Cenozoic structural and metamorphic evolution and geological map and sections of the NW Indian Himalaya

Albrecht Steck

Institut de Minéralogie et Géochimie, Université de Lausanne, BFSH-2, CH-1015 Lausanne, SWITZERLAND

For correspondence, E-mail: albrecht.steck@img.unil.ch

A multidisciplinary geological study of the Mandi–Leh transect through the NW Indian Himalaya has been performed since 25 years by geologists from Lausanne: Aymon Baud, Vincent Baudraz, Hugo Bucher, François Bussy, Mike Cosca, Pierre Dèzes, Jean-Luc Epard, Arthur Escher, Matthieu Girard, Henri Masson, Martin Robyr, Micha Schlup, Laurent Spring, Albrecht Steck, Edgar Stutz, Philippe Thélin, Jean-Claude Vannay and Martin Wyss (References in Steck 2003). These systematic investigations have turned this region into one of the best known geological cross section of the Himalayan range. The outcrops are easily accessible at low altitude (1000- 6000 m). The Barrovian regional metamorphic overprint increases from unmetamorphic to amphibolite facies. These favourable conditions offer the opportunity to recognise the pre-

Himalayan stratigraphy, to decipher the structural and metamorphic history in great detail, to study the mechanisms of nappe formation, and to propose original models for the formation of the Cenozoic Himalayan range.

The palinspastic section of the N Indian passive margin before the formation of the Himalayan range is characterised by a continuous stratigraphic column of Proterozoic to Paleocene sediments, which are cross-cut by Ordovician, Carboniferous and Permian normal faults and magmatic rocks. A low angle unconformity at the base of the Ordovician Thaple conglomerates recorded a Kaledonian extensional tectonic event, which includes a block rotation. No Palaeozoic or Mesozoic compressional structures are recognised. The Himalayan range was formed during the Cenozoic continental
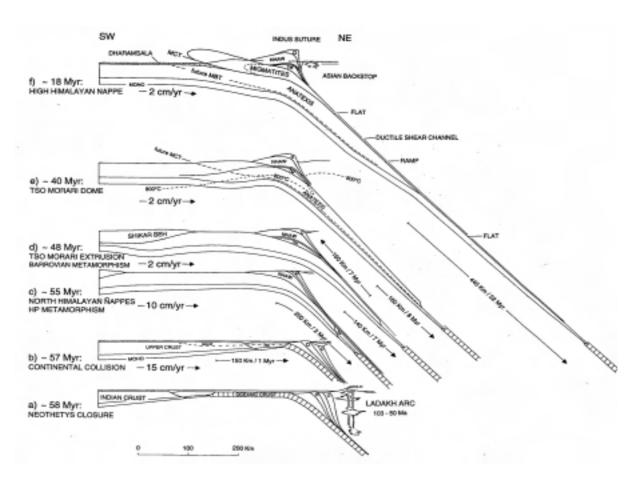

FIGURE 1. Development of the Cenozoic North and High Himalayan nappes (a) – (f). The proposed model is constrained by stratigraphic, structural, thermo-barometric, radiometric, data and rock physics considerations (J De Sigoyer et al. 2000, K Honegger et al. 1982, BK Mukherjee and HK Sachan 2001, RF Weinberg and WJ Dunlap 2000, A Steck 2003 and DL Turcotte and G Schubert 1982). Note that the unknown convergence velocity is assumed to decrease from a value of ~15 cm/yr before continental collision to a value of ~2 cm/yr during the Eocene and Miocene Himalayan range formation.

collision by underthrusting of India below Asia by a typical succession of orogenic structures.

From N to S, and hence from generally older to younger tectonic units, the following main tectonic domains are distinguished (Steck 2003):

1) The Late Cretaceous and Paleocene Transhimalayan batholith and the Indus suture zone are composed of the 103-50 Ma Ladakh arc magmatism (Honegger et al. 1982, Weinberg and Dunlap 2000), the accretion of the Dras-Nindam arc, the accretion and later obduction of the Spongtang immature island arc which formed the southern active border of Asia, and forearc sediment deposition. The Transhimalayan batholith, together with the Asian mantle wedge, represent the Asian backstop for the Himalayan range.

2) The Late Cretaceous-Neogene sediments of the Indus Group are deposited first in a forearc basin of the Ladakh batholith and then in an intermontane molasse basin, after the Early Eocene continental collision.

3) The Shikar Beh nappe is an intracontinental NE-verging structure in the High Himalaya, of an unknown post-Liassic, probably late Palaeocene to Eocene age.

4) The SW-directed North Himalayan nappe stack was created in Eocene time, along with the high pressure Tso Morari nappe, by ductile detachment of the Upper Proterozoic-Early Eocene upper Indian crust during its underthrusting below Asia. The deformational structures of the North Himalayan Nappes confirm the thrust model of E Argand (1916): The imbricate structure of the nappe fronts are related to ductile shear zones in the root of the nappes. The Tso Morari nappe is composed of the mylonitic 479 Ma (Steck 2003) Tso Morari granite which is crosscut by eclogitised mafic dikes. It has been extruded, pushed by buoyancy forces, after its burial to a depths of over 90 km (crystallisation of coesite) some 55 Ma ago (De Sigoyer et al. 2000, Mukherjee and Sachan 2001). High water pressure in the zone of underthrusting derived from dehydration reactions in the subducted oceanic serpentinites may have assisted the Tso Morari granite mylonite detachment and buoyant extrusion by ductile flow and hydrofracturing.

5) The High Himalayan nappe or "Crystalline nappe", composed of Upper Proterozoic-Early Eocene was created in Eocene-Miocene time. The zone of dry intracrustal melting below the North Himalayan range and the Shikar Beh nappe stack determined the future position of the Main Central thrust at the base of the High Himalayan nappe. During under thrusting of the Indian lithosphere, the ductile and light upper Indian crust has been sheared off and extruded, pushed by buoyancy and compressional forces in the zone of plate collision (channel flow, Turcotte and Schubert 1982). The 22
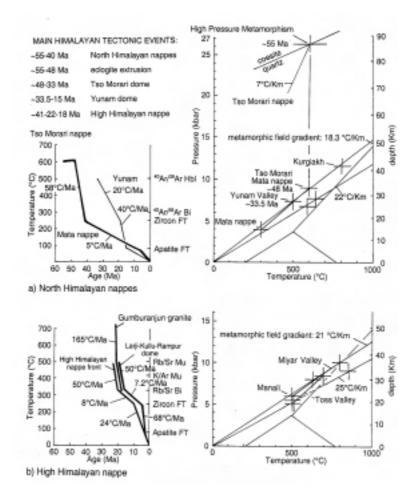

FIGURE 2. Pressure-temperaure-time paths of the North and High Himalayan nappes. The fieldgradients of the Barrovian type orogenic metamorphism increase from 18–22 °C/km in the Eocene North Himalayan nappes to 21–25 °C/km in the Oligo-Miocene High Himalayan nappe (Epard et al. 1995, Sigoyer 2000, Dèzes et al 1999, Robyr et al. 2002, Schlup et al. 2003, Vannay and Grasemann 1998, Wyss et al. 1999, ref. in A Steck 2003).

Ma Gumburanjun leucogranite, intruding the Zanskar extensional shear zone, testifie of the adiabatic muscowite dry melting in the preexisting prograde migmatites during the final extrusion of the High Himalayan nappe (Dèzes et al. 1999 in A Steck 2003).

6) The Lower Crystalline nappe, composed of lower Proterozoic rocks is characterised by an inverted metamorphic zonation similar to the High Himalayan nappe.

7) The Lesser Himalayan nappes, with formation of the deep-seated intracrustal Main Boundary Thrust, are formed from the late Miocene to the present, probably by a mechanism similar to the High Himalayan nappe formation.

8) Thin-skinned nappe structures that detach the up to 9 km thick Miocene to present Subhimalayan Molasse sediments of the Himalayan foredeep, characterise the Subhimalayan thrust which is related to the Active Himalayan thrust at the base of the present Himalayan accretionary wedge.

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