Hill slope instability in parts of neotectonically active Garhwal Himalaya, India

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ABSTRACT

Alaknanda valley in Chamoli Garhwal is marked by frequent landslides and neotectonic activity. NNW-SSE and NE-SW lineament pattern indicates strong control of tectonic on the drainage architecture. High topography, prominent breaks along longitudinal profiles of Alaknanda River, prominent south facing escarpments, river pounding, steep gorges and incised river is indicative of ongoing neotectonic activity. Piedmont deposits of Kalpeshwar temple, fault scarp at confluence of Karmasa and Kalpa Ganga at Helong, subsidence of Dangri village, ponding of Hanuman chatti, off set of talus mass of Pandukeshwar and seismogenic landslide of Titari village along bank of Virahi Ganga are the prominent sites where upliftment is noticed. Study of longitudinal profile of Alaknanda River suggest that rejuvenation and channel sedimentation phases are operative in these regions. OSL dating of Alaknanda terraces at Pipalkoti also suggest upliftment. Values of morphometric parameters related to stream gradient index, drainage basin asymmetry factor, mountain front sinuosity also give evidence that the region is experiencing the dynamic rejuvenation phase.

Keyword: - *Neotectonic, slope instability, Garhwal Himalaya, rejuvenation, upliftment, channel sedimentation phases.*

Introduction

The Himalaya, a unique chain of youngest and lofty mountains in the world has undergone various stages of orogenic episodes. This is evident by poly phase folding, faulting, igneous activities, crustal adjustments and readjustments [8]. The last phase of orogenic event, that took place in Tertiary due to collision of Indian and Eurasian plates culminated in the Middle Miocene time is still undergoing in the processes of crustal adjustments. Therefore, the intra crustal thrust i.e., MCT is still active and represents a fragile geological domain. Himalaya represents the site of collision tectonic model where Indian plate is moving northward and because of which stresses are being accumulated in many places especially along the Main Central Thrust [2]. The release of the stresses major thrusts is responsible for shallow foci earthquake in Himalaya.

Chamoli Garhwal Himalaya structurally forms a duplex thrust system. This zone is marked as zone for seismic events of V of IS code 1899-1984. Workers has provided evidence in support of neotectonic activity. These outline the geomorphological development of the Himalayan Crystalline in the plate tectonic context. However, concentrated geomorphic studies in small areas have proved more revealing on the nature, type and timing of tectonic movements along various faults. Here an attempt is made to delineate modification in the landscape of Alaknanda basin by neotectonic activity of Main Central Crystalline zone.

Gological Set Up of Alaknanda Valley

Central Crystalline zone in Chamoli Garhwal is about 50-60 km in width and has extension in NW-SE direction. This zone has been divided into Vaikrita, Munsiari (Jutogh) and Chail/Bhatwari Groups [15]. The tectonic planes for each groups of the CCZ are considered as the branching of MCT viz MCT-I, MCT-II, MCT-III [9] in Garhwal. The area comprises the rocks of three main tectonic units (a) Jutogh Group (nappe of lower crystalline) (ii) Chails (iii) Gaghwal Group (Precambrian metasedimentary unit of Lesser Himalaya) and Deoban (figure 1). Litho units of the area show low to medium grade of metamorphism. High mountains and stiff cliffs of crystalline comprise mainly of quartz, slate, limestone, schist, gneisses and migmatites topographically distinguish this region. The area is marked by the presence of gorges, deformed solifluction lobes and different generation of terraces, off set fans and triangular facets. These features are attributed to the uplift along NW and NE oriented faults. The area is dominated by NW-SE and NE-SW trending ridges and spur. At Helong rivers Kalpa and Karmnasa join at the right angles apposite to each other. The beds of both the channels have slopes about 25° in steps and theirs straight course indicates the vertical fault line scarp. The Patal Ganga and Birahi Ganga have managed to cut deep gorges at their confluence with the Alaknanda due to presence of NW-SE and NE-SW trending faults. Kauria, Tangri and Pakhi, Chamoli, Gopeshwar, Km5 at Birahi-Pipalkoti, Birahi suffered with seismogenic landslides during Chamoli earthquake. Pipalkoti section is structurally an antiformal structure [4] and is marked by development of radial drainage in which individual drainage is dendritic (figure 2 and 2a).

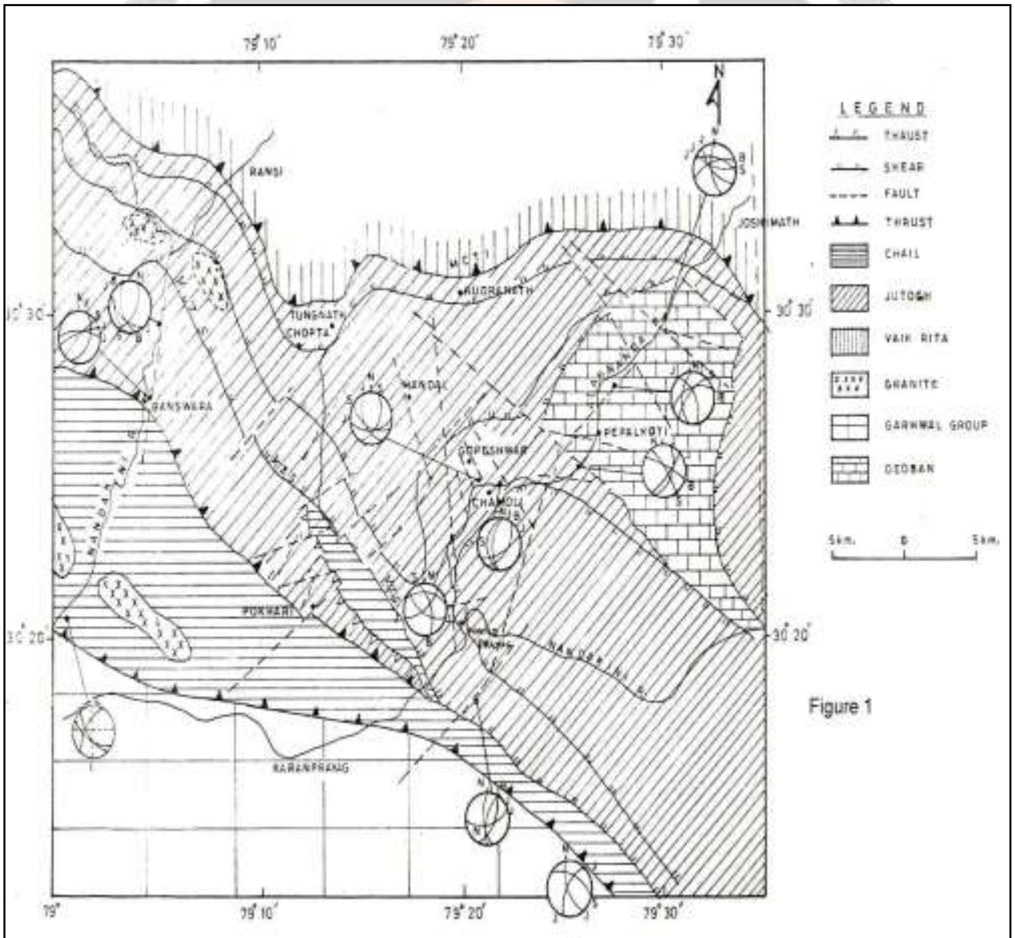

Figure 1 Geological map of the study area.

Figure 2 Drainage map of Chamoli -Pakhi Tangni section showing distribution of lineament extrected from satellite images.

Figure 2a Drainage and lineament map of Helang-Pandukeshwar section

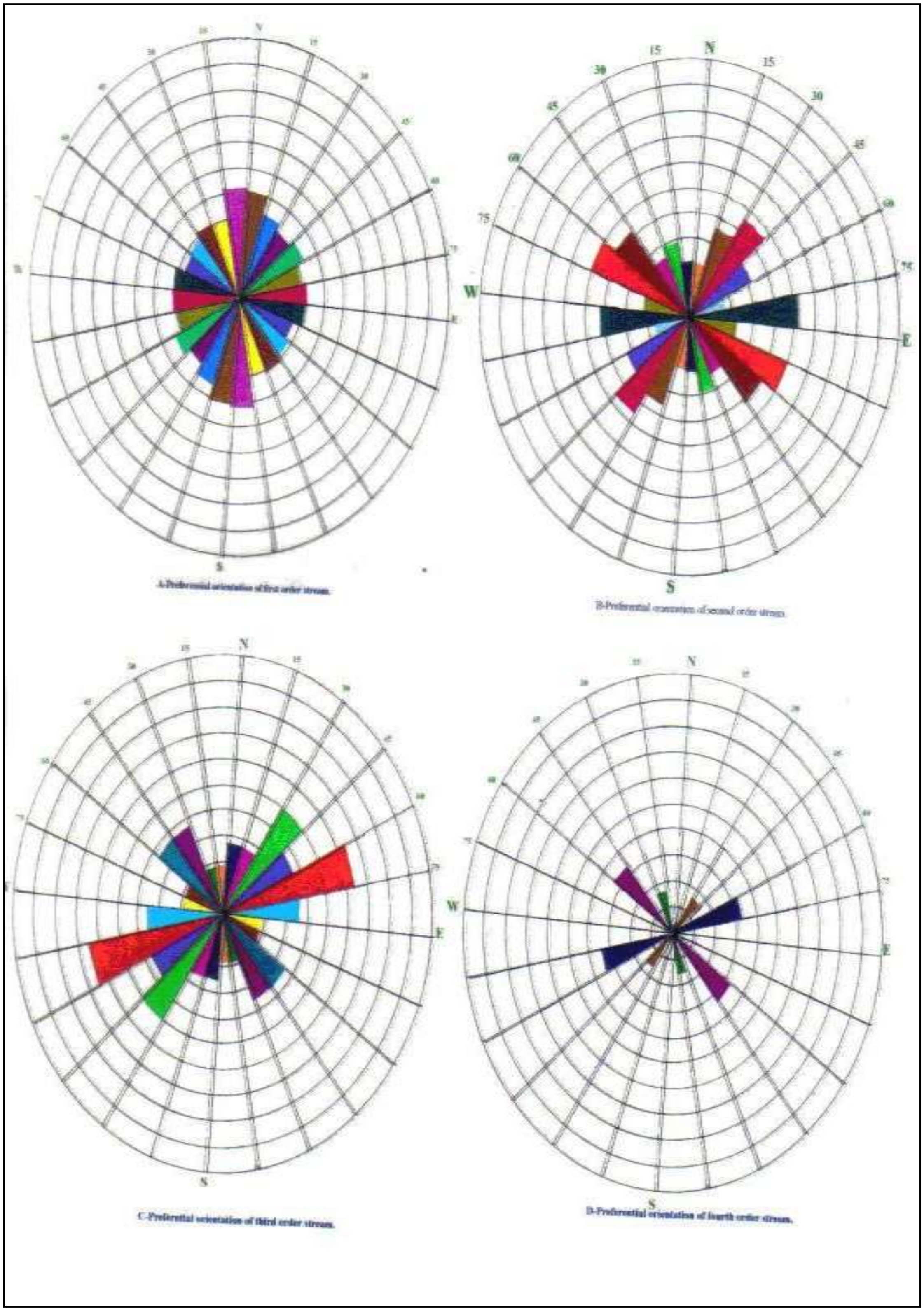

Figure 3 Rose diagram for 1st, 2nd, 3rd and 4th order streams.

The Alaknanda valley is a narrow valley and is represented by dendrtic and radial drainage pattern in between Vishnuprayag and Chamoli. Trend of low and high order streams in between Govindghat and Helong dominates in N-S, NE-SW, ENE-WSW and NW-SE direction as is seen in figure 3.

Terraces: Alaknanda valley is marked at many places by the deposition of terrace material. From Pakhi to Kauria the river follows N-S course as vertical deep gorge over which two levels of terraces are seen on the left bank of Alaknanda. At Tangri folded quartzite is marked by open convex Lense shape fractures which indicate the passing location of transform fault. Helong-Dungri village is situated on the terraces along Karmnasanala comprised of talus material of schist, quartzite, gneisses and sand. Karmnasa nala is running along straight vertical fault line scarp. Wide area of Dungri Village is subsiding. The subsidence is due to creeping of the mass which is evidenced by tilting of power line pole. Rock is marked by E-W trending grooves. Subsidence of terrace is ascribed due to reactivation of NNW-SSE trending fault crossing MCT in this region. Above Kalpeshwar Mahadev temple near Bharki village pebble and sand bed is found at a height of 2294 meter resting over the quartzite rock 50m above the river. An iron leached horizon is also observed here. On right side of river, terraces also show tilting opposite to riverbank. Village Devgram show uplifted type of piedmont deposits. Geomorphic and structural features indicate that NW-SE and NE-SW trending faults have displaced Pipalkoti window thrust (Figure 1) and subsidiary faults has resulted in the development of unpaired terraces, fault scarps and triangular facets. These faults have shifted the course of Alaknanda from NE-SW to almost E-W direction in between Chamoli to Pipalkoti. At the confluence of Alaknanda and Birahi Ganga phyllite is exposed and forms a part of anticline where river takes E-W turn up to Chamoli and terraces are found on the right bank of river. Quartzite, Conglomerates, pebbles and boulders forming the old talus beds are found over and above the river section. Terraces are characterized by the variation of gravel beds associated with varve sand from the bottom to the surface. Liquifactions features and river terraces are exposed along NW-SE trending faults on the way leading to Gohna Lake. Mountain front sinuosity calculated on these points by Joshi (2004) was 66 and 56. East of Chamoli liquefaction features are noticed in the sand bar scrolls and right side of Alaknanda terraces show fresh slides devoid of vegetation and furrows. Here stream gradient index was noticed 600.Right side basin of this area show asymmetric value of 64.Alaknanda takes sharp turn towards south at Chamoli where asymmetric factor for basin was calculated 47.

The uplift of terrace and deposition of clay and mud at upper level and gravel horizon in the basal part is indicative of tectonic activity in this terrace horizon. Gorges, fractured pebbles in shattered quartzite along Pipalkoti thrust near Bhimtalla is the manifestation of neotectonic movements which are further supported by offset of sand bed on right side of Alaknanda before Chamoli. Neotectonic movements have manifested unpaired fluvial terraces with different terrace levels and is seen T1 uplifted by 52 meters only along the river Alaknanda (figure 3). Comparative level difference of unpaired terrace developed by interaction of NE-SW and NW-SE trending faults reflects not only the ongoing Pipalkoti thrust activity controlling morphology of the antiform structure but also unfolds spasmodic rise of the area along the thrust and fault. The movements along faults have led to the formation of large terraces. Joshi (2006) found out probable rate of uplift of the terrace as 24.3 mm per year for T2 and 4.3 mm per year for T1.

River response to active tectonics is generally reflected in longitudinal profile of river [3]. Longitudinal profile of Alaknanda River at Pipalkoti (Figure 5) shows knick points where gradient is being lost and sedimentation phase was started along with upliftment when a gorge was formed.

In this reach stream gradient index was calculated and the value was found to be 1000.Mountain front sinuosity value along this basin is sensitive and reaches to 1.6 in NW of Pipalkoti [5]. In fact, whole section from Chamoli to Helong is in active zone where Birahiganga and Patal Ganga has managed to deep cut at their confluence with Alaknanda due to presence of faults. At Pipalkoti, Pakhi and Tangani Alaknanda traverses through gorges. Here two centers of radial drainage pattern are separated by deep gorges along NW-SE trending joints where Alaknanda passes along rift line of synclinal folded slate and limestone. Shukla et.al (2013) study shows that most of the areas of Alaknanda valley sub-basins are very highly active to low active areas.

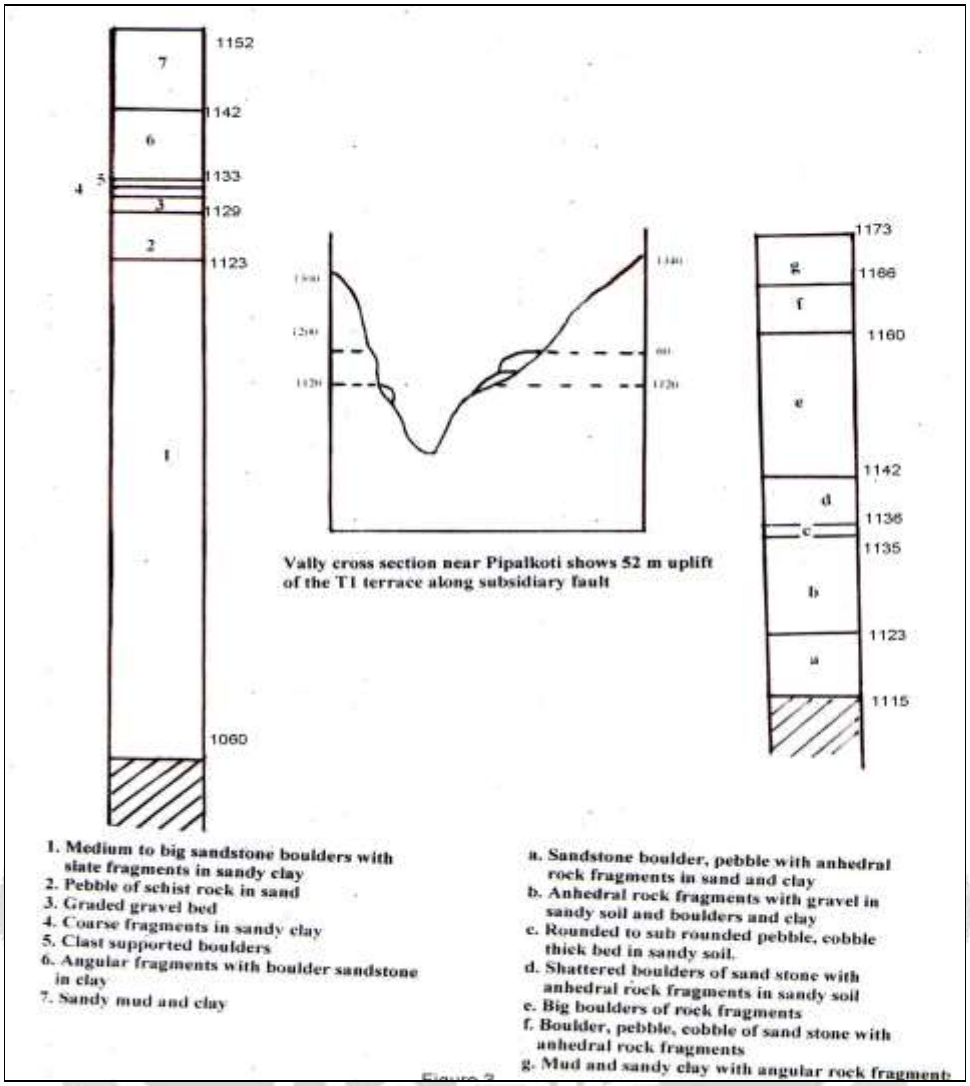

Figure 4 Valley cross section near Pipalkoti

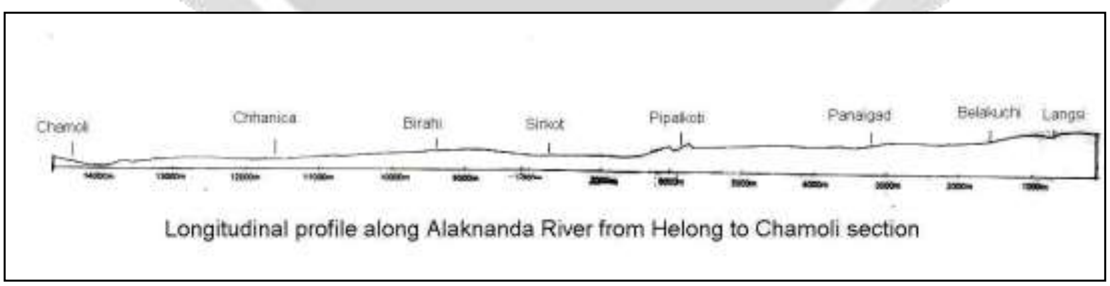

Figure 5 Longitudinal Profile along Alaknanda River

Mass movement during Chamoli earthquakes:

Landslide disaster was observed thoroughly between MBT in the south and MCT in the north in Garhwal Himalaya. The impact of Chamoli earthquake on socio economic environment and loss of life and property was published by Joshi et.al in 2002.In the present work attempt is made to describe various kind of landslide developed by 6.9 magnitude of earthquake in Central Crystalline zone and Lesser Himalayan zone. The disaster took place on 29th

March 1999 having its epicenter near Rudranath [7]. Here an attempt is made to report the pattern of landslides developed at that time as under.

Km. stone 372 on NH 58 in between Rishikesh and Shivpuri: Slide occurred in Infra krol slate and limestone rocks. Shear plane was reactivated as such one foot wide crack developed along crushed mass from crown of slide to bottom of slope as shown in figure 6. Middle portion of slide is weathered and oxidized. The fine powder and small fragments fall down continuously. Cracks are oriented in E-W and NW-SE direction. Slope is inclined in E-W.

Km. stone 10 in between Srinagar to Devprayag:150m long and 80 m wide landslide occurred in weathered phyllite. Movement in highly jointed greenish phyllite took place in form of debris. Fresh fractures as shown in figure 6 appeared on the ENE-WSW trending slope. Attitude of bed is 45° in WNW. Joints dip 45°in N35°E and 25°in S30° E. Measoscopic shear is measured 38°in N60°W.

Km. stone 7 in between Srinagar to Devprayag: Older debris mass moved along foliation of phyllite dipping towards roadside. New water seepages were appeared as is seen in figure 6. One feet wide NNW-SSE trending cracks developed on the slope. Attitude of phyllite is 37°in ESE. Joints trends in NE-SW and due N in vertical dip.

Ukhimath-Chopta road: At Sari village along Deveriatal motar road, Khar Gadera was affected by August 1998 rain. Landslide took place along both existing nala where falling boulders eroded the boundary of Mastura-Dara village reaching up to Akash Kamini Nadi at bottom. Road was also damaged. Quartzite is exposed on the top of slide whereas biotite quartz schist forms lower side lithology (figure 6). ENE-WSW oriented four cracks of 1/2 m to 7m long and ½ m to 1 m wide developed on 29th March and run parallel along ridge thereby extending up to 1 km. Cracks are curved in nature. Inclination of slope is 46° towards SW.

3 Km a head from Chandrapuri towards Beei: Slide occurred on fresh and weathered gneisses and schist as shown in figure 6. Length of slide is 150 meters along road and width is 100 meters. Right hand side portion of slide shows fractured rock blocks in hanging condition. Below hard and compact gneissic rock cubic blocks are developed. A crack of about 18 meter parallel to road was exposed on debris mass.

Km stone 147/2 Karanprayag to Tharali Road: 10 meter long and 10-meter-wide stretch suffered new mud slide along the road. Right corner portion of slide is covered by pebble and cobble bed as is seen in figure 6. Crown and periphery of slide is covered by vegetation. NE-SW oriented fractures are found on 50° SSW dipping slope.

Narayanbagar Landslide: This is major landslide which is reported to occur on September 2 and 3,1995. The whole stretch of about 150 meter long was subsided and road was closed due to debris which blocked Pindari river and raised about 10 meter water level for 8-10 days. Since then, in every rainy season and rains of winter activate landslide. Debris is non cohesive. Sand dyke is exposed and marked by converging crenulations. Water seepages are present and is shown in figure 6. Fine grained chlorite schist forms dominant lithology on right side of slide. Spur of slope is covered by moraine deposits which allow rapid infiltration of water.

Km stone 5 near Maltura bridge along Karanprayag-Gwaldam state highway: On the right bank of river i.e., apposite and near the Harmony slide terrace material is sliding. Length of slide is 50 meter and width extend for about 35 meters. Slope has become almost vertical by falling of debris material. Basement of slide is on hard and compact exposure where debris mass has formed talus cone marked by rill erosion. A layer of about 2 meter thick medium to big size boulders of sandstone bed embedded in mud over lie the hard rock exposures. Uphill slope is again marked by alternate banding of comparable size boulders in mud as is seen in figure 6. Crown of this spur slope is marked by rill erosion features. Lateral part of slide is covered by pine tree forest and agriculture terrace and trees.

Km stone 41 Karanprayag: Slide is on quartz feldspar biotite schist in which quartz veins are running parallel. Left middle portion of slide is showing various seepage points in along E-W trending shear zone (figure6) marked by pulverized and sericitised rock. This side is also covered by perennials drainage. At the contact of shear zone, a thin patch of ½ meter talc chlorite schist is exposed. Above and below of the shear zone migmatite rock has got iron leaching. Right hand portion of slide show crushed mass in form of mud slide. Central and peripheral portion of slide is covered by vegetation. Dip of rock is 63° in SE direction. Attitude of joints are in 67° in SW and 55° in NWN direction.

Km stone 12 Narayanbagar: Slide is located 50 meters before Km. stone 12 at Barkula school (Kulsari): This is a mud slide in which small and big boulders slipped with mudflow. Slide is marked by rill and seasonal nala as is shown in figure 6. Slide periphery is covered by vegetation.

Harmony Landslide: This is a big debris slide. Basement of slide is on biotite schist which is seen insitu on left side of slide on road and dip 45° in WNW. Crown of slide has irregular demarcation from soil of surrounded village. Below crown newly developed fresh slide has developed 70° inclined slope which trends in NW-SE and forms a horizon marked by numerous parallel rills as is seen in**.** This underlain the boulders of gneissic rocks which are covered by grass and few trees as is shown in figure 6a where slope direction has become in ENE-WSW direction. Boulders comprising debris mass are composed of porphyritic migmatite and puckered biotite schist .Left lower portion of slide show non cohesive debris mass comprised of big and medium size boulders embedded in sandy soil. Lower central and right portion of slide is comprised of very big boulders with rock fragments in silt and sandy soil. This debris has advanced for 16 meters towards the bank of Pindar River. Pindar hits the left side portion of slide base first and deposits the load in right side and has made its way curved here. Perennial water seepages are shown in the figure. General slope direction is NNE-SSW. Cracks are oriented in NE-SW°, ESE-WNW and NNE-SSW. Upward tilting of trees are noticed both on uphill and downhill of slope.

Km. stone 5 Birahi to Pipalkoti: This stretch is about 100 long where rock blocks are hanging. After shocks of Chamoli earthquake was triggering the mass movement. Thinly bedded quartzite is so fragile that vibration of bulldozer is bringing down fall of medium to bigger size boulders a product of fluvial deposits over the jointed quartzite. Inclination of slope is 85° in NE-SW direction. Quartzite dip is 26° NNE. Attitude of Joints of the rock is 85° in ESE and 61°ESE.Dry nala are present on the upper portion of slide as is shown in figure 6a.

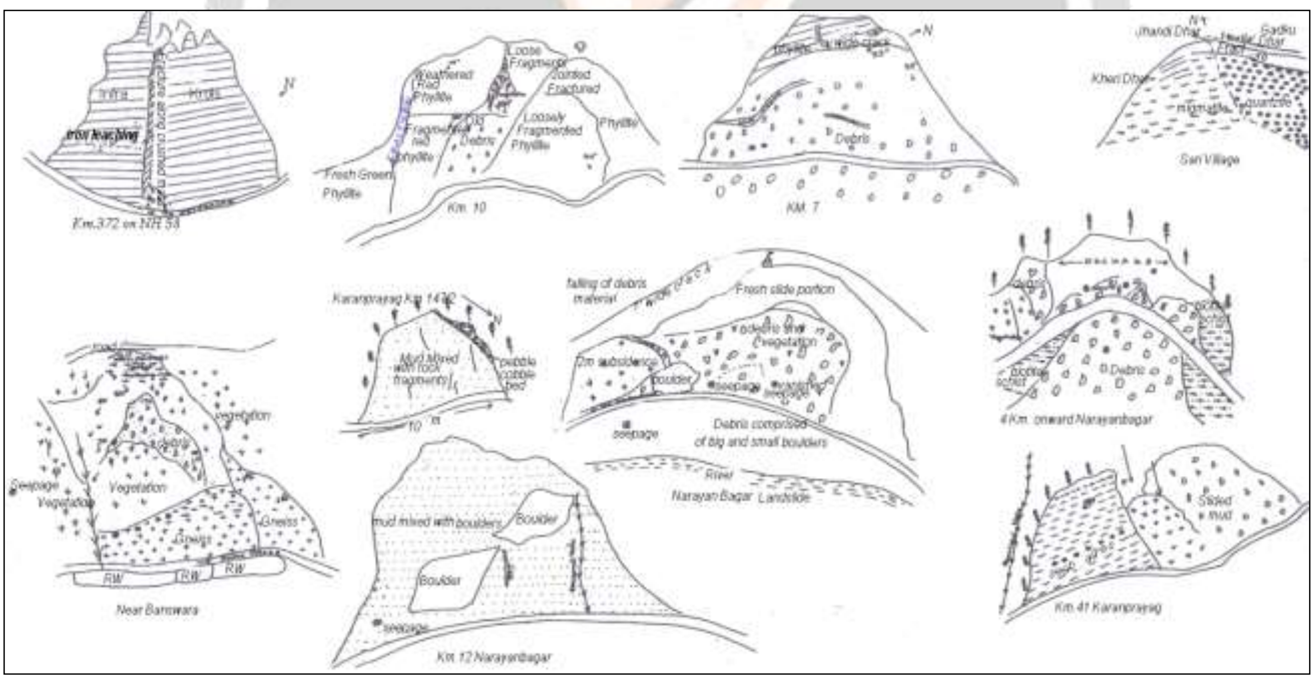

Figure 6 Various landslide in the study area.

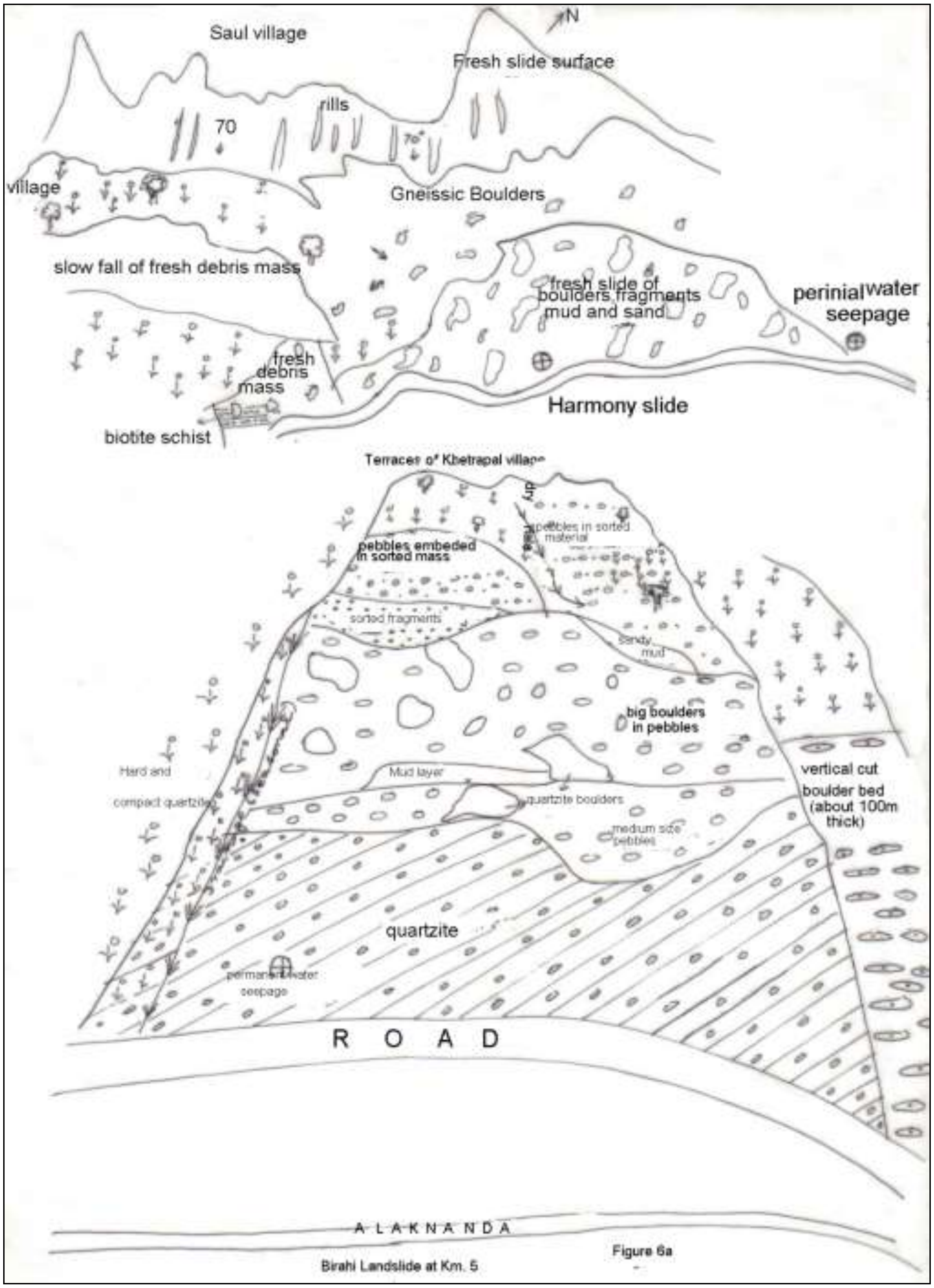

Figure 6a Harmony landslide

Discussion:

Garhwal Himalaya is marked by deep-seated intracrustal weak planes is a manifestation of northward progressing and collision of the Indian plate with Asia. Catlos et al. (2007) reported youngest Th–Pb ages of 1.0 ± 0.5 and 0.8 ± 0.2 Ma in the hydrothermal monazites at the base of the MCT shear zone from Garhwal Himalaya. These ages show that the zone of Indo-Asian plate convergence did not shift systematically southward from the MCT toward the foreland during the mountain-building process. Instead, they support out-of-sequence thrusting and reactivation of

MCT (Ramgarh Thrust) toward the fore land. This push is being accommodated by adjustment in thrust and faults reflected in modification in topography, geological structures in seismic environment. The distribution of elevation across the area of landform was foundout by hypsometric curves in between Chamoli to Langsi (Joshi 2004) by plotting the proportion of total basin height (relative height) against the (relative area) show sigmoidal pattern of curve suggesting mature stage of development of topography in the central crystalline zone. Alaknanda emerges narrow valley in the upstream at the junction of Birahi it becomes a wide and sinuous meandering river and flows through a wide valley. Alaknanda river enters the basin through a gorge in between Govind ghat and Dholi Ganga and then passes Belakunchi-Pakhi-Tangni-Kauria to Birahi through a gorge in NE-SW straight course followed by west ward swing into a wider open valley between Birahi to Chamoli. River is found sinuous and scrolled at points of confluence and fault. Longitudinal profile of Alaknanda valley in between Helong to Chamoli indicate break in channel gradient at Langsi, Belakunchi, Pipalkoti indicating adjustment of channel with geodynamic processes and lithological variations.A change in thalwaj is observed at the contacts of Crystalline with quartzite along the MCT .Differential erosion has developed nick points at Helong, Dungari due to change of lithological character. A nick point (1740m figure4) concides with the surface trace of NW-SE trending MCT in between Helong to Langsi. A marked change in the river profile along NE-SW and NW-SE trending fault at Pipalkoti and Chamoli can be attributed to neotectonic activity where off set of Periglacial lobes and liquefaction features of siesmites are noted respectively. Tilt of terrace is well known near Nandprayag. The lowering of valley gradient from crystalline terrace to Chamoli quartzite terrain can be ascribed to the development of river terraces. The Alaknanda flow along Pipalkoti faulted anticline show nick point indicating its development by faulting the major lineament NE-SW and NW-SE not only govern the course of Alaknanda River but also facilitate development of fluvial landscape of Pipalkoti, Helong, Belakunchi and Birahi-Chamoli section. Moreover, Distinct vertical off set-in terraces in Pipalkoti and Chamoli suggest in grown meander morphology which develops with increasing sinuosity due to pulsating nature of tectonic activity [12]. Sati et.al (2007) disclosed vertical offset in the terraces is attributed to change in river gradient caused due to differential movement along E-W lineament which is in confirmation of the present study in Chamoli Birahi and Pipalkoti section.

Conclusion:

Alaknanda valley in Chamoli Garhwal section shows evidence of neotectonic activity. Lineament pattern indicates strong control of NNW-SSE and NE-SW tectonic trends on the drainage architecture. Longitudinal profile of Alaknanda shows variable slopes. Mass movement activity in Chamoli Garhwal is affected by dynamic rejuvenation phase in recent time. Mass movement observed during Chamoli Earthquake show maximum landslide 60.4% took place in Central crystalline 39.6% landslide was estimated in rocks and sediments of Lesser Himalaya. Failure diagram in figure 1 for landslide activity during Chamoli earthquake shows weak planes was the site for mass movement activity. Sudden appearance and disappearance and fluctuation in discharge was due to slope movement.

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