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 volcanics where 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 interaction. 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 SiO₂ 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 (SiO₂ 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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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) SiO₂ and Sr/Y variations require slab melting. We address each issue in
turn below, as well as reemphasizing our main points: (1) that the geochemical
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 pub-
lished 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 Suma-
co). 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 volca-
nic zone, as it includes representative volcanic rocks 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. Us-
ing a larger databank does not make the slab melting argument more convinc-
ing; indeed Bourdon et al.’s Figure 1 shows volcanic rocks 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 subduc-
tion of the Carnegie Ridge, particularly since there are no time constraints
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 (Gutser 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 melt-
ing, 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 Su-
maco) used to argue for slab melting in the Northern volcanic zone (Bour-
don 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-granodio-
rite), 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 Gutser 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 pre-
clude high-Mg andesites being produced by other mechanisms, such as re-
cycling 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 mecha-
nism 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 effec-
tively 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 exclud-
e 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 SiO₂, underscore this point, that the use of Sr/Y as the sole
indication of slab melting is problematic, which is precisely why we pre-
sented 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 pro-
vided to show that the Carnegie Ridge seaamount chain is actually subduct-
ng, 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 geothermal 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 nor-
mal arc magmatic processes acting on wedge-derived basaltic magmas.

ACKNOWLEDGMENTS

We appreciate the helpful suggestions from Dennis Geist in reviewing
this reply.

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