ANDEAN ADAKITES FROM SLAB MELTING, CRUSTAL THICKENING, AND FOREARC SUBDUCTION EROSION

Suzanne MAHLBURG KAY (1)

(1) Snee Hall, Cornell University, Ithaca, NY, 14853, USA, smk16@cornell.edu

KEYWORDS: Andes, adakites, magmatism, slab melting, subduction erosion, crustal thickening

Neogene Andean magmas with chemical characteristics of adakitic magmas as defined by Defont and Drummond (1990) are common in the Central Andes. Their high-pressure source mineralogy as signaled by trace element characteristics (steep REE patterns, low heavy REE and high Sr contents, etc.) can be produced in at least three ways. In order of descending importance, these are subduction of young oceanic crust, subduction-erosion of forearc crust, and tectonic thickening of the Andean crust. Melting of old subducting oceanic crust in shallow subduction zones (Gutcher et al. 2000) is not required. The origins of adakitic magmas are best deciphered by matching them with specific tectonic conditions and events along the evolving Andean margin (Fig. 1).

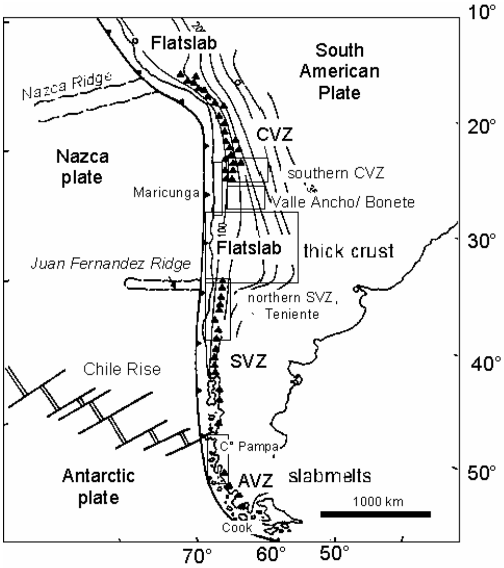

Figure 1. Map of southern and central Andes showing regions referred to in text.

Some of the most convincing Phanerozoic slabmelts on Earth are found among the Neogene to Recent adakitic magmas in the southernmost Andes. The two most convincing cases are lavas erupted at the Recent Mt. Cook center in the southernmost Austral Volcanic Zone (see Stern and Kilian 1996) and at the ~ 12 Ma Cerro Pampa center, which is located east of where the Chilean Rise collided with the Chile trench at ~ 12 Ma (see Kay et al., 1993). The combination of low $^{87}Sr/^{86}Sr$ ratios (~ 0.7028; Fig. 2), extreme Sr concentrations (>1000 ppm; Fig. 3), and steep REE patterns (La/Yb ~ 30; Fig. 4) in these adakites is difficult to explain in other contexts as is the case for the first proposed Neogene slabmelt at Adak Island in the Aleutian arc in Alaska (Kay, 1878). Slab melting in southern Patagonia is further supported by thermal models for young subducting oceanic plates (Peacock et al, 1994). The Cook and Cerro Pampa adakites contrast with other proposed slabmelts in the AVZ whose higher $^{87}Sr/^{86}Sr$ ratios > 0.705 (Fig. 2) can be explained by crustal contamination of melts from the young subducting Antarctic plate (Kay et al. 1993; Stern and Kilian, 1996).

In contrast to southern Andean adakites, Central Andean magmas with adakitic characteristics have

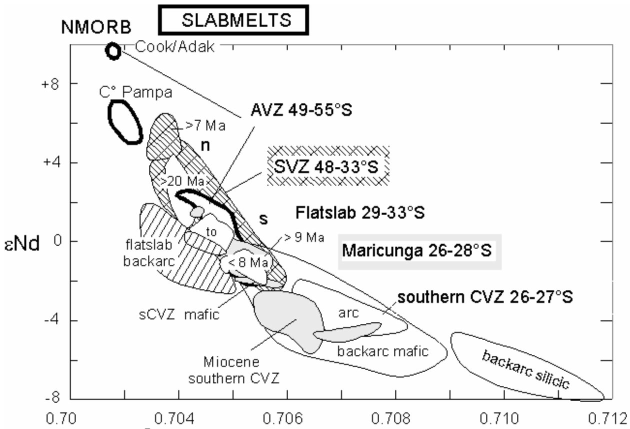

Figure 2. Plot of Nd and Sr isotopic ratios in Miocene to Recent magmas showing characteristics of slabmelt adakites versus those erupted through thickened crust in the central Andes. Data from Stern and Kilean (1994), Kay (1978), Kay et al. (1991, 1993, 1994, 1999, 2002), Hildreth and Moorbath (1988) and sources cited in those papers.

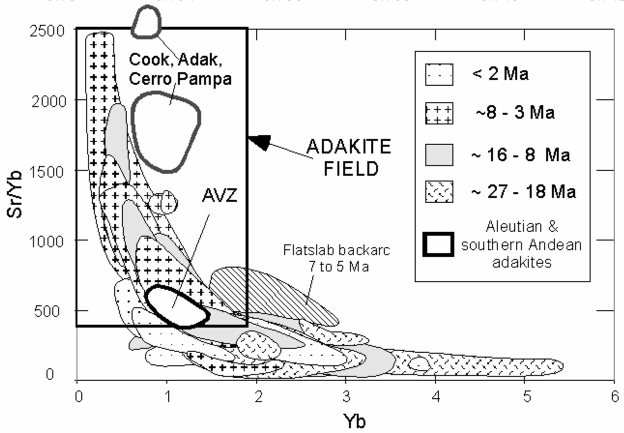

Figure 3. Plot of Sr/Yb ratio versus Yb concentration in ppm for Miocene to Recent magmas showing characteristics of well established slabmelt adakites (Cook, Adak, Cerro Pampa) relative to other central and southern Andean magmas. Graph is one of the discriminants for slabmelt adakites employed by Defant and Drummond (1990). The plot illustrates the increased importance of Andean magmas with adakitic characteristics in the middle to Late Miocene and early Pliocene. This increase correlates with increasing thickness of the Andean crust and frontal arc migration, rather than subduction of hot, young oceanic crust. Data sources as in Figure 2.

erupted over older, colder portions of the subducting Nazca plate. None have the depleted isotopic signatures of the Cook and Cerro Pampa adakites (Fig. 2), and all have lower Sr contents (Fig. 3). A significant number have steeper REE patterns. Their adakitic characteristics are better attributed to partial melting of granulitic to eclogitic facies continental crust. This crust can be added as contaminants in mantle-derived mafic magmas at the base of tectonically thickened crust (e.g., Kay et al., 1991, 1999) or can be incorporated into the mantle wedge as forearc crust removed by the subduction erosion processes (e.g., von Huene and Scholl, 1991; Stern, 1991, Ranero and von Huene, 2000). The chemical characteristics of these two groups are better matches for Archean TTG suite magmas with La/Yb ratios over 100 than are southern Andean slab melts.

Neogene to Recent adakites in the Andean Central Volcanic Zone (CVZ), northern Southern Volcanic Zone (SVZ), and over the Chilean flatslab (Fig. 1) have erupted through crust which has been thickened by structural shortening of ductile crust under compression. Partial melting at the base of this crust in association with injection of mantle-derived basaltic arc magmas in a high-pressure MASH (melting, assimilation, storage and homogenization – Hildreth and Moorbath, 1988) zone leads to magmas with adakitic characteristics. This process is supported by temporal correlations of deformation in foreland fold/thrust belts with eruption of adakitic magmas whose isotopic ratios are best explained by crustal contaminants (e.g., see Kay et al. 1991, 1999, 2002; Figs. 2 to 4). At the extreme, backarc southern Puna Antofalla region adakites with extreme REE characteristics (La/Yb to 100, Sm/Yb > 8; see Fig. 4) are associated with melting of over thickened lower crust that became negatively buoyant relative to the underlying mantle (Kay et al. 1994). Rapid sinking ("delamination") of this gravitationally unstable granulitic to eclogitic crust along with the underlying mantle lithosphere produced a void in the mantle wedge that was filled by asthenosphere. Mafic magmas with intraplate like chemical signatures that segregated in this asthenosphere caused transient heating and partial melting of the crust, including the delaminating lower crust. These melts left eclogitic residues that are denser than the pre-existing (unmelted) lower crust.

Evidence that forearc crust incorporated into the mantle through the forearc subduction erosion (see von Huene and Scholl 1991; Stern 1991) process also plays a role in producing Andean adakitic signatures comes from correlations of eastward migrations of the arc front with abrupt changes in magmatic geochemistry, including the transient appearance of distinctive adakitic signatures at times of arc migration (Kay and Mpodozis, 2000, 2002; Kay et al. 2002). During arc front migrations, peak periods of subduction erosion bring

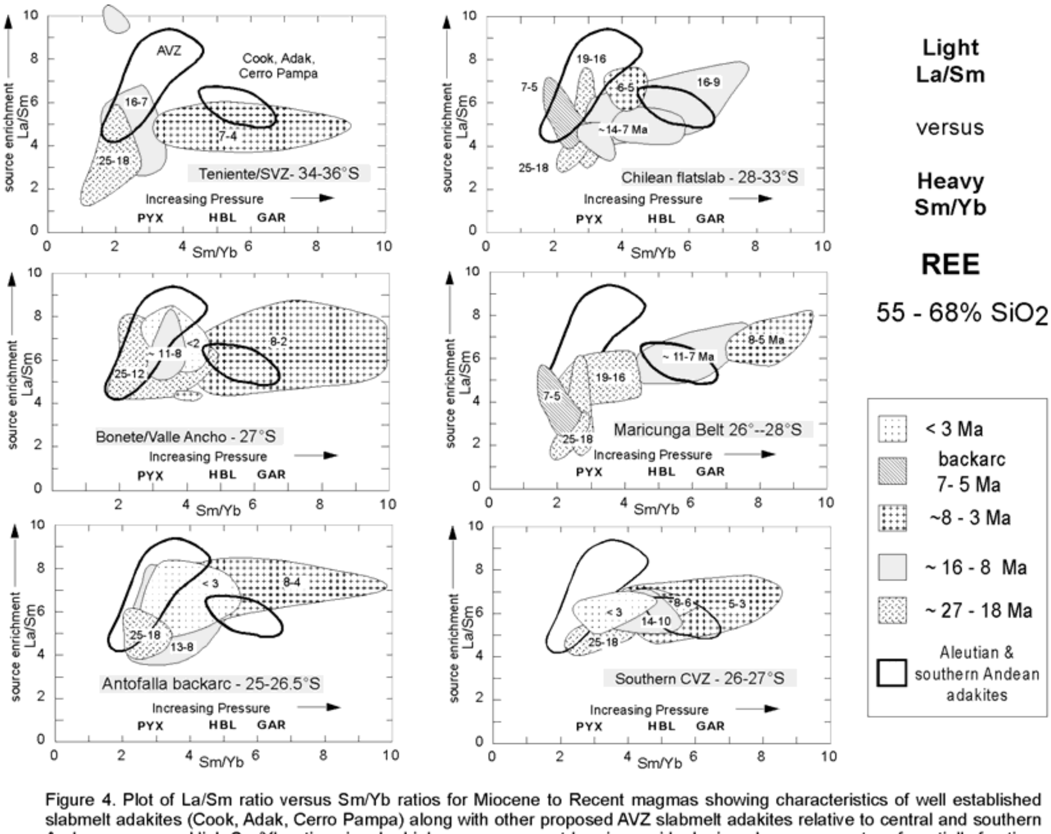

Figure 4. Plot of La/Sm ratio versus Sm/Yb ratios for Miocene to Recent magmas showing characteristics of well established slabmelt adakites (Cook, Adak, Cerro Pampa) along with other proposed AVZ slabmelt adakites relative to central and southern Andean magmas. High Sm/Yb ratios signal a high pressure garnet-bearing residual mineralogy as garnet preferentially fractionates the heavier REEs leading to relatively high Sm/Yb ratios. As in Figure 3, plot illustrates the increased importance of Andean magmas with adakitic characteristics in the middle to Late Miocene and early Pliocene coincident with increasing thickness of the Andean crust and frontal arc migration. As the highest Sm/Yb ratios tend to occur in the most silicic magmas, the garnet signature is a signal of a higher pressure residual crustal mineralogy. Localities shown in Figure 1. Data sources as in Figure 2.

forearc basal crustal material (not only sediment) to high-pressure under the arc, where this transformed granulitic to eclogitic faces crust melts to produce the adakitic signature. The most extreme examples are dacites with ratios of $^{87}Sr/^{86}Sr$ > 0.705, La/Yb up to 100, Sm/Yb > 6 (Fig. 4), and La/Ta up to 80 that erupted as volcanism waned in the Maricunga arc near 26° to 28°S and before the frontal arc was reestablished in the CVZ to the east. Other extreme examples are magmas erupted as volcanism ceased in the southernmost CVZ in the Bonete region near 28°S. Distinctive adakitic magmas are also associated with frontal arc migration at 20 to 16

Ma and at 8 to 4 Ma over the Chilean flatslab and in the northern SVZ (Kay et al. 2002). As crustal thickening accompanied arc migration, these adakites also contain partial melts of thickened continental crust.

In conclusion, most Miocene to Recent central and southern Andean adakites are still best explained by equilibration of mantle wedge derived arc magmas with garnet-bearing continental crust rather than by melting of subducted oceanic slabs. Strong support comes from the positive temporal correlation between the abundance of Central Andean adakitic magmas (Figs. 3 and 4) and patterns of crustal thickening and eastward arc front migration. Marked increases in adakitic magmas at about 19 to 16 Ma and again at 8 to 4 Ma can be correlated with peaks in crustal thickening and forearc subduction erosion that are most likely linked with changes in convergence parameters between the Nazca and South American plate.

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