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Kinematic model for the Main Central thrust in Nepal: Comment and Reply

COMMENT

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In the Main Central thrust zone of the central Nepalese Himalaya, monazites decrease in age downsection between the Main Central thrust and Main Central thrust 1 (MCT-1 in Fig. 1) from ca. 22 to 3.3 Ma (Catlos et al., 2001). This astonishingly systematic result (Kohn et al., 2001) has been criticized, e.g. by Searle et al. (2002), who attributed the monazite growths to fluid infiltrations at low temperatures despite the fact that several of the monazites occur as inclusions in garnets. To explain the downward younging age data Robinson et al. (2003) portray the famous inverted metamorphism as polyphasal, a consequence of successive accretions of thrust slices to the base of the Main Central thrust sheet.

They appear to suggest that monazite/garnet growths resulted from downward heat conduction from overlying thrust sheets. It is likely that burial metamorphism can be ruled out because pre-Cenozoic mica dates show that deepest level in the sections was not significantly heated during the Cenozoic (cf. Copeland et al., 1991). Unfortunately the authors fail to locate the Main Central thrust 1 (see Catlos et al., 2001) or the Ramgarh thrust in the dated sections in central Nepal. Therefore the time lapse between thrusting and the initiation of garnet/monazite growth cannot be estimated. No structural or textural evidence is cited to show that the garnet growths were associated with Himalayan thrusts. Setting aside the significant question of how the monazites formed, their model can be tested using monazite and ^{40}Ar/^{39}Ar mica dates from the Main Central thrust zone in the Marsyangdi and Darondi sections in central Nepal (Catlos et al., 2001).

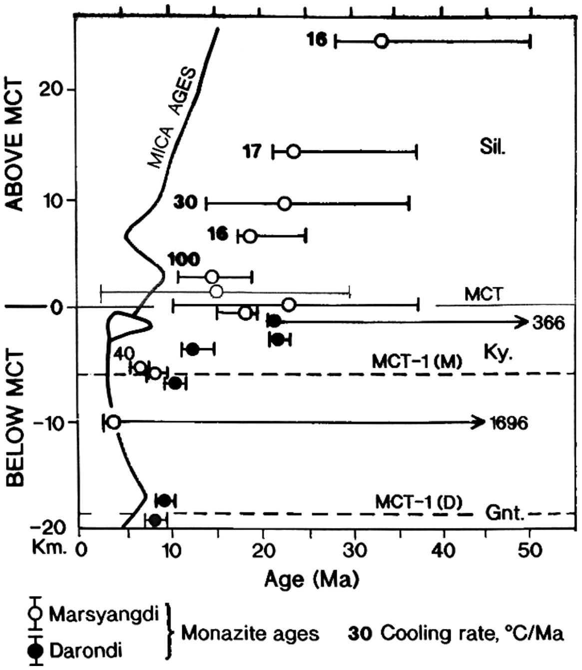

Figure 1. Section of Main Central thrust (MCT) zone along the Marsyangdi (M) and Darondi (D) Kholas with Th-Pb ion probe monazite and ^{40}Ar/^{39}Ar mica ages (from Catlos et al., 2001; Robinson et al., 2003). Circles show weighted mean ages. Sil.—sillimanite, Ky.—kyanite, Gnt.—garnet.

The Greater Himalayan Sequence near to the sections initially cooled extremely rapidly and then resided at temperature (T) $<$350 °C by 15–13 Ma (Vannay and Hodges, 1996; Godin et al., 2001). During the middle to late Miocene, a cooling rate of 6–17 °C/m.y. has been estimated for the Greater Himalaya and the Main Central thrust zone (Searle et al., 1997, 1999; Stephenson et al., 2001). The cooling rates suggested by the age data of Catlos et al. (2001) are 15–100 °C/m.y. (Fig. 1). Taking 16 monazite-mica pairs, 8 are consistent with the cooling rates quoted above, 2 are fairly close (25 and 28 °C/m.y.), and 5 are much higher. Although one is negative, it is clear that most are consistent with the ‘‘regional’’ cooling rate.

Since the hanging wall of the Main Central thrust cooled below 350 °C by ca. 10 Ma. (Fig. 1), it was too cold to heat its footwall enough to permit garnet growth at that time and later (England et al., 1993). Also, the section between Main Central thrust and Main Central thrust 1 cooled below 350 °C at ca. 3–5 Ma and therefore, contrary to Kohn et al. (2001), was too cold to permit garnet growth (3.3 Ma and T $>$500 °C, Catlos et al., 2001) in the underlying rocks. If new garnet did grow at this time in the lower parts of the sections then it occurred at temperatures much less than those estimated by Catlos et al. (2001) and lower also than those generally ascribed to garnet growth in pelites (e.g., Spear, 1993).

Given the questions raised above, it is clear that the tantalizing model of Robinson et al. (2003) requires testing by extensive field and laboratory work not least to establish a sound structural and metamorphic history.

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REPLY

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The model of Robinson et al. (2003) integrates structural data from western Nepal with thermochronologic data from central Nepal. Robinson et al. (2003) suggest that the thermochronologic data can be explained within the framework of a structural model that includes the growth of a large duplex in Lesser Himalayan rocks. Growth of this duplex began in middle Miocene time; as Lesser Himalayan rocks were incorporated into the duplex, overlying Lesser and Greater Himalayan thrust sheets were passively lifted and tilted to their current orientation. The only Lesser Himalayan rocks in direct contact with the Main Central thrust sheet are those carried by the Ramgarh thrust, which is the roof thrust of the Lesser Himalayan duplex. As subsequent Lesser Himalayan thrust sheets were emplaced within the duplex, the underlying rocks were buried by the overburden of the duplex, as well as rock from the Greater Himalaya and Tibetan thrust belt, to depths sufficient to reset muscovite (350 °C with respect to $^{40}Ar/^{39}Ar$) and grow monazite. The resulting structural configuration is northward-dipping thrust sheets to the south of the Main Central thrust supported by hinterland dipping to antiformal thrust sheets in the core of the Lesser Himalayan duplex.

A misconception exists on the part of Johnson and Harley as they state that Robinson et al. (2003) ''appear to suggest that monazite/garnet growths resulted from downward heat conduction from overlying thrust sheets.'' We did not make that statement; instead, we attribute growth of monazite/garnets to burial by overlying thrust sheets. Emplacement of the Main Central thrust sheet and its overburden during early Miocene time buried Lesser Himalayan rocks to depths sufficient to produce garnet and thus, regional (Barrovian) metamorphism. Heat conduction may cause part of that metamorphism but thermal decay after a perturbation of the geotherm by thrusting dissipates too quickly to generate the scale of metamorphism seen in thrust belts. More important factors in generating regional metamorphism may be the radiogenic in situ heat production, hot fluid flow, and the thermal blanketing effect.

Lesser Himalayan rocks yield middle to late Miocene cooling ages up to 30 km southward from the Main Central thrust (Catlos et al., 2001; Wobus et al., 2003) that become younger as the distance south of the Main Central thrust increases. Robinson et al. (2003) suggest that this trend is the result of exhumation of Lesser Himalayan rock once buried by the thrust sheets in the duplex and its overburden. Therefore, the Miocene to Pliocene $^{40}Ar/^{39}Ar$ and monazite/garnet ages are indeed the result of Cenozoic Himalayan orogenesis. Pre-Cenozoic mica dates found in Lesser Himalayan rocks do not pose a problem for our model. They are located >30 km to the south of the Main Central thrust at the leading edge of the Lesser Himalayan thrust sheets (Pearson, 2002), indicating they were not reset with respect to $^{40}Ar/^{39}Ar$ during Cenozoic time.

Some remnant disbelief seems to exist regarding the viability of the Pliocene monazite ages. It is worth noting however, that: (1) these ages are generated from samples where thermobarometric conditions are sound and are consistent with the mineral assemblage, (2) the samples lie along the same trend line as those generated for samples structurally higher, and (3) the results have been peer reviewed and are published in a reputable journal (Catlos et al., 2001).

Johnson and Harley are troubled that we did not locate the Main Central thrust 1 or the Ramgarh thrust on our plot of age versus distance from the Main Central thrust (Robinson et al., 2003, inset of Fig. 2). Our mapping throughout Nepal suggests that the Main Central thrust 1, as it is usually mapped, probably does not exist. The Ramgarh thrust is present in the Marsyandi section where the Catlos et al. (2001) data set is based (Pearson, 2002). However, a discussion regarding the location of the Main Central thrust 1 and Ramgarh thrust is beyond the scope of Robinson et al. (2003). In any case, we clearly state that the structural data come from western Nepal where we have exact locations of the Ramgarh thrust, Lesser Himalayan duplex, and Main Central thrust (DeCelles et al., 2001; Robinson, 2001).

The cooling age data show that monazite ages are generally older than $^{40}Ar/^{39}Ar$ ages from the same sample or from the same general areas along the profile (Robinson et al., 2003, see Fig. 2 inset). Johnson and Harley (their Fig. 1) seem to take exception to this trend. However, the ~5–10 m.y. difference in these ages suggests an exhumation rate of 1–2 mm/yr (a cooling rate of 25–50 °C/m.y.), consistent with recent thermochronological studies. Johnson and Harley note that the hanging wall of the Main Central thrust cooled below 350 °C by 10 Ma. Yet, rocks in the hanging wall of the Main Central thrust cooled through the 350 °C isotherm by 20–15 Ma (Catlos et al., 2001; Wobus et al., 2003). At this time, these Greater Himalayan rocks were above the core of the growing duplex. The younger $^{40}Ar/^{39}Ar$ ages in the Greater Himalayan rocks suggest that those rocks were deep and hot until middle Miocene time, at which time sufficient growth of the Lesser Himalayan duplex had occurred to passively raise these rocks through the 350 °C isotherm. Thus, the duplex model easily explains the spectrum of cooling ages in both the Main Central thrust sheet and in the Lesser Himalayan duplex (Robinson et al., 2003).

Robinson et al. (2003) suggest that the garnets/monazites in the Lesser Himalayan rock up to 30 km south of the Main Central thrust grew during burial as Lesser Himalayan thrust sheets were emplaced within a duplex. Burial was caused by the overburden of the Greater Himalayan rock and Tibetan thrust belt and from the growth of the Lesser Himalayan duplex. The intention of Robinson et al. (2003) was to motivate people to gather petrological, geochronological, microstructural, and thermochronologic data, conduct regional structural analyses and two-dimensional thermal modeling in order to fully understand the tectonics around the Main Central thrust. We look forward to continuing discussions with colleagues regarding the evolution of the Himalaya.

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