Tso Morari Eclogites, Eastern Ladakh: Isotopic and Elemental Constraints on Their Protolith, Genesis, and Tectonic Setting

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ABSTRACT

The Tso Morari Crystalline Complex (TMC), eastern Ladakh, is marked by the presence of eclogites as boudins and lenses within the Puga Formation. These eclogites are composed of garnet, omphacite, amphibole, phengite, glaucophane, quartz, and iron oxide, with rare coesite inclusions in garnet reflecting ultrahigh-pressure metamorphic characteristics. Geochemically, TMC eclogites have high Fe-Ti basaltic compositions and classify as subalkaline tholeiites. Rare earth element and multielement diagrams display enriched patterns similar to enriched mid-ocean ridge basalt coupled with perturbed large ion lithophile elements and higher whole-rock ($^{87}Sr/^{86}Sr$) ratios (0.70884 to 0.72721) reflecting the possible influence of postcrystallization processes rather than variable interaction with host granite gneisses ($^{87}Sr/^{86}Sr$ ratio: ~0.73901). To evaluate the existing protolith possibilities, we calculated $\varepsilon_{Nd}(t = 289\,Ma)$ values (+1.9 to +9.5) and $\varepsilon_{Nd}(t = 140\,Ma)$ values (+1.1 to +8.9) of TMC eclogites; both indicate their derivation from depleted-mantle sources. The $\varepsilon_{Nd}(t = 289\,Ma)$ values of the early Permian enriched Panjal volcanics of Kashmir Valley (−5.3 to +1.3) and Phe volcanics of Zanskar Himalaya (−7.4 to −1.1) are very different from TMC eclogites. However, the $\varepsilon_{Nd}(t = 289\,Ma)$ values of TMC eclogites are similar to the depleted Panjal volcanics (+0.3 to +4.3). Similarly, the $\varepsilon_{Nd}(t = 140\,Ma)$ values of the TMC eclogites closely resemble those of the adjoining Ladakh ophiolites, such as the Nidar-Spongtang-Shergol-Dras ophiolitic mafic rocks (+5.1 to +9.9). These observations partly negate the existing hypothesis of enriched Panjal and Phe volcanics for being the protolith for the TMC eclogites. Thus, we propose that the protolith for the TMC eclogites could be represented by the subducted portion of the early Permian depleted Panjal volcanics and Late Jurassic to Early Cretaceous Ladakh ophiolitic mafic rocks, subducted to eclogite-grade metamorphism (around ~53 Ma) and were subsequently tectonically accreted to the obducting Indian continental crust during their exhumation.

Online enhancements: appendix table.

Introduction

The Alpine-Himalayan orogenic belt preserves the ultrahigh-pressure (UHP) metamorphic rocks (viz., eclogites) of polygenetic origin (Spencer et al. 1995; Ernst and Liou 1999). Occurrences of such UHP metamorphic rocks are related to the processes of subduction followed by exhumation in orogenic belts (de Sigoyer et al. 2000, 2004). Various UHP metamorphic rocks have been reported from Dabie-Sulu terrain, eastern China (Tang et al. 2007); Tso Morari Complex, eastern Ladakh (Guillot et al. 1997); Kaghan Valley, Pakistan (Rehman et al. 2008, 2012); Sesia-Lanzo Zone, Italy (Inger et al. 1996); and Tavsanli Zone, Turkey (Sherlock and Arnaud 1999). Most of these UHP metamorphic belts have continental affinities (Carswell and Cuthbert 2003). Presence of such UHP metamorphic rocks along the Indus Suture Zone (ISZ) delimits the early phase of collision and/or exhumation of the northern margin of the Indian plate at the Paleocene-Eocene boundary (Leech et al. 2005; St. Onge et al. 2013).

The Tso Morari Crystalline Complex or Tso Morari Complex/Nappe (TMC) is situated toward the southeastern part of the Ladakh Himalaya. It

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