

Field Trip 4

Mafic intrusive rocks from western Himalaya

7th February – 12th February 2010

Leaders

Talat Ahmad

Department of Geology, University of Delhi

V. C. Thakur

Emeritus Scientist, Wadia Institute of Himalayan Geology, Dehradun

Deepak C. Srivastava

Department of Earth Sciences, Indian Institute of Sciences, Roorkee

FIELD TRIP ITINERARY

Day 1 (7th February): Departure from Varanasi to Delhi by air afternoon.

Day 2 (8th February): Departure DELHI AT 7:30 AM – Arrival Dehradun 03:30 PM, check in Hotel and visit Wadia Institute of Himalayan Geology, Dehradun & overnight stay.

Day 3 (9th February): Field excursion along Dehradun –Srinagar (Garhwal) showing Sub-Himalayan and Outer and Inner Lesser Himalayan sequences, crossing Main Frontal Thrust & Main Boundary Thrust. DEPARTURE DEHRADUN 8:00 AM – arrival Srinagar (Garhwal), about 5: 00 PM, night halt at Srinagar (Garhwal).

Day 4 (10th February): Field excursion along the Srinagar (Garhwal)-Joshimath section showing Inner Lesser Himalayan and Higher Himalayan Crystalline Sequences, crossing Tons Thrust and Main Central Thrust.

DEPARTURE SRINAGAR (GARHWAL) ~8:00 AM – Arrival Joshimath ~5:00 PM

Day 5 (11th February): Return from Joshimath to Reshikesh.

DEPARTURE JOSHIMATH ~8:00 AM – Arrival Rishikesh ~6:00 PM

Day 6 (12th February): Departure Rishikesh ~8:00 AM – Arrival Delhi ~4:00 PM

1. Garhwal Himalayas: An Introduction

Garhwal is a region and administrative division of Uttarakhand state, India, lying in the Himalayas. It is bounded on the north by Tibet, on the east by Kumaon region, on the south by Uttar Pradesh state, and on the west by Himachal Pradesh state. It includes the districts of Chamoli, Dehradun, Haridwar, Pauri Garhwal, Rudraprayag, Tehri Garhwal, and Uttarkashi. The region consists almost entirely of rugged mountain ranges running in all directions, and separated by narrow valleys which in some cases become deep gorges or ravines.

Garhwal abounds with natural beauty, flora and fauna. It is so beautiful and spiritually enchanting that it is also known as *DEV BHOOMI - The Land of the Gods*. Garhwal is the birthing ground of the holy Ganga, its two feeder streams, the Alaknanda and the Bhagirathi, wending their way from west and east, to join at Devprayag - the confluence of the Gods.



(Panoramic view of Badrinath (Higher Himalayan crystalline) at sun. Photograph taken from Helong south of MCT)

Here, is a great 40 mile long conglomeration of peaks and glaciers that give rise to the various source streams of the holy Ganga. While from the east the Bhagat kharak and Satopanth glaciers feed the Alaknanda, towards the west is the Great Gangotri glacier, a 40 km long river of ice, which gives birth to the other source stream-the Bhagirathi..

Dehradun - It is the capital city of the Uttarakhand state in India, and the headquarters of Dehradun District. It is located in the Doon valley, 230 kilometers north of India's capital New Delhi and the Delhi metropolitan area. Dehradun is well known for its relatively high standards of living (enjoying higher per capita income). The district is surrounded by the Himalayan mountains in the north, Shivalik Hills in the south, the river Ganga in the east, and the river Yamuna in the west. It is also located on the northern side of the fertile Gangetic plains of India.

Srinagar – It is a city and a municipal board in Pauri Garhwal District in the Indian state of Uttarakhand. Srinagar is situated on the banks of Alaknanda river. Srinagar was the capital of Garhwal before the arrival of British rule

Joshimath- It is a city in Chamoli District in the Indian state of Uttarakhand. Just below Joshimath, two rivers, the Alaknanda and the Dhauliganga, meet at the confluence of Karnaprayag. Joshimath, located at a height of about 6,000 ft, is one of the four great "maths", or monasteries, established by the great Adi Guru Shri Shankaracharya in the 8th century AD. Joshimath was the heart of religious and cultural activity in those days and continues to be the same even today.

2. OVERVIEW OF THE HIMALAYA

The Himalayan orogenic belt has been a topic of interest for geoscientists from all over the world because it represents the southern border of the largest zone of active crustal deformation on the Earth, resulting from the continental collision between India and Asia since the Eocene, about 55 million years ago (Figure1) The Himalayan kinematic evolution is largely controlled by major thrusts, bounding the various terrains that have been gradually scraped off the underthrusting Indian plate and accreted to the orogen. The Himalayas is thus subdivided into five major longitudinally continuous lithotectonic zones (Figure2) and the most popular tectonic model is shown in Figure 3.

From south to north the zones are: (1) the Sub-Himalayan Zone (SHZ) consisting of Tertiary molassic sediments separated from the Quaternary alluvial deposits of the Indo-Gangetic plain by the Main Frontal Thrust (MFT); (2) the Lesser Himalaya Zone (LHZ) composed of Proterozoic to Palaeozoic sedimentary cover of the Indian continent, thrusting over the Sub-Himalaya zone along the Main Boundary Thrust (MBT); (3) the High Himalayan Crystalline Zone (HHCZ) corresponds to a metamorphic and plutonic complex, thrusting over the Lesser Himalaya Zone along the Main Central Thrust (MCT)

and representing the metamorphic basement of the Tethyan zone; (4) the Tethyan Sedimentary Zone (TSZ) or the Tethyan Himalayas (TH) or the Higher Himalayan sedimentary Zone(HHSZ), made up of a nearly complete stratigraphic section of Upper Precambrian to lower Eocene sediments, deposited on the northern margin of the Indian plate; and (5) the Indus-Tsangpo Suture Zone (ITSZ) made up of ophiolites and oceanic sediments, representing the remnants of the Neo-Tethys ocean and the collision event (Gansser 1964, Le Fort 1975 and others)

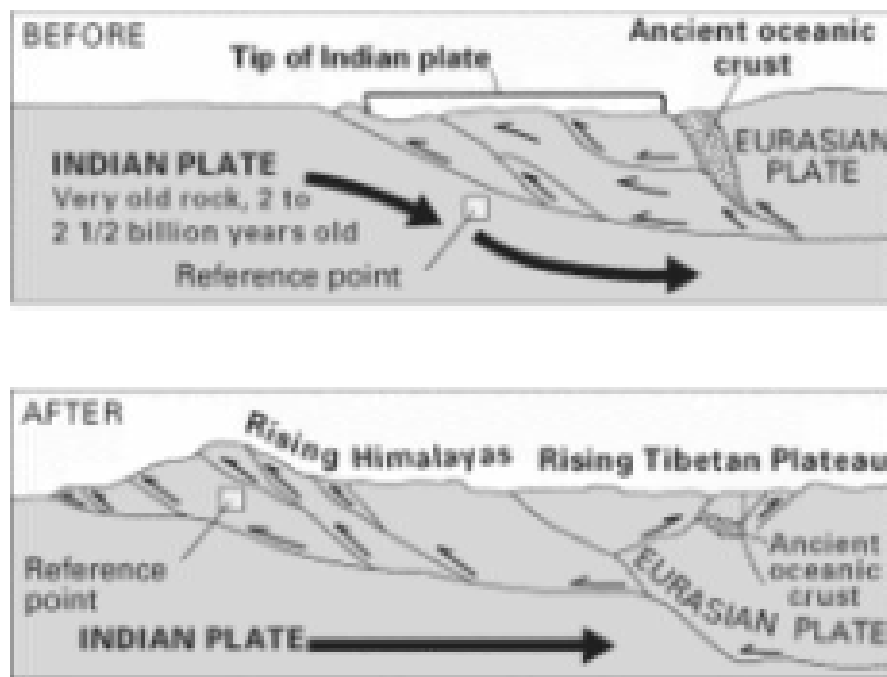


Figure1 : Major Himalayan lithotectonic zones.

An increasing amount of evidence indicates that the Himalayan crystalline core zone is composed of two distinct lithotectonic units [e.g., Valdiya, 1980; Srivastava and Mitra, 1994; Ahmad et al., 2000]. The upper unit is the High Himalaya Crystalline Sequence (HHCS), a thick sequence of amphibolite facies to migmatitic gneisses,

bounded at its base by the Main Central Thrust (MCT; Figure 2). Beneath the MCT, the lower unit is the Lesser Himalayan Crystalline Sequence (LHCS), predominantly composed of amphibolite facies augengneisses, and bounded at its base by the Munsiri Thrust.

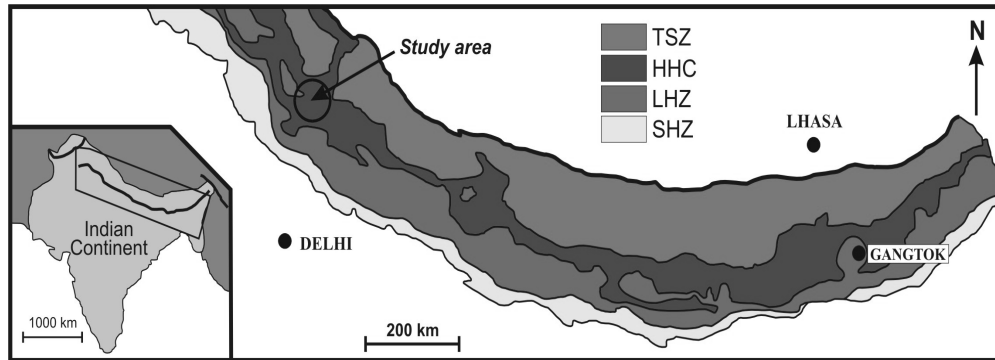


Figure2: Simplified Geological map(after Gansser 1981) of the Himalayas

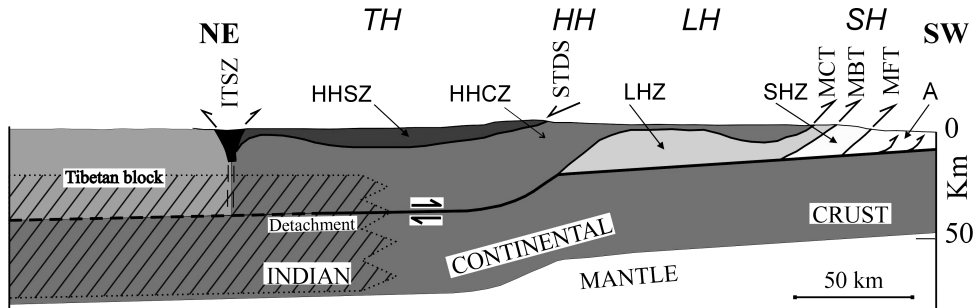


Figure3: Cross Section Of The Himalayan Continental Subduction

The Subhimalaya forms the foothills of the Himalayan Range and is essentially composed of Miocene to Pleistocene molassic sediments derived from the erosion of the Himalaya. The SubHimalaya is thrust along the Main Frontal Thrust over the Quaternary alluvium deposited by the rivers coming from the Himalaya (Ganges, Indus, Brahmaputra and others), which demonstrates that the Himalaya is still a very active orogen

Lesser Himalaya

The Lesser Himalaya is mainly composed of Early Proterozoic detrital sediments deposited between approximately 1900 and 1800 Ma [Parrish and Hodges, 1996; Ahmad et al., 2000; DeCelles et al., 1998], and subsequently overthrust during the Himalayan orogenesis onto Sub-Himalaya units along the Main Boundary Thrust (MBT).



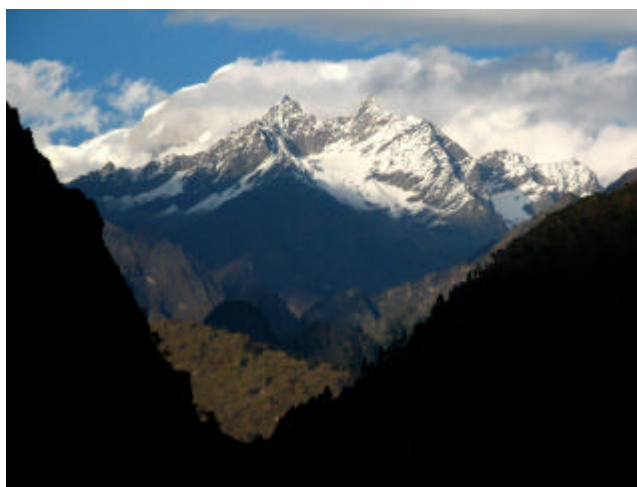
(Lesser Himalayan sequence at Helong south of MCT)

Lesser Himalayan Crystalline Sequence (LHCS)

Overthrusting the Lesser Himalaya along the Muniari Thrust, the LHCS unit is a medium- to high-grade metamorphic sequence derived from Lesser Himalayan lithologies. From Garhwal to Nepal, the LHCS unit (locally known as the Muniari Group or MCT zone) is characterized by widespread Lower Proterozoic granitic gneisses, such as the Muniari granite dated at 1865 ± 60 Ma [e.g., Valdiya, 1980; Srivastava and Mitra, 1994; Upreti and Le Fort, 1999; Catlos et al., 2001]. In Garhwal, the LHCS and the Lesser Himalayan sediments are characterized by a comparable Sr and Nd isotopic signature indicative of an Early Proterozoic deposition age [Ahmad et al., 2000].

High Himalayan Crystalline Sequence (HHCS)

Along the entire Himalaya, the HHCS represents the main metamorphic unit forming the crystalline core zone of the orogen. The HHCS is bounded at its base by the Main Central Thrust (MCT), a major fault that accommodated up to 250 km of shortening during collision [e.g., Hodges, 2000]. In numerous sections across the belt, the HHCS is separated from the overlying, weakly metamorphosed sediments of the Tethyan Himalaya by extensional faults collectively referred to as the South Tibetan Detachment System (STDS) [Burchfield et al., 1992]. The main phase of tectonic exhumation of the HHCS was associated with coeval thrusting along the MCT and extension along the STDS during early Miocene [Hodges et al., 1992]. In some Himalayan sections, a gradual metamorphic transition is observed between the HHCS and the base of the Tethyan Himalaya [e.g., Vannay and Steck, 1995], and these units are characterized by comparable Sr, Nd and O isotopic signatures [Vannay et al., 1999; Ahmad et al., 2000; Robinson et al., 2001].



[Badrinath peak on a clear day (higher Himalayan Crystalline)]

Tethyan Himalaya

The Tethyan Himalaya corresponds to a nearly continuous, Upper Proterozoic to Eocene sedimentary sequence deposited on the northern Indian margin. These sediments generally underwent only very low-grade metamorphic conditions as a consequence of thin-skinned tectonics during the Himalayan orogenesis.

Main Central Thrust (MCT)

The Main Central Thrust (MCT) is a major intracontinental thrust in the Himalayas which plays central role in any discussion on the geodynamic evolution of the Himalayas. It is responsible for a significant proportion of the shortening consequent upon the India-Asia collision. However, identification and location of MCT has always been problematic in all the sectors of the Himalayas. In Garhwal, Valdiya (1980) recognized a higher Vaikrita thrust, which he regarded as the MCT, and a lower Munsiri thrust. The latter is the MCT of Heim and Gansser (1939). Arita (1983) in Nepal recognized an MCT1 and an MCT2. At many places it is still not clear on what structural criteria the MCT has been mapped (Stephenson *et al.*, 2000). This difficulty has led many authors (e.g., Pecher 1989) to consider the MCT to be a several-km wide ductile shear zone, the so-called Main Central Thrust Zone (MCTZ).

Another important feature of the MCT is that it is associated with an inverted metamorphic sequence where the grade of metamorphism increases towards the higher topographic and structural levels. This is the so called *inverted metamorphism* originally described by Pilgrim and West (1928) from the Chur area (Himachal Pradesh) but later

made famous from the Darjeeling Hills by Ray (1976). A fairly noncontroversial definition of the MCT was given by Stephenson et al. (2001) as follows:

“The MCT is the large scale high strain zone of distributed deformation commonly coincident with the zone of inverted metamorphism from kyanite to biotite, which places the mid Tertiary metamorphic rocks of the High Himalayan complex southwards over relatively unmetamorphosed Precambrian-Palaeozoic rocks of the Lesser Himalayan”

Several but conflicting models have been proposed to explain the Himalayan inverted metamorphism (e.g., Harrison *et al.*, 1999). Some interpretations suggest a tectonic inversion of isograds through recumbent folding, thrusting, or shearing (e.g., Brunel and Kienast, 1986; Swapp and Hollister, 1991). Other models invoke complex interactions between the tectonic evolution and thermal processes such as crustal radiogenic heating, heat advection; shear heating, heat transfer between hot hanging wall and colder foot wall during thrusting, and heat focusing beneath the sediments capping the metamorphic core (e.g., Hubbard, 1989; Davidson et al., 1997). According to Le Fort (1975) frictional heating along the MCT has been responsible for Himalayan inverted metamorphism and generation of Cenozoic leucogranites.

3. Geology of Garhwal Himalaya along the Traverse

The Garhwal Himalaya, like the other sectors of the western Himalaya has four principal tectonic zones. From south to north these are the Outer or Sub Himalaya, the Lesser Himalaya, the Higher Himalaya, and the Tethys Himalaya.



(Garhwal mafic volcanics of vesicular nature)

The Sub-Himalayan Zone in Garhwal consists predominantly of Tertiary molassic sediments, stratigraphically referred as the Siwalik group, and named after the Siwalik hills. This represents one of the thickest fluviatile sequences of the world. The Siwalik group is divided into three subgroups *viz.* Lower Siwalik, Middle Siwalik and Upper Siwalik. The sequence has yielded a rich assemblage of vertebrate fauna first described in 1868 by Falconer. On the basis of vertebrate fauna, Pilgrim (1913) divided the Siwalik succession into three units (Lower Siwalik, Middle Siwalik and Upper Siwalik) assigning them Middle Miocene, Late Miocene to Early Pliocene, and Late Pliocene to Early Pleistocene ages respectively.

In the Sub-Himalayan region of Garhwal, the Middle and Upper Siwalik formations consist mainly of sandstone and conglomerate. Magnetic-polarity stratigraphy of the Middle and Upper Siwalik strata has yielded ages from 6.6 to 4.8 Ma to 5 to 0.5 Ma, respectively (Sangode et al., 1996; Kumar et al., 2003).

The Lesser Himalaya is bounded by the MBT or Krol thrust in the south separating it from the Sub Himalaya and by the MCT in the north separating it from the

Higher Himalaya. The Garhwal Himalayas is characterized by a number of thrust sheets. Each of this tectonic unit has its own lithology, structural pattern and magmatic history.

The kyanite and sillimanite grade metapelites and metaquartzite of the Vaikrita group (Higher Himalayan crystalline series) overthrust the Munsiri group comprising quartzites, phyllites, calc silicates, granitic gneisses and pelitic schists along the Vaikrita thrust (VT). The base of the Munsiri group is marked by a contact known as the Munsiri thrust (MT). Within the Munsiri group, chlorite bearing schists grade up in an inverted metamorphic sequence to staurolite bearing schists.

South of the Munsiri thrust, a sequence of southward propagating thrust sheets is bounded on the south by the MBT or Krol thrust (Valdiya, 1980; Srivavastava and Mitra, 1994). The Ramgarh group, overthrust by the Munsiri group, comprises garnet bearing quartz porphyry, schists and phyllites. The Ramgarh group is throughout delimited by thrust planes. The lower boundary is defined by the Ramgarh thrust. The Ramgarh group has previously been identified as a klippe rooted in the HHCS, but more recent publications classify it with the lesser Himalayan lithologies.

The remaining thrust sheets are composed of Lesser Himalayan lithologies. Only chlorite or biotite grade metamorphism is observed here. The formations comprise carbonaceous shale, limestone and dolomites of the Deoban formation, quartzarenites and mafic volcanic rocks of the Berinag formation, and phyllites and siltstones of the Chandpur formation.

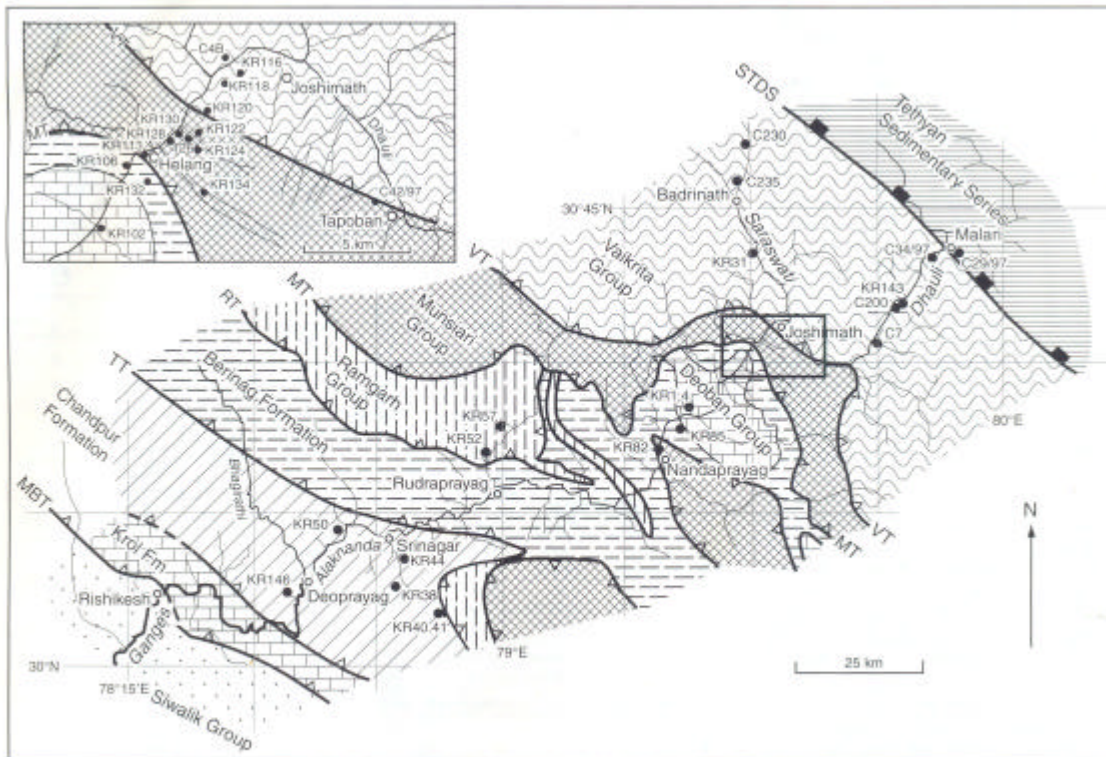


Figure 4. Geologic sketch map of Malari-Rishikesh section of the Garhwal Himalaya showing sample locations. Geologic boundaries after Valdiya (1980) and Srivastava and Mitra (1994). STDS—South Tibetan detachment system, VT—Vaikrita thrust, MT—Munsiari thrust, RT—Rangarh thrust, TT—Tons thrust, MBT—Main Boundary thrust. Inset shows detail of Joshimath area outlined in main figure.

Ahmad et al. (2000) defined the MCT as the site of major displacement which can therefore be distinguished from minor thrust systems (that may appear identical in the field.) by contrasting provenance ages between the metasediments in the footwall and hanging wall of the thrust. These can be recognized by Nd and Sr isotope studies. Their studies suggested that the High Himalayan Crystalline Series, that constitutes hanging wall lithologies of the MCT, is characterized by Nd model ages (T_{DM}) of 1400-2100Ma. ($\epsilon_{Nd} -10$ to -18). In contrast, formations from the Lesser Himalayan Series in the footwall of the MCT have significantly older model Nd ages (2300-2600 Ma; $\epsilon_{Nd} -23$ to -26). Moreover Sr isotope systematics indicates partial equilibration at ~ 550 Ma for the High Himalayan Crystalline Series, whereas more radiogenic Sr isotopes from metasediments

of the Lesser Himalayan Series indicate partial equilibration at ~1800 Ma. In the Garhwal Himalayas, Nd-Sr isotope systematics of metasediments from the *Vaikrita Group* correlate closely with those from the *High Himalayan Crystalline Series*, whereas those from the *Munsiari group* (also known as the MCT zone) show remarkable similarities with the *Lesser Himalayan Series*. Thus the Vaikrita thrust that juxtaposes these two formations is recognized as the MCT, which coincides, approximately, with the location of the kyanite isograd in the Alaknanda transect. This information confirms that inverted metamorphism is characteristic of both hanging and foot walls of the MCT. Furthermore, klippen emplaced south of the Vaikrita thrust, such as the Ramgarh and Tons sheets, are also indistinguishable, isotopically, from the Lesser Himalayan Series.



[Sunset near Deoprayag (Lesser Himalaya)]

REFERENCES

- Ahmad, T., Harris, N., Bickle, M., Chapman, H., Bunbury, J. & Prince, C. 2000. Isotopic constraints on the structural relationships between the Lesser Himalayan Series and the High Himalayan Crystalline Series, Garhwal Himalaya. *Geological Society of America Bulletin*, **112**, p. 467–477
- Brunel, M. and Kienast, J.R. 1986. Etude Petro-Structurale des chevauchements ductiles himalayens sur la transversale de Everest-Makalu (Nepal-Oriental). *Canad. J. Earth Sci.*, **23**, 1117-1137.
- Burchfield BC, Chen Z-L, Hodges KV, Liu Y-P, Royden LH, Deng C-R, Xu J-N (1992) The South Tibetan Detachment System, Himalayan Orogen. *Geol Soc Am Spec Pap* **269**, p.1–41

- Catlos, E.J., Harrison, T.M., Kohn, M.J., Grove, M., Ryerson, F.J., Manning, C.E., and Upreti, B.N., 2001, Geochronologic and thermobarometric constraints on the evolution of the Main Central thrust, central Nepal: *Journal of Geophysical Research*, **106**, p.16,177–16,204.
- Davidson, C., Grujic, D.E., Hollister, L.S. and Schmid, S.M., 1997. Metamorphic reactions related to decompression and synkinematic intrusion of leucogranite, High Himalayan Crystallines, Bhutan. *J. Metamorphic Geol.*, **15**, 593-612.
- De Celles, P. G., Gehrels, G. E., Quada, J., Ojha, T. P., Kapp, P. A., and Upreti, B. N., 1998, Neogene foreland basin deposits, erosional unroofing, and the kinematic history of the Himalayan fold-thrust belt, western Nepal. *Geological Society of America Bulletin*, **110**, p. 2-21
- Gansser, A. 1964. *Geology of the Himalayas*, Wiley-Interscience, London.
- Harrison, T.M., Grove, M., Lovera, O.M., Catlos, E.J. and D'Andrea, J. 1999. The origin of Himalayan Anatexis and inverted metamorphism: models and constraints. *J. Asian Earth Sci.*, **17**, p. 755-772.
- Hodges, K. V. 2000. Tectonics of the Himalaya and southern Tibet from two perspectives. *Geological Society of America Bulletin*, **112**, p. 324–350.
- Hodges, K. V., R. R. Parrish, T. B. Housh, D. R. Lux, B. C. Burchfiel, L. H. Royden, and Z. Chen (1992), Simultaneous Miocene extension and shortening in the Himalayan orogen, *Science*, **258**, 1466 – 1469.
- Hubbard, M.S. 1989. Thermobarometric constraints on the thermal history of the Main Central Thrust Zone and Tibetan slab, Eastern Nepal Himalaya. *Tectonics*, **8/4**, p. 865-880.
- Kumar, R., Ghosh, S.K., Mazari, R.K., Sangode, S.J., 2003. Tectonic impact on the fluvial deposits of Plio-Pleistocene Himalayan foreland basin, India. *Sedimentary Geology*, **158**, p. 209–234.
- Le Fort, P. 1975. Himalayas: The collided range, Present knowledge of the continental *Arc. Amer. J. Sci.*, **275**, p. 1-44.
- Le Fort, P., 1986. Metamorphism and Magmatism during Himalayan Collision. *Collision Tectonics*, **19**, 159-172
- Parrish R.P., and Hodges, K.V., 1996, Isotopic constrains on the age and provenance of the Lesser and Greater Himalayan Sequences; *Geological Society of America Bulletin*, **108**, p.904-911
- Pecher, A. 1989. The metamorphism in the Central Himalaya. *J. Metam. Geol.*, **7**, 31-41.
- Pilgrim, G.E. and West, W.D. 1928. The structure and correlation of Simla Rocks. *Mem. Geol. Surv. India*, **53**, 140.
- Ray, K.K. 1976. A review of the Geology of Darjeeling-Sikkim Himalaya. *Seminar Himalayan Geology*, New Delhi (Abstract).
- Robinson, D. M., DeCelles, P. G. Patchett, P. J. & Garzzone, C. N. 2001. The kinematic history of the Nepalese Himalaya interpreted from Nd isotopes. *Earth and Planetary Science Letters*, **192**, p. 507–521
- Sangode, S.J., Kumar, R., Ghosh, S.K., 1996. Magnetic polarity stratigraphy, the Siwalik sequence of Haripur area (HP), NW Himalaya. *Journal of Geological Society of India*, **47**, p. 683–704
- Srivastava, P. and Mitra, G. Thrust geometries and deep structure of the outer and lesser Himalaya, Kumaon and Garhwal (India): Implications for evolution of the Himalayan fold-and-thrust belt, *Tectonics*, **13**, no. 1, p 89–110, 1994.
- Stephenson, B.J., Waters, D.J. and Searle, M.P. 2000. Inverted metamorphism and the Main Central Thrust: Field relations and thermobarometric constraints from the Kishtwar Window, NW Indian Himalaya. *J. Metam. Geol.*, **18**, 571-590.
- Swapp, S.M. and Hollister, L.S. 1991. Inverted metamorphism within the Tibetan slab of Bhutan: Evidence for a tectonically transported heat source. *Canad. Mineralogist*, **29**, p. 1019-1041.
- Valdiya, K.S., 1980. Geology of Kumaun Lesser Himalaya; Deharadun, India, Himachal Times Presss, p 291.
- Vannay J.-C., Sharp Z.D. & Grasemann B. (1999): Himalayan inverted metamorphism constrained by oxygen isotope thermometry. *Contributions to Mineralogy and Petrology* **137**, 90-101.
- Vannay, J.C., Steck A., 1995. Tectonic Evolution of the High Himalaya in Upper Lahul (NW Himalaya India). *Tectonics*, **14**, p. 253-263