, et al., 2010). In order to place better constraints on this genetic link, in this manuscript we present new geochemical and geochronologic data from the Dysart and Redstone thrust sheets and compare it to the previously published work throughout the Grenville Province.

RESULTS

Field relationships and thin sections

Field relationships within the Redstone and Dysart thrust sheets were examined along road cuts northwest of Haliburton, Ontario (Fig. 1A Peck et al., this volume). The Redstone thrust sheet outcrops exhibit variably strained zones of foliation-concordant tonalites, quartz diorites, and amphibolites, which are all intruded by late K-feldspar-rich granitic dikes. In thin section, tonalites (+ amphibole ± biotite ± relict clinopyroxene) and amphibolites (± biotite ± relict clinopyroxene) show clear biotite and amphibole-defined foliation. The coarser-grained quartz diorite (+amphibole ± biotite ± clinopyroxene) sample shows clinopyroxene breaking down to amphibole and annealing fabrics suggestive of a prolonged high-temperature environment.

The Dysart thrust sheet outcrops display predominately medium-grained biotite–amphibole tonalitic orthogneiss, which are foliation-concordant with coarse granodiorites and up to 1 m thick amphibolite layers. Intricate contact relationships in the low-strain zones between concordant granodiorite (± biotite, ± amphibole; 11KA5) and amphibolite are characterized by coarse amphibole crystals on contact margins. Late K-feldspar-rich granitic dikes crosscut the tonalitic and amphibolitic orthogneiss. In thin section, tonalites (+amphibole ± biotite) display biotite and amphibole-defined foliation, while amphibolites (± clinopyroxene) show amphibole-defined foliation and some amphibolite samples exhibit clinopyroxene breaking down to amphibole.

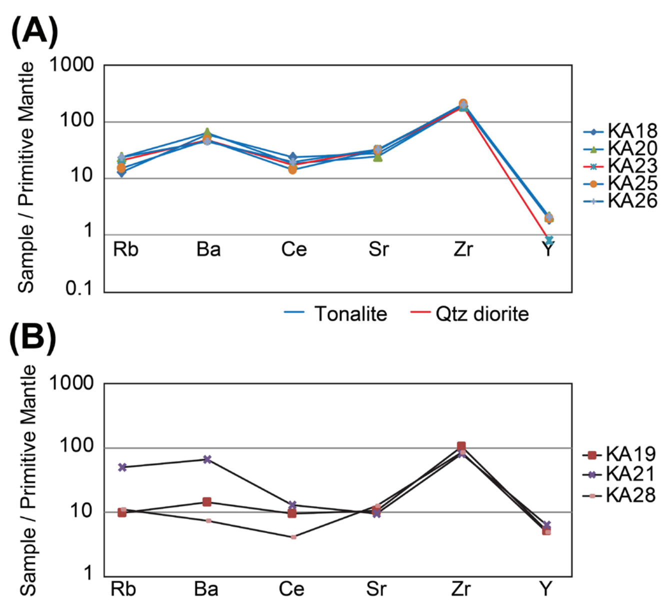

Figure 2. Primitive mantle-normalized diagram using select trace elements for the Redstone thrust sheet (A) tonalites and quartz diorite, and (B) amphibolites. Normalizing values of Sun and McDonough (1989) are used.

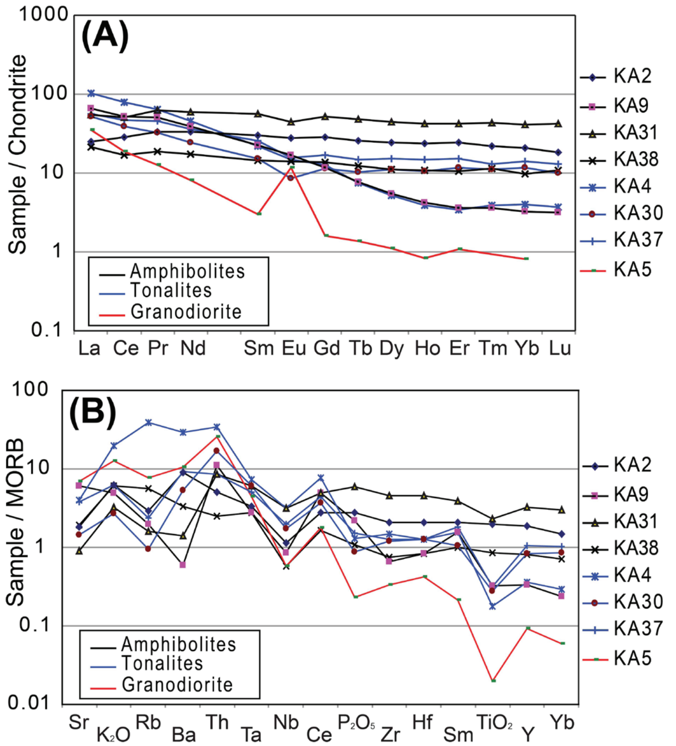

Figure 3. Dysart trace element profiles. (A) Chrondrite-normalized REE diagram using normalizing values after Taylor and McLennan (1985). (B) MORB-normalized spider diagram using normalizing values after Pearce (1983).

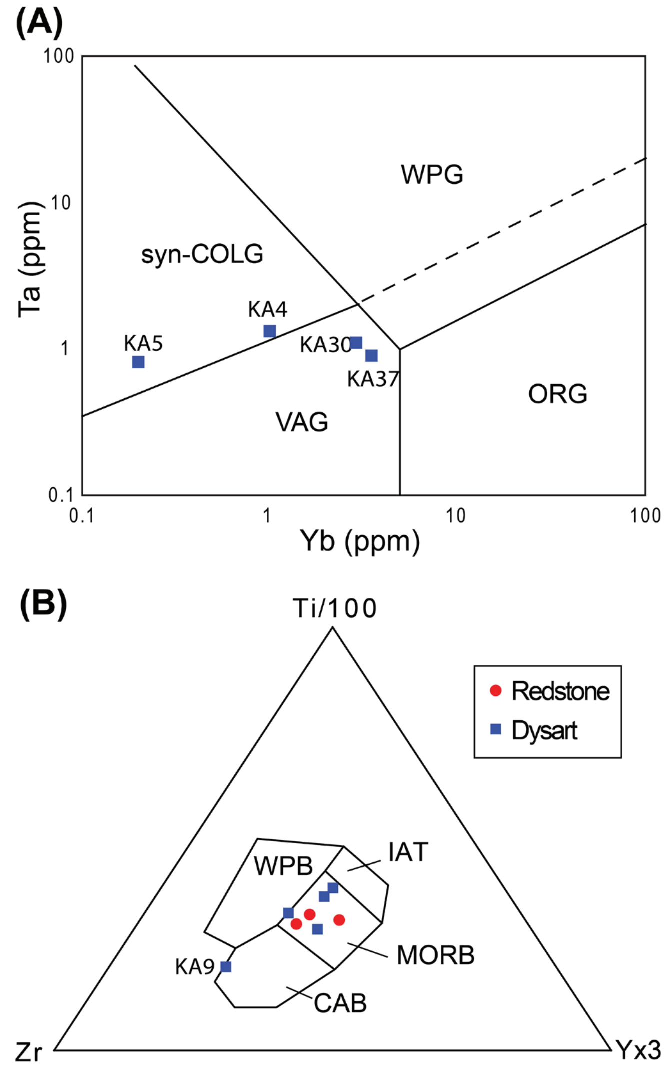

Figure 4. (A) Granite discrimination diagram with divisions and fields after Pearce et al. (1984). WPG, within-plate granites; ORG, ocean-ridge granites; VAG, volcanic-arc granites; syn-COLG, syn-collisional granites. (B) Basalt discrimination diagram with divisions and fields after Pearce and Cann (1973). WPB, within-plate basalts; IAT, island-arc tholeiites; MORB, mid-ocean ridge basalts; CAB, calc-alkali basalts.

Geochemistry

Twenty rock samples from seven outcrop localities (5 Dysart and 2 Redstone) were selected and prepared for major and trace element analysis at Colgate University. Glass disks were analyzed for major elements and pressed powder pellets were analyzed for minor elements using a Philips PW2404 X-ray fluorescence spectrometer at Colgate University by Sarah Lemon with the assistance of Dianne Keller and William Peck. In addition, eight selected samples from the Dysart thrust sheet were sent to SGS Mineral Services, Toronto, ON for additional trace and rare earth element (REE) analysis.

The Redstone tonalites and amphibolites display linear calc-alkaline trends (Fig. 1A). The Redstone tonalites exhibit homogenous primitive mantle-normalized trace element patterns with minute variations in Rb, Ba, and Ce (Fig. 2A). The Redstone amphibolites exhibit slightly more variable patterns than the tonalites with some amphibolites showing more enriched Rb and Ba concentrations in primitive mantle-normalized trace element plots than the other amphibolite samples.

In comparison to the Redstone thrust sheet, the Dysart thrust sheet displays more variable geochemical and mid-ocean ridge basalt (MORB)-normalized trace element profiles with strong variations in Rb and Ba, but more similar Zr and Y concentrations (Fig. 1, 3B).

Chrondrite-normalized REE patterns show significant Nb depletion in the tonalitic and granodioritic samples (Fig. 3A). Dysart thrust sheet tonalites plot in the syn-collisional granitic field or volcanic arc granitic field based on discriminate diagrams that utilize fluid-immobile elements (Fig. 4A). Sample 11KA4 exhibits more enriched, large-ion lithophile (LIL) concentrations compared to the other Dysart tonalites. Dysart sample 11KA35 also displays anomalous trends with the other Dysart samples suggesting affinity to a different suite, and may have been affected by the late K-feldspar rich dikes. Also, a coarse-grained granodiorite (11KA5) is Fe and Mg poor, depleted in HFS elements, and shows a strong positive Eu anomaly, which does not match the trends of other Dysart rocks and may suggest 11KA5 may have derived from a different suite of rocks (Fig. 1A, 3A).

The Dysart amphibolites exhibit both tholeiitic and calc-alkaline affinities (Fig. 1A). The tholeiitic samples 11KA2 & 31 display flat MORB-like rare earth element patterns. Sample 11KA38 also displays a flat REE pattern but plots near the calc-alkaline–tholeiitic division on an AFM diagram, indicating it may represent a more primitive tholeiitic composition (Fig. 1A, 3A). Sample 11KA9 displays a steep negative rare earth element pattern that is relatively enriched in LREE and depleted in HREE, TiO_2 and Y with respect to the other Dysart amphibolites.

Zircon geochronology

Two samples from the Dysart thrust sheet and one from the Redstone thrust sheet were analyzed for U–Pb zircon geochronology. ~ 40 zircons from magnetic and non-magnetic splits of each sample were picked and mounted in epoxy, and imaged under cathodoluminescence (CL) to observe zoning and determine core–rim morphologies within individual zircon grains. U–Pb isotopes were analyzed at the University of California, Santa Barbara using LA-ICP-MS with 15-µm spots.

Isotopic analyses from the Redstone (11KA25) zircons yield a group of 23 concordant analyses with low U–Th ratios and give an igneous 1326 ± 14 Ma age (Fig. 5A). Seven nearly concordant younger analyses range from 1267–1238 Ma, although there

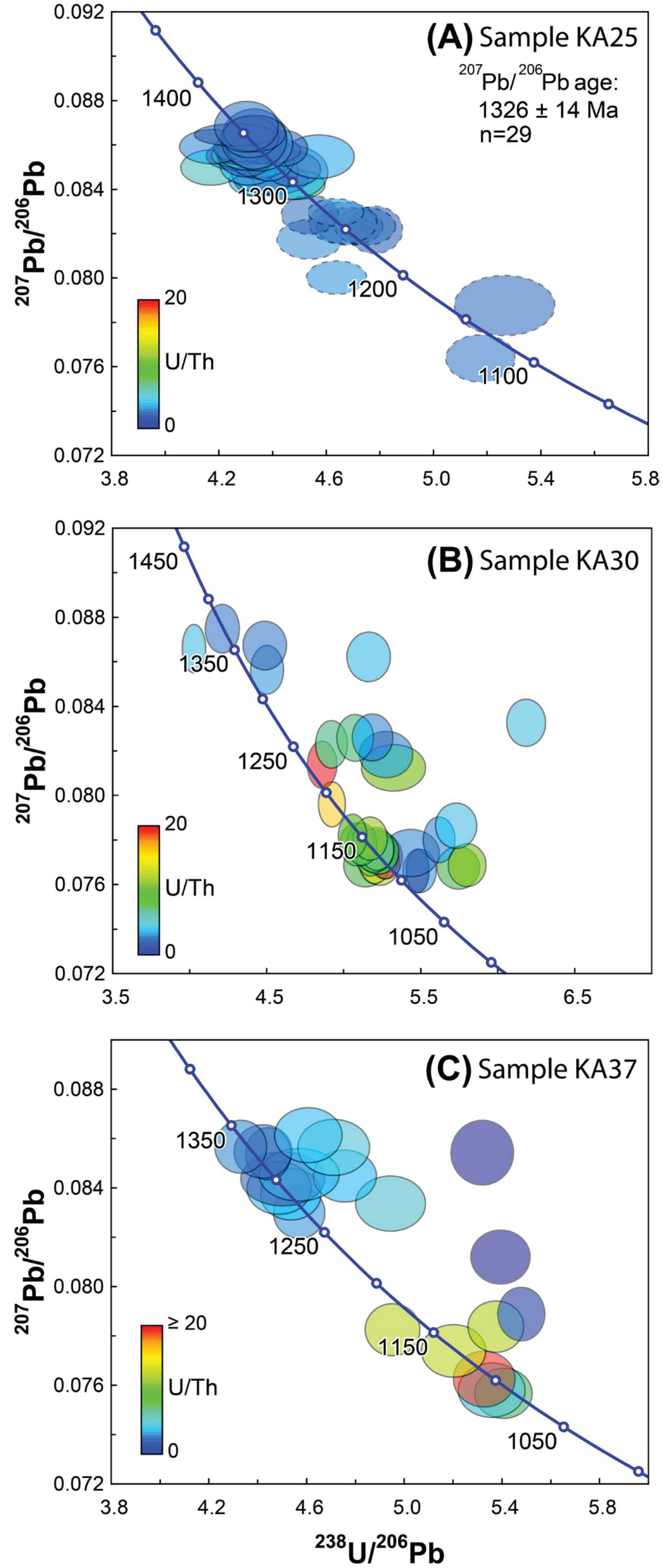

Figure 5. Concordia diagrams for zircon samples. (A) KA25 (Redstone) shows clusters of young ages represented by ellipses with dashed outlines. (B) KA30 and (C) KA37 are Dysart samples. Error ellipses are shown at 2σ.

is no apparent spatial relationship with respect to the core–rim morphology.

Dysart tonalite samples 11KA30 and 11KA37 exhibited relatively smaller, amber, subhedral, mottled zircons compared to the Redstone zircons. U–Pb analyses were made on cores and rims from both magnetic and non-magnetic spilts. Although the high-U concentration of these samples have resulted in Pb-loss, near concordant analyses have 207Pb/206Pb ages that cluster at 1330–1300 Ma and show 1150–1100 Ma metamorphic ages (Fig. 5B, 5C). The younger concordant analyses have high U/Th ratios, while the older concordant analyses have low U/Th ratios. In both samples, cores and rims can be distinguished and give separate igneous and metamorphic ages respectively.

DISCUSSION

The Redstone and Dysart thrust sheet tonalites display calc-alkaline trends and are 1326 ± 14 Ma and ca. 1330–1300 Ma, respectively (Fig. 1A, 5), which are similar to previous age estimates for CMBbtz tonalites (1.4–1.3 Ga, Lumbers, et al., 1990). The Dysart thrust sheet plots within syn-collisional or volcanic arc granite fields on granitic discrimination diagrams utilizing fluid-immobile trace elements (Fig. 4A). Samples 11KA4 and 11KA5 plot in the more-evolved continental arc field, while the Dysart tonalites plot in the volcanic arc field (Fig. 4A), and suggests an evolving continental arc-type setting on the Laurentian margin for the formation of the Redstone and Dysart thrust sheets. The similarity of these data with 1.4–1.3 Ga calc-alkaline early trondhjemites and tonalites of the Adirondack Highlands–Mount Holly Belt (McLelland et al., 2010; Ratcliffe et al., 1991; Lumbers et al., 1990) supports the correlation of these currently distant terranes, and suggests that both belts were originally emplaced together as part of a larger 1.4–1.3 Ga arc on the pre-Grenvillian Laurentian margin (e.g. McLelland et al., 2010).

While the Redstone and Dysart thrust sheets display calc-alkaline tonalitic trends suggesting arc affinity, there is evidence of tholeiitic amphibolites within the Dysart thrust sheet. Although the timing of mafic intrusions within the Dysart is uncertain due to poorly constrained cross-cutting relationships, the tholeiitic amphibolites have MORB affinity based on flat chrondrite-normalized REE patterns and discrimination diagrams plotting these samples within the MORB field (Fig. 4B). These results suggest the Dysart tholeiitic amphibolites may be related to 1276 Ma Mazinaw amphibolites, which have an oceanic crust affinity (Corfu and Easton, 1995). Alternatively, the CMBbtz tholeiites may be related to a later period of metamorphosed bimodal 1.26–1.24 Ga tholeiitic volcanic rocks exposed in the central and eastern CMB indicative of a backarc rift setting on an older magmatic arc (Davis and Bartlett, 1988; Corfu and Easton, 1995). Geochronological data for the Dysart tholeiitic amphibolites or synchronous felsic rocks may better constrain the timing of these intrusions.

Unique from the tholeiitic amphibolites, the calc-alkaline amphibolite (11KA9) displays enriched LREE patterns, depleted HREE patterns, and plots within alkaline basalt fields on discrimination diagrams. These data suggest that the calc-alkaline amphibolite is of island arc or continental arc affinity and is closely related to the Dysart calc-alkaline tonalites, which have similar trace element patterns. Another possibility is that the calc-alkaline amphibolite may correlate to 1230-1220 Ma suites to the east of the CMBbtz. Further geochronological and geochemical data need to be analyzed to better constrain the timing and relationships of these amphibolites within the Dysart to the other mafic intrusions across the CMB.

CONCLUSIONS

New geochemistry and zircon geochronology data for the Dysart and Redstone tonalitic thrust sheets of the Central Metasedimentary Belt boundary thrust zone in southern Ontario indicate that (i) 1330–1300 Ma tonalitic–trondhjemitic plutonism occurred within the Dysart and Redstone thrust sheets, (ii) the Dysart and Redstone tonalites and the Redstone amphibolites are of calc-alkaline affinity, and (iii) the Dysart amphibolites are of both calc-alkaline and tholeiitic affinities. These calc-alkaline trends suggest an arc margin and rifting episode within the Central Metasedimentary Belt. Also, widespread ca. 1.35 Ga crust in association with volcanism may suggest the formation the Dysart–Mount Holly suite plutons was followed by rifting. These interpretations support models proposed by McLelland et al. (2010) for the formation and subsequent rifting of the 1.4 –1.3 Ga plutons of the CMB.

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