Geochemistry of metabasalts from the Knob Hill complex and Anarchist Group in the Paleozoic basement to southern Quesnellia

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Abstract

The Knob Hill complex and Anarchist Group constitute part of the Paleozoic basement to southern Quesnellia. These units occupy adjacent northward dipping, south-vergent thrust sheets extending along the Canada-Washington State border. Metabasalts in both units are tholeiitic to transitional or alkalic, comprising three magma types. The ophiolitic Knob Hill complex contains rocks of predominantly island arc affinity (IAT), with local MORB and E-MORB varieties. They probably formed by subduction-related rifting processes, but the precise setting remains unclear. The Anarchist Group metabasalts display predominantly within-plate E-MORB geochemical traits; local IAT and MORB signatures are indistinguishable from those in the Knob Hill Complex. The basalt geochemistry suggests that the two units share a magmatic history and may have once been contiguous, with the Anarchist Group having formed off axis relative to spreading represented by the Knob Hill complex.

Keywords: Quesnellia, Okanagan subterrane, Knob Hill complex, Anarchist Group, basalt geochemistry, supra-subduction zone basin

1. Introduction

Various Paleozoic mafic volcanic and pelitic successions form basement to the Quesnel terrane in the southern Okanagan along the Canada-USA border (Figs. 1, 2). Depending on geographic locale, different workers have assigned different names to these successions. They are called: the Knob Hill complex and Attwood Formation in the Greenwood area; the Anarchist Group in the Osoyoos-Rock Creek and Beaverdell areas; and the Kobau Group and Apex Mountain Complex in the area between Oliver and Keremeos (Fig. 2). The terms 'Kobau' and 'Anarchist' have also been used in Washington State, though not always for directly correlatable rock packages. Most of these packages have been included in the Okanagan subterrane (Monger, 1977; Peatfield, 1978).

The multiplicity of lithostratigraphic terms is likely an artifact of different geologists mapping in different areas. Recent mapping has revised some stratigraphic designations, recognizing that the successions define an east-trending belt, with individual units separated by northward-dipping, south-vergent thrust sheets (Fig. 2; Fyles, 1990; Massey, 2007; Massey and Duffy, 2008). Nonetheless, relationships between structurally separated units remain unclear. Tertiary extensional faults have disrupted and modified the thrusts, which limits correlating units by lateral tracing. With the exception of ~390-380 Ma ages from the Knob Hill complex (Massey et al., this volume), reliable U-Pb zircon data are lacking for the Paleozoic successions. In an effort to address correlation questions, herein we present geochemical data from mafic rocks in the Knob Hill complex and the Anarchist Group. We also use these data to test field-based models that regard these successions as recording Devonian intraoceanic subduction processes.

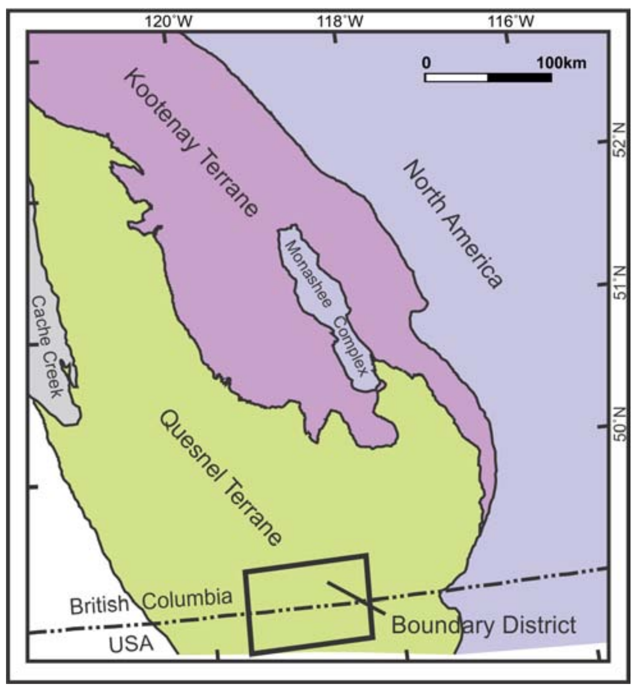

Fig. 1. Simplified terrane map of southeastern British Columbia (amended from digital geology of Massey et al., 2005). Location of the Boundary District shown by rectangle.

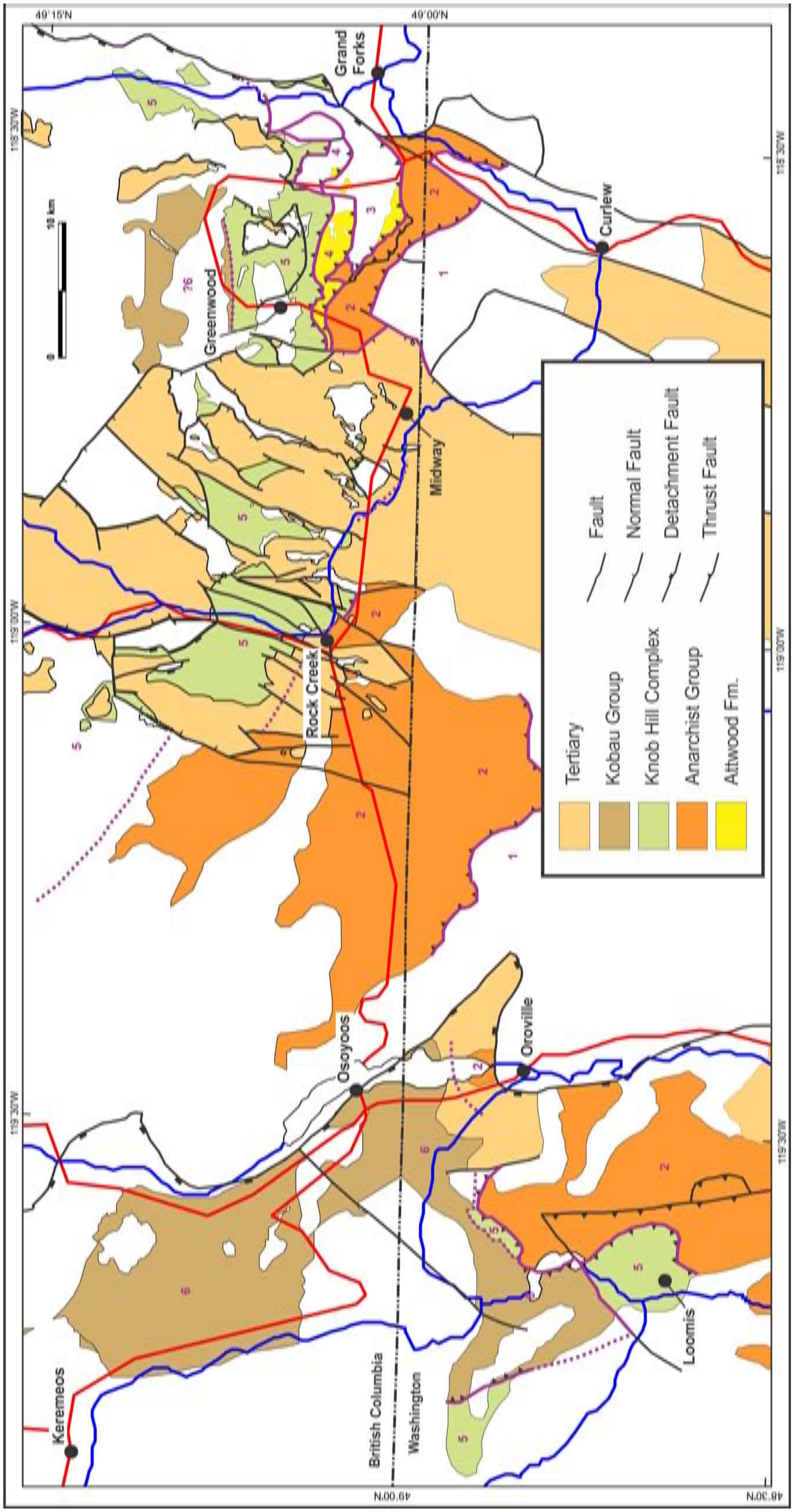

Fig. 2. Distribution of Paleozoic Quesnellian rock suites in the southern Okanagan region and adjacent Washington State, amended from digital geology maps of British Columbia (Massey et al., 2005) and from geological maps of Washington State (Ludington et al., 2005; Cheney et al., 1994). Purple lines and numbers identify the east-west trending thrust sheet packages.

2. Paleozoic successions

2.1. Knob Hill complex

Interpreted stratigraphic arrangement of map units in the Kettle River valley area north of Rock Creek suggest that Knob Hill complex constitutes a disrupted ophiolite (Little, 1983; Dostal et al., 2001; Massey, 2006). Gabbro and serpentinite pass northwards, and probably upwards, into greenstones, mixed greenstones and cherts, and finally into cherts and argillites (Massey, 2007a). This pattern is repeated on the west side of the valley in the Johnstone Creek area (Fig. 2), although disrupted by north-northeast trending Tertiary faults. Stratigraphic relationships between map units are less clear in the Greenwood area. However, outcrops along the power line adjacent to the Winnipeg Mine, east of Greenwood, show well developed chilled margins in medium-grained diabase and microgabbro, suggesting they may be part of a yet-to-be delineated sheeted dike complex. The stratigraphic thickness of the Knob Hill complex is uncertain and difficult to estimate due to structural disruption. Nonetheless, Little (1983) suggested "a minimum of a few thousands of metres", and Fyles (1990, 1995) gave an estimate of at least 5 km.

U-Pb zircon (Massey et al., this volume) and biostratigraphic data (Orchard, 1993) show that the complex originated from Middle to Late Devonian (380-390 Ma); biostratigraphic data from a chert bed in the mixed greenstone-chert succession (Cordey in Massey, 2007) indicate that it continued to evolve into the Late Pennsylvanian or Early Permian (290-295 Ma.). This 80 to 100 million year time span seems excessive for a single ophiolite as small as the Knob Hill Complex (see Woodcock, 2004). It suggests a complex tectonostratigraphy, probably involving more than one extensional event, and cryptic stratigraphic or structural breaks in the sequence.

2.1.1. Serpentinite and gabbro

Serpentinite is typically black to bright green. It is commonly phyllitic to schistose but locally contains coherent serpentinite lozenges in a foliated matrix. Cores of relict pyroxenite occur, though rarely. Listwanite is exposed in outcrops along Highway 33. This carbonate-rich rock is pale buff on fresh surfaces but typically bright orange on weathered surfaces.

Gabbro is composed of white plagioclase and green to black pyroxenes extensively replaced by hornblende. Chlorite is common on fractures and in shears. The gabbros are generally coarse grained and massive but can show a characteristic variable and patchy texture, with coarse-grained gabbro phases grading into finer microgabbro or even coarser pegmatitic phases.

2.1.2. Greenstone

Greenstones are mostly massive basaltic flows. They are medium grey to green and, although typically aphyric, contain rare feldspar, pyroxene and magnetite phenocrysts. Chlorite, epidote, calcite, and quartz are common alteration minerals in veins, fractures, and within the rock. Pillow structures are rare. Minor breccia, agglomerate, tuff, and chlorite schist are interlayered with the flows, as are chert, cherty argillite, and rare grey limestone beds. In some areas, the abundance of chert beds defines a mixed greenstone-chert unit transitional to the overlying chert-argillite unit.

Medium-grained diabase to micro-gabbro bodies also occur within the greenstone unit. Although typically massive, outcrops along the power line adjacent to the Winnipeg Mine, east of Greenwood, show well developed chilled margins which suggest they are part of an unmapped sheeted dike complex. Diabase dikes preserve screens of gabbro, and diabasic xenoliths occur within the gabbro itself. These complex crosscutting relationships are typical of ophiolitic complexes.

2.1.3. Chert-Argillite Unit

Fine-grained sedimentary rocks are predominant in the Knob Hill complex and consist mainly of grey to white cherts that are interbedded with grey to black argillites, black siliceous argillites, and local chert breccia. Cherts are highly fractured and jointed, tend to be massive to thickly bedded, and only rarely show ribbon structures. Recrystallization of the cherts has produced a fine- to medium-grained saccharoidal texture and limited preservation of radiolaria. Chert breccias contain angular to subrounded clasts of chert and cherty tuff in a siliceous matrix.

2.2. Anarchist Group

Based on predominant rock type, the Anarchist Group can be subdivided into a metasedimentary unit and a metavolcanic unit in the Greenwood-Rock Creek area (Massey and Duffy, 2008). The stratigraphic relationship between the two units is uncertain, and isotopic and paleontological age determinations are unavailable. Rubidium-strontium geochronology in the Osoyoos area only records Tertiary metamorphic ages (Ryan, 1973). Broad similarities between the Anarchist Group and the upper parts of the Knob Hill Complex suggest that the two, now structurally disrupted, were originally continuous.

2.2.1. Metasedimentary unit

The metasedimentary unit consists mainly of chert, argillaceous chert, and meta-argillite with minor metabasalt and limestone. The cherts are recrystallized, displaying a fine to-medium grained, sugary texture, and are typically white to pale grey or darker blue grey. Beds are usually 1 to 2 metres thick, but some are up to 10 metres. Some beds are massive, others show dark and light layering; ribbon bedding is rarely preserved.

Phyllitic to schistose argillaceous metasedimentary rocks are darker, with fine grained black chlorite or biotite schist layers interbedded with lighter quartz-rich layers. Epidote laminae and bands suggest fine grained tuffaceous interbeds. Some less siliceous meta-argillites are carbonaceous. Minor fine- to medium-grained, recrystallized limestones form beds 2 cm to 10 m thick.

2.2.2. Metavolcanic unit

The metavolcanic unit comprises greenstone flows with minor breccias, tuffs, and metasedimentary rocks. The flows are massive and medium to dark grey or black. They are fine grained and generally aphyric, though rare feldspar and pyroxene crystals are seen. Chlorite ± epidote alteration is common, along with veining of quartz±chlorite±calcite. Chlorite and brown to black oxides are present on fractures. Tuffaceous interbeds are altered to green quartz-chlorite±sericite schists with epidote pods and laminae .

3. Geochemistry

A suite of metabasalts from the Knob Hill Complex and Anarchist Group were analyzed for whole-rock major, minor, and trace elements. Major elements and Rb, Sr, Ba, Y, Zr, Nb, V, Ni and Cr were determined by XRF (majors on fused disc, traces on pressed powder pellet) by St Mary's University or Teck (Global Discovery) Labs. REEs, Th, Ta, Hf were determined by peroxide fusion-ICPMS by Memorial University of Newfoundland. Full analyses, including details of duplicate analyses, are tabulated in Massey and Dostal (2013).

3.1. Knob Hill complex

Interpretation of these new data and previously published (Dostal et al., 2001) data from the Greenwood area suggests three distinct suites in the Knob Hill Complex: a) typical ocean basalt (MORB); b) enriched MORB; and c) island-arc tholeiite (IAT). Although subjected to alteration, which affected the alkalis and, to some extent, silica, most samples display a subalkaline, tholeiitic character, though the E-MORB suite is transitional to alkalic (Figs. 3a, b). Most of the samples are basalts, though some are basaltic andesites and andesites. Petrotectonic discrimination plots using the immobile high-field strength elements help to distinguish the three magma types (Figs. 3c-f).

Chondrite-normalized REE patterns further support the discrimination of the three suites (Fig. 4). The IAT samples have a LREE depleted pattern, whereas the MORB samples show a flat pattern and the E-MORBs have LREE enriched patterns.

Spatial or stratigraphic control on the occurrence of the three suites is equivocal. The IAT suite, found throughout most of the section, is predominant. In the Rock Creek – Kettle Valley area, the MORB suite is restricted to horizons higher, and younger, in the basalt package and in the mixed greenstone-chert unit. Relations in the Greenwood area are, however, less clear. E-MORB samples appear to lack a stratigraphic control, and are intermixed with both IATs and MORBs.

3.2. Anarchist Group

Metabasalts from the Anarchist Group show strong similarities with samples from the Knob Hill Complex. They are predominantly basalts, with minor basaltic andesite to andesite, and generally classify as subalkaline, tholeiitic to transitional (Figs. 5a, b). They also show a division into three distinct suites, directly comparable to those in the Knob Hill complex (Figs. 5c-f). However, the E-MORB samples are predominant in the Anarchist Group, and the IAT and N-MORB samples are less common.

The immobile high-field strength elements and REES help to distinguish and characterize the three groups (Figs. 5c-f, 6a-c). REE patterns are comparable to those in the Knob Hill Complex suites, except for the IAT samples which, though lower in overall REE content, have less LREE-depleted patterns (Fig. 6c).

4. Discussion

The ophiolitic field character of the Knob Hill complex has long suggested an oceanic origin (Little, 1983; Dostal et al., 2001; Massey, 2006). Rather than a mid-ocean ridge setting however, the mixed IAT, MORB, and E-MORB geochemistry likely represents intraoceanic subduction processes, although the precise setting (back arc? fore arc?) remains unclear. The 80 to 90 million year time span indicated by U-Pb zircon and paleolontologic data (Massey et al., this volume) indicates a complex history that may have included more than one arc rifting event now hidden by cryptic stratigraphic breaks in the voluminous basaltic sequence.

The basalt geochemistry also offers evidence for a shared magmatic history between the Anarchist Group and at least the upper part the Knob Hill complex. However, the predominance of E-MORB samples and the relative abundance of argillites in the Anarchist Group, may point to its formation more off axis relative to active spreading represented by the Knob Hill complex.

The Old Tom and Shoemaker assemblages in the Keremeos area are lithologically similar to the Knob Hill complex, and Mortensen et al. (2011a, b) have reported similar geochemical data, including IAT, MORB and E-MORB types, consistent with correlation between these units. West of the Okanagan Fault, the Palmer Mountain greenstone in Washington comprises mafic flows and pyroclastic rocks with varitextured gabbro and serpentinite (Rinehart and Fox, 1972) that can be correlated with the Knob Hill complex. As in British Columbia, these rocks are thrust over "Anarchist Group" (which in the Loomis area appears to include significant Triassic Brooklyn Formation) and are structurally overlain by metamorphic rocks of the Kobau Group (Cheney et al., 1994). Two samples from possible Kobau Group greenstones in the Mount Roderick Dhu area yield IAT chemistry (Massey and Dostal, 2013). However, a larger suite of samples from the Kobau Group of the Keremeos area (Mortensen et al., 2011a, b) displays predominantly E-MORB or OIB-types with minor MORB, similar to the Anarchist Group. Because the Kobau and Anarchist groups occupy different thrust slices, with the Knob Hill Complex and equivalents intervening (Fig. 2), it remains unclear if these two units represent the same lithologic package structurally

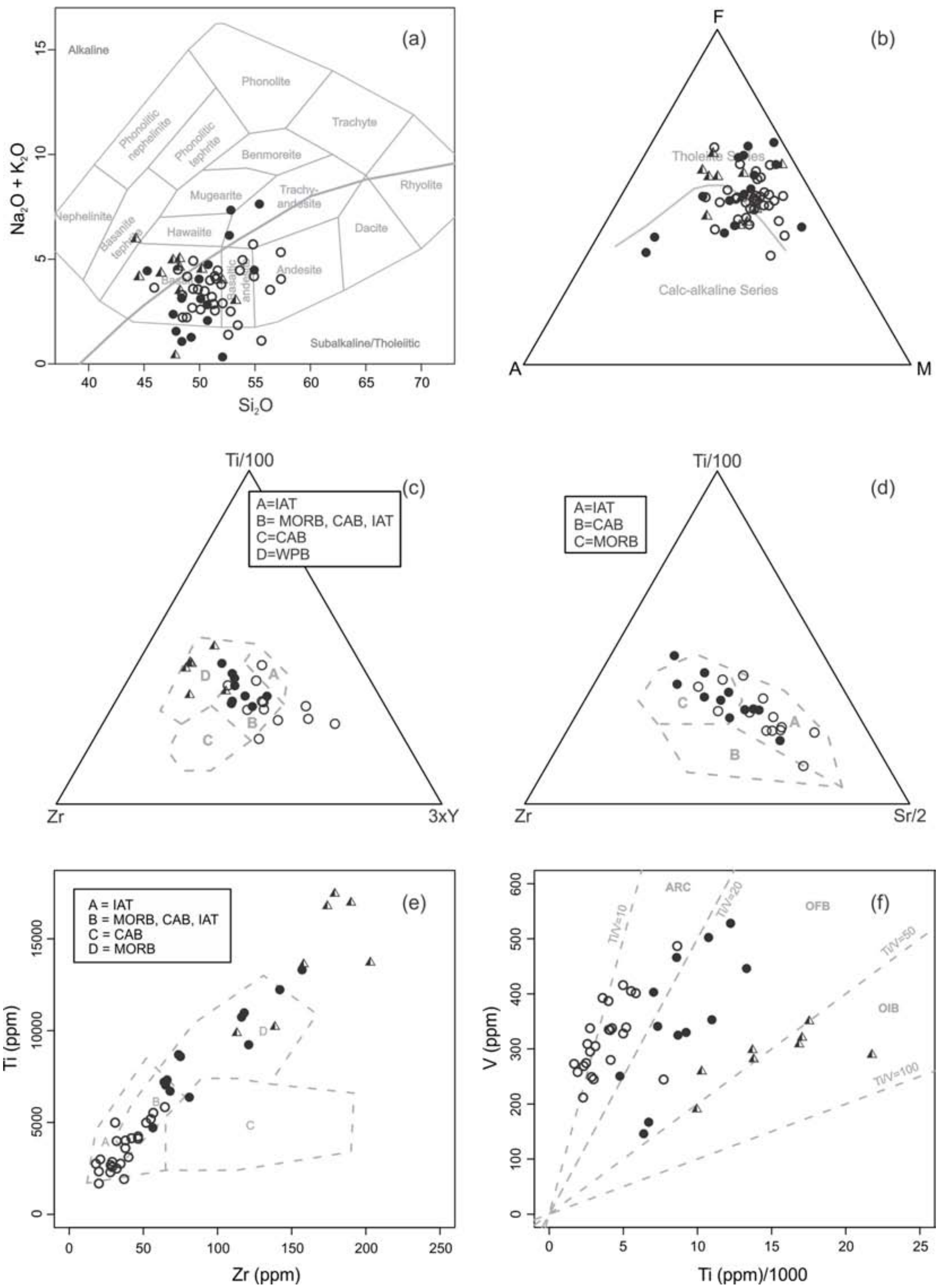

Fig. 3. Geochemical discrimination diagrams for Knob Hill complex metabasalts. Filled circles: MORB suite samples; half filled triangles: E-MORB suite; open circles: IAT suite. **a)** Total alkali vs. SiO_2 (anhydrous weight %) diagram. Classification fields and nomenclature after Cox et al. (1979). The alkaline-subalkaline dividing line after Irvine and Baragar (1971). **b)** AFM diagram after Irvine and Baragar (1971), A = $Na_2O + K_2O$; F = FeO_{total}; M = MgO. **c)** Ti-Zr-Y discriminant triangle diagram; petrotectonic fields after Pearce and Cann (1973). IAT: island arc tholeiites; MORB: mid-ocean ridge basalts, CAB: calcalkaline basalts, WPB: within-plate basalts. Only basaltic samples with 12<CaO + MgO<20 are shown. **d)** Ti-Zr-Sr discriminant triangle diagram; petrotectonic fields after Pearce and Cann (1973). IAT: island arc tholeiites; MORB: mid-ocean ridge basalts, CAB: calcalkaline basalts, WPB: within-plate basalts. Only basaltic samples with 12<CaO + MgO<20 are shown. E-MORB samples are not plotted as this diagram is not designed to discriminate such within-plate basalts. **e)** Ti-Zr discriminant diagram; petrotectonic fields after Pearce and Cann (1973). IAT: island arc tholeiites, MORB: mid-ocean ridge basalts, CAB: calcalkaline basalts. Only basaltic samples with 12<CaO + MgO<20 are shown. **f)** Ti-V discriminant diagram; petrotectonic fields after Shervais (1982). ARC: island arc tholeiites, OFB: ocean floor basalts, OIB: ocean island basalts and alkalic basalts.

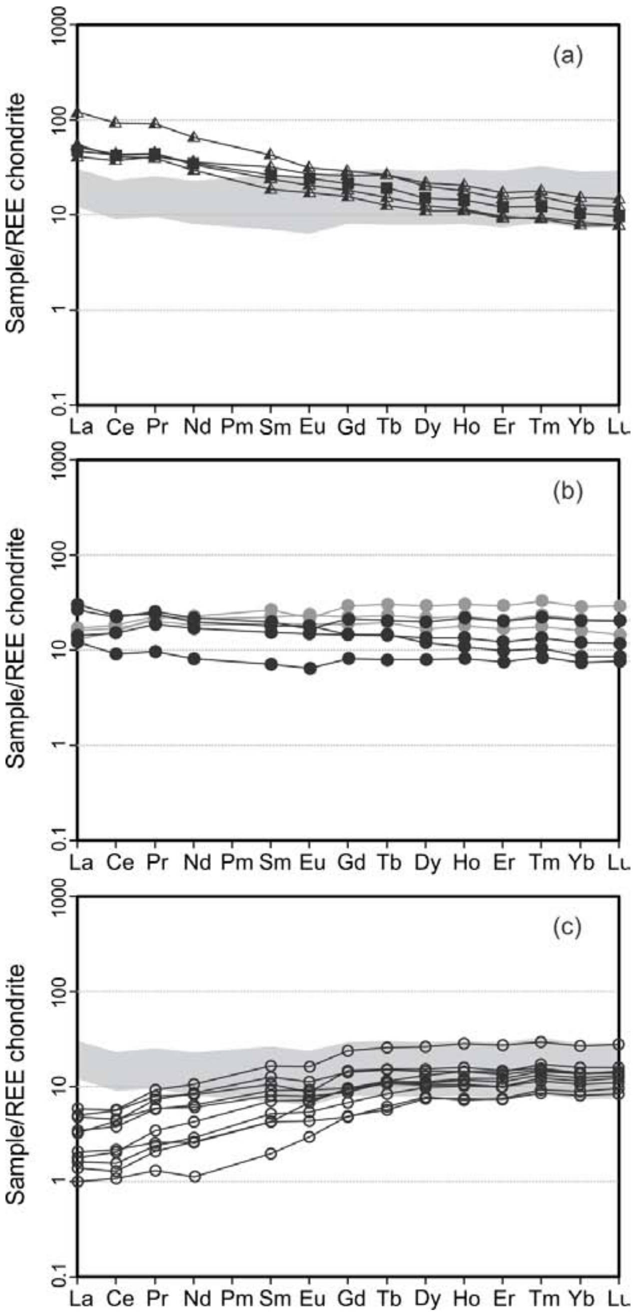

Fig. 4. Rare earth element abundances for Knob Hill Complex metabasalts; analyses normalized to chondrite (after Nakamura, 1974). **a)** E-MORB samples, including one sample (solid squares) from Dostal et al. (2001). Grey shaded field includes all MORB samples in b), shown for comparison. **b)** MORB samples, including three samples (filled grey circles) from Dostal et al. (2001). **c)** IAT samples. Grey shaded field includes all MORB samples in b), shown for comparison.

repeated or represent opposite sides of a basin centred by the Knob Hill complex that is now closed and telescoped.

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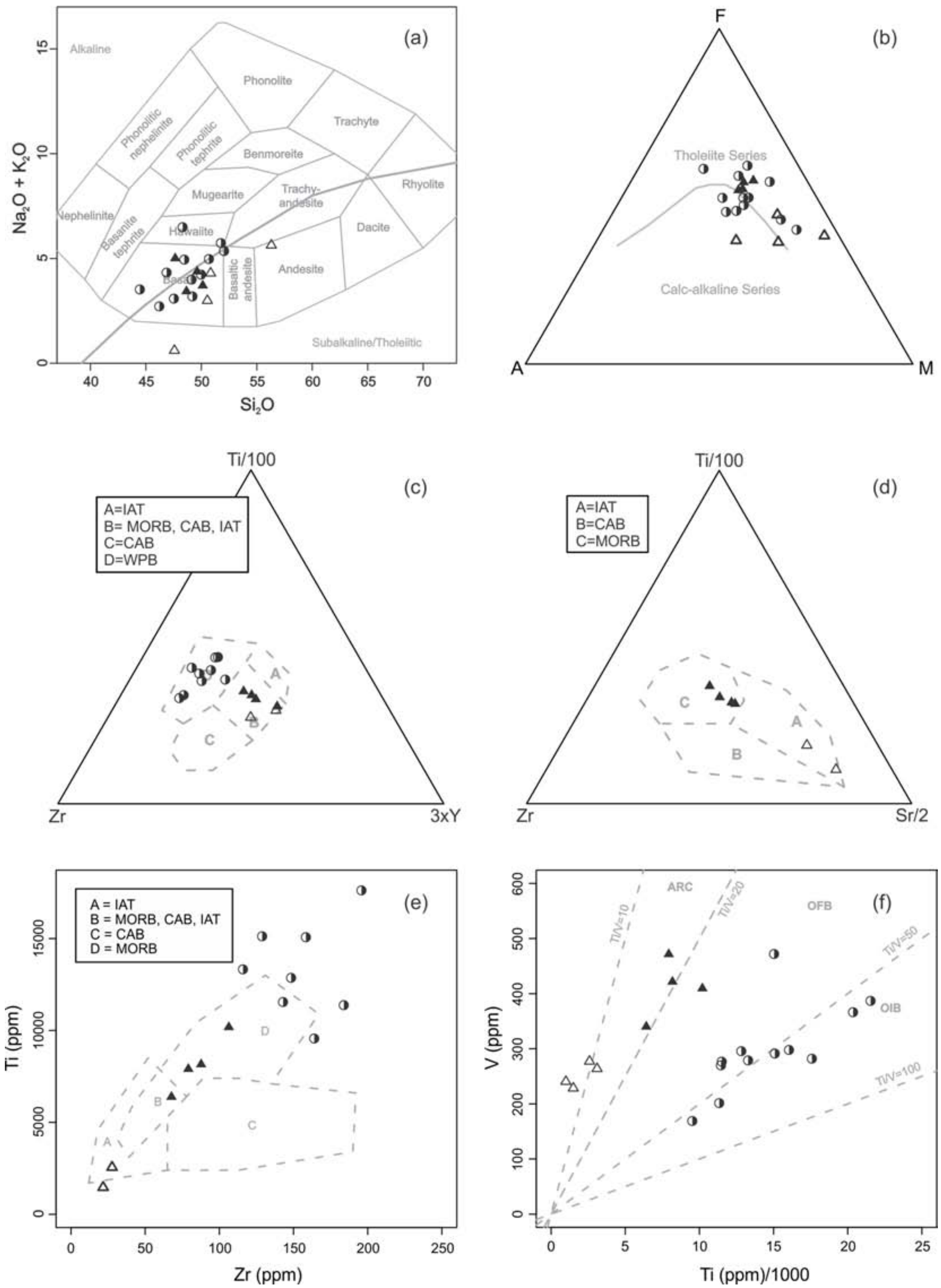

Fig. 5. Geochemical discrimination diagrams for Anarchist Group metabasalts. Filled triangle: MORB suite samples; half filled circles: E-MORB suite; open triangles: IAT suite. **a)** Total alkali vs. SiO_2 (anhydrous weight %) diagram. Classification fields and nomenclature after Cox et al. (1979). The alkaline-subalkaline dividing line after Irvine and Baragar (1971). **b)** AFM diagram after Irvine and Baragar (1971). A = $Na_2O + K_2O$; F = FeO_{total}; M = MgO. **c)** Ti-Zr-Y discriminant triangle diagram; petrotectonic fields after Pearce and Cann (1973). IAT: island arc tholeiites; MORB: mid-ocean ridge basalts, CAB: calcalkaline basalts, WPB: within-plate basalts. Only basaltic samples with 12<CaO + MgO<20 are shown. **d)** Ti-Zr-Sr discriminant triangle diagram; petrotectonic fields after Pearce and Cann (1973). IAT: island arc tholeiites; MORB: mid-ocean ridge basalts, CAB: calcalkaline basalts, WPB: within-plate basalts. Only basaltic samples with 12<CaO + MgO<20 are shown. E-MORB samples are not plotted as this diagram is not designed to discriminate such within-plate basalts. **e)** Ti-Zr discriminant diagram; petrotectonic fields after Pearce and Cann (1973). IAT: island arc tholeiites, MORB: mid-ocean ridge basalts, CAB: calcalkaline basalts. Only basaltic samples with 12<CaO + MgO<20 are shown. **f)** Ti-V discriminant diagram; petrotectonic fields after Shervais (1982). ARC: island arc tholeiites, OFB: ocean floor basalts, OIB: ocean island basalts and alkalic basalts.

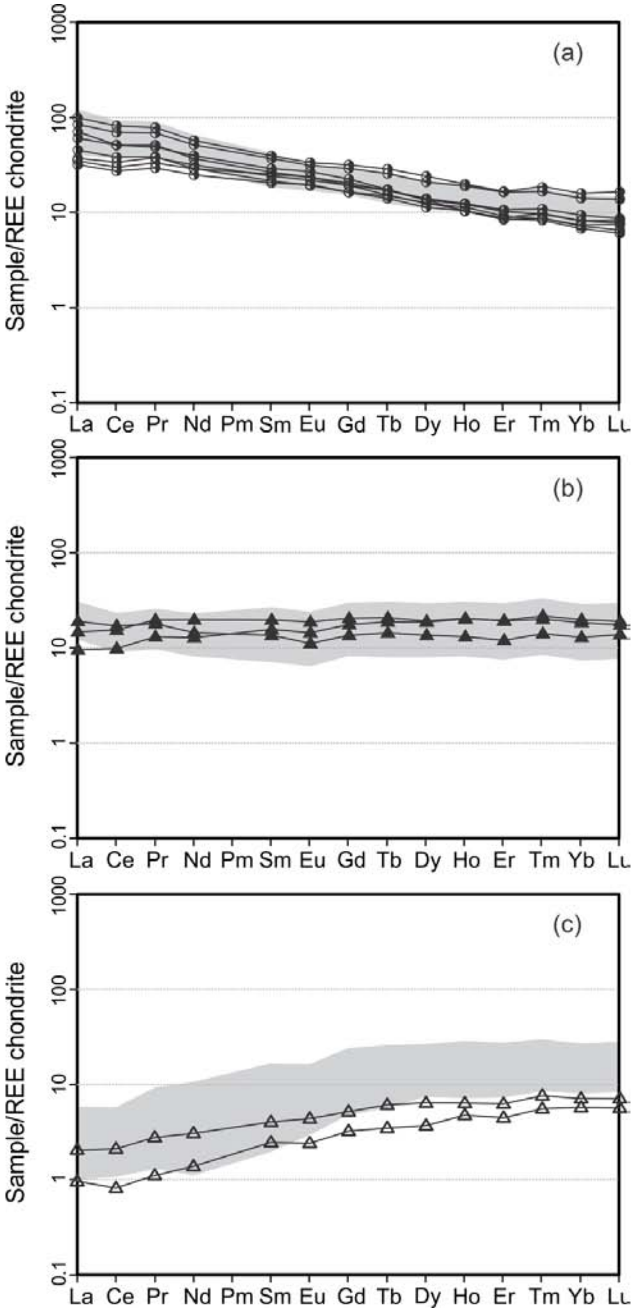

Fig. 6. Rare earth element abundances for Anarchist Group metabasalts; analyses normalized to chondrite (after Nakamura, 1974). **a)** E-MORB samples. Grey-shaded field includes all Knob Hill Complex E-MORB samples (Fig. 4a) shown for comparison; **b)** MORB samples. Grey-shaded field includes all Knob Hill Complex MORB samples (Fig. 4b) shown for comparison; **c)** IAT samples. Grey-shaded field includes all Knob Hill Complex IAT samples (Fig. 4c) shown for comparison.

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