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Geochemistry of Cenozoic Volcanic Rocks in Tibet: Insight into Deep-crustal and Mantle Processes during the Transition from Oceanic Subduction to Continental Collision

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Continental collisional belts are commonly magmatic, despite earlier suggestions that magmatism shuts off as oceanic plates are completely consumed in convergent margin settings. How long lived are collisional arcs after collision initiation? How do magmas change, if at all, during the transition from oceanic subduction to collision?

To answer these questions, we focused on three geologic units of southern Tibet which span the transition from subduction to collision: (a) The Linzizong Formation, a 3-5 km thick volcanic-bearing succession (69 -40 Ma) within the Gangdese arc (Dong, 2002; Chung et al., 2005; Mo et al., 2007; Mo et al., 2008), (b) the Kailas Formation, an alluvial fan-lacustrine unit (20-24 Ma) that was primarily sourced from the Linzizong Formation and the Gangdese plutonic arc (Decelles et al., 2011) and (c) the Lamuka Formation, a potassic calc-alkaline volcanic unit (11-12 Ma), which unconformably overlies the Linzizong Formation and allows us to extend this study into the Neogene.

We systematically described and sampled the Linzizong, Kailas, and Lamuka formations along two transects, in the Sangsang area of south central Tibet, in an effort to produce a chemical, isotopic and chronostratigraphic section that places firmer bounds on the changing arc chemistry over time. For the Linzizong and Lamuka formation rocks, we obtained major and trace element geochemistry on these rocks as well as Sr and Nd whole-rock isotopic ratios, and U-Pb ages and Hf isotopic ratios on zircons. The Oligo-Miocene Kailas Formation add additional insight via U-Pb ages and Hf isotopic ratios on detrital zircons.

The Linzizong Formation has variable petrographic compositions from andesites to rhyolites, with rhyolites being dominant by volume. Isotopic data, εNd_i = -13.0 to +3.5 and $^{87}Sr/^{86}Sr_i$ = 0.704 to 0.754 have been reported, suggesting multiple melt sources

(Chung et al., 2005; Mo et al., 2007; Mo et al., 2008; Lee et al., 2009; Zhu et al., 2011; Lee et al., 2012). Trace element plots show typical arc patterns with enrichments of light ion lithophile elements (LIL) like Rb and Ba and depletions of high field strength elements (HFSE) such as Zr and Ti. The rare earth elements (REE) patterns are mildly depleted in heavy rare earth elements (HREE) relative to light rare earth elements (LREE) with La/Yb ratios of 3-15. Some samples show negative europium anomalies.

Miocene Lamuka Formation rocks show similar LIL and HFSE patterns to the Linzizong Formation samples. They are enriched in LIL such as Rb and Ba and depleted in HFSE like Ti and Zr. The Lamuka formation is more enriched in LIL and HFSE than the Linzizong formation (i. e. Ba 1350 ppm vs 200-500 ppm and Ti 0.9 ppm vs 0.1-0.35 ppm). The REE pattern of the Lamuka Formation shows more depletion of the HREE relative to LREE with La/Yb ratios of 50 compared to the Linzizong formation. Neither sample of the Lamuka Formation shows a europium anomaly. The rocks have Sr/Y ratios >50, placing them at the lower reaches of the adakite field.

550 detrital zircons from the Sangsang section of the Kailas formation have been dated and show that it was dominantly sourced from the Gangdese arc with the greater than 80% of ages between 100 and 37 Ma. Minor peaks (2-5 zircons) at 22 Ma, 130 Ma, 250-670 Ma are present with 20 individual zircons with Proterozoic ages. The major peaks from Late Cretaceous through the Neogene were analyzed for their Hf isotopic ratios for this study.

New isotopic data from the Sangsang area show that the Cenozoic volcanic rocks of southern Tibet show distinct changes in melt source over time and can be divided into three broad phases based on isotopic data. The first trend

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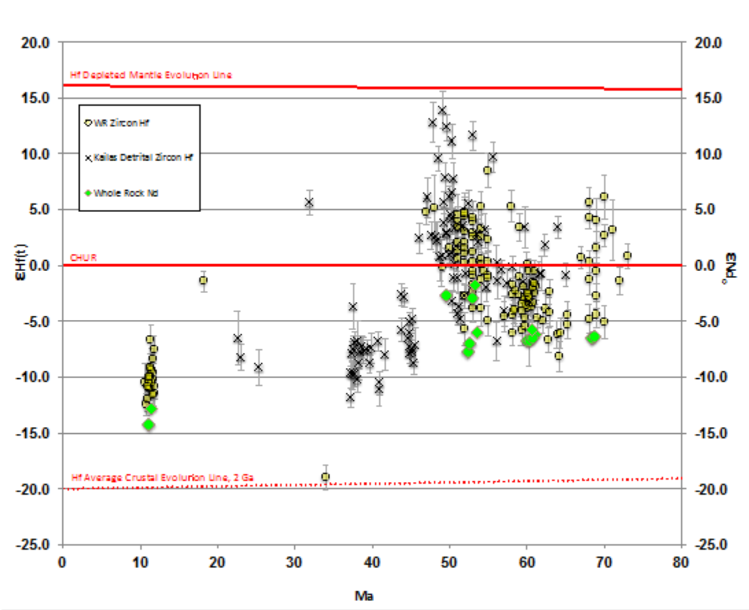

Fig. 1. εHf(t) from whole rock and detrital zircons and whole rock εNd$_o$ from Cenozoic volcanic rocks from the Sangsang region of southern Tibet plotted versus zircon/rock age determined by U/Pb LA-ICPMS zircon analysis.

is from 70 to 55 Ma and it shows a general decrease in mantle contributions to the melt. $^{87}Sr/^{86}Sr_i$ ratios increase from 0.705 to 0.728 and the ƐHf(t) of individual zircons decreases from 6.1 to -6 during this period. However, the ƐNd$_o$ value is relatively constant during this the period at -6.0. From 55 to 47 Ma, there is an increase in mantle contribution to the melt. $^{87}Sr/^{86}Sr_i$ ratios decrease to 0.708 and ƐHf(t) increase to 13.9 at 49 Ma. ƐNd$_o$ also increases to -2.8. The third phase includes rocks < 47 Ma. They show a dramatic shift in isotopic values. ƐHf(t) values from detrital zircons immediately decrease to ƐHf(t) 2.4 at 46 Ma and continue to decrease down to ƐHf(t) -7.6 by 45 Ma and ƐHf(t) -12.4 at 11 Ma. No Linzizong Formation rocks less than 49 Ma were located in the Sangsang transect, but the whole rock Nd and Sr isotopic data from the Lamuka Formation have $^{87}Sr/^{86}Sr_i$ ratios as low as 0.7239 and ƐNd$_o$ of -14.3, in agreement with the Hf isotopic data.

The overall major trends in these Cenozoic rocks reveal that major and trace element trends show an increase in K_2O, CaO and MgO over time with increasing HREE depletion relative to LREE. The most dramatic geochemical change in Cenozoic volcanism in the Sangsang region is seen in the isotopic data for rocks and zircons between 56 Ma and 46 Ma. There is a consensus between Sr, Nd and Hf isotopic systems that there was an increased contribution of juvenile material to the melt at 56 Ma followed by a dramatic increase in crustal contributions to the melt at 46 Ma.

While there is disagreement about the timing of the initial India-Asia collision, there is growing consensus that the Tethyan Himalaya collided with Asia in the early Eocene (Zhu et al., 2005; Dupont-Nivet et al., 2010; Najman et al., 2010; Wang et al., 2011; van Hinsbergen et al., 2012). Models with an early Eocene collision differ in their interpretation of the arc's geochemical response after the initial collision and an Eocene slab breakoff event. These can be divided into end-member models involving: (1) Eocene-Oligocene underthrusting of Greater Indian lithosphere and subsequent rollback of this lithosphere during Oligo-Miocene time (e.g Decelles et al., 2011); or (2) internal thickening of the southern Lhasa terrane lithosphere and associated crustal anatexis, followed by delamination or convective removal of lithosphere (Chung et al., 2003; Chung et al., 2005; Guo et al., 2007; Chung et al., 2009; Lee et al., 2009; Zhu et al., 2011; Chu et al., 2011; Chen et al., 2012). These aforementioned models may be distinguishable by exploiting Hf, Nd and Sr isotope studies to better constrain melt sources and importantly, by placing these data into a high-resolution geochronological framework.

Key words: India-Asia continental collision, arc magmatism, Tibet

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