Proc. Indian Acad. Sci. (Earth Planet. Sci.), Vol. 104, No. 3, September 1995, pp. 499–508.

Normal faults in Panjal Thrust Zone in Lesser Himalaya and between the Higher Himalaya Crystallines and Chamba sequence in Kashmir Himalaya, India

V C THAKUR, PIYOOSH RAUTELA and M JAFARUDDIN
Wadia Institute of Himalayan Geology, Dehra Dun 248 001, India

Abstract. Normal faults on mesoscopic scale are observed in the Panjal Thrust Zone in the Dalhousie area of western Himachal. The boundary between the southern margin of the Higher Himalaya Crystalline (HHC) of Zanskar and the Chamba syncline sequence is also described as a normal fault, referred to as Bhadarwah Normal Fault in the Bhadarwah area of Doda district on the basis of field mapping and shear sense criteria using S-C fabric and porphyroblast rotation. The occurrence of these normal faults suggests that the extensional tectonic regime was not restricted only to the Zanskar shear zone area but that it also occurs south of the Higher Himalayan range. This suggests NE-directed subhorizontal extension and exhumation of deeper level rocks of Higher Himalaya Crystallines.

Keywords. Himalaya; Panjal Thrust Zone; extensional tectonics.

1. Introduction

The Himalayas were formed as a result of continent-continent collision between India and Asia. The collision took place 45–50 Ma, and the northward convergence of India continued through the present. In this convergent tectonic zone, the major thrusts like Main Mantle Thrust (MMT), Main Central Thrust (MCT) and Main Boundary Thrust (MBT) and major folds and other deformational structures indicate compressional tectonic regime in the Himalaya. However, lately, extensional tectonic features and normal faulting have been recognized along the tectonic contact between the Higher Himalaya Crystallines (HHC) and the overlying Tethyan sedimentaries in southern Tibet, north of Nepal and in Zanskar, Ladakh. In the Qomolangma (Everest area) Wang and Zheng (1975) described south vergent thrust faults. Later in 1984 Burg and his co-workers reported various mesoscopic and microscopic evidences of normal faulting towards the top of the Higher Himalaya Crystallines (HHC) and its contact with the overlying Tethyan sedimentaries. Based on these evidences, they have placed the contact between these two contrasting rock types as a normal fault. This normal fault dips towards north at low to moderate angles and extends laterally along strike for a distance of 600 km. Similarly the Zanskar shear zone in Ladakh Himalaya has been described as a normal fault on the basis of shear sense determined from microstructures developed in the shear zone (Herren 1987). In the Zanskar shear zone, the sense of movement is top-to-north and the normal faults dip towards northeast at moderate angles. The extensional tectonic structures are also described from the northern part of the HHC and the tectonic contact zone between the HHC and the overlying Tethyan sedimentaries in Zanskar (Patel *et al* 1993) (figure 1). The normal

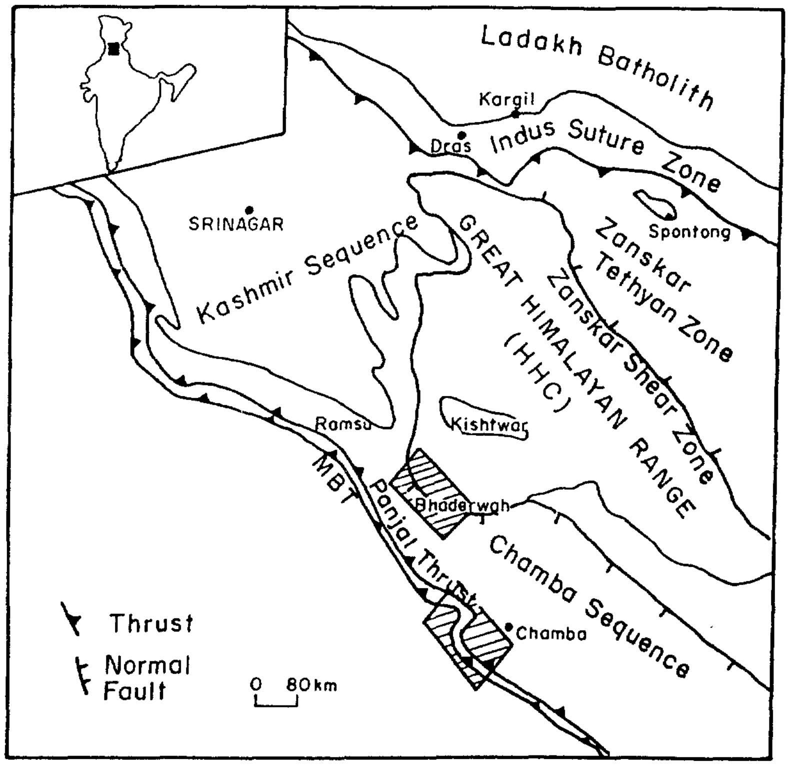

Figure 1. Outline tectonic map showing location of the study area.

faulting and the synconvergence thrusting on regional scale were considered to be synchronous and of the same age and the normal faulting was attributed to the gravity collapse of the topographic front (Burchfiel and Royden 1985; Royden and Burchfiel 1987).

We report here extensional tectonic structures from two separate regions located south of the HHC and south of the Chamba syncline. These are: **a**) Meso- and micro-structures in the Panjal Thrust Zone in the Dalhousie region in Chamba district of western Himachal; and **b**) Normal faulting between the HHC and the overlying Chamba (Tethyan) syncline sequence in Bhadarwah area of Doda district in Kashmir.

2. Normal faulting in Panjal Thrust Zone

The Panjal Thrust Zone is comprised of the Salkhala Formation, imbricates of Lesser Himalayan formations and Tertiary sedimentaries of the Outer Himalaya (figure 2). The tectonostratigraphy of the Panjal Thrust Zone is summarized in table 1, north to south.

The Salkhala Formation, occurring at the base of Palaeozoic sequence of Chamba syncline, is made of mylonite gneiss band towards the base succeeded by predominantly phyllite and quartzitic phyllite. The upper part of the Salkhala Formation is intruded

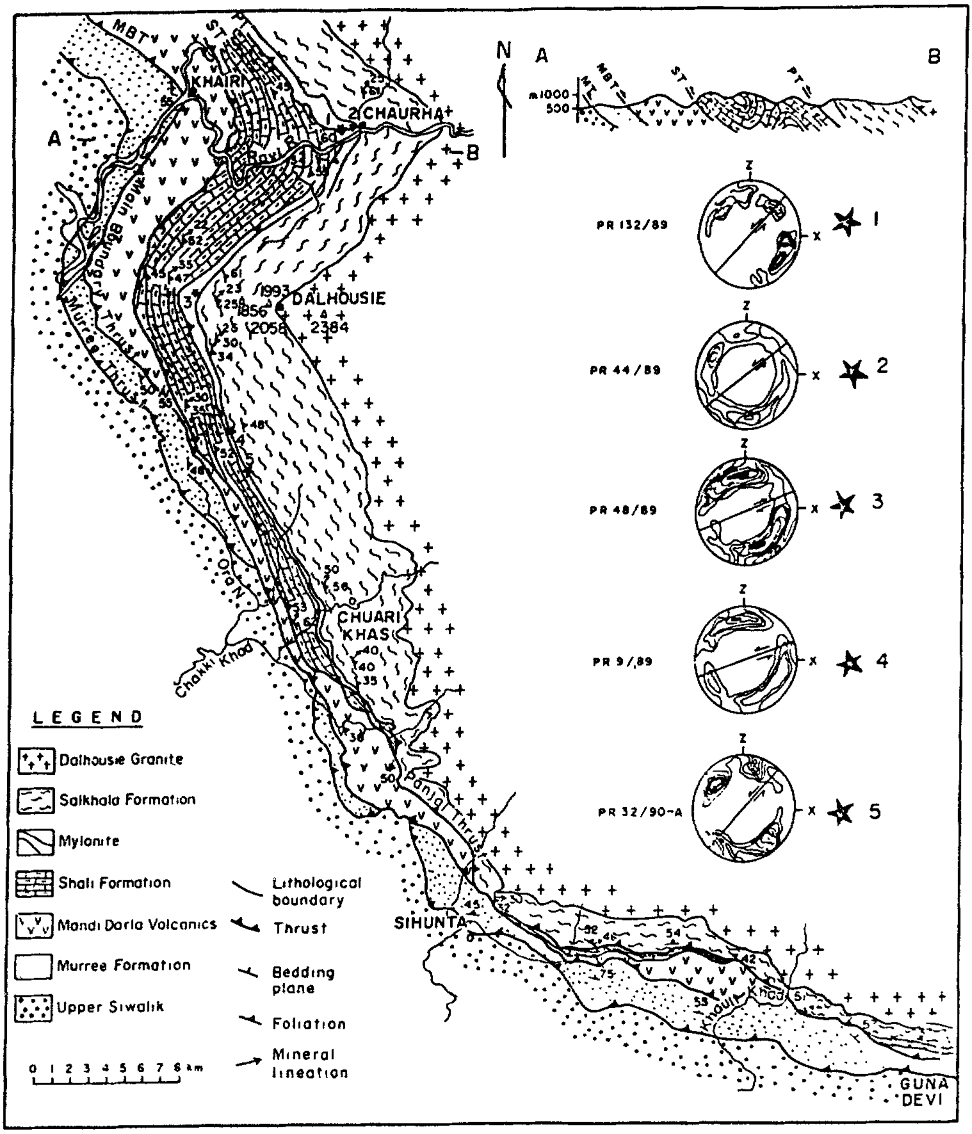

Figure 2. Geological map of the Panjal Thrust Zone between Guna Devi (Kangra) and Chaurha (Chamba), showing the quartz microfabric orientation pattern on the XZ sections in the Salkhala Formation.

by 500 Ma dated Dalhousie granite (Bhanot *et al* 1975). The base of the Salkhala Formation, characterized by mylonite gneiss, is demarcated by the Panjal Thrust (PT). The Lesser Himalayan formations, representing northwestern extension of the Shali structural belt, occur between the Panjal Thrust (PT) and the Main Boundary Thrust (MBT) (figure 2). They are composed of Lower Proterozoic dated Mandi Darla Volcanics, and the Riphean calcareous sequence comprising of limestone and black slate of Shali Formation (Thakur 1992).

Table 1. Generalised tectonostratigraphy of the Panjal Thrust Zone.

		Age
Dalhousie granite	Foliated biotite and muscovite granite	450 ± 50 Ma (dated by Rb/Sr, whole rock) (Bhanot *et al* 1975)
Salkhala Formation	Quartzite, schist, phyllites. Augen mylonite	1430 ± 150 Ma (dated by Rb/Sr, whole rock)
—— **Panjal Thrust** ——		
SHALI UNIT: Shali Formation	Phyllites, slates and limestone	Upper Riphean (Tewari 1985)
—— **Shali Thrust** ——		
SHALI UNIT: Mandi-Darla volcanics	Basic volcanics with intercalations of quartzite.	
—— **Main Boundary Thrust** ——		
Murree Formation	Sandstone and shale	Lower Miocene
—— **Murree Thrust** ——		
Upper Siwalik	Conglomerates	Plio-Pliestocene.

Similar to the observations made in the Tethyan sequence and the Higher Himalaya (Burg *et al* 1984; Herren 1987), there is evidence of normal faulting in the Panjal Thrust Zone.

The foliation planes (S_1) are curved along the shear planes and their relationship exhibits the sense of movement indicating normal faulting. Quartz-rich layers lying

Figure 3. Displaced quartz vein exhibiting normal sense of movement in the rocks of Mandi Darla volcanics in Luned Khad section near Sihunta.

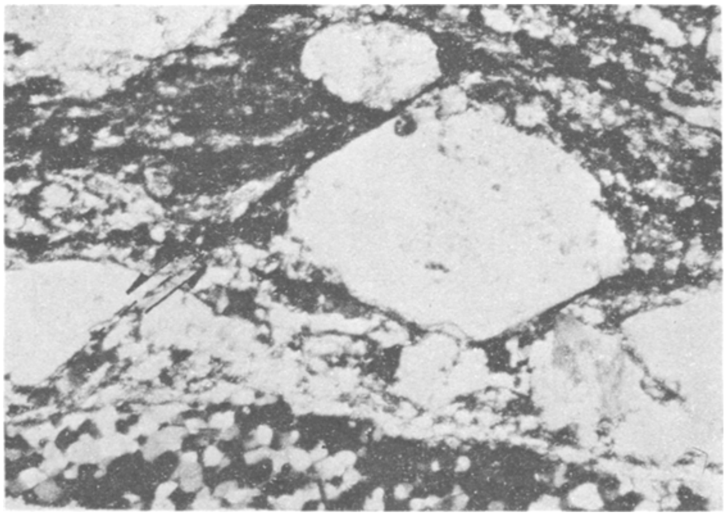

Figure 4. Feldspar grains in oriented microsections from Salkhala Formation showing normal sense of movement.

parallel to foliation planes show normal faulting on mesoscopic scale (figure 3). Under thin sections of oriented samples, feldspar grains show displacement along shear plane indicating normal faulting on microstructural scale (figure 4). The extensional structural features preserved in the form of normal faults are observed in the Tertiary sedimentary rocks, Shali and Salkhala Formations. The displacement observed is not large (few cms) but the sense of movement is easily deciphered using the relationship of the foliation planes with the shear planes. As evident from the disposition of the fault planes the least stress axis (σ_3) during this episode of deformation was in NE-SW direction. Maximum (σ_1) and minimum (σ_3) stress axes therefore exchanged their positions when the waning compressional regime gave way to this extensional deformational environment. Quartz fabric study of the Salkhala thrust sheet shows both sinistral and dextral sense of shear (figure 2). Such anomalous behaviour has been reported over and again in different Himalayan sectors (Pecher 1975; Baud *et al* 1984). Sample numbers 132/89, 44/89, 9/89 and 32/90 A indicate a sinistral sense of shear. These samples showing a sinistral sense of shear are indicative of the extensional environment that caused the thrust sheets to backglide.

3. Normal faulting in Bhadarwah area

The Bhadarwah area is located south of the Kishtwar window in Kashmir Himalaya. Thathri lies along the left bank of river Chenab along the Batote-Kishtwar highway and Bhadarwah is located 47 km south of Thathri.

The Higher Himalaya Crystallines (HHC) of Zanskar extends southward across the Kishtwar window to Thathri and to adjoining Bhadarwah region to the south (figure 5). The rocks of Thathri region, locally called the Chenab HHC, have been divided into the Thathri and Warrai Formations. The Thathri Formation is high-grade

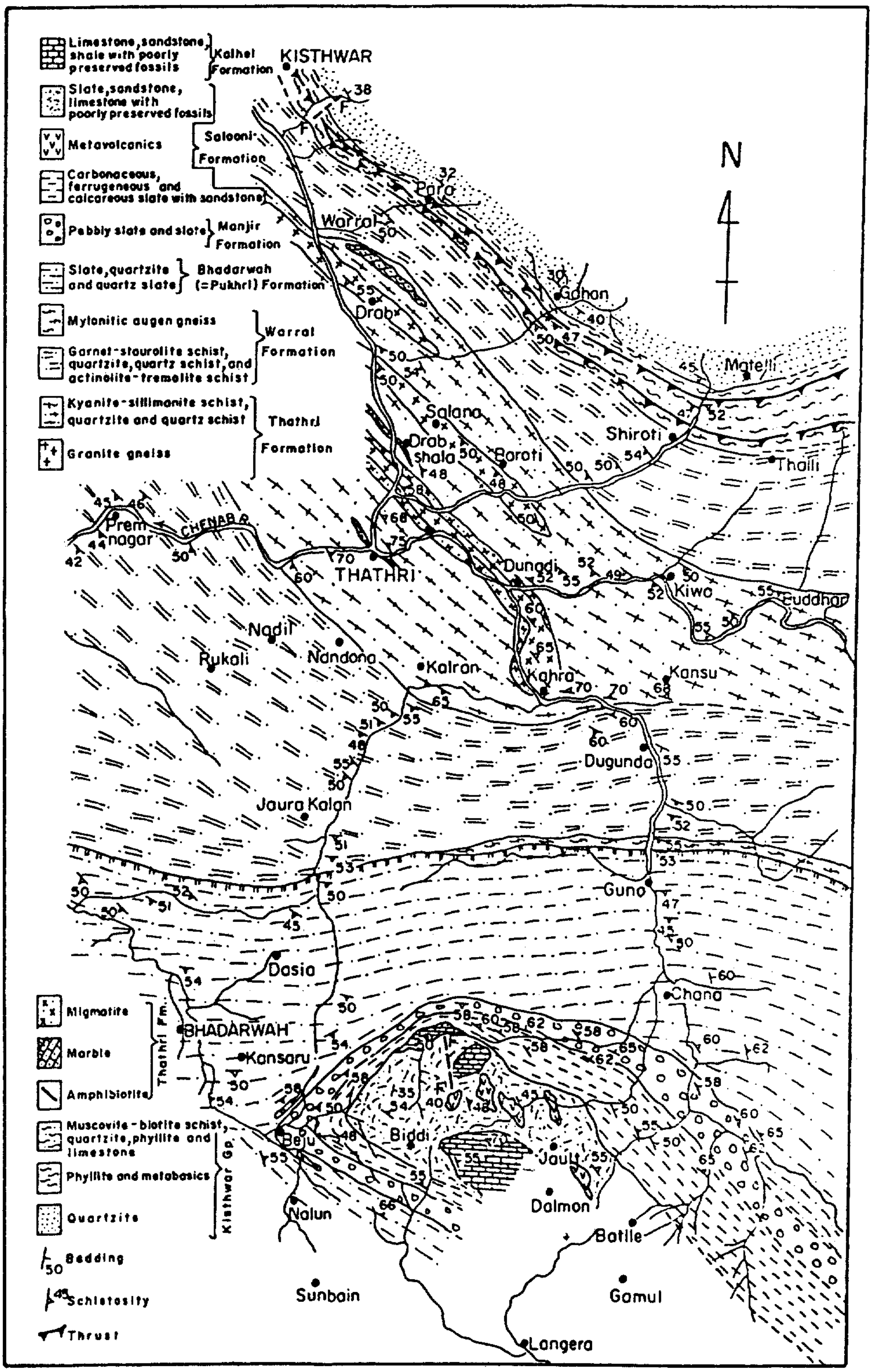

Figure 5. Geological map of Thathri-Bhallesh area, Doda district (J & K).

comprising of kyanite-sillimanite schists and gneisses with interbands of quartzite and quartz schist, migmatite, granitic gneiss together with marble and amphibolite. The Warrai Formation is medium-grade consisting of garnet-staurolite schist, actinolite-tremolite schist, quartzite, quartzitic schist and mylonitic augen gneiss. The Chenab HHC is overlain by the slate, quartzite and quartzitic slate of the Bhadarwah Formation. The Bhadarwah Formation is succeeded upward by the Palaeozoic sequence of northwestern closure of the Chamba syncline which is composed of conglomerates of Manjir Formation, sandstone, calcareous slate and volcanics of the Salooni Formation and the fossiliferous limestone of the Kalhel Formation.

3a. *Bhadarwah Normal Fault*

The Bhadarwah Normal Fault (BNF) is a steep south-dipping fault that separates the Bhadarwah Formation of the Chamba syncline sequence from the underlying Warrai Formation of the Chenab HHC. This fault extends further eastward and represents the westward continuation of the south-dipping normal fault that separates the northern contact of the Chamba syncline sequence from the HHC in the Chenab valley (figure 1).

3b. *Evidence of normal faulting*

Examination of the LANDSAT TM FCC (148-037) imagery exhibits light grey to very light tone, good tonal banding, external drainage, very light resistance to erosion, coarse density and banded to linear texture in the area occupied by the Chenab HHC; whereas the rocks of Chamba syncline sequence show dark to very dark tone, no tonal banding, smooth to fine texture, external drainage, smooth vegetation, very dense density and low resistance to erosion. In between the rocks of HHC and the Chamba syncline, a sharp linear to curvilinear boundary trending WNW-ESE is recognized. This linear boundary corresponds to the Bhadarwah Normal Fault mapped in the field. Morphotectonically the rocks of Chamba syncline show a geomorphic depression indicating a downward, top-to-south, movement relative to the HHC along the fault.

The mylonitic augen gneiss, 300–400 m thick, and forming the top of HHC occur along the Bhadarwah Normal Fault separating the overlying slates and quartzite of Bhadarwah Formation from the underlying rocks of the HHC. The mylonitic gneiss shows development of blastomylonites, and the recrystallized quartz and feldspars define the schistosity. The mesoscopic scale normal faults are also observed along the fault contact. A stretching mineral lineation defined by quartz fibres plunges down-dip towards SSW-SW.

The oriented samples were collected from different sections across the fault to determine the sense of movement along the fault using asymmetric pressure shadows in rotated garnet porphyroblasts, asymmetric augen structures, S-C fabric relationships and displaced broken K-feldspars.

Under thin section, garnet porphyroblasts show characteristic features which indicate direction of grain rotation. The relationship of internal fabric (S_i) and external fabric (S_e) indicates clockwise rotation (figure 6). The garnet porphyroblast showing asymmetric pressure shadow with convex shape on the left and concave shape on the right also indicates a clockwise rotation. These features suggest top-to-south sense of

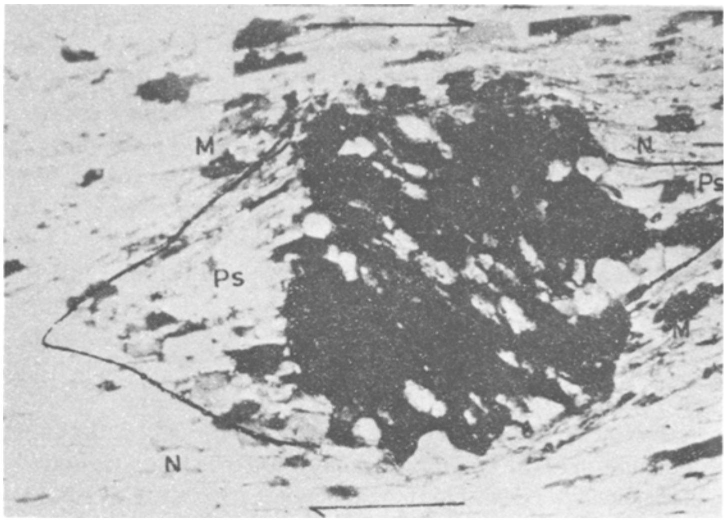

Figure 6. Oriented microsection from rocks exposed along the Bhadarwah Normal Fault in Doda-Bhadarwah section showing top-to-south sense of movement.

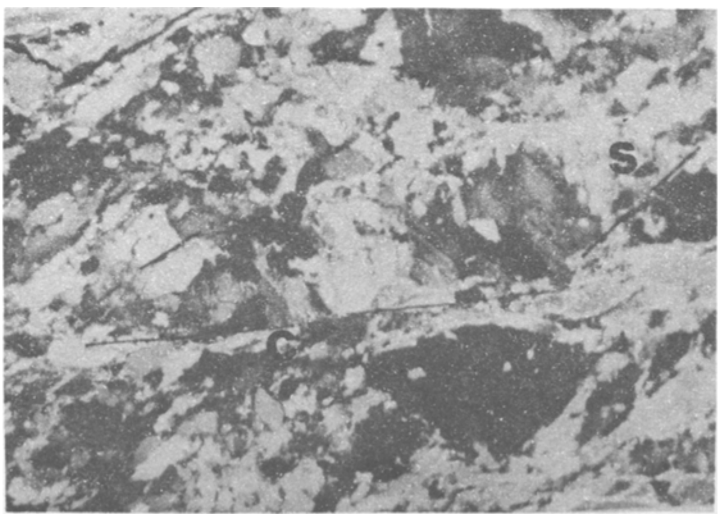

Figure 7. S-C surfaces in the oriented microsection from mylonitic gneisses along Bhadarwah Normal Fault showing a dextral sense of movement.

movement along the Bhadarwah Normal Fault. In the mylonitic augen gneiss the S-surface is defined by preferred alignment of asymmetric feldspar porphyroblasts (figure 7) representing plane of flattening, and the C-surface is defined by recrystallized polygonal aggregates of fine quartz grains representing shear plane of relative movement. The low angular relationship between S-C surfaces indicate a dextral sense of movement along the Bhadarwah Normal Fault.

4. Regional tectonic significance

Normal faults have been described at the base of Tethys Himalaya sedimentary sequence and across a 25–50 km-wide zone of the HHC and the Tethyan sequence in southern Tibet and Zanskar, Ladakh (Burg *et al* 1984; Herren 1987). These extensional structures are reported along the northern margin and to the north of the HHC. Royden and Burchfiel (1987) interpreted the development of the N-dipping normal faults as broadly contemporaneous with the S-directed major thrusts like MCT and MBT and the back-thrust in the Yarlung-Tsangbo area. The extensional faulting resulted due to gravity collapse of the Himalayan topographic front during late Miocene or early Pliocene. The Bhadarwah Normal Fault (BNF) occurs along the southern tectonic contact of the HHC with the overlying less metamorphosed sedimentary sequence of Chamba. The BNF and its eastern extension in the Chenab valley demarcates the southern boundary of the HHC with the overlying Chamba sequence, showing south-dipping normal-faulted contact between the two major Himalayan tectonic units.

The Kashmir and Chamba sequences represent Tethyan facies, and the palaeogeographic reconstruction suggests that these represent the southerly facies extension of the Zanskar Tethyan zone which were deposited over the Precambrian basement before the Himalayan orogeny. The collision between India and Asia produced crustal shortening and uplift in the Himalaya. The major uplift took place during Miocene along the central axis that constituted the HHC.

At present the Higher Himalayan Crystallines (HHC) occupy the highest relief in the Great Himalaya range and lie between the Zanskar valley to the north and the Chenab valley to the south. The northern and southern margins of the HHC are overlain by the Zanskar Tethyan sequence and the Chamba nappe sequence along the north and south dipping normal faults respectively (figure 1). These observations suggest a subhorizontal NE-SW extension that was responsible for exhumation of the deeper level rocks of the HHC. It appears that the rise of Higher Himalayan range in late Miocene resulted in gravitational gliding of the Tethyan sequence of Zanskar and Chamba nappe sequence along normal faults, both to the north and south of the main topographic uplift respectively. The Kishtwar window in Chenab valley exposes the rocks of the Lesser Himalaya sequence in the window zone which are overlain and surrounded by medium-grade metamorphics of the HHC. The thrust separating the HHC from the window zone rocks is defined as the MCT (Thakur *et al* 1990). This MCT emerges as the Panjal Thrust south of the window zone, and the BNF post-dated the MCT.

References

Baud A, Gaetani M, Garzanti E, Fois F, Nicora A and Tintori A 1984 Geological observations in South Eastern Zanskar and adjacent Lahaul area (North Western Himalaya); *Eclogae Geol. Helv.* **77** 171–197

Bhanot V B, Goel A K, Singh V P and Kwatra S K 1975 Rb-Sr radiometric studies for the Dalhousie and Rohtang areas, Himachal Pradesh; *Curr. Sci.* **44** 219–22

Burchfiel B C and Royden L H 1985 North-South extension within the convergent Himalayan region; *Geology* **13** 679–682

Burg J P, Brunel M, Gapais D, Chen G M and Liu G H 1984 Deformation of the leucogranites of the crystalline Main Central Sheet in southern Tibet (China); *J. Struct. Geol.* **6** 535–542

Herren E 1987 Zanskar shear zone: Northeast-southwest extension within the Higher Himalayas (Ladakh, India); *Geology* **15** 409–413

Patel R C, Singh S, Asokan A, Manickavasagam R M and Jain A K 1993 Extensional tectonics in the Himalayan orogen Zanskar NW Himalaya; In *Himalayan Tectonics* (eds) P J Treloar and M P Searle (*Geol. Soc. London Spl. Publ.*) **74** pp 445–459

Pecher A 1975 The Main Central Thrust of the Nepal Himalaya and the related metamorphism in the Modi-Khola cross-section (Annapurna Range); *Himalayan Geol.* **5** 115–131

Royden L H and Burchfiel B C 1987 Thin-skinned N-S extension within the convergent Himalayan region; Gravitational collapse of a Miocene topographic front; In *Continental Extensional Tectonics* (eds) M P Coward, J F Dewey and P L Hanback; (*Geol. Soc. London Spl. Publ.*) **26** pp 611–619

Tewari V C 1985 On the occurrence of *conophyton cylindricus* from the Dharamkot limestone, Himachal Himalaya with special reference to age and biostratigraphic correlation; *Publ. Cont. Adv. Stud. Geol. Punjab University* **1** 59–70

Thakur V C 1992 Geology of western Himalaya; (Oxford: Pergamon Press) pp 363

Thakur V C, Rawat B S and Islam R 1990 Zanskar crystallines – Some observations on its lithostratigraphy, deformation, metamorphism and regional framework; *J. Himalayan Geol.* **1** 11–25

Wang Y and Zheng X 1975 Imbricate structure in the slope of Jolmo Lungma and discussion on the uplift of the Himalaya; In *Scientific exploration on Jolmo Lungma* (Beijing: Science Publishing House) pp 199–211