The ca. 90 Ma Mg-rich volcanic rocks from SE Nyima, central Tibet: Products of lithospheric delamination?

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The Early Cretaceous tectonomagmatic events in the northern Lhasa Terrane have been associated with subduction, slab breakoff of the Bangong–Nujiang Ocean seafloor, and final Lhasa–Qiangtang amalgamation [1]. However, mantle dynamic processes involving crust-mantle interaction in the northern Lhasa Terrane during the Late Cretaceous are poorly known largely due to the limited understanding of the nature of related magmatic records. In this paper we report a dataset of bulk-rock major and trace element, Sr-Nd isotope, zircon U-Pb age, and zircon Hf isotopic data of the Zhuogapu volcanic rocks, ~50 km SE Nyima in the northern Lhasa Terrane. Zircon SHRIMP U-Pb dating reveals that the Zhuogapu volcanic rocks were emplaced at ca. 91 Ma. These rocks consist of andesites and dacites, having MgO of 2.78–5.86 wt.% and 2.30–2.61 wt.% with $Mg^{\#}$ of 54–64 and 55–58, respectively, comparable to high-Mg andesite and high-Mg dacite elsewhere [2]. Eight andesite samples have small negative $\varepsilon_{Nd}(t)$ (–3.2 to –1.7), with $(^{87}Sr/^{86}Sr)i$ of 0.7054–0.7065. Similar Sr-Nd isotopic compositions are also present in the three dacite samples [$\varepsilon_{Nd}(t)$ = –2.7 to –2.2, $(^{87}Sr/^{86}Sr)i$ = 0.7056–0.7060]. Thirteen analyses from a dacite sample give positive zircon $\varepsilon_{Hf}(t)$ (+5.6 to +8.7). Geochemical data indicate that the dacites could not have been produced by fractional crystallization (or plus assimilation) of the andesites. In combination with the other coeval magmatic rocks that show within-plate basalt [3] and adakitic affinities [4] recently reported in the northern Lhasa Terrane, the Zhuogapu Mg-rich volcanic rocks are interpreted as a result of varying extents of mixing between the juvenile lower crust-derived melts and ancient Lhasa basement-derived melts. Considering the development of the Upper Cretaceous molasse that unconformably overlies the underlying strata and the timing of lithospheric stacking or crustal thickening that occurs during the Late Cretaceous [5], we propose that the generation of the coeval 90 Ma magmatism in the northern Lhasa Terrane may be a result of lithospheric delamination. The abundant inherited zircons of ca. 90 Ma with positive zircon $\varepsilon_{Hf}(t)$ from Miocene ultrapotassic rocks in the central Lhasa Terrane (Zhidan Zhao, personal communication, 2011) suggest an extensive magma underplating at the base of the central–northern Lhasa lower crust, corroborating our lithospheric delamination model.

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Breakdown of the Ostwald step rule: The precipitation of calcite and dolomite from seawater at 25^{o} and 40^{o}C

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The scarcity of modern dolomite contrasts strongly with its common abundance in Precambrian sedimentary rocks of marine origin, leading to the paradox commonly referred to as the "dolomite problem". Whereas dolomite can readily be precipitated from aqueous solutions above 100ºC [1], many researchers have attempted unsuccessfully to synthesize dolomite at room temperature from natural seawater [2,3,4]. Nevertheless, by alternating between intervals of dissolution and precipitation in artificial brines, Deelman (1999) succeeded in synthesizing dolomite at low temperatures (between 313K and 333K) [5]. He concluded that multiple cycling of a solution between supersaturation and undersaturation with respect to calcite and/or aragonite would cause the metastable phases to dissolve, while preserving more stable nuclei (i.e. dolomite and/or low-magnesian calcite) in solution. In this study, natural seawater was equilibrated with $CaCO_3$ (mixture of calcite and aragonite) at a pCO_2 of 10%. After the solution reached equilibrium, the solid was removed by filtration and ambient air (pCO_2 ~390 ppm) was bubbled through the CO_2-charged seawater solution, leading to a highly supersaturated solution and the nucleation and precipitation of aragonite. Following the precipitation, the ambient air-equilibrated solution and the precipitate were purged with a 10% CO_2:N_2 gas mixture and most of the original precipitate was redissolved. Once equilibrium was reached with the gas phase, the solution should be undersaturated with respect to aragonite, in equilibrium with calcite, but remain supersaturated with respect to dolomite. The cycle was repeated 18 times and ultrapure N_2, instead of ambient air, was used in the last cycle, to maximize precipitate recovery. As the solution remains supersaturated with dolomite at all times, after each cycle, dolomite nuclei should be preserved and accumulate at the expense of aragonite and calcite. The experiments described above were carried out at 25º and 40ºC. Preliminary results show that, whereas aragonite was obtained during the first few cycles, only calcite was detected in the last cycle of the experiments carried out at 25ºC.

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