Pre-Cenozoic peak metamorphism and deformation of Lesser Himalayan rocks in Nepal

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Several lines of evidence indicate that the stratigraphically lower part of the Lesser Himalayan series in Nepal, the Nawakot unit, reached peak metamorphic conditions prior to the Cenozoic:

(1) We used a three point Sm/Nd isochron to date crystallization of a single garnet from the Benighat Formation in the uppermost Lesser Himalayan thrust sheet exposed in the Modi river valley of central Nepal. The three points come from isotopic analyses of a whole rock powder, an unleeched garnet aliquot, and a garnet aliquot leeched in two steps with HCl. The three point isochron age is 1230 ± 180 Ma (95% confidence level, MSWD=9). The unleeched garnet analysis plots very near a two point isochron between the leeched garnet and the whole rock analyses, indicating at most minimal heterogeneity of the ^{143}Nd/^{144}Nd ratio at the time of garnet crystallization and/or very minor gain or loss of Sm or Nd from the analyzed rock. The dated garnet and other garnets in a thin section cut from a sample taken from the same outcrop preserve growth zoning of major elements, and garnet-ilmenite Fe-Mn exchange thermometry yields a peak temperature of 580 ± 70 °C. For the garnets in the thin section, and probably the dated garnet as well, the presence of internal foliations, their curvature inside the garnets, and their rotation relative to the external foliation indicate garnet growth during deformation. The interpretation that most consistently integrates the Sm/Nd isochron age, major element growth zoning in the garnets, microstructural evidence for garnet growth during deformation, and peak temperature estimate is that the sampled formation reached amphibolite facies conditions and was deformed at c. 1230 Ma. There is no evidence for garnet growth or temperatures near the overall metamorphic peak during the Cenozoic Era.

(2) Muscovite from the uppermost Lesser Himalayan thrust sheet commonly preserves pre-Cenozoic ^{40}Ar/^{39}Ar ages revealed as old age steps produced during step heating analyses (summarized by Herman et al., 2010). These old age steps nearly always reach into the Mesozoic and sometimes into the Proterozoic. The preservation of these pre-Cenozoic age steps requires that the Cenozoic maximum temperature did not exceed the closure temperature for diffusive Ar loss from muscovite. The closure temperature for white mica cooling during metamorphism in a continental fold-thrust belt currently is the subject of debate: it may be 380-430 °C (Harrison et al., 2009) or 550-600 °C (Villa, 2006). The overall peak metamorphic temperature attained by these rocks was 550-600 °C (Martin et al., 2010 and references therein). Thus if the lower closure temperature is correct, these Lesser Himalayan rocks must have attained their peak temperature prior to the Cenozoic.

(3) Monazite ^{232}Th/^{208}Pb ages also support the interpretation that the lower part of the Lesser Himalayan series enjoyed metamorphism in the Proterozoic. Catlos et al. (2001) analyzed two spots in one monazite crystal from structurally high Lesser Himalayan rocks that yielded latest Paleoproterozoic ^{232}Th/^{208}Pb ages. These authors also found a few grains in the same sample and in a nearby sample that produced Mesozoic and Paleozoic spot ages, which presumably result from mixing Proterozoic and Cenozoic generations of monazite during analysis (cf. Martin et al., 2007).

The recognition that the Benighat Formation in the uppermost Lesser Himalayan thrust sheet exposed in the Modi river valley was deformed and reached its peak metamorphic temperature during the Mesoproterozoic, not the Cenozoic, leads to three implications. First, it places a constraint on the minimum depositional age of the Benighat Formation of 1050 Ma, considering the uncertainty on the isochron age (see also Martin et al., 2011). Second, it points to a previously unrecognized orogeny that affected at least part of the northern margin of India at c. 1200 Ma. This orogeny could be related to initial amalgamation of Rodinia. And third, it indicates that tectonic models that use the conclusion that Lesser Himalayan rocks attained their peak temperatures during the Cenozoic must be revised if the Mesoproterozoic age is found to be broadly applicable to Lesser Himalayan rocks across the thrust belt.

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