Quest Journals
Journal of Research in Environmental and Earth Sciences
Volume 8 ~ Issue 9 (2022) pp: 48-58
ISSN(Online) :2348-2532
www.questjournals.org

Research Paper

Structural Evolution and stratigraphic significance of Sor Valley in Pithoragarh district, Kumaun Lesser Himalaya

Laxman Singh[1*], Rajeev Upadhyay[1] and R Anshu[2]
1(Department of Geology (CAS), Kumaun University, Nainital, 263001)
2 (Department of Geology, University of Madras, Guindy Campus, Chennai, 600025)

ABSTRACT: *Sor valley of Pithoragarh consists of the Tejam Group of rocks bounded by the Berinag Thrust in the north and North Almora Thrust (NAT) in the south. The rocks around Sor valley consisting different mesoscopic planar and linear structures and show multiple phases of deformation. The foliation geometry and attitude reveal three phases of ductile deformation in Sor valley. F1 folds are tight to isoclinal folds trends in the ENE-WSW direction. F2 folds are tight to close, and trends in NNW-SSE with low to moderate amount of plunge and F3 folds are chevron-shaped trends towards the NNE-SSW direction. The F2 type folds are generated by the compression directed from ENE towards WSW by North Almora Thrust (NAT). Similarly, the F3 type folds compressed from the NW-SE direction and can be related to Berinag Thrust. Based on mesoscopic folds, structural data, geological cross-section, and paleontological evidence, it is interpreted that the large-scale fold of the study area is an ENE-WSW striking overturned synform fold developed during D1 deformation. Consequently, the older Gangolihat Dolomite/Deoban Formation lies above the Sor Slates/Mandhali.*
KEYWORDS: *Sor valley slates; North Almora Thrust (NAT); Berinag Thrust (BT); Gangolihat Dolomite; Overturned Syncline*

***R**eceived 02 Sep, 2022; **R**evised 12 Sep., 2022; **A**ccepted 14 Sep., 2022 © The author(s) 2022.*
P**ublished with open access at **www.questjurnals.org

I. INTRODUCTION

The Himalayas is known as the youngest mountain chain on the earth. It was originated as a consequence of the collision among the Indian and Eurasian continents that initiated in the Early Eocene (Molnar and Tapponnier 1975; Norton and Sclater 1979; Powell 1979; Patrait and Achache 1984; Searle *et al*. 1987; Joshi and Patel 1997; Yin 2006; Mukherjee 2005, 2013, 2015; Webb 2011, 2013; Mukherjee *et al.* 2012, 2015). The shortening of the Indian plate has been accommodated by crustal overlapping by a series of parallel to sub-parallel SW-heading major thrusts/faults, produced through a series of parallel tectono-metamorphic units within the length of the Himalayan chain (Gansser 1964; Molnar and Tapponnier 1975).

The Himalayan arc has been divided into five distinct tectonically and stratigraphically contrasted domains, extending continuously from east to west and sharply delimited by major thrusts/faults. These successions were previously deposited on the Indian passive margin and deformed and metamorphosed during the collision (Upreti 1999; Hodges 2000; Antolín *et al*. 2011; Dunkl *et al.* 2011; Montomoli *et al*. 2017b; Carosi *et al*. 2019). The major thrusts/faults from south to north are the Himalayan Frontal thrust (HFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT), the Indus-Tsangpo Suture Zone (ITSZ) (Sathyaseelan *et al.* 2018 and references therein). The MCT and MBT bounded the northern and southern boundaries of Lesser Himalaya, respectively (Heim and Gansser 1939; Gansser 1964; Misra and Sharma 1972; Pecher 1977; Valdiya 1980, 1988, 2001; Thakur 1987; Chamyal and Vashi 1989; Thakur 1992; Jain and Manickavasagam 1993; Jain *et al*.2000; Patel et al., 2011;Dubey 2014).

The Lesser Himalaya is further subdivided into the Inner and Outer Lesser Himalaya (Valdiya 1980). Our study is mainly focused on Sor valley, the Inner Lesser Himalayan part of the Kumaun region, located in the Pithoragarh district of Uttarakhand, located between 29°31'-29°38' N and 80°8'-80°15' E (figure1)**.** The Kumaun Lesser Himalaya was formed by a general foreland thrusting sequence, with a few out-of-successions or reactivated thrust anomalies (Srivastava and Mitra 1994; Mukherjee *et al*. 2012; Mukherjee 2015; Joshi *et al.* 2017).

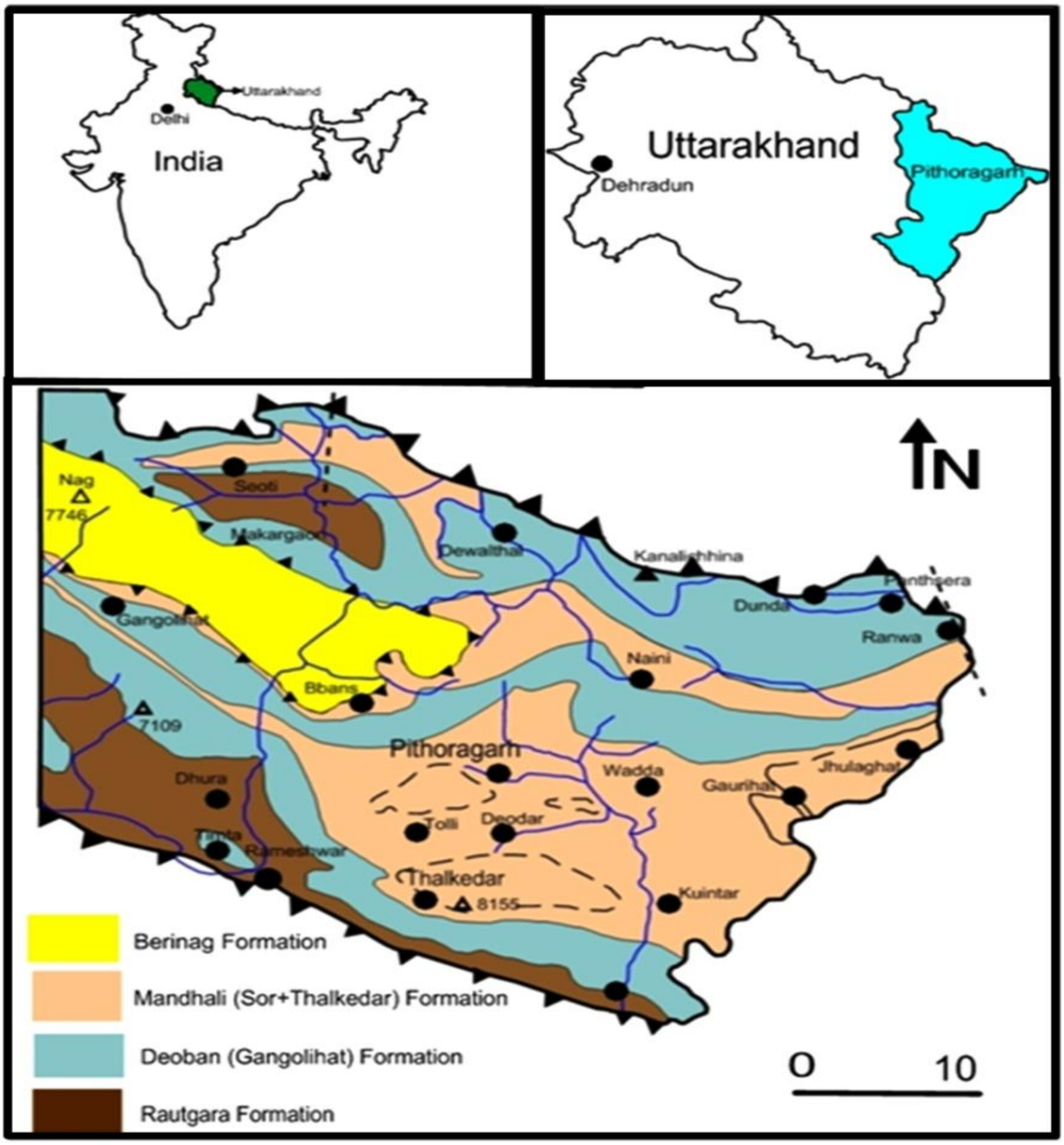

Figure 1: Geological map of the Sor valley of Pithoragarh area (After Valdiya, 1980).

Table-1. The Following sequence of rock formation is present in the study area (Valdiya 1980)

Age	Group	Formation	Lithology
Palaeozoic		Berinag Formation	Quartzite and Phyllites with interbedded chert quartzite
Neoproterozoic	Tejam Group	Mandhali Formation	Sor slates, Thalkedar Limestone, Bracciated Limestone, Thinly bedded Limestone, Mafic Dykes and sills
Mesoproterozoic		Deoban Formation	Stromatolite-Limestone, Dololmotic Limestone, Magnesite, Phyllites, Mafic Dykes, and sills

The Sor valley consists of calcareous rocks of the Deoban Formation and argillaceous rocks of the Mandhali Formation of the Tejam Group (table-1). However, the subdivision line between both formations is unclear; hence, both are taken as a single unit called the Calc Zone of Pithoragarh (Valdiya 1968, 1969, 1972).

This zone contains limestones, dolomitic limestones, shales, slates, stromatolitic limestone, and magnesites. Further, the Deoban Formation in southern Kumaun is known as the Gangolihat Dolomite (Valdiya 1962), and Mandhali is designated as Sor Slates (Valdiya 1962). Gangolihat Dolomite is separated from Berinag Formation by Berinag Thrust (BT) in the north (Phartiyal *et al.* 2003). In the south of the Sor valley, the argillaceous Rautgara Formation changes to the calcareous rocks of Gangolihat Dolomite without any structural discontinuity. The North Almora Thrust (NAT) separates the Rautgara Formation and Saru Formation of the Almora Group (figure 2).

Gangolihat Formation lies on the top and bottom of the Mandhali Formation or Sor slate in the study area. Which shows the repetition of the Deoban Formation? Based on paleontological data, the Deoban Formation or Gangolihat Dolomite is older than the Mandhali Formation or Sor Slates (Valdiya 1980). However, the palaeontological data is not enough to say that the study area contains an inverted sequence without the support of any structural evidence. So far, preliminary work has been done on the structural evolution of Sor valley and its stratigraphic significance. To address the problem related to above mentioned inverted sequence in Sor valley and its stratigraphic significance, detailed geological and structural data has been collected. These data were used to prepare the structural-geological map and cross-section of the study area to understand the geometry of the rock sequence.

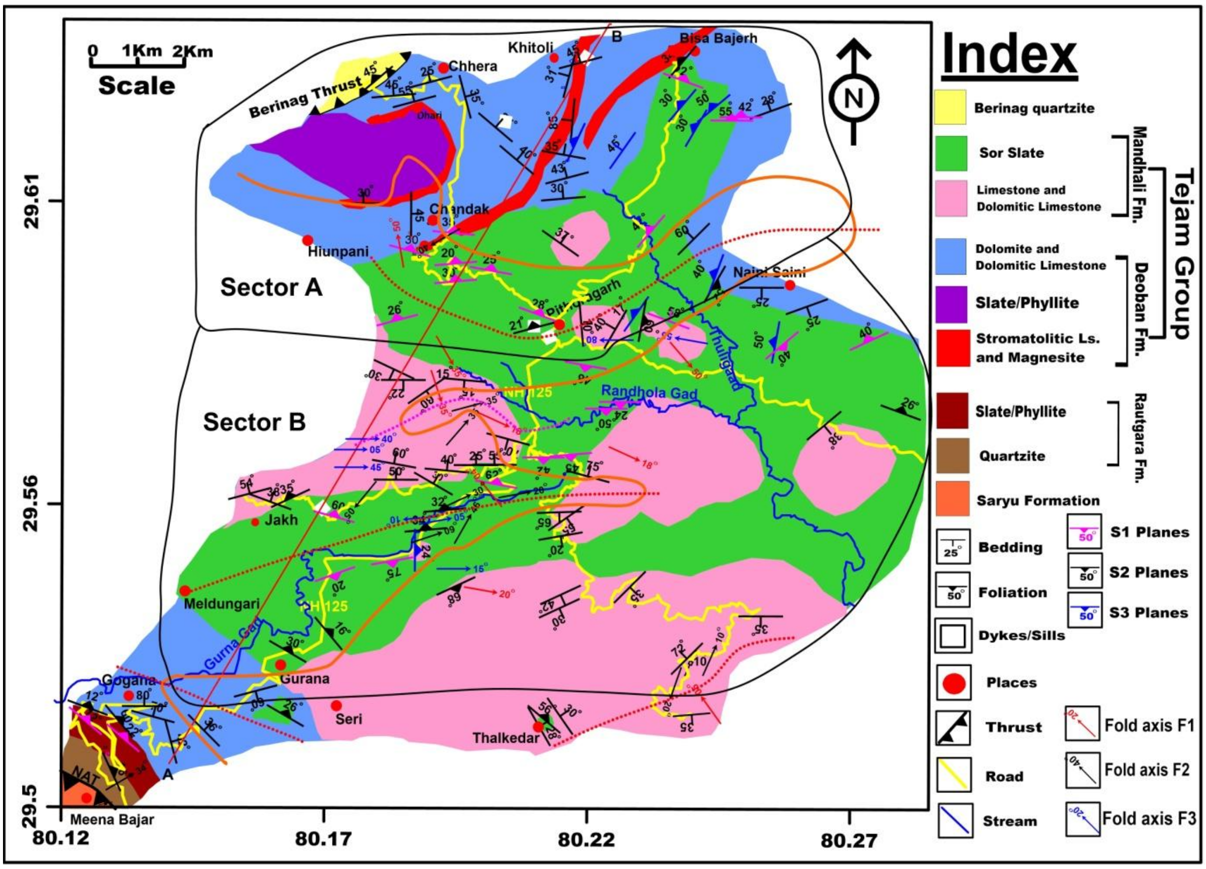

Figure 2: Structural-Geological map of the study area (Sor valley).

II. FIELD OBSERVATIONS AND STRUCTURAL INVESTIGATIONS

2.1 Regional structures

The structural-geological map of the studied area has been prepared on the contour map of the area with the help of field data (figure 2). Two regional-scale thrusts bound Sor valley. The North Almora thrust (NAT) strikes NW-SE and dips towards SW, demarcates the southern boundary of Sor valley, and separates the Rautgara Formation from the Almora Group of rocks (figure 2). Further, the Berinag thrust strikes NE-SW, and dipping towards NW demarcates the northern boundary and differentiates Gangolihat Dolomite from Berinag Formation (figure 2).

2.2 Lithological contact and disposition of rocks

The SW part of the Sor valley contains the Rautgara Formation, which consists of quartzite and slate. Gangolihat/Deoban Formation exists above the Rautgara Formation, consisting of dolomite, limestone, phyllite, and stromatolite. Sor slate consists of slate, phyllite, brecciated limestone, and dolomite and lies over the Deoban Formation (figure 2). In the NW part of the study area, the Gangolihat formation is exposed conformably above the Sor slate, consisting of Stromatolites, dolomite, magnesite, dolomitic limestone, and pockets of talc. The Berinag formation crops out in the NW part of the study area. This Formation consists of purple quartzite and has thrust contact with Deoban Formation (figure 2).

2.3 Geological Cross-section

A geological cross-section of the study area has been prepared with the help of the geological and structural data collected from the field (figure 3). In the cross-section, foliation planes dipped towards NE from Gogana to Khitoli with an apparent moderate dip amount.

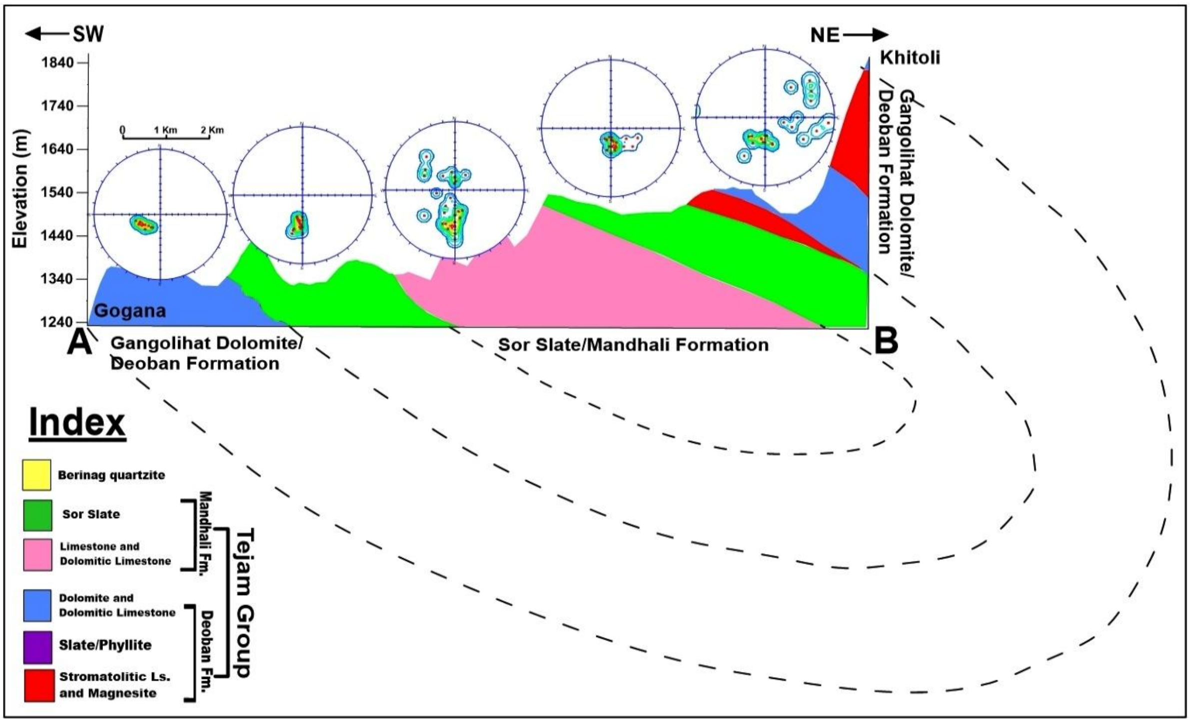

Figure 3: Geological cross-section Gogana to Khitoli (AB).

2.4 Deformational structures

The foliation plane, fold, linear structures, faults, shear, and joints show that the rocks of areas had undergone different episodes of ductile and brittle deformation. The Study area consists of planar structures such as the primary bedding plane (S0) and axial plane foliations of different generations of folds. The primary bedding (S0) has been documented by the color variation, lithological layering, and sedimentary structures. Beddings planes show a gentle to moderate dip in southern and northern directions (figure 2). The foliation planes of the rocks strike NW-SE, NE-SW, and E-W directions with a gentle to moderate dip amount (figure 4a b, c, and d). Folds are produced due to compressive stress as a consequence of a primary deformation, which means that folding took place throughout the formation, or as a consequence of a secondary, i.e., tectonic deformation. The study area has undergone tectonic deformation, resulting in different folds. (a) tight to isoclinals folds trends in ENE-WSW direction (figure 5a), (b) open to tight folds trend NNW-SSE direction (figure 5b), and (c) F3 chevron folds trends NNE-SSW direction (figure 5c and d).

The linear structures formed due to deformation have been observed and documented in the field, like Crenulation Lineation in phyllite, which plunges towards the south (figure 5e), striations were showing ESE plunging direction (figure 5f), and quartz boudinage structures were NNE-SSW trending parallel to foliation plane (figure 5g). Two fault planes were observed in phyllite, the first moderately dipping towards the north and the second having a gentle dip towards SE (figure 5h).

Four sets of joints (J1, J2, J3, and J4) have been documented (figure 6). J1 dips towards the west, J2 dips towards NE, and J4 dips towards the east, showing a moderate to high dip amount. J3 type of joints dip towards the south and are further subdivided as J3 and J3a types based on their dip amount; J3 has a high to moderate dip amount, whereas the J3a exhibits a low to moderate dip amount (figure 6).

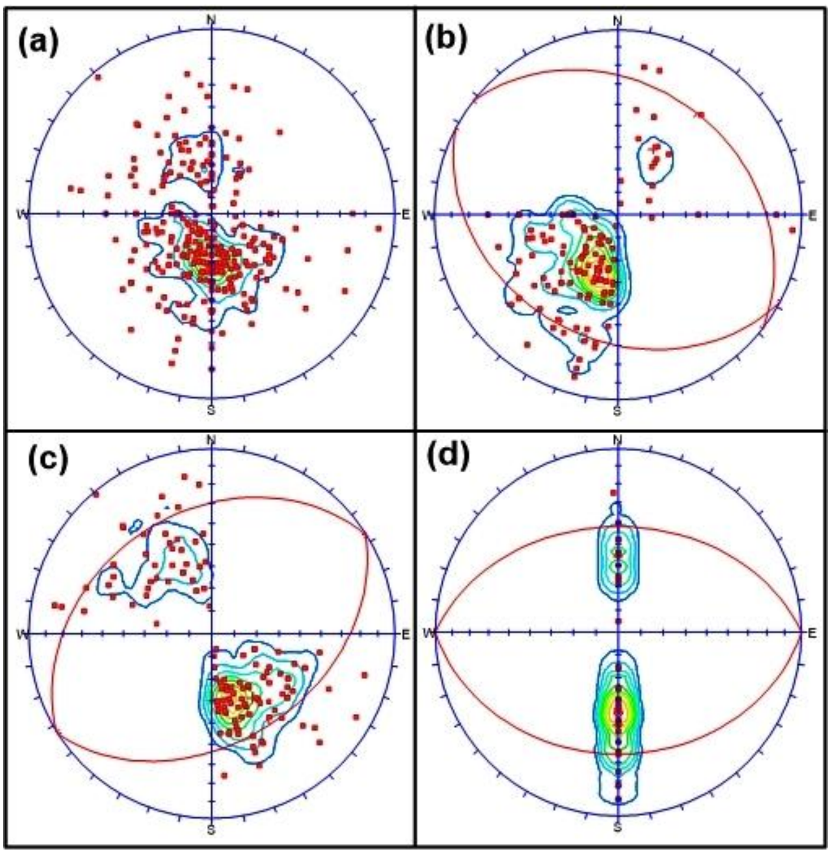

Figure 4: Equal area lower hemisphere Stereonet showing the poles of (a) All foliation planes in Sor Valley, Pithoragarh (b) Foliation plane strike in WNW-ESE direction (c) Foliation plane strike in ENE-WSW direction (d) Foliation plane strike in E-W direction**.**

III. DISCUSSION AND CONCLUSIONS

A lot of work has been carried out on the deformation history of the Kumaun Himalaya (e.g., Bhattacharya 1982, 1987; Thakur and Choudhury 1983; Roy and Valdiya 1988, Patel *et al*. 2011, Ojha *et al.* 2019 and Agarwal *et al*. 2021). Thakur and Choudhury (1983) have described three phases of ductile deformation (D1, D2, and D3). In contrast, Roy and Valdiya (1988) identified two types of folds based on the broad orientation of prevalent lineation indicating tectonic movement direction: (i) the hinges of folds are sub-parallel to the lineation, and (ii) folds with hinges that are at a high angle to the lineation. Dubey and Paul (1993) distinguished two types of folds: (i) the early group (F1a, F1b, and F2), which develops concurrently with thrusting along MCT, and (ii) the later group of folds (F3).

The deformation history of the study area can be correlated to the Satengal, Lesser Garhwal Himalaya. In the area mentioned above, rocks have experienced four phases of deformations. The three ductile deformation phases, D1, D2, and D3, are synchronous to three stages of folding, F1, F2, and F3. The F1 folds primarily trend in ENE-WSW, the F2 fold mainly trend in the NNW-SSE direction with a low to moderate amount of plunge, and the F3 trend in an NNE-SSW direction. The fourth phase of deformation is brittle deformation and is responsible for developing joints, fractures, and faults (Srivastava 2004; Srivastava *et al*. 2011). The rocks in the present study have shown the development of planar structures such as foliation and axial planes of various generations of folds. Three generations of axial planes (S0 and S1) strike in the E-W to ENE-WSW direction (figure 4d), the axial planes (S2) strike in the NW-SE to NNW-SSE direction (figure 4b), and the axial planes (S3) strike in the NE-SW to NNE-SSW direction (figure 4c) have been measured in the present study. These observations suggest three phases of deformation in the study area. The mutual associations between axial plane foliations and three generations of folding documented at the outcrop scale (figure 7c) also point out three tectonic phases (D1, D2, and D3). The relative chronology of these phases is revealed by fold interference patterns (figure 7c).

Figure 5: (a) Tight fold present in slate (b) Open fold present in limestone (c) and (d) Chevron fold in slate (e) Crenulation lineations in phyllite (f) Striations in shale (g) Quartz boudinage (h) Two sets of shear in phyllite.

D1 deformation produced S1 foliation plane of F1 folds trending ENE-WSW direction. D2 deformation is related to the S2 foliation plane of F2 open to tight fold with round hinges (trends NNW-SSE). D3 (NNE-SSW) deformation is related to the S3 foliation plane of F3 chevron folds.

The study of deformation structures like crenulations lineation, striations, boudinage, and faults is essential in understanding rock's deformation history. Two sets of fault planes were observed in phyllite, one set dipping towards the north with a moderate amount of dip and other set dipping towards SE with a gentle dip amount. The Drag folds have been observed (figure 5h), most probably formed due to the movement of blocks along the fault plane in opposite directions. The Striations over the bedding plane plunging in the ENE direction (figure 5f) indicates that successive layers have slipped over one another as the folds tightened, correlated with D1 deformation. E-W trending pinch and swell structures like boudinage (figure 5g) parallel to the foliation plane are related to D1 deformation. Crenulations lineation towards south plunging is related to D2 deformation (figure 5e).

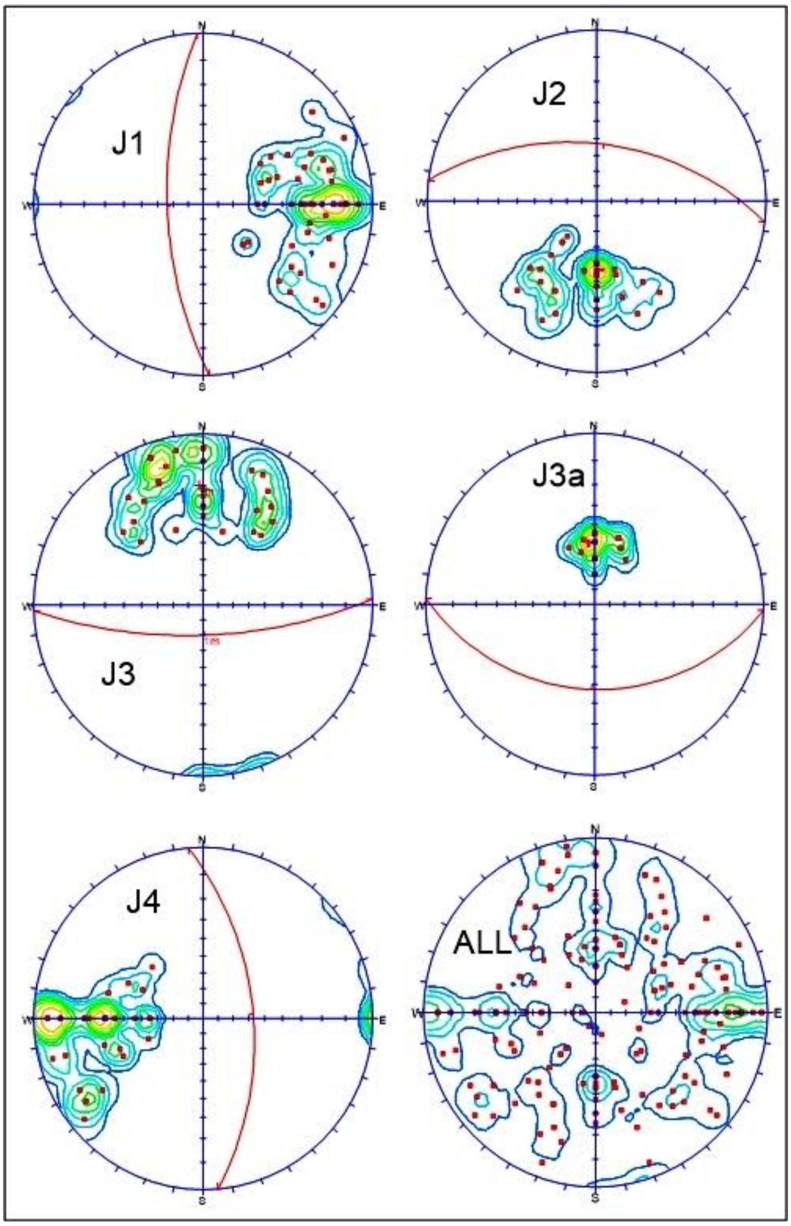

Figure 6: Equal area lower hemisphere Stereonet shows the poles of four sets of joints.

Further, the following interpretations have been made by studying the structural-Geological map of the area (figure 2).

a) The systematic variation of the bedding planes reveals a large-scale easterly plunging fold whose northern limb strikes NW and the southern limb strikes ENE-WSW.

b) One set of foliation changes its attitude conformably with the bedding planes. This foliation is to be co-folded with the bedding plane. Accordingly, this foliation is S1 and parallel to axial traces of the fold (F1) trending ENE-WSW.

c) In the easterly plunging fold (F2, trending NNW-SSE), the axial traces of the F2 folds are marked as the thick red stippled line.

d) The second set of foliations striking nearly parallel to the F2 axial trace can be considered S2 planes.

Figure 7: (a) The laminae of the stromatolites showing arched downwards in the inverted limb of overturned fold (b) The laminae of the stromatolites showing arched upwards in the normal limb of overturned fold.

e) A set of third-generation folds (F3) trending NNE-SSW has developed on the F2 fold. This set of folds is more strongly developed on the northern limb of the F2 fold than on the southern limb. All F3 folds are asymmetric and verging towards the east. This implies that the main compression during F3 was directed from NW towards SE and possibly related to Berinag thrust.

f) Similarly, the NAT could be related to F2 in the southern boundary.

The foliation/bedding plane data has been analyzed using a stereonet (figure 8), and the entire area has been subdivided into sector A and Sector B (figure 2). All F3/L3 lineations plunge towards NNE in sector A and plunge towards SSW in Sector B. The poles of S3 cluster on the eastern side of the girdle and the poles of all other planes (figure 8a).

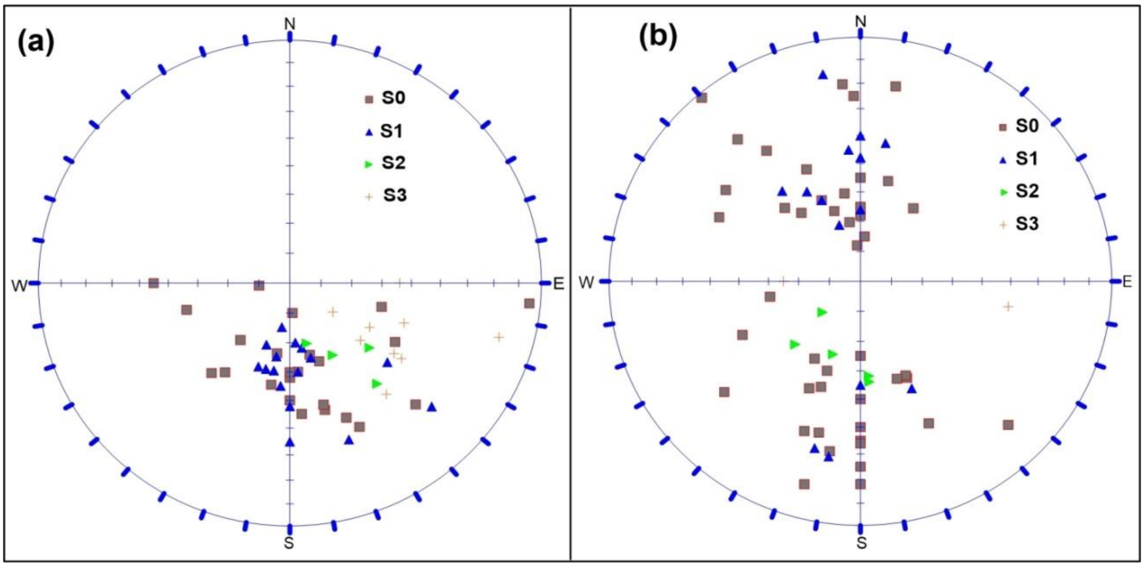

Figure 8: Equal area lower hemisphere Stereonet showing (a) the bedding and foliation poles of Sector A of figure2 and (b) Bedding and foliation poles of Sector B of figure2.

A geological cross-section from Gogana to Khitoli (figure 3) shows that the foliation planes dipped towards NE, and lithology repetition was observed in the field. These lithological repetitions indicate the presence of a significant deformational structure. The attitude of beddings, folds, associated foliation, and recurrence of older Gangolihat dolomite structurally above the younger Sor slate suggests the presence of a large overturned synform fold where its north-eastern limb is inverted. In this fold, Gangolihat Formation lies on limbs, and Sor slates lie on the core of the overturned fold. This mesoscopic overturned fold (trend ENE-WSW) shows an F1-type fold related to D1 deformation. In typical cases, the laminae of the stromatolites are arched upwards; specifically, the convexities point upwards (Mishra and Valdiya 1961; Valdiya 1980). It has been observed that the Stromatolites present in the North-Eastern limb show convexities of laminae point downwards (figure 7a), showing inversion of sequence (Cloud 1942; Shrock 1948). The Stromatolites present in the south-western limb show convexities of laminae pointing upwards (figure 7b), showing a typical sequence. These features also reveal that the Sore valley represents an overturned synform fold.

Based on the above discussion, we can conclude that Sor valley represents three phases of ductile deformation, D1, D2, and D3, associated with F1, F2, and F3 folding. A large-scale easterly plunging fold whose northern limb strikes NW and the southern limb strikes ENE-WSW is related to D1 deformation. This fold shows the repetition of the Gangolihat Formation and the presence of the older Gangolihat Formation/ Deoban Formation over the younger Sor Slates/Mandhali Formation.

This large fold is further associated with two phases of ductile deformation. In which easterly plunging F2 is correlated with the compression generated from North Almora Thrust (NAT) and F3 fold trending NNE-SSW is related to compression directed from Berinag thrust.

ACKNOWLEDGMENT

The authors are highly grateful to Late Padma Bhushan Prof. K.S. Valdiya for his guidance in the preliminary fieldwork and fruitful discussions. LS is thankful to the Council of Scientific and Industrial Research (CSIR) for providing the research fellowship which helps to complete this research work. GK is grateful to University Grant Commission (UGC) for providing a research fellowship (202850). The authors also present their gratitude to the Head of the Department of Geology, DSB Campus, and Kumaun University for equipping the required amenities.

REFERENCES

[1]. Agarwal, A., et al., Magnetic fabrics in an apparently undeformed granite body near Main Boundary Thrust (MBT), Kumaun Lesser Himalaya, India; Tectonophysics, 2021. **815:** p.1-18.

[2]. Antolín, B., et al., Kinematic evolution of the eastern Tethyan Himalaya: Constraints from magnetic fabric and structural properties of the Triassic flysch in SE Tibet; Geological Society of London Special Publications, 2011. **349:** p. 99-121.

[3]. Bhattacharya, A. R., Geology of the Thal–Tejam–Girgaon Area, Kumaon Himalaya with special reference to the record of schuppen structure and measurement of flattening of folds; Geosci. Jour., 1982. **3**: p. 27-42.

[4]. Bhattacharya, A. R., A “Ductile Thrust” in the Himalaya; Tectonophysics, 1987. **135**: p. 37-45.

[5]. Carosi, R., Structural evolution, metamorphism and melting in the Greater Himalayan Sequence in central-western Nepal; Geological Society, London, Special Publications, 2018. **483:** p. 305-323.

[6]. Chamyal, L. S. and N. M. Vashi , Tectonic framework and structural characteristics of the crystalline rocks of Kumaun Himalaya; Current trends in geology (eds) P S Saklani (New Delhi: Today and Tomorrows Printers and Publisher), 1989. **11:** p**.** 91–106.
[7]. Cloud, P. E., Notes on Stromatolites; Am. Jour. Sci., 1942. **240:** p. 363-379.
[8]. Dubey, A. K. and S. K. Pal, Map patterns produced by thrusting and subsequent superposed folding: Model experiments and example from the NE Kumaon Himalayas; Eclogae, Geol. Helv, 1993. **86/3:** p. 839-852.
[9]. Dubey, A., Understanding and orogenic belt: structural evolution of the Himalaya; Springer International Publishing, Switzerland, 2014. p. 292–294.
[10]. Dunkl I, et al., Metamorphic evolution of the Tethyan Himalayan flysch in SE Tibet. In R. Gloaguen, L. Ratschbacher (eds.): Growth and Collapse of the Tibetan Plateau; Geological Society of London, Special Publications, 2011. **353:** p. 45-69.
[11]. Gansser, A., Geology of the Himalayas; Interscience, London, 1964. p. 289.
[12]. Heim, A. and A. Gansser, Central Himalaya; Societe Helvetique des Sciences Naturelles, 1939. **73**: p. 1-245.
[13]. Hodges, K. V., Tectonic of Himalaya and southern Tibet from two perspectives; Geological Society of America Bulletin, 2000. **112:** p. 324–350.
[14]. Jain, A. K. and R. M. Manickvasagam, Inverted metamorphism in the intracontinental ductile shear zone during Himalayan collision tectonics; Geology, 1993. **21:** p. 407-410.
[15]. Jain, A. K. et al., Timing, quantification and tectonic modeling of Pliocene-Quaternary movements in the NW Himalaya: evidence from fission track dating; Earth Planet. Sci. Lett., 2000. **179:** p. 437-451.
[16]. Joshi, A. and R. C. Patel, Modelling of active lineaments for predicting a possible earthquake scenario around Dehradun, Garhwal Himalaya, India; Tectonophysics, 1997. **283:** p.289-310.
[17]. Joshi, G. et al., Microstuctures and strain variation: Evidences of multiple splays in the North Almora Thrust Zone, Kumaun Lesser Himalaya, Uttarakhand, India; Tectonophysics, 2017. **694:** p. 239-248.
[18]. Misra, R. C. and K. S. Valdiya, The Calc zone of Pithoragarh, with special reference to the occurrence of stromatolites; Jour. Geol. Soc. Ind., 1961. **2:** p. 78-90.
[19]. Misra, R. C. and R. P. Sharma, Structure of Almora Crystalline, Lesser Kumaun Himalaya. An interpretation; Him. Geol., 1972. **2:** p. 330–341.
[20]. Molnar, P. and P. Tapponnier, Cenozoic tectonics of Asia: Effects of a continental collision; Science, 1975. **189:** p. 419-426.
[21]. Montomoli, C. et al., Tectonometamorphic evolution of the Tethyan Sedimentary Sequence (Himalayas, SE Tibet); Italian Journal of Geosciences, 2017. **136:** p. 73–88.
[22]. Mukherjee, S., Channel flow, ductile extrusion and exhumation of lower mid-crust in continental collision zones. Current Science, 2005. **89**: p**.** 435-436.
[23]. Mukherjee, S. et al., Implications of channel flow analogue models for extrusion of the Higher Himalayan Shear Zone with special reference to the out-of-sequence thrusting; International Journal of Earth Sciences, 2012. **101:** p. 253-272.
[24]. Mukherjee, S., Channel flow extrusion model to constrain dynamic viscosity and Prandtl number of the Higher Himalayan Shear Zone; International Journal of Earth Sciences, 2013. **102:** p. 1811-1835.
[25]. Mukherjee, S., A review on out-of-sequence deformation in the Himalaya. In: Mukherjee S, Carosi R, van der Beek P, Mukherjee BK, Robinson D (Eds) Tectonics of the Himalaya; Geological Society, London. Special Publications, 2015. **412:** p. 67-109.
[26]. Mukherjee, S. et al., A review on intrafolial folds and their morphologies from the detachments of the western Indian Higher Himalaya. In: Mukherjee S, Mulchrone KF (Eds) Ductile Shear Zones: From Micro- to Macroscales; Wiley Blackwell, 2015. p. 182-205.
[27]. Norton, I. O. and J. G. Sclater, A model for the evolution of the Indian ocean and the breakup of the Gondwana land; J. Geophys, Res., 1979. **84:** p. 6803-6830.
[28]. Ojha. A. K. et al., Polyphase development of chocolate-tablet boudins in the SAT zone, Kumaun Lesser Himalaya, India; Journal of Structural Geology,2019.**127:** p.1-15.
[29]. Patel, R. C. et al., Geology, Structural and Exhumation History of the Higher Himalayan Crystallines in Kumaon Himalaya, India; Journal geological society of India, 2011. **77**: p. 47-72.
[30]. Patfiat, P. and J. Achache, India-Eurasia collision chronology has implications for crustal shortening and driving mechanisms for plates; Nature, 1984. **311:** p. 615-621.
[31]. Pecher, A., Geology of Nepal Himalaya: Deformation and petrography in the Main Central Thrust Zone; Ecologie et Geologie de l'Himalaya, Colloques Internationaux du Centre National de la Recherche Scientifique, Paris, 1977. **268:** p. 301-318.
[32]. Phartiyal, B. et al., Palaeoclimatic significance of magnetic properties from Late Quaternary lacustrine sediments at Pithoragarh, Kumaun Lesser Himalaya, India; Quaternary International, 2003. **108:** p. 51-62.
[33]. Powell, C. M., A speculative tectonic history of Pakistan and surroundings; Some constraints from the Indian Ocean, in Geodynamics of Pakistan, edited by A. Farah and K. A. DeJong; Geological Survey of Pakistan, Quetta, Pakistan, 1979.p. 5-24.
[34]. Roy, A. B. and K. S. Valdiya, Tectonometamorphic evolution of the great Himalayan Thrust Sheets in Garhwal Region, Kumaon Himalaya; Jour. Geol. Soc. India, 1988. **32:** p. 106-124.
[35]. Sathyaseelan, R. et al., Micro-Tremor Induced Gravity and Seismic Noise Spectra in the Garhwal Himalaya and the Adjoining Regions; Journal of the Geological Society of India, 2018. **91:** p. 273–280.
[36]. Searle, M. P. et al., The closing of Tethys and the tectonics of the Himalayas; Geol. Soc. Am.Bull, 1987. **98:** p.678-701.
[37]. Shrock, R. R., Sequence In Layered Rocks; McGraw-Hilo Book Co. Inc, NY., 1948. p. 286-293.
[38]. Srivastava, P. and G. Mitra, 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, 1994. **13:** p. 89–109.
[39]. Srivastava, H. B., Finite strain and deformation from a refolded region of the Dudatoli-Almora Crystalline, Kumaun Lesser Himalaya; Journal of Asian Earth Sciences, 2004. **24:** p. 115-125.
[40]. Srivastava, H. B. et al., Mesoscopic structures from the area around Satengal, Lesser Garhwal Himalaya; Journal of Scientific Research Banaras Hindu University, Varanasi, 2011. **55:** p. 25-34.
[41]. Thakur, V. C. and B. K. Choudhury, Deformation, metamorphism and tectonic relations of Central Crystallines and Main Central Thrust in Eastern Kumaon Himalaya; In: P.S. Saklani (Ed.), Himalayan Shears, Himalayan Books, New Delhi, 1983. p.45-47.
[42]. Thakur, V. C., Development of major structures across the northwestern Himalaya, India; Tectonophysics, 1987. **135:** p.1-13.
[43]. Thakur, V. C., Geology of western Himalaya; Pergamon Press, New York, 1992. 363.
[44]. Upreti, B. N., An overview of the stratigraphy and tectonics of the Nepal Himalaya; Journal of Asian Earth Sciences, 1999. **17:** p.577–606.
[45]. Valdiya, K. S., An outline of the stratigraphy and structure of the southern part of the Pithoragarh district, UP; Jour. Geol. Soc. Ind., 1962. **3:** p. 27-48.
[46]. Valdiya, K. S., Origin of the magnesite deposits of southern Pithoragarh, Kumaun Himalaya; Economic Geol., 1968. **63**: p**.**924-934.

[47]. Valdiya, K. S., Stromatolites of the lesser Himalaya carbonate formation and Vindhyan; Jour. Geol. Soc. Ind., 1969. **10**: p**.** 1-25.
[48]. Valdiya, K. S., Origin of phosphorite of the Late Precambrian Gangolihat Dolomite of Pithoragarh, Kumaun Himalaya, India; Sedimentology, 1972. **19:** p. 115-128.
[49]. Valdiya, K. S., Geology of Kumaun Lesser Himalaya; Wadia Institute of Himalayan Geology, Dehra Dun, India, 1980. p. 291.
[50]. Valdiya, K. S., Tectonics and evolution of the central sector of the Himalaya; Philos. Trans. R. Soc. London, Ser. A., 1988. **326:** p. 151–175.
[51]. Valdiya, K. S., Himalaya: emergence and evolution; Universities Press, 2001.
[52]. Webb, A. A. G. et al., Cenozoic tectonic history of the Himachal Himalaya (northwestern India) and its constraints on the formation mechanism of the Himalayan orogen; Geosphere, 2011. **7:** p.1013.
[53]. Webb, A. A. G., Preliminary balanced palinspastic reconstruction of Cenozoic deformation across the Himachal Himalaya (northwestern India); Geosphere, 2013. **9:** p. 572.
[54]. Yin, A., Cenozoic tectonic evolution of the Himalayan orogen as constrained by along-strike variation of structural geometry, exhumation history, and foreland sedimentation; Earth Sci. Rev., 2006. **76:** p**.**1–131.