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Channel flow and ductile extrusion of the high Himalayan slab-the Kangchenjunga–Darjeeling profile, Sikkim Himalaya☆

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Abstract

The geology of the Kangchenjunga–Darjeeling profile in west Sikkim and north Bengal is consistent with the interpretation of the High Himalaya metamorphic sequence as a ductile channel approximately 15–20 km thick, extruding southwards, bounded by major ductile shear zones above (South Tibetan Detachment) and below (Main Central Thrust zone). In the Yoksam to Kangchenjunga section the entire slab is composed of migmatites or leucogranite sheets. Massive sills, or sub-horizontal to gently north-dipping sheets, of leucogranite make up the entire Kangchenjunga massif and extend west at least as far as Jannu. Shear sense indicators show both pure shear flattening fabrics and non-coaxial south-directed simple shear fabrics. The carapace of the melt-filled channel is seen around the southern margin of the Singallila ridge and the Darjeeling klippe, where inverted metamorphic isograds from sillimanite + K-feldspar grade down through kyanite and staurolite to garnet–biotite grade have been well documented. We present an interpretation of the crustal structure of the Sikkim Himalaya, based on field structural observations and utilizing the INDEPTH seismic profile to constrain sub-surface structure to the north. We suggest that widespread melting within sillimanite grade gneisses, triggered sudden and rapid ductile extrusion during the Miocene, by critically affecting the rheology of the middle crust under south Tibet. Leucogranite melts lubricated shear zones, facilitating rapid transport of heat towards the surface. When the leucogranite melts began to cool, ductile extrusion ended, as thrusting propagated down-section into the Lesser Himalaya. Since leucogranite expulsion was largely horizontal, rather than vertical, and since the STD normal sense shear zone is very low-angle, dipping to the north, decompression melting cannot be invoked as an origin for the leucogranites. The heat source for such widespread melting at such shallow levels in the crust can only be explained by having a highly radioactive protolith of Indian plate Proterozoic sediments. The overall map distribution and geometry of leucogranites, migmatites and metamorphic isograds is compatible with both the Everest-Makalu section to the west, and the Bhutan section, east of the Yadong-Gulu rift. We conclude that the channel flow model is a viable explanation for this section of the Himalaya.

Keywords: Kangchenjunga–Darjeeling; Channel flow; Leucogranite; Inverted metamorphism

1. Introduction

The large-scale structure and P–T constraints across the Greater Himalayan sequence (GHS) have led to many mechanical and thermal models (e.g.: Hodges et al., 1992, 1996; Searle et al., 1999a, 2003). Although these differ in some aspects along the strike of the mountain range, several first order observations and facts form the basis for meaningful models. The GHS along the High Himalaya is comprised of a mid-crustal layer of high-grade metamorphic rocks and migmatites with sheets of crustal melt leucogranites prominent along the higher structural levels (Fig. 1). The upper contact of the GHS is a low-angle normal fault, the South Tibetan Detachment (STD) with dips at angles around 10–20° north beneath the Tibetan plateau (Burg, 1983; Burg et al., 1984; Burchfiel et al., 1992). The lower boundary of the GHS is a high strain ductile shear zone, called the Main Central Thrust (MCT), which is coincident with a zone of inverted metamorphic isograds from kyanite grade down to biotite-chlorite grade (Hubbard, 1996). The MCT also dips at low angles to the north and places Proterozoic and Palaeozoic rocks, metamorphosed during the Himalayan orogeny, south over

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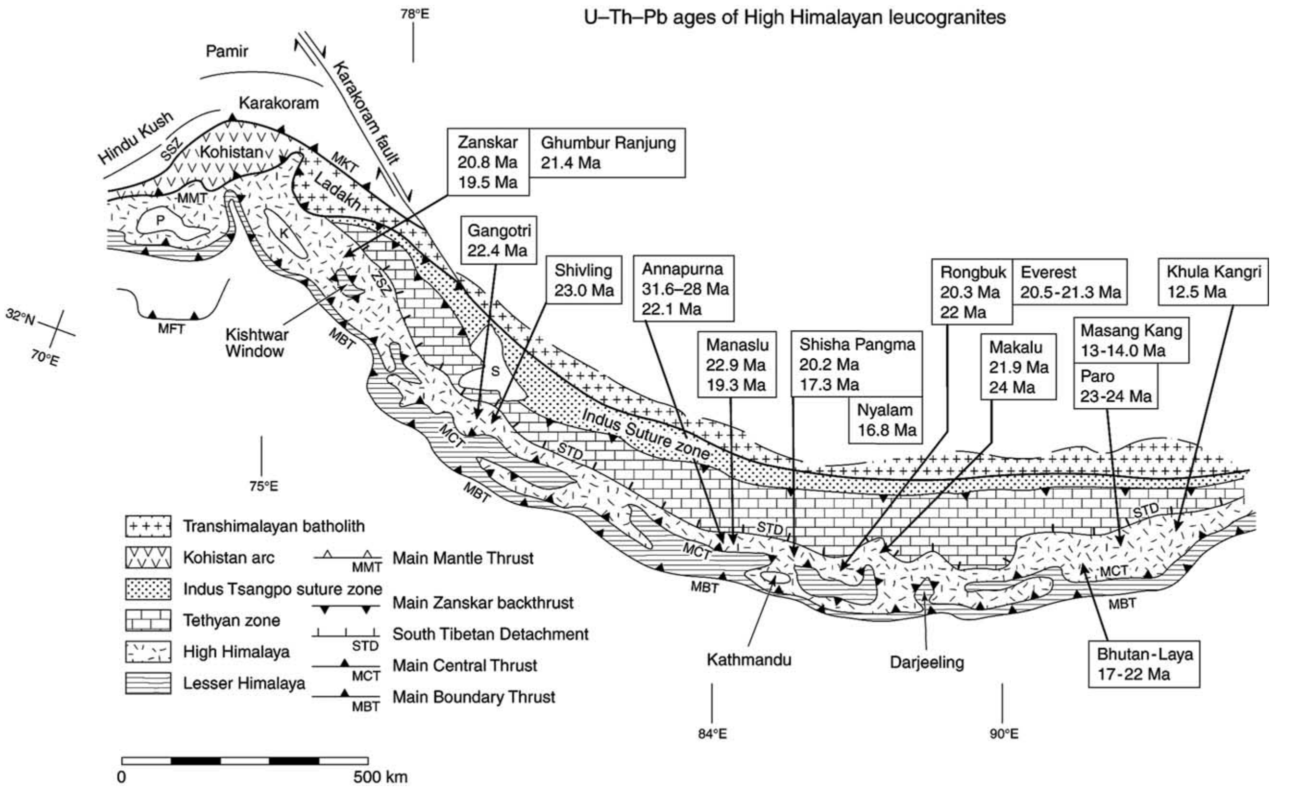

Fig. 1. Geological map of the Himalaya showing U–Th–Pb ages of the dated leucogranites along the High Himalaya. Ages from Zanskar are from Noble and Searle (1995) and Walker et al. (1999), Gangotri and Shivling from Searle et al. (1999b), Annapurna from Hodges et al. (1996), Manaslu from Harrison et al. (1999), Shisha Pangma from Searle et al. (1997), Rongbuk from Hodges et al. (1998) and Murphy and Harrison (1999), Everest from Simpson et al. (2000), Makalu from Schärer (1984), and Bhutan granites from Edwards and Harrison (1997) and Grujic et al. (2002).

Lesser Himalayan thrust sheets, which were largely unaffected by Himalayan metamorphism (Gansser, 1964, 1983; Hodges, 2000).

The thermal structure of the Greater Himalaya has been interpreted with the help of petrologic and thermobarometric data. P–T profiles across the GHS generally show inversion of T and P across the narrow MCT zone (e.g.: Stephenson et al., 2000, 2001). Above the kyanite grade rocks pressures decrease into the sillimanite grade rocks structurally above, but temperatures remain high (above 600 °C for most of the width of the GHS). In some places, such as Zanskar, the upper parts of the GHS show decreasing metamorphic grade up-section (Walker et al., 1999), whereas in others, such as Garhwal and Shisha Pangma, normal faulting has cut out the right way-up isograd section, placing sedimentary rocks of the Tethyan zone directly onto sillimanite gneisses or leucogranites of the GHS (Searle et al., 1997, 1999a,b).

U–Th–Pb dating of leucogranites has provided age constraints on the high-temperature metamorphism and melting. Crystallisation ages of leucogranites along the High Himalaya range from 24 to 12 Ma but most are in the region of 22–19 Ma. (Fig. 1; see summary in Searle et al., 1999b). The youngest leucogranite dated in the eastern Himalaya is the Khula Kangri leucogranite which has a Th–Pb monazite age of 12.5 ± 0.4 Ma (Edwards and Harrison, 1997). Since all the leucogranites are cut by later brittle faulting along the STD, this puts a maximum age constraint on STD brittle faulting. Ductile shearing was occurring earlier and some of the earlier leucogranites are also deformed with the gneisses.

Several recent papers have interpreted these structural and thermal data in the GHS as a channel flow model whereby the middle crust is extruding southwards between coeval thrust and normal sense shear zones (Grujic et al., 1996, 2002; Beaumont et al., 2001). In this paper we examine the structures in a profile across the GHS of western Sikkim from Darjeeling to Kangchenjunga (Figs. 2 and 3) in order to test whether field structural and petrologic data conform with the model.

2. Deep crustal structure from the INDEPTH profile

Fig. 4 shows two sections across the Himalaya west and east of the Yadong–Gulu rift which separates northern Sikkim and Bhutan, after Hauck et al. (1998). They utilized geological data from Acharya and Ray (1977) and Schelling and Arita (1991) for the section across far eastern Nepal, and from Gansser (1983) for the section across western Bhutan, combined with seismic data from the INDEPTH profile. The Main Himalayan Thrust (MHT) is the basal