Forum

Dubious case for slab melting in the Northern volcanic zone of the Andes: Comment and Reply

COMMENT

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Recently, Garrison and Davidson (2003) questioned the possibility that the adakites of the Northern volcanic zone of the Andes were generated by slab melting. The conclusions of the authors, involving a lower-crustal source for adakites, are in clear contradiction with ideas already proposed for the Northern volcanic zone and have implications not only for the understanding of the petrogenesis of this particular province but also more generally for adakite genesis. Based on a databank significantly wider than the one presented by Garrison and Davidson (2003), we observe different geochemical patterns, which lead to different conclusions.

The volcanic arc of Ecuador consists of three volcanic chains, which are clearly identified on the basis of geological, geochemical, and isotopic data. The western Volcanic Front and the Main Arc form the major chains, whereas backarc volcanism builds a smaller chain in the east. As a whole, volcanics consist of medium-K andesites and dacites, and subordinate rhyolites. Our databank consists of major and trace elements analyzed in ~1650 samples from 40 volcanoes, between latitudes 2.5°N and 2°S. Adakitic character is found in many volcanoes from the Main Arc and in almost all the edifices from the Front Arc (Bourdon et al., 2003). Moreover, Samaniego et al. (2002) showed that magmas in a single edifice changed in geochemical characteristics through time (from classical calc-alkaline to adakitic; e.g., Cayambe), reflecting the start of subduction of the Carnegie Ridge.

The samples used by Garrison and Davidson (2003) are almost exclusively from the Main Arc, and their study does not take into account these temporal constraints. Thus, the data set used by Garrison and Davidson is not representative of the Northern volcanic zone as a whole.

Garrison and Davidson (2003) assert that none of the Northern volcanic zone samples shows high-Mg andesite, yet high-Mg andesites have been found in several volcanoes of the Front Arc (e.g., Pichincha; Bourdon et al., 2003). If it is accepted that due to their high-MgO, Ni, and Cr contents, such rocks cannot be direct slab melts, geochemical and experimental work has shown that they can represent slab melts re-equilibrated with the mantle (Rapp et al., 1999). Consequently, we consider that the Mg, Ni, and Cr enrichments observed in some of the Northern volcanic zone lavas demonstrate adakitic melt–mantle peridotite interactions. Such exchanges may occur *only* if adakite source is located under a mantle slice, thus in the subducting slab (Martin and Moyen, 2002).

Garrison and Davidson (2003) use Sr/Y and silica contents to refute slab melting. The authors note that the Northern volcanic zone rocks overall have low Sr/Y ratios and stress that the highest values are from Sangay, a volcano of the Main Arc, precisely located above a dipping slab and probably not related to slab melting (Monzier et al. [2003] noted that high Sr/Y values at Sangay result more from strong Sr enrichment than marked Y depletion). In addition, their model implies predicted Sr/Y values higher than 100 for adakites in Ecuador. This is not in agreement with the original definition: adakites have Sr/Y values higher than 40, whatever the geodynamic situation (Defant and Drummond, 1990).

Moreover, the SiO_2 range of "putative slab melts" is assumed to represent the silica content of primary magmas produced in front of the Carnegie Ridge. Such an assumption should be valid only if all magmas represent true primary melts. However, fractional crystallization is an efficient process able to strongly modify silica content of magmas (including in the Northern volcanic zone). Consequently, silica definitely appears to be an inappropriate geochemical feature to distinguish slab melts.

Garrison and Davidson (2003) also argue that the lack of unequivocal geochemical variation along the arc excludes slab melting. However, data recently presented (Monzier et al., 2003) show systematic geochemical variation along the arc, all showing a negative or positive peak between 0.5°N and 1°S. Among those, Y and La/Yb display clear minimums and maximums, respectively, precisely where the Carnegie Ridge is subducting (Fig. 1). Such behavior reflects the intervention of slab melts in the petrogenesis of the magmas, directly related to the subduction of the Carnegie Ridge.

We agree with the Garrison and Davidson (2003) conclusion that the magma geochemical signature characterizes the source and not any specific geodynamic environment. The presence of adakites only indicates hydrous basalt melting, with a garnet ± amphibole residue. In Ecuador, the close spatio-temporal association of adakites, high-Mg andesites, adakite-like lavas, and high-Nb basalts (from front arc to backarc; Bourdon et al., 2003) is strong evidence of adakitic melt–mantle peridotite interaction, thus also pointing to slab melting.

The paper by Garrison and Davidson (2003) emphasizes the risk of making assumptions about regional geochemical variations based on an incomplete data set. Although discerning between slab and lower-crustal melting is challenging, we believe that Northern volcanic zone lava geochemical variations (across and along the arc) are best accounted for by slab melting beneath Ecuador. To discuss the petrogenesis of such a complex volcanic arc and try to approach the origin of its magmas, one needs to consider more than three geochemical characteristics (SiO_2 being extremely weak). Only an exhaustive geochemical data set is able to show definitively the existence, or lack, of spatial and/or temporal variations.

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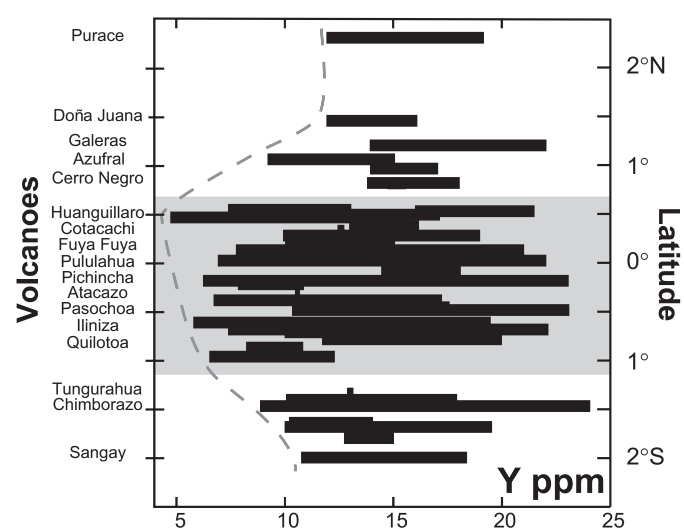

Figure 1. Variations in Y concentrations in Quaternary volcanic rocks of the Northern volcanic zone between 2.5°N and 2.5°S.

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REPLY

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The arguments presented by Bourdon et al. are threefold: (1) our data set is not representative of the Northern volcanic zone, (2) the presence of high-Mg andesites is unambiguous evidence of slab–mantle wedge interaction, and (3) SiO_2 and Sr/Y variations require slab melting. We address each issue in turn below, as well as reemphasizing our main points: (1) that the geodynamic setting of the Northern volcanic zone is not suitable for producing adakites, particularly given geophysical evidence that the slab beneath Ecuador dips 25° (Guillier et al., 2001), and (2) we do not exclude slab melting in the Northern volcanic zone, we simply make the point that identification of slab melts based on geochemical criteria alone is a fallacious and inadequate approach, and that any such signature in the Northern volcanic zone is weak at best.

While our data set is indeed smaller, it includes all data that were published for the Northern volcanic zone at the time of submission, from north to south (i.e., Galeras to Sangay), as well as west to east (i.e., Atacazo to Sumaco). It is of course regrettable that the large data set accumulated over several years available to Bourdon and colleagues is not available to other researchers. We maintain that our abbreviated set is representative of the Northern volcanic zone, as it includes representative volcanoes from what Bourdon et al. consider to be three volcanic chains. Our goal was to construct a geochemical traverse of the Northern volcanic zone, which spans the range of the alleged subducting Carnegie Ridge, and for this purpose our data set is sufficient. Using a larger databank does not make the slab melting argument more convincing; indeed Bourdon et al.'s Figure 1 shows volcanoes at the same latitude with both high- and low-Y concentrations. Slab melting would be expected to produce ubiquitous "adakitic" signatures over a significant length of arc. The temporal constraints for Cayambe volcano do not necessarily reflect subduction of the Carnegie Ridge, particularly since there are no time constraints on when, and even if, the Carnegie Ridge was subducted, a point which was made in our original paper. It is worth pointing out here that the original slab melting hypothesis for the Northern volcanic zone (Gutscher et al., 2000) was based on geochemistry, not geophysics, so using geochemistry as evidence for slab melting is circular. In fact, there is no geophysical evidence for slab melting, and the evidence for the alleged "flat slab" is equivocal at best.

As for high-Mg andesites at some Northern volcanic zone volcanoes, we specifically stated in our paper that none of the published data included high-Mg andesites. As this is now an issue, we point out that of the eight data points (representing three volcanoes: Pinchincha, Antisana, and Sumaco) used to argue for slab melting in the Northern volcanic zone (Bourdon et al., 2003), only three of these have unusual Mg#s, and these range from only 0.32 to 0.40. These are not particularly high compared to the values of 0.45–0.65 for Archean TTGs (tonalite-trondhjemite-granodiorite), which we agree are most likely due to eclogite melting (Drummond and Defant, 1990). In fact, the lack of widespread high-Mg andesites in the Northern volcanic zone argues against models of slab melting, since the Gutscher et al. (2000) and Bourdon et al. (2003) models predict that most andesites should be high-Mg andesites. Experimental literature (Rapp et al., 1999) shows that high-Mg andesites can be produced by slab melts that interact with the mantle wedge. This is true, but does not preclude high-Mg andesites being produced by other mechanisms, such as recycling of lower crust into the mantle wedge (Gao et al., 2003) or hydrous melting (Kushiro, 1972). Another possibility is that mixing of primitive and evolved melts, a likely process during the protracted passage through 60 km of Northern volcanic zone crust, will produce much more Mg- and Ni-rich magmas than crystal fractionation. Furthermore, if there is mantle wedge, the slab is not flat. If the slab is not flat, there is no thermal mechanism by which the slab would melt, a point that is avoided by Bourdon et al. Indeed, high-Mg andesites are in danger of suffering the same fate as adakites (that is high Sr/Y rocks) in that they are used as evidence of slab melting. This argument is based only on geochemical signature and effectively circumvents the issue of the viability of slab melting.

In our paper, we show that the Sr/Y signature that characterizes slab melting can also be produced by crystal fractionation and through melting of hydrated metamorphosed basalt in the lower crust. We do not argue that Sr/Y values above or below 100 exclude slab melting, and in fact we never exclude the possibility of slab melting in the Northern volcanic zone. We simply present a logical case to show that the geochemical evidence for slab melting is highly equivocal, and that the geodynamic setting is not suitable. The arguments presented by Bourdon et al., criticizing our use of Sr/Y and SiO_2, underscore this point, that the use of Sr/Y as the sole indication of slab melting is problematic, which is precisely why we presented these data in conjunction with the overall geodynamic setting in the Northern volcanic zone, a point that remains uncontested. Bourdon et al.'s Figure 1 does not show that Y concentrations are lowest above the alleged trace of the Carnegie Ridge, only that they are more variable.

We maintain that the geodynamic setting of the Northern volcanic zone is not conducive to the formation of adakites. The geochemical signature that would be expected from slab melting is weak at best, and could have been produced by many different igneous processes. No evidence has been provided to show that the Carnegie Ridge seamount chain is actually subducting, whether it contributes any anomalous material to the wedge, or that the slab is flat. There remains no geodynamic justification for the steep-flat-steep slab geometry proposed by Bourdon et al. (2003). We reassert the conclusions made in our original paper, that regional geochemical trends in the Northern volcanic zone and their relationship to the subduction-zone architecture are not a priori indications of slab melting and can be fully accounted for by normal arc magmatic processes acting on wedge-derived basaltic magmas.

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