Chemical subdivision of the A-type granitoids: Petrogenetic and tectonic implications

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ABSTRACT

The A-type granitoids can be divided into two chemical groups. The first group (A_1) is characterized by element ratios similar to those observed for oceanic-island basalts. The second group (A_2) is characterized by ratios that vary from those observed for continental crust to those observed for island-arc basalts. It is proposed that these two types have very different sources and tectonic settings. The A_1 group represents differentiates of magmas derived from sources like those of oceanic-island basalts but emplaced in continental rifts or during intraplate magmatism. The A_2 group represents magmas derived from continental crust or underplated crust that has been through a cycle of continent-continent collision or island-arc magmatism.

INTRODUCTION

Since the introduction of the term "A-type granitoid" (Loiselle and Wones, 1979) into the geological literature, this particular class of granitoids has generated a great deal of discussion. Much of this discussion has revolved around the question of whether these granites should be considered a separate group and what criteria should be used to distinguish between A-type and other types of granitoids. In the tectonic discriminant-diagram scheme of Pearce et al. (1984), the A-type granitoids are equivalent to within-plate granites. Collins et al. (1982) proposed that the A-type granitoids could be identified on the basis of their high Ga/Al ratios, and Whalen et al. (1987a) used this ratio as a basis for a number of A-type granitoid discriminant diagrams. Sylvester (1989) distinguished a class of granites that he referred to as postcollisional A types. Maniar and Piccoli (1989) subdivided the anorogenic granites into several classes and separated them from the postorogenic granites. Rogers and Greenberg (1990) considered the A-type granites to consist of postorogenic, anorthosite-rapakivi, and ring-complex subtypes. As part of a review of the geologic setting, geochemistry, and mineral content of the A-type granitoids, Eby (1990) suggested that several chemical subgroups of A-type granitoids could be recognized and that these subgroups were petrogenetically significant. Creaser et al. (1991) proposed that the term "A-type" granitoid be abandoned because, as defined, it conveyed a different meaning from the other members (I, M, and S) of the granite alphabet soup and that, as previously proposed by Collins et al. (1982), A types be considered a subtype of the I types. In this paper, further consideration is given to the question of A-type nomenclature and the petrogenetic significance of the various chemically defined A-type groups.

A-TYPE GRANITOID SUBDIVISION

The A-type granitoids can be chemically divided into two groups according to data presented in a recent review paper (Eby, 1990). In terms of element ratios, one group shows certain similarities to oceanic-island basalts whereas the other group has certain similarities to average crust and island-arc basalts. The granites of the first group were emplaced during intraplate rifting, usually with abundant coeval mafic rocks, or as the result of inferred plume or hotspot activity. The granites of the second group represent a much broader range of environments and include postcollisional granites and those that were emplaced at the end of a long period of apparently high heat flow and granitic magmatism. Although this division is strictly chemical, there does seem to be a correlation between the chemical characteristics and the inferred environments of emplacement.

From a relatively large data base, representative (and, I hope, geologically unambiguous) examples have been chosen to define the two groups. For group 1 the following have been selected as representative of a rift environment: Naivasha, East African Rift system (MacDonald et al., 1987); Zomba-Malosa, Chilwa province, Malawi (Woolley and Jones, 1987); Yemen rift (Capaldi et al., 1987); and the Eastern Trans-Pecos magmatic province, Texas (Nelson et al., 1987). As representative of a hotspot or plume environment the following have been selected: White Mountain batholith, New Hampshire (Eby et al., 1992); Kaerven complex, East Greenland (Holm and Praegel, 1988); Ras ed Dom complex, Sudan (O'Halloran, 1985); and Velasco, Bolivia (Fletcher and Beddoe-Stephens, 1987). For group 2 the following have been selected as representative of the postcollisional or postorogenic environments: Gabo and Mumbulla, Lachland fold belt, Australia (Collins et al., 1982); Topsails complex, Newfoundland (Whalen et al., 1987b); Habd-Aldyaheen, Arabian Peninsula (Radain et al., 1981); Malani suite, northern India (Eby and Kochhar, 1990); Narraburra granite, Lachland fold belt (Wormald and Price, 1988); and subalkalic-peralkalic rhyolites of the southern British Caledonides (Leat et al., 1986). The rapakivi granites are also members of this second chemical group, and a rapakivi suite (Suomenniemi complex) from Fennoscandia (Ramo, 1991) is included as an example.

Although some of the selected suites are bimodal (Naivasha, Yemen, Trans-Pecos, and southern British Caledonides), in most cases mafic rocks are absent or of only minor significance. Petrographically the rocks classified as A-type granitoids include quartz syenites, subalkalic-peralkalic granites, rhyolites, and comendites.

In terms of commonly used chemical discriminant diagrams (Fig. 1), all of the selected suites are A types. Element-ratio plots (Fig. 2) show that the two groups form two distinct clusters, one with ratios similar to oceanic-island basalts (A_1 group) and the other with ratios between average continental crust and island-arc basalts (A_2 group). Some other element-ratio diagrams and triangular diagrams, utilizing the incompatible elements Rb, Ce, Y, Nb, Zr, Hf, Th, and Ga, also successfully discriminate between the two A-type groups. Examples of these discriminant diagrams are shown in Figures 3 and 4. A complete listing of the data used to construct these diagrams and the complete set of diagrams can be obtained from me. These A_1 and A_2 discriminant diagrams should only be used for granitoids that plot both in the within-plate granite field of Pearce et al. (1984) and the A-type granitoid field of the Ga/Al plots of Whalen et al. (1987a).

DISCUSSION

The diagrams constructed in the previous section depend to a large extent (as in fact do many of the tectonic discriminant diagrams) on the relatively constant character of the Y/Nb and Yb/Ta ratios. During the evolution of most magmas, fractional crystallization of clinopyroxene and amphibole will lead to a decrease in these ratios. This effect can be calculated by using known partition coefficients. Such a calculation, using the average partition coefficients reported in Henderson (1982), indicates that 50% fractional crystallization involving only clinopyroxene and amphibole will lead to a factor of 2 decrease in these ratios for mafic magmas and a factor of 3 decrease in these ratios for felsic magmas. These are undoubtedly extreme cases, and the effect would not be as large in most magmatic systems. The crystallization of various opaque phases that have partition coefficients greater than 1 for Nb and Ta (Green and

Pearson, 1987) could lead to an increase in these ratios, but, given the small amounts of these phases in the granitoids, the effect is probably insignificant. The crystallization of certain minor phases such as allanite and zircon (see Eby, 1990, for a more complete discussion) can also have an impact, but this is generally a late-stage event that can be distinguished.

The Y/Nb and Yb/Ta ratios can also be changed if the magma interacts with the continental crust. As a general rule, A-type granitoid magmas have higher absolute trace-element abundances than normal continental crust. Thus, significant amounts of continental crust would have to be assimilated to produce significant changes in the ratios. This effect has been quantitatively considered in the case of the White Mountain batholith (Eby et al., 1992), where it was shown that up to 15%–20% assimilation of continental crust produced only minor variations in these ratios. However, it is prudent, when possible, to consider both isotopic and trace element data in attempting to classify A-type granitoids on the basis of trace element compositions. This is particularly important in the case of the A_1 group because continental crust has Y/Nb and Yb/Ta ratios of 2 or greater (Taylor and McLennan, 1985), so that interaction of the magma with the crust could move these ratios out of the A_1 field.

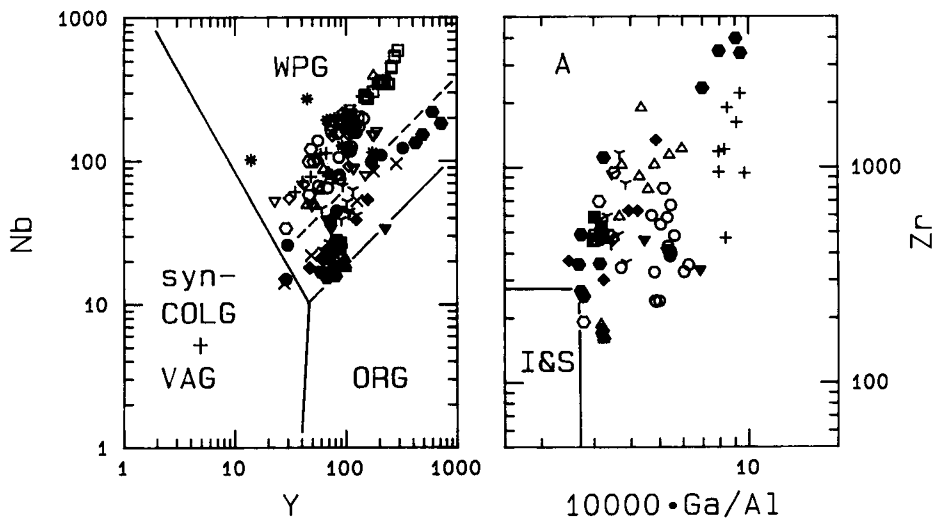

Figure 1. Selected A-type suites plotted on Y vs. Nb tectonic discriminant diagram of Pearce et al. (1984) and Ga/Al vs. Zr A-type discriminant diagram of Whalen et al. (1987a). A_1 granitoids from rift, plume, and hotspot environments—open symbols, plus sign and asterisk, respectively. A_2 granitoids from postcollisional, postorogenic, and anorogenic environments—solid symbols, X, and Y, respectively. WPG—within-plate granites; COLG—collisional granites; VAG—volcanic-arc granites; ORG—ocean-ridge granites; I & S—I-type and S-type granites.

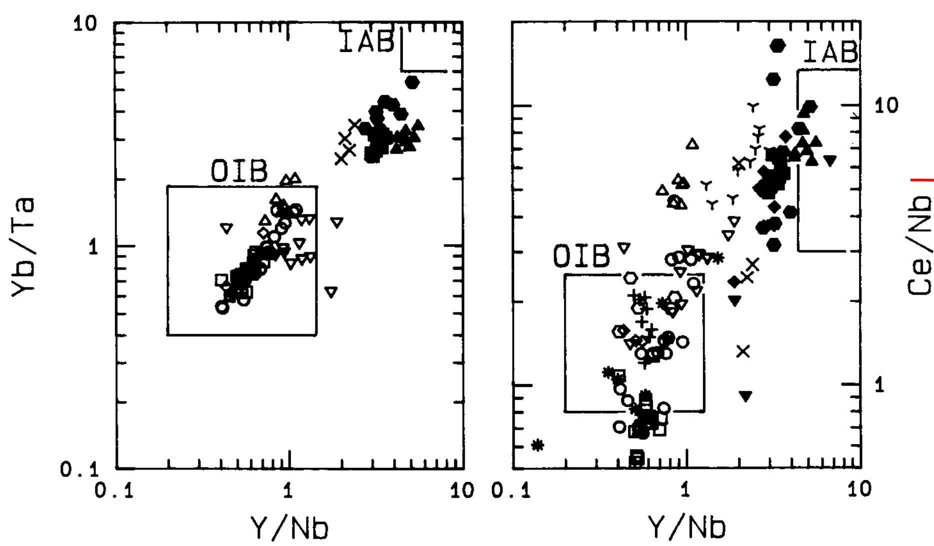

Figure 2. Yb/Ta vs. Y/Nb and Ce/Nb vs. Y/Nb plots for various A-type granitoid suites. A_1 group plots within or near oceanic-island basalt (OIB) field, suggesting a source for these granitoids similar to that of oceanic-island basalts. A_2 group plots along a trend extending from average continental crust to island-arc basalts (IAB), suggesting that the sources from which these granitoids were extracted were originally formed by subduction or continent-continent collision. OIB and IAB fields are from Eby (1990). Symbols as in Figure 1.

Given that two groups of A-type granitoids can be chemically distinguished, what is the significance of the observation? Low Y/Nb and Yb/Ta ratios are invariably associated with silica-undersaturated to silica-saturated mafic rocks emplaced in intraplate or rift settings. In cases such as the White Mountain igneous province (Eby et al., 1992) these mafic rocks can be linked directly to the more highly evolved silica-rich rocks. Thus, it seems reasonable to conclude that the A_1 group represents mantle differentiates (contaminated to a greater or lesser degree by continental crust) from the same types of sources that produce oceanic-island, intraplate, and rift-zone magmas. The A_2 group plots in the region of continental margin and island-arc basalts. Thus, it is suggested that this group may be related to processes or the results of the processes that form these types of magmas. The A-type granitoids that have received most of the attention in the geological literature, and on which experimental work has been conducted (see, for example, Collins et al., 1982; Clemens et al., 1986), are found in this group. Thus, it is the A_2 group that has served to develop the model of A-type granite formation by the partial remelting of a part of the lithosphere from which a previous melt had been extracted. As an alternative model, Creaser et al. (1991) proposed that at least some A-type magmas are generated by melting of crustal igneous rocks of tonalitic to granodioritic composition. In either case, the pattern to the trace element ratios suggests that the partially melted lithosphere was originally produced by continental margin or island-arc magmatism. Although both of these models presume that the magmas were derived by partial melting of crustal materials, it is not possible on the basis of the trace element data to rule out a subcontinental mantle source for some of these A-type magmas.

Whalen et al. (1987a) have previously considered the possibility that A-type granitoids represent highly fractionated I-type magmas, and they have attempted to discriminate between these two possibilities by using various chemical criteria. If the A-type granitoids were highly fractionated I types, then the observed enrichment in trace elements would be a function of the degree of fractional crystallization. In granitic systems the feldspars would be among the most important minerals in any fractional crystallization scheme, and the size of the negative Eu anomaly would be a measure of the degree of feldspar fractionation. For the suites considered in this paper, plots have been constructed of various element ratios and element abundances vs. Eu/Eu*. One of these sets of plots is illustrated in Figure 5. Note that for any degree of feldspar fractionation (as measured by the Eu/Eu* ratio), the A-type granitoids tend to be enriched in Th and have higher Ga/Al ratios than the I- and S-type granitoids. In addition, although there is a tendency for the suites having low Eu/Eu* ratios to be enriched in Ga and Th, the regular trend that might be expected if this was due solely to fractional crystallization is not observed. Other plots utilizing the Eu/Eu* ratios show similar patterns. Thus, it seems unlikely that the A-type granitoids used as examples in this paper are simply highly fractionated I-type magmas. There may, however, be cases where extensive fractional crystallization can lead to residual magmas having trace element abundances typical of A-type granitoids. Plots involving the Eu/Eu* ratio may be useful in identifying these cases, in that regular trends of increasing enrichment in incompatible elements with an increase in the size of the negative Eu anomaly might be expected.

TECTONIC DISCRIMINANT DIAGRAMS

As for the other granite types, attempts have been made to relate the chemically defined A-type granitoids to tectonic environment. Given the wide range of geologic settings in which the chemically defined A-type granitoids can be found, such a correlation is of questionable value. The A_1 group seems to offer the best hope in that all of the examples of which I am currently aware are related to hotspots, plumes, or continental rift zones located in anorogenic settings. However, there seems to be no chemical difference between magmas emplaced in continental rift zones (e.g., East African Rift) and those emplaced in regions of crustal doming (e.g., White Mountain igneous province). The A_2 group contains granitoids emplaced in a variety of tectonic settings, including postcollisional and what may be true anorogenic magmatism, as exemplified by the rapakivi granites. At present there seems to be no way to chemically distinguish between these tectonic possibilities. What the chemical data do seem to imply is that these magmas were generated from crust that had been through a cycle of subduction-zone or continent-continent collision magmatism.

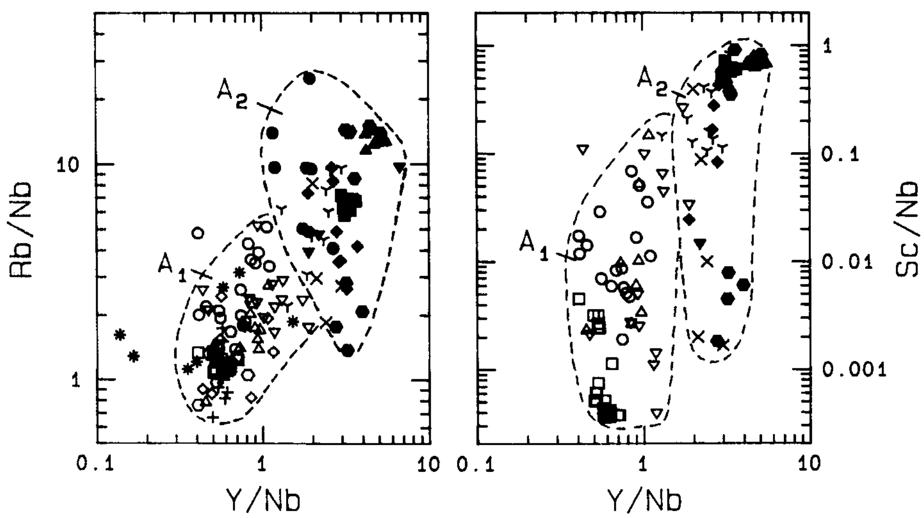

Figure 3. Rb/Nb vs. Y/Nb and Sc/Nb vs. Y/Nb plots for various A-type granitoid suites. A_1 and A_2 groups form distinct fields in both of these diagrams. Same symbols as in Figure 1.

ALPHABET SOUP

Creaser et al. (1991) have quite correctly raised the point that there is an incompatibility between the A and the I, S, and M classifications. They proposed, as did Collins et al. (1982), that the A type be considered a subtype of the I. If we follow the reasoning of Creaser et al. (1991), then the two A-type granitoid groups defined in this paper would be assigned as follows: the A_1 group would be considered a subtype of the M, because it apparently has a mantle origin, and the A_2 group would be considered a subtype of the I because it has an apparent crustal(?) source that is not metasedimentary. This scheme is not entirely satisfactory because it is possible that some of the A_2 granit-

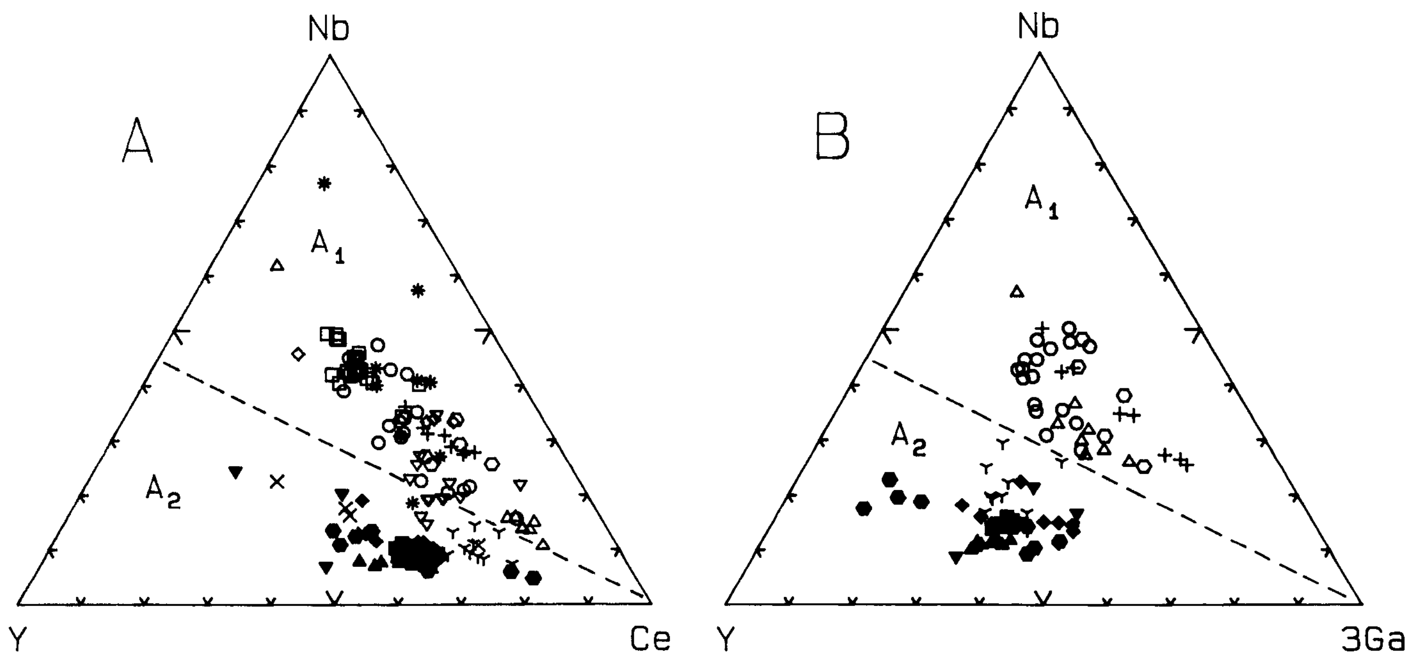

Figure 4. Representative triangular plots for distinguishing between A_1 and A_2 granitoids. On both diagrams, dashed line corresponds to Y/Nb ratio of 1.2. Symbols as in Figure 1.

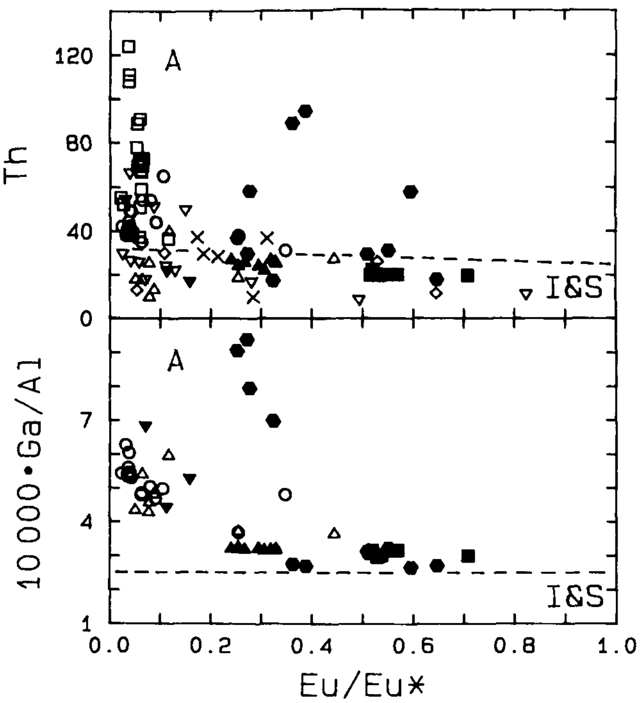

Figure 5. Variations in Ga/Al and Th as function of size of negative Eu anomaly (Eu/Eu*). Most suites plot in A-type field, and, except in the case of very large negative Eu anomalies, there is no apparent correlation between size of Eu anomaly and Ga/Al ratio or Th abundance. Data used to construct boundary of I-type and S-type (I&S) granite field are from sources in Eby (1990), Pearce et al. (1984), Vogt and Flower (1989), and unpublished data of Eby and Currie for New Brunswick granitoids. Symbols as in Figure 1.

oids have a mantle origin and the A_1 granitoids apparently are derived from a very specific type of mantle source.

Although the term A-type, as currently defined, does not fit the I, S, and M classification scheme, at least chemically we can define a rather diverse group of granitoids that can be grouped under this designation. These granitoids apparently form in a variety of ways, not all of which are necessarily confined to an anorogenic environment, but they represent a group of mineralogically distinct and economically important granitoids distinguishable from those normally included in the I, S, and M types. Thus, it is proposed that the term "A-type granitoid" be retained, recognizing that there are at least two, if not more, distinct types of granitoids within this classification. This subdivision of the A-type granitoids is proposed in the spirit of focusing research on the differences among members of this class of granitoids with the ultimate goal of constructing a more useful classification scheme.

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