Contrasting fluid–deformation–melt histories within the High Himalayan Crystallines, Langtang Valley, Nepal

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Introduction

The High Himalayan Crystallines (HHC) are a sequence of kyanite- to sillimanite-grade metasediments which outcrop along the length of the Himalayas. The metamorphic and tectonic history preserved in these rocks has been widely studied, since they provide the only exposed record of deep crustal processes during Himalayan orogenesis. Many studies have suggested the importance of both melting and fluid movements during the Himalayan orogeny, and some have intrinsically linked these two processes. Stable-isotope data from along the length of one well-exposed section of the Himalayan metamorphic core, the Langtang Valley, is combined with other isotopic, metamorphic and structural data (Reddy *et al.*, 1993) in order to investigate relations between metamorphism, melting and fluids both during Himalayan orogenesis and during high-grade metamorphism in general.

The Langtang tectono-metamorphic record

The lowest structural levels show evidence for only one metamorphic event, in the stability fields of kyanite and muscovite. P-T estimates using both stable-isotope thermometry and thermodynamic datasets (Holland and Powell, 1990) are around 700–750°C, 8–10kbar. Foliation development at these levels predated both movement along the MCT and the growth of kyanite, and the rocks have been uplifted without evidence of internal deformation.

The remainder of the HHC preserves sillimanite-grade assemblages, and muscovite is only locally stable, usually as a retrograde phase. Mid-levels are characterised by migmatites. Stable-isotope data provides minimum temperature estimates of 600-650°C, while both garnet-biotite thermometry and thermodynamic dataset calculations indicate temperatures in excess of 700°C. Pressure estimates are 4–6kbar, indicating that the major change in metamorphic conditions between the kyanite and sillimanite zones is one of decreased pressure at roughly uniform temperatures. A coarse augen-gneiss unit separates these migmatites from a sequence of fine-grained gneisses, into which are intruded the numerous sheets and dykes of the Langtang granites. The top of the HHC is not encountered in the Langtang Valley and lies further north, in Tibet.

The deformation history of the sillimanite-zone is much more complex than that of the kyanite-zone, and begins with syn-metamorphic deformation. Deformation continues to lower temperatures, particularly at high structural levels, and becomes concentrated along discrete shear-zones. Evidence for extension is present at all grades from sillimanite to chlorite and there is no simple transition between extensional and thrust-related shear, with both regimes operating in close temporal and spatial proximity during uplift.

The much-cited Himalayan inverted metamorphism appears to result from tectonic juxtaposition during thrusting (Reddy *et al.*, 1993), rather than representing an isograd in a continuous crustal section, based on the following evidence: i) the contrasting deformation histories of the kyanite and sillimanite-grade rocks, ii) textural evidence of both sillimanite-grade shear and heating of the top of the kyanite-zone and iii) Sr-O isotopic discontinuities coincident with the kyanite-sillimanite boundary.

Textural evidence indicates a polymetamorphic history for the sillimanite-zone (Inger and Harris, 1992), with the first of these metamorphic events at kyanite-grade, whereas kyanite-zone rocks record only one metamorphic event. Both sillimanite-grade metamorphism and migmatisation may therefore simply result from decompression of previously kyanite-grade rocks during crustal stacking. A tectonic, decompressive origin for sillimanite assemblages in the HHC removes the need for models which either attempt to derive some form of localised heat source restricted to high structural levels, or to explain the consistently high temperatures across the section by the movement of melts.

Crustal anatexis in Langtang

Two products of crustal anatexis are recorded, as in most sections through the HHC. Migmatisation accompanies sillimanite-grade metamorphism, but these migmatites and the larger, intruded granites have strongly contrasting strontium and oxygen isotopic ratios. Possible feeder dykes to the Langtang granites show sharp contacts with the migmatites, suggesting that these magmatic events are distinct in time.

Langtang migmatites. P-T estimates in the sillimanite-zone lie on the melt-stable side of both fluid-absent and fluid-present muscovite melting reactions and thus provide little constraint on the presence or absence of fluids during migmatisation. However the strong correlation between the appearance of melt + K-feldspar and the breakdown of muscovite support a fluid-absent regime, as do the preserved scatter in $\delta^{18}O$ and the preservation of pre-Himalayan $^{87}Sr/^{86}Sr$ ratios. Hydrogen isotopes are similarly heterogeneous with decreasing δD along the section explicable by closed-system dehydration reactions. A fluid-absent regime would allow melting to result from high-temperature decompression of the previous kyanite-grade assemblages.

The Langtang granites. $^{87}Sr/^{86}Sr$-$\delta^{18}O$ relations indicate a source equivalent to the kyanite-zone (unmelted at the current erosion level) for the Langtang granites. A fluid-absent origin for these melts is consistent with the > 10km melt transport observed, and with P-T conditions in the exposed kyanite-zone. Although trace-element models (Harris *et al.*, 1993) and experimental data (Scaillet *et al.*, 1994) indicate that the melts which crystallised to form these granites were formed under conditions of low a_{H_2O}, it is impossible to rule out an important role for fluid flux during their petrogenesis, since even a minor flux could have an important catalytic effect in initiating melt reactions. Temperature and isotopic data presented here merely indicate that a fluid influx is not essential, since metamorphic grades are unlikely to be lower at the deeper source levels.

Retrograde fluids

The retrograde fluid histories of the various units in Langtang show considerable variation. At the base of the section, mineral $\delta^{18}O$ data from the kyanite-zone preserve high temperature values, requiring that the cooling history of these rocks took place under anhydrous conditions. Retrograde oxygen-isotope exchange in the migmatites continued down to 600–650°C and its cessation may have been dependent on the crystallisation of melt material or the ending of post-metamorphic, internal deformation.

The highest structural levels record the most extensive fluid–rock interaction. Whole-rock $\delta^{18}O$ values of both gneisses and rare calc-silicates are consistent with equilibration with magmatic fluids. The granites themselves show uniformly disequilibrium mineral $\delta^{18}O$ values, best modelled by open-system exchange with low $\delta^{18}O$ fluid under a regime whereby fluid percolation was ubiquitous. The minimal alteration of muscovite limits the timescales of this event to $< 10^3-10^4$ yrs. At a later stage in the uplift history of these rocks (chlorite-grade, ~400°C), retrogressive alteration became concentrated along discrete, brittle fractures and involved cm-scale exchange with meteoric fluids.

Summary

The Langtang section records strongly contrasting fluid and deformation histories between the upper and lower levels of the HHC. In general, the proportion of melt and the length and complexity of both the deformation and the fluid histories all increase with distance from the base of the section.

Fluid-absent conditions probably prevailed during peak metamorphism, with anatexis occurring via dehydration-melting reactions. Evidence for fluids during the cooling history, as an aid to both closed- and open-system oxygen-isotope exchange, appears to relate to the presence of melt material, suggesting that melting has been an important mechanism in the redistribution of aqueous fluids within the HHC. Although a small fluid influx could have been important in triggering melting, fluid transport has largely been a passive response to melt movements. An exception to this is the local influx of surface-derived fluids late in the exhumation history at the top of the HHC, associated with brittle deformation.

The relationship between anatexis and deformation is much more difficult to define. In the sillimanite-zone, the onset of migmatisation during peak metamorphism may have aided distributed syn-metamorphic deformation, in contrast to the unmelted, undeformed kyanite-grade rocks beneath. The fact that pervasive, internal deformation ceased soon after peak metamorphic conditions (and hence melt crystallisation) supports this idea. However, deformation may merely record the tectonic process by which the rocks passed into a pressure-temperature regime suitable for melting, or may have provided an energy input necessary to initiate melting (e.g. Hand and Dirks, 1992).