Metamorphism and melting within the Nanga Parbat syntaxis, Pakistan Himalaya

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Introduction.

The Nanga Parbat syntaxis, in the northwest Himalaya, is a region of increasingly rapid neotectonic uplift. Synchronous with uplift has been the emplacement into the syntaxis, within the last 10 Ma, of leucogranite sheets and bodies enriched in radiogenic Sr, the generation of which has been linked to processes of decompressive, vapour-absent melting of a continental crustal source (George *et al.*, 1993; Zeitler *et al.*, 1993; Smith *et al.*, 1992). Recently published age data on monazites (Smith *et al.*, 1992), zircons (Zeitler *et al* 1993) and amphiboles (Treloar *et al.*, in prep) demonstrate that parts of the syntaxis experienced high (> 500°C) temperatures during the Neogene, interpreted by Smith *et al.* (1992) as a regional scale high grade metamorphism associated with granite generation and emplacement. If this argument follows, there is a causal link between Neogene high temperature metamorphism, melting and, granite emplacement during regional uplift and metamorphism. Here, we question some of the assumptions implicit in this model, in particular in relation to the timing of high grade metamorphism and melting.

In the northwest Himalaya, collision was between the Kohistan island arc and the Indian Plate, Kohistan being thrust southward onto the leading edge of the Indian Plate. The Nanga Parbat syntaxis is a north trending structural half window, within the core of which Indian Plate gneisses have been uplifted from beneath the structurally overlying arc rocks. The tectonics responsible for this uplift have been outlined by Treloar *et al.* (1991). The Indian Plate rocks exposed within the core of the syntaxis include early Proterozoic biotite-rich quartzo-feldspathic basement gneisses, and late Proterozoic cover sediments intruded by Cambrian granites. Both sequences carry intense S-, L- and S-L-tectonite fabrics, are intruded by basic sheets and Neogene Himalayan leucogranites, and are characterised by variable, often extensive, migmatisation.

Main phase metamorphism and melting.

Within the metasediments, the main paragenesis is: quartz-plagioclase-orthoclase-garnet-biotite-kyanite or sillimanite-rutile. Garnet and perthitic K-feldspar appear as porphyroclasts with ragged margins in a foliated matrix. K-feldspar shows core and mantle structure with small new grains around the margins forming trails into the matrix. Garnet may be surrounded by aggregates of decussate biotite and kyanite which pass outward into fine-grained, foliated bands of the two minerals. Within the matrix, quartz showing undulose extinction may form ribbons or more equant grains. Muscovite, sporadically present as a post tectonic mineral, is rarely present in large quantities. When present, it is a late stage mineral, occurring as small flakes within, and along the margins of feldspar crystals, as rather ragged grains cross-cutting biotite fabrics, or as mats parallel to the main biotite fabric.

Peak metamorphic conditions have been calculated using the Grt-Pla-Ky(Sil)-Qtz (Koziol & Newton 1988), and Grt-Rt-Ilm-Ky(Sil) geobarometers (Bohlen *et al.*, 1983) and the Grt-Bt geothermometer (Ferry and Spear 1978) as modified by Hodges and Spear (1982) and Indares and Martignole (1985). Pressures and temperatures derived from the least deformed gneisses, were at about 10 kbar and 800°C. The presence of sillimanite fibres within garnet cores and kyanite crystals in the fabric are consistent with prograde metamorphism having occurred along a P-T path with positive slope.

Over much of their outcrop the paragneisses are clearly migmatitic, with a leucogranite melt segregated from the restitic pelite and layered parallel to the main tectonic fabric. The field relations imply this to be an *in situ* anatectic melt. The presence of kyanite rather than sillimanite in equilibrium with the melt is consistent with the calculated high pressures and temperatures, and of orthoclase with kyanite or garnet in equilibrium with the melt is consistent with vapour-absent melting. The common absence of muscovite implies that this mineral was completely destroyed during melting, although the calculated temperatures are consistent with vapour-absent biotite melting reactions. The migmatitic history must therefore have been a combination of melting through vapour-absent muscovite and biotite melting reactions, such as (Le Breton and Thompson, 1988; Vielzeuf and Holloway 1988):

$$\mathrm{Ms + Pl + Qtz = Bt + Als + Kfs + M} \quad (1)$$

$$\mathrm{Ms + Bt + Pl + Qtz = Grt + Kfs + M} \quad (2)$$

$$\mathrm{Bt + Qtz + Als + Pl = Grt + Kfs + M} \quad (3)$$

The preservation of centimetre-scale leucosomes within the metapelites demonstrates that melt extraction was inefficient. Crystallisation of the retained pockets and layers of melt caused some back reaction within the restites. Textural relationships consistent with such back reaction include the growth of muscovite flakes within feldspar and cross-cutting biotite; and the development of decussate aggregates of biotite and kyanite around garnet through a retrogressive back reaction such as:

$$\mathrm{Grt + Kfs + melt = Bt + Ky + Qtz} \quad (4)$$

The operation of this back-reaction is indicative that reaction (3) above was a important melt generating reaction.

Timing of melting

The age data presented by Zeitler *et al.*, (1993) and Smith *et al.*, (1992) have been interpreted as suggesting a Neogene age for high grade metamorphism and melting. However, a number of lines of argument suggest that, although this may be true for the leucogranite sheets which cut the migmatite complex, it is not so for the migmatite complex itself. Firstly, the layered rocks of the migmatite complex are cut by a sequence of basic sheets which locally contain xenoliths of migmatitic material. These sheets, which we tentatively correlate with the Permo-Triassic Panjal traps, have undergone a subsequent amphibolite facies metamorphism, yield Ar cooling ages of *c.* 20 Ma (Treloar *et al.* in prep) and carry a strong internal tectonite fabric subparallel to that of the migmatite complex. We interpret them to be post peak metamorphism but pre-Himalayan in age. Secondly, the migmatites show evidence for intense ductile shearing after peak metamorphism. Kyanite has been cataclased with kyanite cleavage rhombs parallel to the main tectonic fabric; tectonic fabrics wrap-around garnet porphyroclasts surrounded by kyanite-biotite aggregates; and quartzo-feldspathic layers have been highly strained with the development of quartz ribbons, subsequently re-annealed to polygonal fabrics, and with rounded feldspar porphyroclasts showing evidence of dynamic recrystallisation, and with sub-grain development along their margins. Lineations within this fabric are consistent with regionally developed Himalayan transport directions, and we argue that this S-L fabric which postdates dyke emplacement is Himalayan in age. Thirdly, these fabrics are folded by the large scale folds that dominate the Nanga Parbat syntaxis and which date from syntaxial growth, and are cut by large garnet-tourmaline bearing leucogranite sheets dated by Zeitler *et al.* (1993) as <10 Ma old. That the fabrics which deform, and thus post-date, the formation of the migmatite complex also predate the initial stages of syntaxial uplift implies that the main phase migmatisation cannot be the result of late-Himalayan Neogene-aged decompressive melting.

These relationships imply that two melting events affected the Nanga Parbat region. The first, under granulite facies conditions, is, at latest, Palaeozoic in age. The second, which is Neogene in age, is related to decompressive vapour-absent melting during uplift and unroofing of the syntaxis. Having melted once, and thus being infertile, the migmatite terrain cannot have been the source for the Himalayan leucogranite sheets which cut it. A more appropriate source for these are Indian Plate shelf sediments underthrust beneath the Nanga Parbat massif, which underwent Neogene to Recent metamorphism and melting. Isotopic data show that the migmatite complex, itself, was reheated during the Himalayan orogeny, cooling back through 500°C at about 20Ma (Treloar *et al*, in prep). Localised pockets of Neogene-aged metamorphism (Smith *et al.*, 1992; Zeitler *et al.*, 1993) are probably related to heat advection associated with the emplacement of late-Himalayan leucogranite bodies.

References.

Bohlen, S.R., Wall, V.J. and Boettcher (1983) *Contrib Mineral Petrol,* **68**. 1059–75.

Ferry, J.M. and Spear, F.S. (1978) *Contrib. Mineral. Petrol,* **66**. 113–7.

George, M.A., Butler, R.W.H. and Harris, N.W.B. 1993. In: P.J. Treloar and M.P. Searle (eds) *Himalayan Tectonics,* Geol. Soc. London. Sp. Publ. 74. 173–91.

Hodges, K.V. and Spear, F.S. (1982) *Amer. Mineral,* **72**. 671–90.

Indares, A. and Martignole, J. (1985) *Amer. Mineral,* **70**. 272–8.

Le Breton, N. and Thompson, A.B. (1988) *Contrib. Mineral. Petrol,* **99**. 226–37.