



Research Paper

# Interpreting of Fault Activation with New High Resolution Digital Elevation Model with Himalayan and Azad Kashmir

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In the research area compressional stresses caused by the collision of Indian and Eurasian plates developed the northwest- southeast trending faults which are Riasi Fault (RF), Palandri Fault (PF), Godri Badshah Fault (GBF) and Chhechhan Fault (CF). The objective of research was to interpret the Fault activation on the basis of Geo-hazard parameters includes active faults, slope gradient and Geo-hazard zonation on the basis of Geographical Information System, restrain with the previously known geological and structural information. Digital Elevation Model use to contemplate the faults, slopes, topography, contours, watershed, hill shade, aspect, and stream network. Faults activation is also mark on the basis of geomorphological features, outcrops and linear landslides. It's required to creating a new high-resolution DEM using GIS Software Arc GIS v10.2 with its 3D Analyst extension. The faults are reverse in nature and have Strike Slip movement bearing Fault gouge and crushing. The folds in research area are open to gentle and northeast southwest vergent. Mapping disclose the well exposure of Siwalik group of Early Miocene ( $T_m$  Formation) to Late Miocene ( $T_{dp}$  Formation) rocks in the research area.

**Keywords:** Restrain, Contemplate, Gouge, Vergent

## Introduction

The research area lies in the Sub-Himalayas. The fold and thrust procedure is the result of Indian and Eurasian collision in Himalayan territory. The project area is bounded by Main Boundary Thrust (MBT) to the East, Jhelum Fault (JF) to the West, Salt Range Thrust (SRT) to the South and it lies in the south of Bagh Basement Fault (BBF)

Figure 1. The area is the part of Sudhnoti and Kotli districts of Azad Kashmir, Pakistan.

The major folds in the area are Androt Syncline, Mangriot Anticline, Namb Peprian Syncline, Palandri Anticline, Dhardarch Syncline, Chhechhan Anticline and Holar Syncline. The northern part of study area have been separated by northwest-southeast trending faults and folds

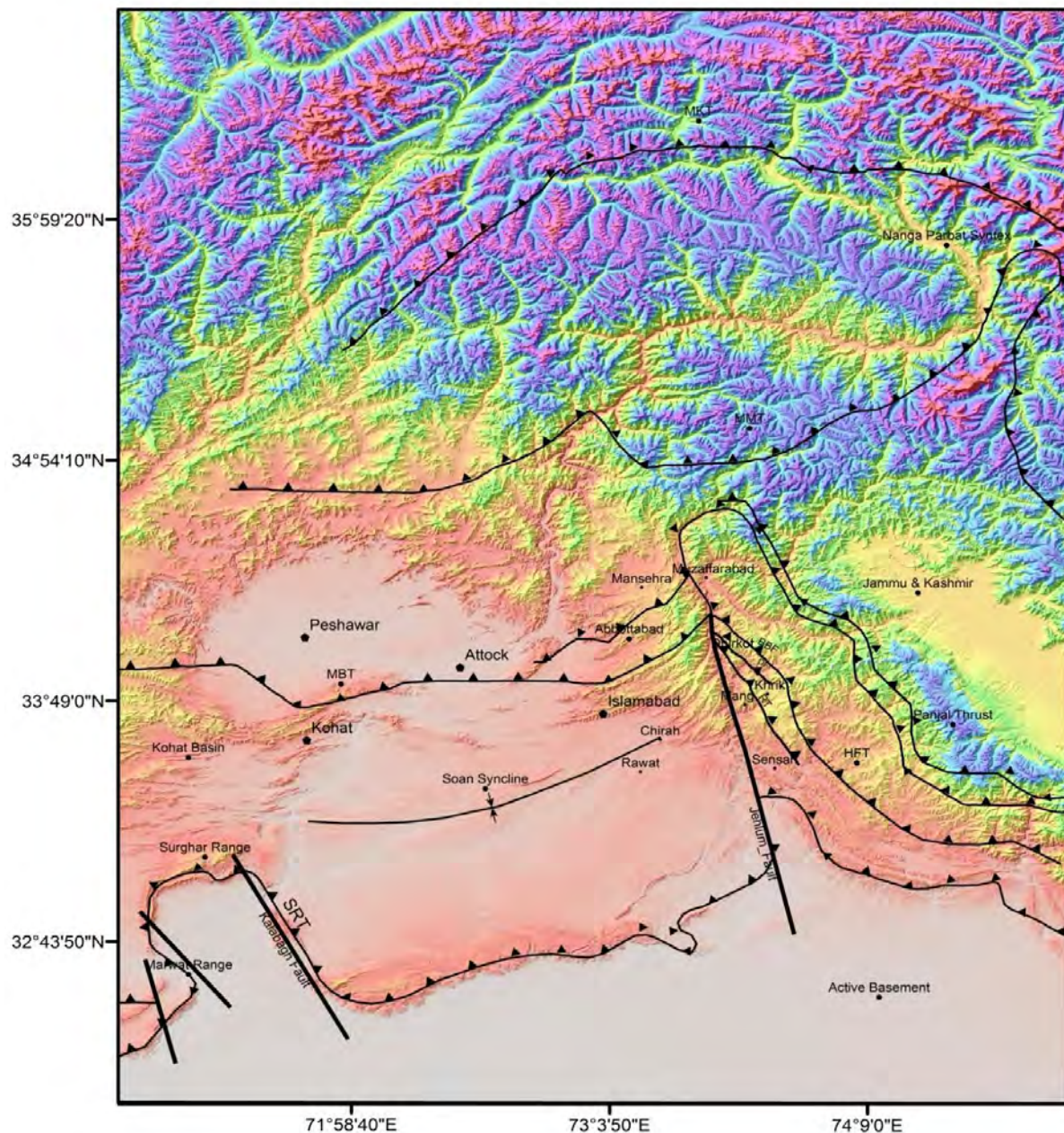
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and are related to Himalayan compression. These faults are Riasi Fault (RF), Palandari Fault (PF), Godri Badshah Fault (GBF) and Chhechhan Fault (CF). The Riasi Fault is the major fault

passing through the area. The geo-morphological features proposed that Riasi Fault, Palandari Fault, Godri Badshah Fault and Chhechhan Fault are active.

**Figure 1: Regional Tectonic Map of Pakistan on Digital Elevation Model**



**Note:** No Rectangle shape show the location of study area.

## Stratigraphy

The research area lies in the sub-Himalayas. It is essentially composed of Miocene to Pleistocene molassic sediments derived from the erosion of Himalayas and these molasse deposits, known as the Murree and Siwaliks Formations are internally folded and imbricated [1]. Stratigraphic sequence of research area includes the Murree Formation, Kamliyal Formation, Chingi Formation, Nagri Formation and Dhok Pathan Formation (Figure 2).

### Murree Formation

The "Mart Group" of Wynne (1874), "Murree Beds" of Lydekker (1876) and "Murree Series" of Pilgrim (1910) have been formally named Murree Formation by the Stratigraphic Committee of Pakistan. The series of alternate beds of sandstone, siltstone and shale with subordinate conglomerates Bell (2007).

In the area, the Murree Formation consists of light greenish grey calcareous cyclic sequence of sandstone, clay and layers of conglomerates (Photo1). It has transitional contacts with overlying Kamliyal Formation and underlying Kuldana Formation. Early Miocene is the age of Murree formation Wadia (1931).

### Kamliyal Formation

The "Kamliyal beds" of Pinfold (1928) have been named as Kamliyal Formation by Stratigraphic Committee of Pakistan Shah (1977). The Middle to Late Miocene Kamliyal Formation that largely consists of sandstone and interbedded clay/mudstone sequences is exposed in the southwestern part of the Kohat plateau, which constitutes the westernmost extension of the Himalayan Foreland Basin Ullah, K., Arif, M., Shah, M.T., (2015).

In the area, Kamliyal Formation consist of dark

brick-red sandstone and intraformational conglomerates (Photo2). Wood fossils and leaves prints are also present near Tahlian (Photo3). The lower gradational contact of Kamliyal Formation with Murree Formation and the upper contact with the Chingi Formation. The age of Kamliyal Formation is Middle to Late Miocene. Shah (1977).

### Chingi Formation

The name Chingi Formation was recognized by the Stratigraphic Committee of Pakistan Shah (1977). Lewis (1937) further work on it.

In the study area Chingi Formation is not well exposed but small beds of red clay and brownish grey sandstone (Photo 4) are disclose near Panjera and Nandi Chhanni. The upper contact with Nagri Formation and lower contact of Chingi Formation with Kamliyal Formation are gradational. Middle to Late Miocene is the age of Chingi Formation Shah (1977).

### Nagri Formation

Lewis (1937) give the name "Nagri Formation" accepted by the Stratigraphic Committee of Pakistan.

In the area, the Nagri Formation consists of sandstone, clay and layers of conglomerates.

The sandstone is compacted massive and medium to coarse grained. The color of sandstone is grey, light grey and greenish grey (Photo5). Chingi Formation exposed in Atkora and Holar. The volcanic clasts are also present in Nagri Formation (Photo 6). The upper contact with Dhok Pathan Formation and lower contact with Chingi Formation are gradational. Early Paleocene is the age of Nagri Formation Shah (1977).



**Photo 1: Photograph Shows the Cyclic Sequence of Clays and Sandstone in Murree Formation near Palandri. Coordinates 73° 41' 04" E, 33° 42' 49" N**



**Photo 2: Photograph Shows Intraformational Conglomerates in Kamliyal Formation near Namb Peprian. Coordinates 73° 41' 00" E, 33° 44' 51" N**



**Photo 3: Photograph Shows Wood Fossil in Kamliyal Formation near Tahlian. Coordinates 73° 43' 28" E, 33° 39' 43" N**



**Photo 4: Photograph Shows Sandstone and Clay of Chingi Formation near Panjera. Coordinates 73° 46' 51" E, 33° 35' 11" N**



### **Dhok Pattan Formation**

The Stratigraphy Committee of Pakistan accepted the name Dhok Pathan Formation given by Lewis (1937).

In research area, the Dhok Pathan Formation exposed in Holar and consist of sandstone, clays and compacted conglomerate level. The sandstone in Dhok Pathan Formation is relative

soft with respect to Nagri Formation (Photo 7). The sandstone is grey, light grey and reddish brown. Flaser bedding are characteristic features of Dhok Pathan Formation.

The lower and upper contact contact of Dhok Pathan Formation with Nagri Formation and Soan Formation are gradational. The age of Dhok Pathan Formation is Early to Middle Pliocene Pascoe (1963).

**Photo 5: Photograph Shows Massive Sandstone in Nagri Formation near Holar. Coordinates 73°36'55" E, 33°35'20" N**



**Photo 7: Photograph Shows Soft and Friable Sandstone of Dhok Pathan Formation near Holar. Coordinates 73°37'40" E, 33°36'06" N**



**Photo 6: Photograph Shows Volcanic Clast in Nagri Formation near Holar. Coordinates 73°38'35" E, 33°37'14" N**



## Structure

Major Structures in the research area are folds and faults. The northern part of study area have been separated by northwest-southeast trending faults and folds and are related to Himalayan compression. These folds are open to gentle and northeast southwest vergent.

## Faults

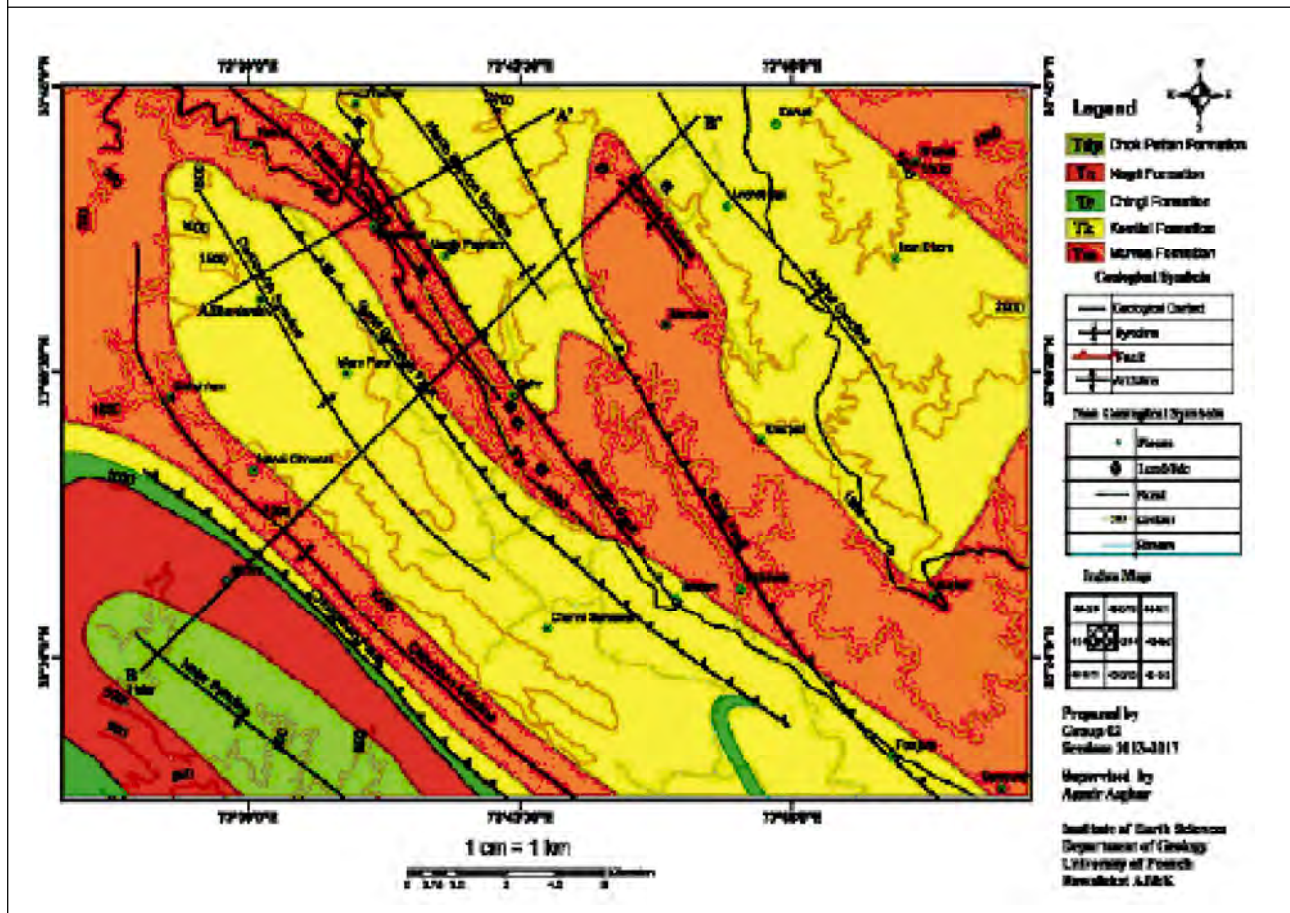
The rocks in the research area is highly signifier due to the collision of Indian Plate and Eurasian Plate in the Himalayan terrotriary (Aitchison, Jonathan C.; Ali, Jason R.; Davis, Aileen M. 2007). In the study area compres- sional stresses caused by the collisional of Indian and Eurasian plates developed the northwest- southeast trending faults which are Riasi Fault, Palandri Fault, Ghodri Badshah Fault and Chhechhan Fault.

### Riasi Fault

The >60-km-long Riasi fault system is the southeastern most segment of a seismically active regional fault system that extends more



Figure 2: Structural and Stratigraphic Investigation of Namb Peprian, Chhechhan, Holar and Sarsawah areas Of Sudhnoti and Kotli, Azad Jammu and Kashmir, Pakistan



than 200 km stepwise to the southeast from the Balakot-Bagh fault in Pakistan into northwestern India Y. Gavillot *et al.* (2016).

In study area Riassi Fault is northwest-southeast trending fault and runs from the Manuta (Photo8) and west of the Magnriot Anticline and to east of the Namb Peprian Syncline. It is NE dipping fault and Kamlial Formation thrusts over the Murree Formation in some areas (Figure 2). It runs from Murree Formation near Kulkhala and Panjera.

The fault is mark on the basis of dislocation, fault gouge, shearing, crushing and bending of streams in the research area (Photo 8). Bending

of streams and dislocation suggested that the hanging wall block moves upwards and foot wall block moves downwards.

### Palandri Fault

The Palandri Fault is a northwest-southeast trending and northeast dipping reverse fault. It is an intraformational fault that runs in the Murree Formation (Figure 2). It runs from west of the Namb Peprian Syncline and east of the Palandri Anticline and it passes from Sehr area. In some areas the attitude of fault plane is  $N60^{\circ}W/68^{\circ}NE$ . The fault is mark on the basis of Truncation of strata, dislocation, gouge, tilting of trees, shearing and crushing in the research area (Photos 9 and 10).

Figure 3: Subsurface Cross-sections of Research Area

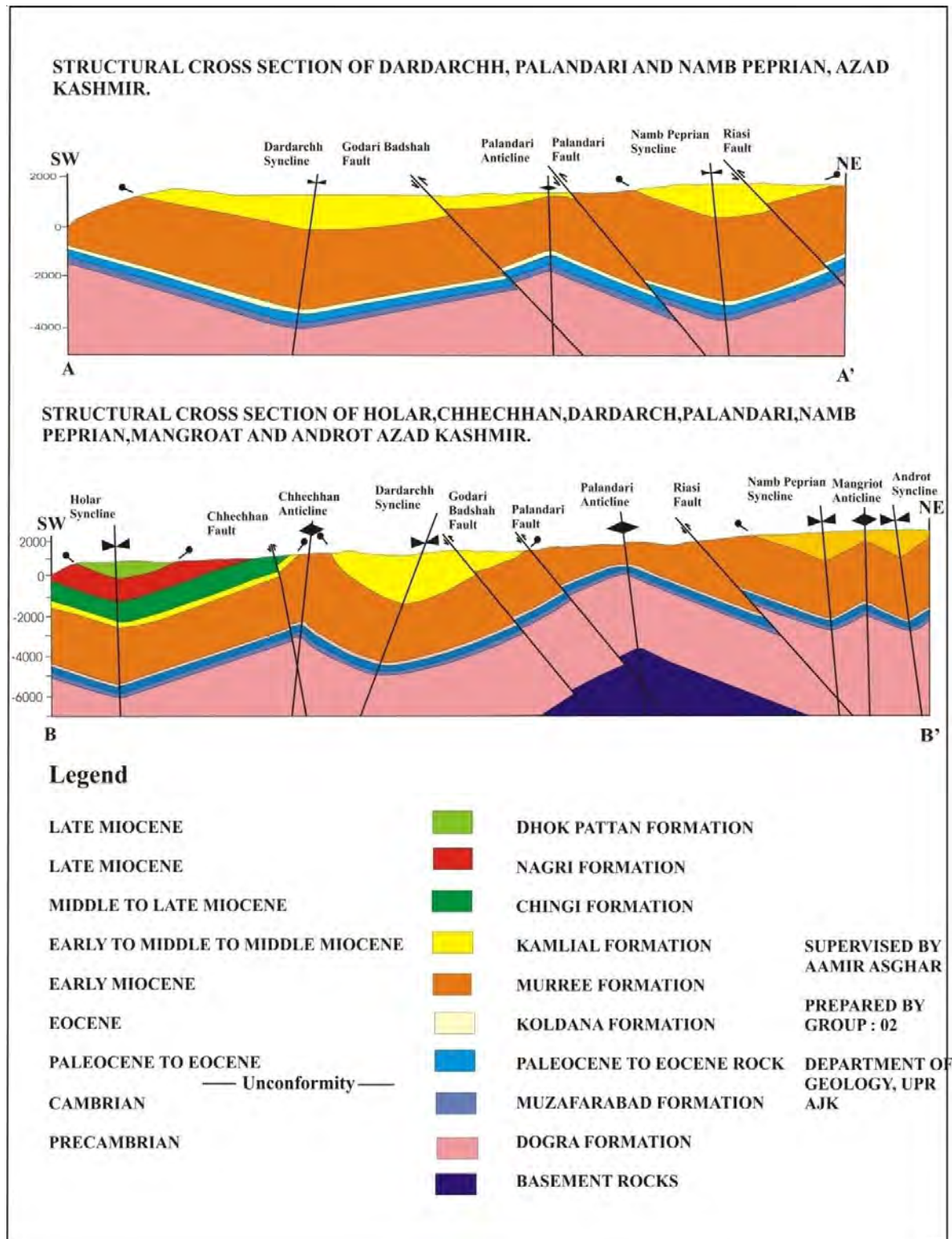


Table 1: Folds in Research Area

Folds	Attribute of Bedding		Plunge and Trend of Fold Axis	Attitude of Axial Plane	Internlimb Angle	Type of Fold
	Northeastern Limb	Southwestern Limb				
Androt Syncline	N45R°W/35R°NE	N48R°W/40R°SW	2R°/133R°	N47R°W/87R°NE	105R°	Open
Mangriat Anticline	N45R°W/35R°NE	N31R°W/32R°SW	4R°/322R°	N39R°W/88R°SW	113.6R°	Open
Namb Peprian Syncline	<b>Northwestern Part</b> N45R°W/15R°NE	N46R°W/30R°SW	1R°/134R°	N46R°W/82R°NE	135R°	Gentle
	<b>Southwestern Part</b> N40R°W/26R°NE	N31R°W/32R°SW	2R°/325R°	N36R°W/87R°NE	122.2R°	Gentle
Palandari Anticline	<b>Northwestern Part</b> N42R°W/32R°NE	N51R°W/30R°SW	3R°/134R°	N47R°W/89R°SW	118.2R°	Open
	<b>Southwestern Part</b> N40R°W/26R°NE	N51R°W/30R°SW	3R°/134R°	N46R°W/88R°NE	124.3R°	Gentle
Dardarchh Syncline	<b>Northwestern Part</b> N24R°W/25R°NE	N26R°W/15R°SW	1R°/156R°	N25R°W/85R°SW	140R°	Gentle
	<b>Southwestern Part</b> N44R°W /65R°NE	N51R°W/30R°SW	4R°/134R°	N36R°W/17R°NE	94.8R°	Open
Chhechhan Anticline	N44R°W/65R°NE	N58R°W/55R°SW	12R°/130R°	N17R°E/12R°NW	118.6R°	Open
Holar Syncline	N51R°W/20R°NE	N53R°W/18R°SW	1R°/128R°	N38R°W/89R°SW	142R°	Gentle

### Godri Badshah Fault

The Godri Badshah Fault is a major fault passing through near Channi and Sarsawah areas. The Godri Badshah Fault is northwest-southeast trending fault. In the northwestern part Murree Formation is thrust over the Kamliyal Formation and in southeastern part Kamliyal Formation thrust over Chinji Formation. The folding, banding of streams, tilting of trees, crushing and linear landslides are present along the fault plane (Photo 11).

### Chhechhan Fault

The Chhechhan Fault is a major fault passing through the Chhechhan area. The Chhechhan Fault is northwest-southeast trending fault. The

Kamliyal Formation is thrust over the Chingi Formation. The attitude of fault plane is N41°W/62°NW. The crushing, dislocation and folding are present along the fault plane (Photo 12).

**Photo 8: Dislocation Along Riasi Fault Near Manuta Area. Coordinates 73°44'51" E, 33°44'05" N**





**Photo 9: Truncation of Strata Along Palandri Fault Near Jail Building Ring Road Palandri.**  
Coordinates 73° 41'51" E, 33° 42'53" N



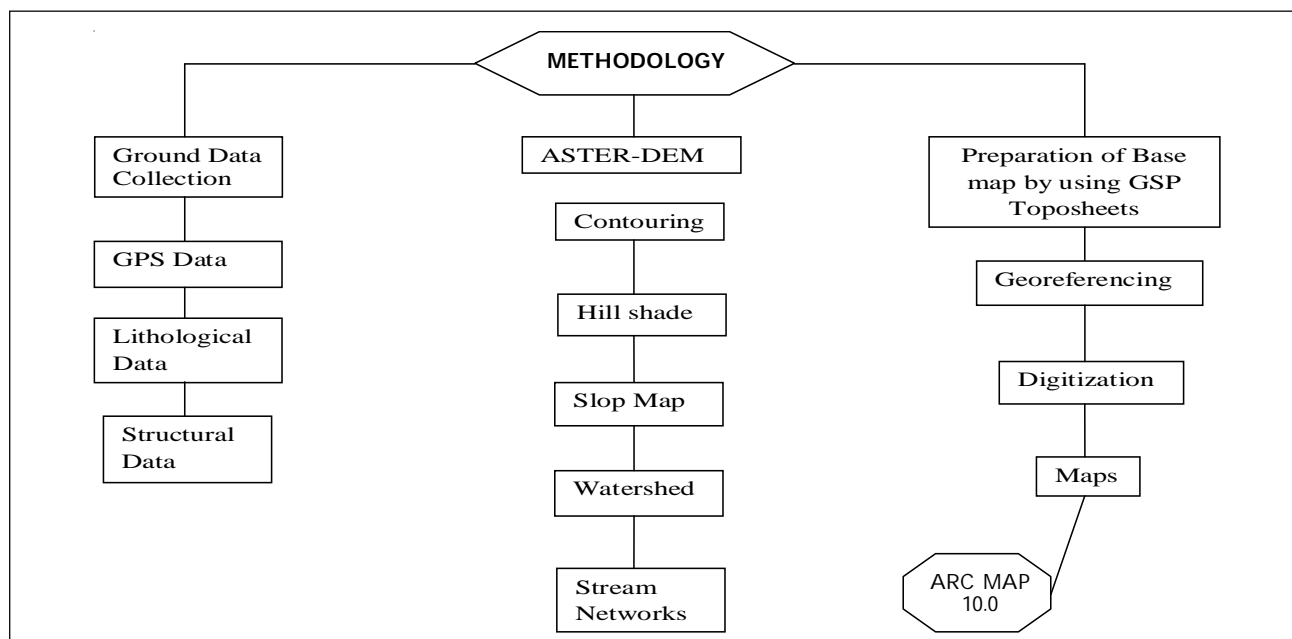
**Photo 11: Linear Landslide Along Godri Badshah Fault.**  
Coordinates 73° 40'42" E, 33° 43'55"N



**Photo 10: Dislocation Along Palandri Fault on the Gora Road.**  
Coordinates 73° 40'42" E, 33° 43'55"N



**Photo 12: Dislocation Along Chhechhan Fault Near Nandi Channi.**  
Coordinates 73° 40'42" E, 33° 43'55"N



## Discussion

Northwest Himalayan fold and thrust belt is baccilar due to collision of Indian and Eurasian plate. The Indian plate is presently poignant at the rate of 3.7 mm/year with respect of Eurasian plate (Molnar and Toponnier, 1975). The uninterrupted movement and collision of plates wrought the structural geometry of the Himalayan orogenic belt.

The Early Miocene to Late Miocene sedimentary rock sequence is uncovered in the project area. This molasse sequence comprise the Murree, Chingi, Nagri and Dhok Pathan Formation. This molasse sequence is formed by the uplift and erosion of Himalayas and deposition of these sediments in the southward migrations foreland basin.

The major folds of the area are Androt Syncline, Mangriot Anticline, Namb Peprian Syncline, Palandari Anticline, Dhardarchh Syncline, Chhchhan Anticline and Holar Syncline. Mostly folds in the study are northwestern and southeastern trending, northeastern or southwest plunging and open to gentle. The major faults of the area are Riasi Fault, Palandri Fault, Godri Badshah Fault and Chhechhan Fault. The Riasi Fault is the major fault of project area. It is between the Murree Formation and Kamli Formation. The rocks are fractured and crushed along Riasi Fault. Tilting of trees along the Raisi Fault shows that the fault is an active fault. The Palandri Fault is well exposed in Palandri area. The imbricate style of thrusting is dominant in the area.

## Conclusion

In Conclusion, the purpose of our research is to interpret the Fault activation on the basis of Geo-

hazard parameters includes active faults, slope gradient and Geo-hazard zonation on the basis of Geographical Information System, restrain with the previously known geological and structural information. Digital Elevation Model use to contemplate the faults, slopes, topographic, contours, watershed, hill shade, aspect, and stream maps. Fault activation is also marked on the basis of Gouge material, crushing and shearing, Tilting of trees, outcrops and geomorphological features. This required creating a new high-resolution DEM using GIS Softwear ArcGIS v10.2 with its 3D Analyst extension. In the research area compressional stresses caused by the collision of Indian and Eurasian plates developed the northwest- southeast trending faults which are Riasi Fault (RF), Palandri Fault (PF), Godri Badshah Fault (GBF) and Chhechhan Fault (CF). The faults are reverse in nature and have Strike Slip movement bearing Fault gouge and crushing. The folds in research area are open to gentle and northeast southwest vergent. Mapping disclose the well exposure of Siwalik group of Early Miocene ( $T_m$  Formation) to Late Miocene ( $T_{dp}$  Formation) rocks in the research area.

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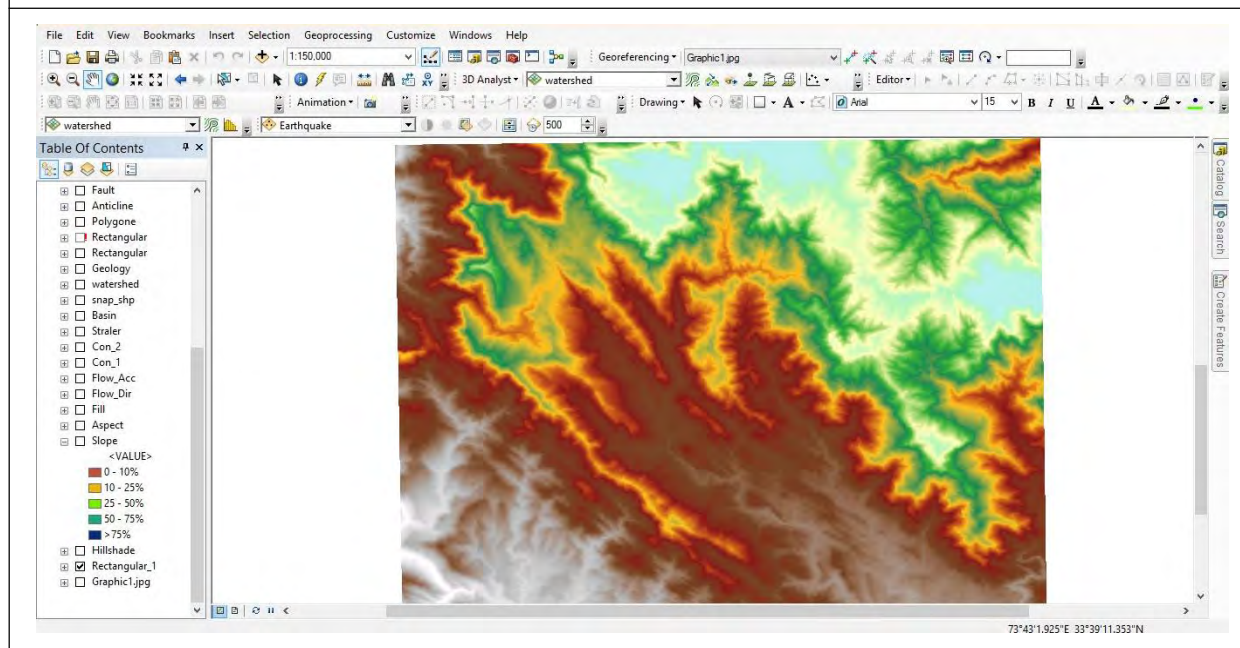
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## Appendix 1

### Method for Creating Digital Elevation Model Map

A digital elevation model (DEM) is a 3-dimensional shaded relief map that shows topography with different colors assigned to each small range of elevation (Figure 4).

**Figure 4: Shows the Digital Elevation Model of Research Area**





## Appendix 1 (CONT.)

Figure 5: Shows the Topographic Change Along Faults on Google Earth

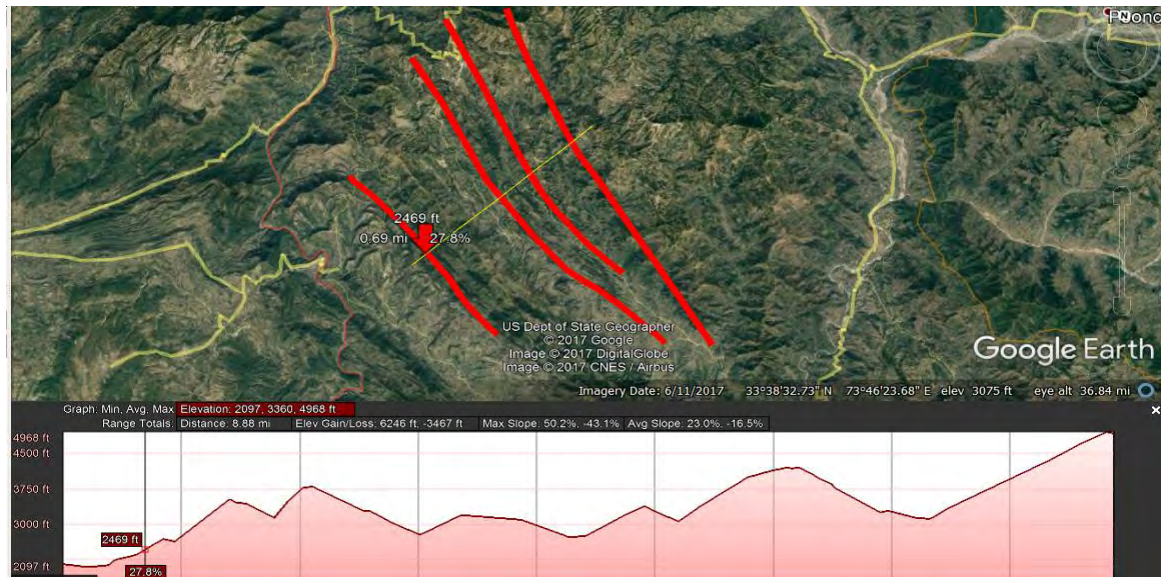
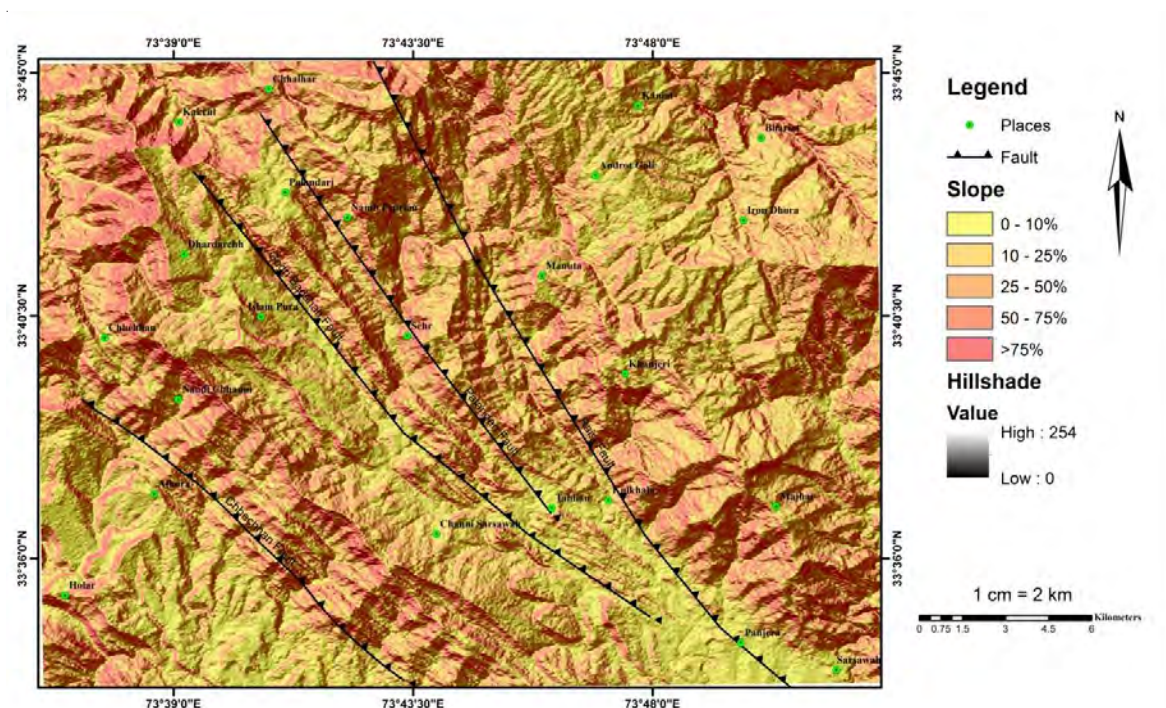


Figure 6: Shows the Hill Shade and Slope Map of Research Area on Digital Elevation Model



## Appendix 1 (CONT.)

## Stream Network

The Purpose of Stream network on DEM is use to check the Bending of stream and Strike slip movement along Faults. In research area, stream network shows the Strike slip movement along Riasi Fault, Palandri Fault, Godri Badshah Fault and Chhechhan Fault. In stream network Riasi fault shows the Right lateral strike slip movement, Palandri Fault shows the Left lateral strike slip movement, Godri Badshah Fault shows the Right lateral strike slip movement and Chhechhan Fault shows the Left lateral strike slip movement (Figure 8).

Figure 7: Shows the Step to Make Stream Map on Digital Elevation Model

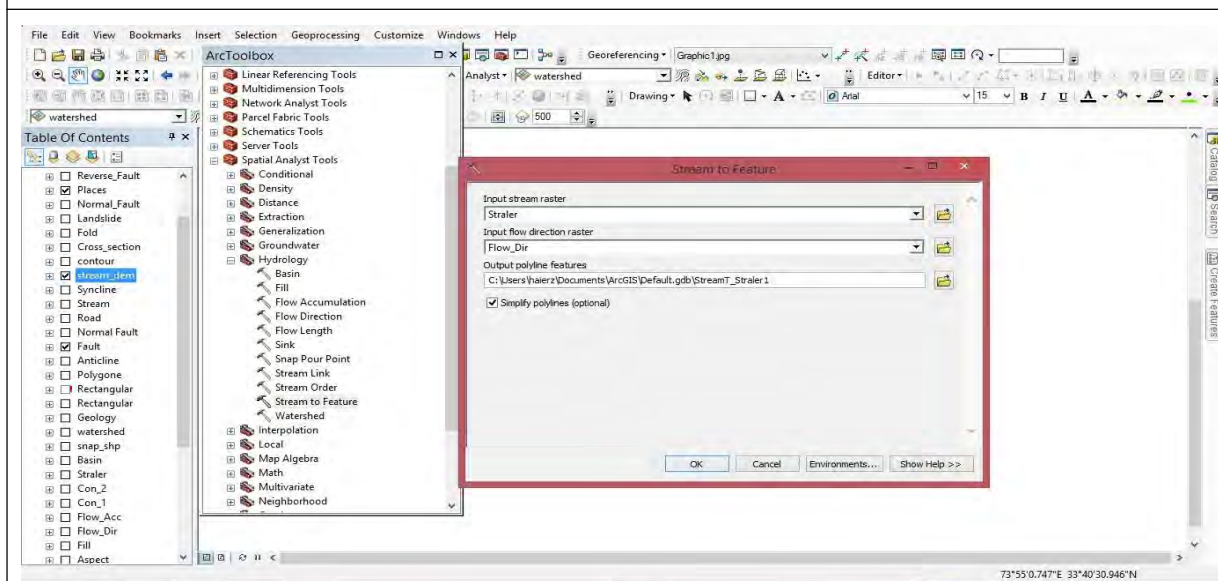
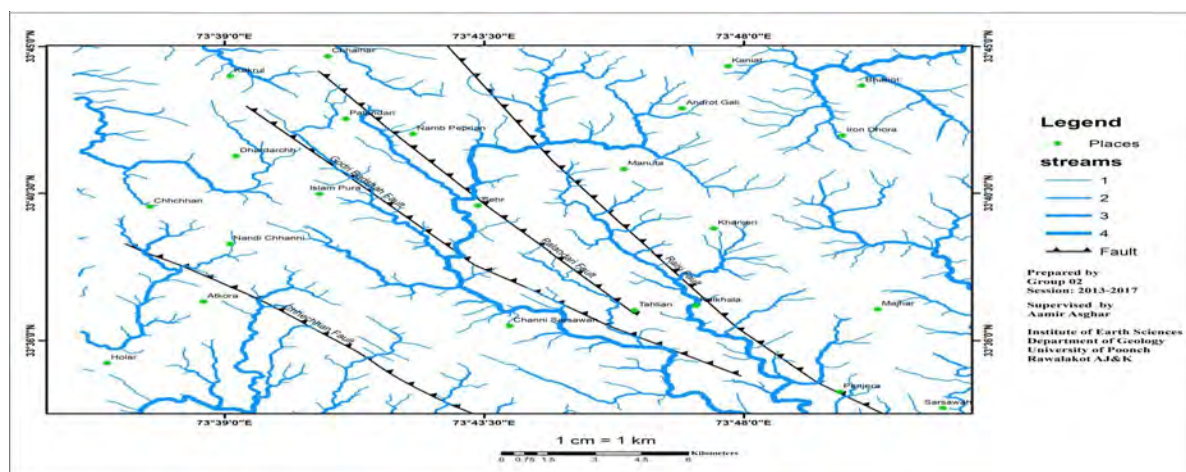


Figure 8: Shows the Stream Network on Digital Elevation Model





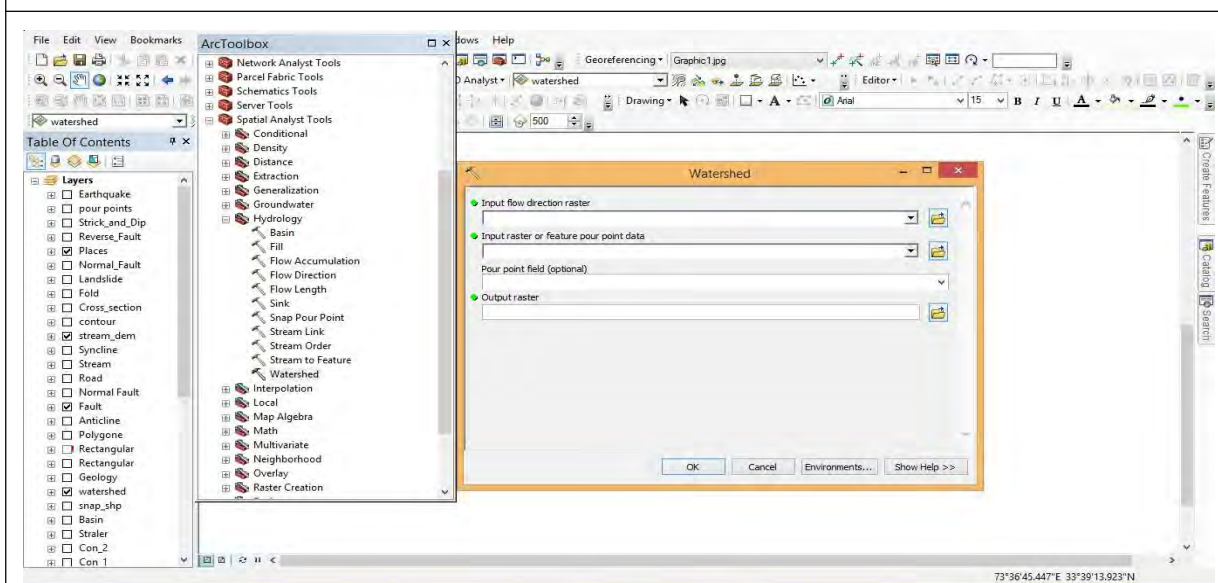
## Appendix 1 (CONT.)

## Watershed Map

Watershed is an area of land where all the surface water drains into the same place, whether it's a creek, a stream or a river. Therefore, all precipitation, such as rain or snow, that falls on a watershed ends up flowing to the same place.

In research area, watershed are linear along Riasi Fault, Palandri Fault, Godri Badshah Fault and Chhechhan Fault. Which shows that the Faults are active and mostly watershed are Northeast trending. Along Riasi fault, the watersheds are clear as compare to other faults as shown in Figure 10.

**Figure 9: Shows the Steps to Make Watershed Map on Digital Elevation Model**



**Figure 10: Watershed Map of Research Area**

