MAJOR AND TRACE ELEMENT TECTONIC DISCRIMINATION OF THE PIKES PEAK BATHOLITH

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Introduction

The Pikes Peak batholith (PPB) has major element and petrographic characteristics that define it as an A-type granitoid (Loiselle and Wones, 1979). The Keck project on the PPB has greatly expanded the data base from which to compare the batholith to other A-type granitoids on a global scale, particularly with regards to trace element characteristics. Prior to this project, geochemical data for PPB samples were relatively limited, especially considering its immense size (~3800 km^2 total surface area). Barker et al. (1975; 1976) published major element analyses of ~50 samples from the PPB, but only 23 rare earth element patterns were presented (other trace element data were not included). The Keck project involves ~100 samples of a wide range of rock types occurring in the batholith, including gabbros, syenites, granodiorites, riebeckite and fayalite granites, and fine-grained potassic granites. From this greatly expanded data base, the PPB is compared to other A-type granitoids with the goals of establishing its geochemical character and constraining its tectonic setting.

The A-type classification

As originally defined by Loiselle and Wones (1979), A-type suites consist of highly alkaline, anhydrous rocks that are emplaced into an anorogenic tectonic setting. Besides the PPB, examples of A-type granitoid suites include the Ras ed Dom complex (Sudan - O'Halloran, 1985), the Gabo and Mumbella plutons (southeastern Australia - Collins et al., 1982), the Yemen rift (Capaldi et al., 1987), and the White Mountain magma series (New Hampshire - Eby, 1987). These suites include highly alkaline rocks with high SiO_2 and Fe contents, high Ga/Al and Fe/Mg ratios relative to I- and S-type granitoids, and relatively low concentrations of Al, Mg and Ca (Whalen, 1987). Minerals include late, interstitial crystallization of annite-rich biotite, alkali amphiboles, sodic pyroxene, and alkali feldspar (Whalen, 1987). Iron-rich minerals such as ferrohedenbergite, ferrohastingsite, and fayalite are also present (Eby, 1990). Riebeckite occurs in peralkaline A-type suites (Eby, 1990), where it frequently exhibits intergrowth of albite and orthoclase and quartz and feldspar (Whalen, 1987). Trace element characteristics of A-type granitoids include an abundance of REE (except Eu), Zr, Y, Nb, Ta, Pb, Ga, Zn and halogens, and depletion of Sc, V, Ni, Co and Cr relative to I- and S-type granitoids (Collins et al., 1982; Whalen, 1987; Eby, 1990).

Since its definition, petrologists have broadened the A-type classification to include a greater range of compositions, mineralogies and tectonic settings, and thus some confusion over the usage of the term "A-type" granite has resulted. The classification is useful in that it denotes a chemically distinct group of granitoids, however, as noted by Eby (1992b), it complicates the current "alphabet soup" classification for granitoids in that I- and S-type classifications are defined by source composition and the M-type granites are defined on the basis of tectonic setting. In other words, I-, S-, and M-type granites are distinguished on the basis of petrogenetic and/or tectonic relations, whereas the A-type classification is loosely based on geochemical characteristics. Several schemes have been developed that attempt to discriminate among granitoid types on the basis of their compositions (Pearce et al., 1984; Maniar and Piccoli, 1989; Eby, 1992a) and are discussed below.

Methods

Whole-rock major and trace element data for PPB samples were collected via XRF and/or ICP by students on the project. Facilities used include geochemical laboratories at Carleton, Beloit, Franklin & Marshall, and Colorado Colleges, and the University of Massachusetts. A subset of 40 samples and another subset of 16 samples were submitted to XRAL (a commercial laboratory) for neutron activation and XRF analysis, respectively. Although the project involved rock types ranging in composition from gabbro to granite, the results included here are for samples with > 60 wt.% SiO_2, and include syenite, granodiorite, and granite. Analytical errors for major elements are generally < 5% (relative to the amount present), and for trace elements are 5 - 10%, with the exception of Ga for which errors may be as high as 20%. Error bars are shown in all figures unless errors lie within the symbols.

Discussion

As previously mentioned, the major element and petrographic characteristics of the PPB are those shared by all A-type granitoids. PPB granodiorites and granites are metaluminous to peraluminous in nature (cf. Anderson, 1983), but some syenites appear to be peralkaline. New trace element data for the PPB further corrobate their geochemical affinity with other occurrences of A-type granitoids. They are enriched in Ce, Zr, Y, Nb, and Zn, and have high Ga/Al compared to I- and S-type granitoids They have high abundances of REE, generally large LREE/HREE ratios, and exhibit negative Eu anomalies.

Pearce et al.'s (1984) classification scheme distinguishes granitoids according to their environment of emplacement on the basis of their trace element chemistry. According to Pearce's (1984) scheme, A-type suites plot as within plate granites (WPG) which are geochemically distinct from syn-collision (syn-COLG), volcanic arc granites (VAG), and ocean ridge granites (ORG). The PPB granitoids clearly plot as WPG on both Yb vs. Ta (Figure 1) and [Yb + Ta] vs. Rb diagrams. Unfortunately, Pearce et al. do not offer further discrimination for WPG/A-type granites.

Maniar and Piccoli (1989) utilize major element chemistry to discriminate among granitoids of different tectonic environments. Orogenic and anorogenic granitoids are each broken down into tectonic environments of emplacement through a series of discrimination diagrams. The orogenic granites include island arc granitoids (IAG), continental arc granitoids (CAG), continental collision granitoids (CCG), and post-orogenic granitoids (POG). The anorogenic granitoids are split into rift-related granitoids (RRG), continental epeirogenic uplift granitoids (CEUG), and oceanic plagiogranites (OP). The PPB is clearly distinguished from OP on the basis of their relatively high K_2O contents (> 1 wt. %). PPB granitoids classify as RRG or CEUG on Al_2O_3 vs. SiO_2 and [FeO(T)/FeO(T) + MgO] vs. SiO_2 diagrams, and on AFM and AFC ternary diagrams (Figure 2). Post-orogenic granitoids have overlapping fields with RRG and CEUG on Figure 2 and other discrimination diagrams of Maniar and Piccoli (not shown). Although some PPB samples fall in the POG field, the batholith is not considered to have POG affinities because the last major orogeny or thermal event that affected this region occurred at least 370 Ma before the emplacement of the batholith (Hutchinson, 1976). PPB granitoids tend to plot within the CEUG field on Maniar and Piccoli's TiO_2 vs. SiO_2 diagram (Figure 3), but the overlap between the RRG and CEUG fields is significant enough to prevent relying on this diagram for discrimination between these two tectonic settings.

According to Eby's (1992a) classification scheme, A-type suites can be subdivided into two chemically distinct groups (reflecting differences in source composition) based on trace element characteristics. Granitoids of Eby's group A_1 are related to hotspots, plumes, or continental rift zones located in anorogenic settings. However, as Eby points out, there seems to be no chemical distinction between granitoids emplaced in continental rift zones and those emplaced in regions of crustal doming. Thus, group A_1 appears to include the RRG and CEUG groups of Maniar and Piccoli. The A_2 group includes granitoids emplaced in a variety of tectonic settings, including postcollisional and what may be "true" anorogenic magmatism, but there seems to be no way to chemically distinguish between these two possibilities (Eby, 1992a). However, the chemical data seem to imply that such magmas were generated from crust that had been through a cycle of subduction-zone or continent-continent collision magmatism (Eby, 1992a). Although relatively few PPB samples were analyzed for elements that Eby relies on to distinguish between A_1 and A_2 granitoids (e.g., Nb, Ga), the available data show that PPB granites plot in the A_2 field, whereas the syenites plot within the A_1 field on a Y-Nb-Ce ternary (Figure 4). On other discrimination diagrams that Eby uses, the PPB data show large overlaps between the A_1 and A_2 fields, with no systematic trend in the potassic vs. sodic trends (cf. Wobus et al., 1976). Thus, Eby's classification appears to complicate the situation for the PPB in that it broadens the tectonic possibilities.

Conclusions

Trace element characteristics of PPB granitoids confirm their geochemical similarity to other A-type granitoids. In terms of major elements, the PPB granitoids have affinities with both rift-related and continental epeirogenic uplift granitoids. A classification that more clearly distinguishes between RRG and CEUG is necessary for assignment of the PPB granitoids to one of these tectonic settings. Discrimination schemes based on trace elements are also not capable of defining the tectonic setting for the PPB. The difficulty in assigning a specific tectonic setting to the PPB may arise from the possibility that the regional tectonics and/or the nature of the source rocks changed during the course of the batholith's formation.

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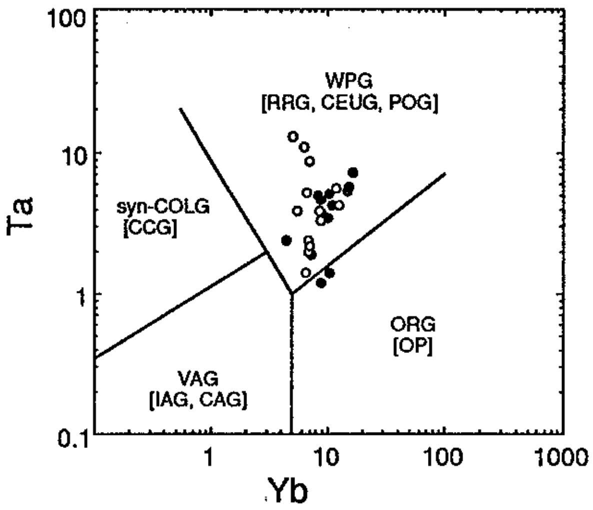

Figure 1. Ta (ppm) vs. Yb (ppm) in PPB samples. Open and filled circles are for sodic and potassic trend samples, respectively (cf. Wobus, 1976). The fields for WPG, syn-COLG, VAG, and ORG are from Pearce et al. (1984); tectonic classifications of granitoids given by Maniar and Piccoli (1989) are indicated in brackets (see text for further discussion).

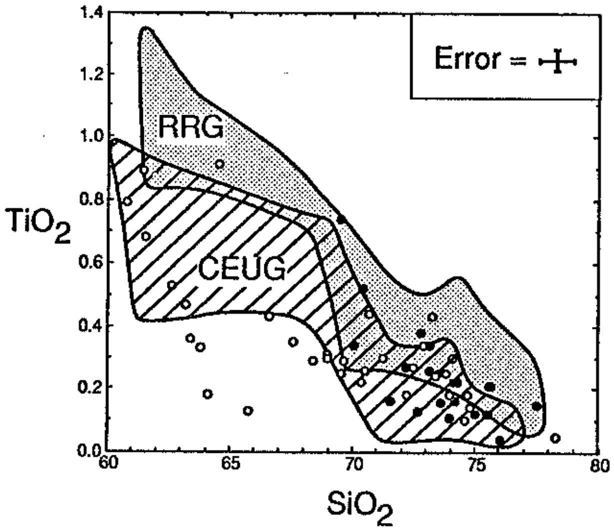

Figure 3. TiO_2 (wt. %) vs. SiO_2 (wt. %) in PPB samples. Fields for RRG and CEUG are from Maniar and Piccoli (1989). Symbols as in Figure 1.

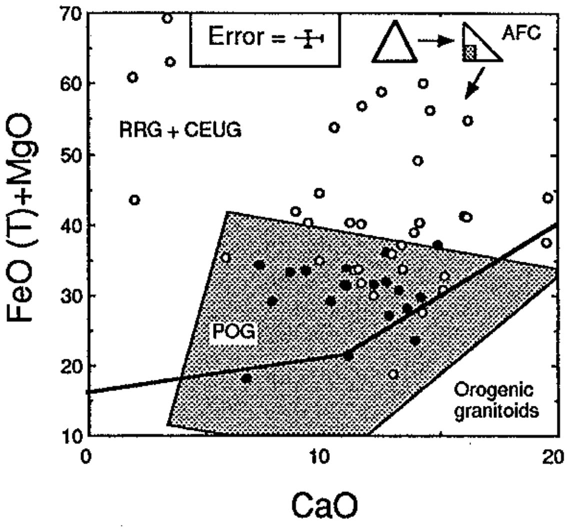

Figure 2. [FeO(T) + MgO] (wt. %) vs. CaO (wt. %) in PPB samples (after Maniar and Piccoli, 1989). The boundary between RRG + CEUG and orogenic granitoids and the field for POG are given by Maniar and Piccoli (1989). Symbols as in Figure 1.

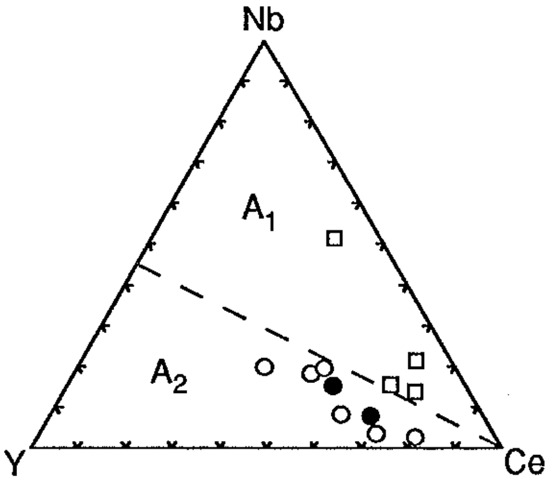

Figure 4. Nb-Ce-Y ternary used in discriminating between A_1 and A_2 granitoids (after Eby, 1992a). PPB samples include syenites (open squares), riebeckite and fayalite granites (open circles), and potassic granites (filled circles).