Dynamic Nature of Fan Shape Geometry of Garubathan Surface Under the Controles of Neotectonics, Eastern Himalayan Foothills, North Bengal, India

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Abstract

In a monsoonal environment,the Gorubathan surface is an alluvial fanof the eastern Himalayan foothills.It shows a typical geometry,whichis the consequence of neotectonics of the Main Central Thrust (MCT), Ramgarh Thrust (RT) and Main Boundary Thrust (MBT). Analysis of neotectonics effect on fan shape geometry is the focus of study. The fan segment, lithology and morphology are identified in the field with a GPS survey. The Survey of Indiatoposheet(20 m contour interval), SRTM DEMand other base maps are processed with the help of ArcGIS 10.3 software to measure and understand geometry and geotectonic. A break in slope of the long profile separates the elevated northward inclined fossilized old fan surface and southward slanted younger loose deposits. The average height variation between Younger and older fan surfaces is about 300m. At the fan apex, about 400m deep incision by Chel and Mal River is observed. The fan shape co-efficient and conicality index conclude that the fan head incision and the break-in slope along long profiles are the consequence of RT neotectonics. Thus the RT modifies the fan geometry from triangular to typical by controlling the locus of sedimentary deposits.

KEYWORDS: Tectonic thrust, Serve and No-Serve Zone, Triangular Co-efficient, Fan-shape co-efficient

1. INTRODUCTION:

Although the alluvial fans are of fluvial origin, the slope has great control over its formation. Relatively high frequencies of tectonic incidences and relatively humid climate provide a better favourable condition of alluvial fan development to the foothills of eastern Himalayas (Bhattacharya, S.; 2004) than the western Himalaya. Because, due to high tectonics the eastern Himalayas become steeper, which provides a prominent break in slope between the Ganga-Brahmaputra plain and the Himalayas. Alternatively, due to wet climatic conditions, the rivers transport a huge number of sediment loads from the Himalayas (Basu, S. R. and Sarkar, S. 1990) and as there is a presence of a break in the slope, the rivers realize their loads at the foothill. The steepness of the Himalayas also accelerates the supply of fluvial sediments. As a result, extensive alluvial fans are developed along the foothills of the eastern Himalayas. There are some minor thrusts and faults, which are the outcome of neotectonics, also control the locus of sedimentary deposits. Thus, the tectonic activities control the geometry of the alluvial fan.

2. AIMS AND OBJECTIVES:

Here is an attempt to understand the tectonic effects on alluvial fan geometry of the Garubathan Geomorphic surface of North Bengal foothills in the Eastern Himalayas. For this purpose, the following objectives are considered:

i. To delineate and quantify the geometric properties of the alluvial fan
ii. To analyze the impact of neotectonics on fan geometry

3. METHODOLOGIES:

To establish the aim of this paper, both primary and secondary data are used. First, the toposheet of the survey of India (R.F. 1:50000, 1971) is used to delineate the study area and the contours (20 m interval) of this toposheet are digitized and analyzed with the help of GIS software ArcGIS 10.3 to perceive the vertical geometry of the study area. The Arial geometry of the area is measured using a different formula. Second, different tectonic maps are collected and digitized with the same GIS software. GPS (Garmin 550) and DGPS surveys are also done in different years to collect the microlevel neotectonics and lithological data in the field. The data are verified with the collected maps with the help of aforesaid different GIS softwares. The lithological data are used to perceive the oldness of this geomorphic surface. Lastly, there has been an attempt to establish a correlation between the neotectonics of the study area and its geometry.

4. LOCATION:

At the north Bengal foothill of Eastern Himalayas, the study area is located in Garubathan P.S. of Kalimpong district and Mal P.S. of Jalpaiguri district, between the river Chel in the west and river Mal in the east. Geomorphologically the area is an alluvial fan and is known as Gorubathan surface. This area is bounded by 27°N to 26°52’52” N latitude and 88°40’E to 88°45” E longitude (Fig: 1).

5. TECTONIC SETTING:

The study area is located in the eastern Himalayan, which is known as Darjiling–Sikkim–Tibet (DaSiT) Himalayan Wedge (HW). This part of the eastern Himalayas is bordered by the Tibetan plateau to the north and the North Bengal plain to the south. Geo-tectonic units of this part comprise South Tibetan Detachment (STD), Main Central Thrust (MCT), RT, Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT) (Yin, A., 2006; Mukul, M., 2010). The MCT, RT and MBT meet Main Himalayan Thrust (MHT) (Srivastava, P. and Mitra, G., 1994; DeCelles, P. G., Gehrels, G. E., Quade, J. and Ojha, T. P., 1998.) at a very low angle (Gansser, A., 1983; Lavé, J. and Avouac, J. P., 2001). Near-surface the MFT is expressed as MHT (Mukul, M. et al. 2014). RT comparatively a small-scale regional thrust than STD, MCT, MBT and MFT. To the south of MBT, the Siwalik belt is partly missing between the Chel and Pana Rivers where the Himalayan front retreats several kilometres toward the north following N–S directed fault lines along the rivers Chel (Mukul, M. et all., 2008; Mukul, M., 2010). Here the MFT sheet of Quaternary bolder and recent alluvium deposits replace the Siwalik belt.

To the north of MCT, the Tibetan part of HW is known as Trans Himalayan Wedges (THW) and to the south of MCT, the HW is known as Darjeeling-Sikkim-Himalaya (DSH). The DSH wedge has formed a duplex is known as Lower

Himalayan Duplex (LHD), which causes to split of MCT into MCT1 and MCT2 (Mitra, G. et. al., 2010; Mukul, M. et all. 2014,). South of MCT2 the MBT is located. A minor thrust between MCT2 and MBT is to be found, which is known as Ramgarh Thrust (RT) (Mitra, G. et. all. 2010; Mukul, M. et. all. 2014).

To the east of the Darjeeling Himalayas, the Gorubathan Surface (GS) has been developed in the foothill region. Surrounding this surface is experienced some tectonic structures such as lineaments, thrusts-faults and salient-recess. The Ghish Transverse Fault (GTF) and Gorubathan Recess (GR) are the dominant tectonic settings at the outer border of the study area and the RT and MBT are tectonically active within the study area.

The DSH is experienced with 4 lineaments such as Tista lineament, Gangtok lineament, Goalpara lineament and Kanchenjunga lineament which are mapped (Fig:2) as straight lines and as they run through all high and low lands, its things that they are vertical faults (Mukul, M. et. all. 2014). The Tista lineament cross-cut the western part of LHD as well as the thrust sheets in the NNW-SSE direction. This lineament is located to the west of the study area. The Gangtok lineament cross-cut the eastern part of LHD as well as the same thrust sheets of Tista lineament. The Gangtok lineament is moral-less parallel to the Tista lineament and is found in the east at the outer margin of the study area. Away from MCT, the Kanchenjunga lineament is located to the NW of LHD. In the area of NE Nepal, this lineament is arranged in a NE-SW direction. In the NE of the study area, the Goalpara lineament is an oblique feature to the overall transport direction of the Himalayas and located to the north of MCT of LHD and mostly parallel to MBT. GTF in the near west of the study area is a strike-slip fault in the transition zone between the Dharan salient and the Gorubathan recess trending NNE–SSW direction (Mukul, M; et all; 2014).

From west to east, throughout the Himalayan wedges (HW), most of the earthquake epicentres are clustered near the three major zones of MCT, MBT and MHT/MFT (Fig:2). However, this clusterization of earthquake epicentres began to increase from the western Himalayas to the eastern Himalayas. For this reason, Nepal Himalaya tectonically is more active than Garhwal-Kumaon Himalaya. Alternatively, eastern Nepal HW seismically is more active than the western and central parts. Where uniformity is the main seismic character of the entire eastern Nepal Himalayan wedges (HW), neighbouring it, the Sikkim Himalaya shows the variable characteristics of seismic occurrence and intensity. In the Sikkim Himalaya, the presence of LHD (Fig:2) between MCT and MBT proves that these thrusts are seismically more active than the other thrust zone of HW (Mukul, M. et. all. 2014), whereas to the north of MCT the seismicity is found to be little or absent. Thus, in the Sikkim HW to the south of MCT, LHD is experienced only moderate to small-scale earthquakes, whereas to the north of the MCT or LHD the HW is experienced only small-scale earthquakes (Mukul, M; et al.; 2014). The India Meteorological Department (IMD) has measured the earth quack magnitude to the south of the MCT in several consecutive years continuously (Table: 1). The magnitude does not exceed their scale of 7.

Table: 1 (Observation of Earthquake to the South of MCT in DSH)

TIME	No. OF EARTHQUAKE OBSERVATION	MAGNITUDE OF EARTH QUACK
1982–1992	15	> 4.5
December 1992–April 1993	15	5.0

	4	~ 4.0
December 1994–March 1995	DSH	~ 4.0
March–June 2000		
1999–2002	12	> 5
October 2004 and February 2010	9	≤4 to 5.3
2007–2009	756	< 6.0
Source: Indian Metrological Department		

Although the MCT, MBT and MHT/MFT in the DaSiT Himalayan wedge are the earth quack prone area the major earthquake epicentres are concentrated on DSH to the south of MCT and a few epicentres are found in THW to the north of MCT (Mukul, M; et al.; 2014). The MCT has been folded by LHD in DSH between MCT and MBT and is eroded over THW. Here the seismicity is recorded at a shallow depth of 0–20 km below the eroded plane of MCT (Mukul, M. et all. 2014). For this erosion, the seismogenic fault of MCT in THW has been deactivated. Alternatively, the folding of MCT by LHD in DSH indicates its active seismicity.

In the south of LHD, the MBT tectonically is less effective than MCT, because the earthquake hypocenters are also located to the north of the MBT over an area between eastern Nepal and the Gish Transverse Fault (GTF) (Fig: 2). The tectonically inactive MBT presently is getting active by folding of younger footwall along South Kalijhora Thrust (SKT) and here the Moho is located to the depth of 40–80 km (Mukul, M. et. all. 2014). The location of earth quack hypocenters is to the depth of 45 km at frontal DSH and 70 km at LHD. These depths prove that the basal detachment of the MHT is extended up to the Moho below the MBT. The strike-slip movement of MBT, MCT and MHT/MFT causes all the earth quacks between MBT, MHT and Moho within the area of eastern Nepal and the Gish Transverse Fault (GTF) whereas the thrustal movements cause earth quacks near MCT (Mukul, M. et. all. 2014)

A small-scale sinuosity has been developed both in front of the western and eastern Himalayan Mountain belts and in their hinterland due to the collision between arch-shaped Indian plates with the Duration plate. Salient and recess transitions cause this type of sinuosity. Salients are formed by imbricate faults and attached with mountain front whether Recesses become folded by a single thrust fault and may open to mountain front or may form intermountain longitudinal valleys or may form Duns of high mountain frontal landform (Mukul, M; et all; 2014). In the eastern Himalaya the Gorubathan recess, where the study area is located, becomes folded by the Ghish Transverse fault. Mukul, M; et all. (2014) deeply studied the Darjeeling Himalayan front in the 1990s. He pronounced that a prominent frontal recess in the Darjeeling Himalaya near Gorubathan is called Gorubathan recess (Fig: 2). The Siwalik section is absent in this recess because the recess has led to a new transverse structure of GTF at a high angle. The trend of the transverse structure to the Himalayan belt continues up to the Yadong-Gulu cross structure of the Tibetan Plateau. The Ghish River presently flows through this transverse zone at the mountain front. The Quaternary Siwalik deposits characterize the mountain front in the western part of this transverse fault, whereas a thrust of Proterozoic Daling Formation of rock on Gondwana rocks defines the mountain front in the eastern part of a transverse fault. There are blind imbrications in the south of mountain fronts, which form E-W trending fault scarp. From north to south, these scarps are arranged as MCT-1, MCT-2, RT, MBT, BT, and MFT (Fig: 2).

In this recess, the MCT-1 is similar to MT (Yin, A. 2006; Srivastava, V. et. all., 2017). The RT (Pearson, O. N. and DeCelles, P. G., 2005) is recognized regionally or locally in a different name. To the west of GTF, the RT is identified as North Kalijhora Thrust (NKT) (Mitra, G. et. all. 2010), whereas to the east, near Gorubathan market, this NKT is replaced by Gorubathan thrust (Matin and Mukul, 2010), which is also comparable to MBT (Nakata, T.,1989). Further to the east, near Mal bridge, the Gorubathan thrust is branched. The southern branch of this thrust locally is named Matialli Fault. The Gorubathan fault extends up to the Jaldhaka river and here it is known as the Thalijhora-Jiti fault. About 10km south of Matialli Fault the Chalsa scarp (Mohapatra, S. R. et. all., 2012) is the regional identification of MBT (Srivastava, V. et. All., 2017) and attribute to the MFT (Nakata, T., 1989). To the southern edge of Gorubathan recess, the MFT/HFT locally is recognized as Baradighi Fault (Mohapatra, S. R. et all., 2012).

6. RESULT

6.1. Geometry of Studied Fan:

The study of fan propagation helps to understand the evolutionary history of that fan. Analyses of geometric characteristics are the primary stapes to study fan propagation. To serve this purpose here the researcher analysis the geometry of aerial view as well as a vertical profile of the fan.

6.2. Arial Geometry ofthe Fan:

The aerial view of an alluvial fan shape in different forms of geometry i.e., cone, oval, arrow, circle, triangle (Amron, T. Y., 2019). All these fan shapes are unstable. A fan transforms from one geometric shape to other geometric shapes because the sediments change their locus of deposits due to repeated floods or neotectonics. As a result, with the change of fan shape, the total area of the fan surface change. This entire dynamic phenomenon also signifies the stage of fan development. For this reason, here, the researcher tries to identify the actual fan shape and quantify their conicality and a geometric coefficient for better understanding.

6.2.1. Conicality analysis:

Most of the alluvial fan tends to be a conical shape of its planimetric view. Fan Conicality Index (FCI) (Mukharji, A. B.;1976) is the measure of conicality of any geomorphic surface of fluvial deposits. It is the ratio between the actual area of fluvial deposits (ADA) and the ideal area of a cone shape (ICA) (Fig: 3). ICA is the pie of a circle. The centre of the circle is located to the apex of a fan; its periphery touches to an outermost margin of geomorphic surface and the two radial straight lines encompass touching the outermost side boundary.

$$\mathrm{FCI} = \frac{\mathrm{ADA}}{\mathrm{ICA}} = \frac{57.98\ sq.km.}{123.30\ sq.km.} = 0.47$$

When the value of FCI is less than 1 then it is considered as an alluvial fan. Here the FCI value becomes 0.47. So, the geomorphic surface of fluvial deposits is an alluvial fan.

6.2.2. Delineation of geometric shape on studied fan surface:

Triangularity or circularity is the two basic shapes of an alluvial fan. Some alluvial fans are composite of these two types of shape, which is termed as a typical geometric shape. Four points i.e. A, B, C, and D (Fig: 3) have been placed to delineate the fan shape of the study area. The point 'A' sets to the apex of the fan, where the sediment depositions were started. Points 'B' and 'C' are placed in the easternmost and westernmost tip of the study area. The joining ling of 'B' and 'C' is representing the maximum radial extension of the fan surface toward the downslope area. The point 'D' has been marked to the centre of the line $\overline{BC}$. Now a triangle ΔABC and a half-circle with the radius (r) of $\overline{BD}$ or $\overline{CD}$(Fig: 3) has been drawn on the fan surface.

Table No: 2 (Measurement of fan Geometry of Arial view)			
Fan Surface		Actual Geometric Shape	
No serve zone area	19.95 sq. km.	Triangle area	16.63 sq. km.
Serve zone area	38.03 sq. km.	Half circle area	29.88 sq. km.
Total area	57.98 sq. km.	Total area	46.51 sq. km.
Source: Toposheet 78B/9			

6.2.2.1. Recognition of serve and no-serve zone:Now, the pink part (Fig: 3) of the fan surface above the line $\overline{BC}$ resemblesthe triangular shape. This situation indicates that the sediments of this part are unable to move downstream and flatland sideward. So, this zone of an alluvial fan is identified as a no-serve zone (Amron, T. Y., 2019). On the other hand, the periphery of the half-circle is the maximum limit of sedimentary deposits under the normal condition of equilibrium. However, to the south of the line $\overline{BC}$the lower part (blue coloured area) of the fan understudy crosses the periphery of the half-circle. That indicates the activeness of force flow sediment deposition due to rejuvenation (Amron, T. Y., 2019). The tectonic upthrust of RT and the advancement of wet climate causes this rejuvenation. This part of the alluvial fan is recognized as a serving zone. The serving zone of this fan developed after the development of the no-serve zone.

6.2.2.2. Identification of present geometric shape:Triangular geometry and circular geometry are the main two ideal types of fan shape geometry. Another type is typical geometry, which is the composition of both triangular and circular shapes. To perceive the fan geometry of the study area a comparative study has been conducted between the area of ideal geometric shape and the area of different surveying zones, which have been identified based on ideal geometric shapes of the fan (Fig: 3). To fulfil this purpose, the areas of actual geometric shapes and surveying sectors of the fan are measured (Table: 2). It reveals that the total area of fan surface (57.98 sq. km.) is near about three times greater than the area of actual triangular shape (16.63 sq. km.), suggests that the fan changes its geometric shape from triangle to other. Alternatively, the area of half circle (29.88 sq. km.) is about half of the total area of the actual fan surface (57.98 sq. km.), is denying the possibility of a circular geometry of the fan under study. The area of half circle (29.88 sq. km.) is close to an area of serve zone (38.03 sq. km.) and the area of a triangle (16.63 sq. km.) is close to an area of no serve zone (19.95 sq. km.), implies that the real shape of a fan is closer to the form of typical-shape of a fan. However, to understand the degree of fan shape typicality, the researcher measures the different geometric co-efficient of the fan (Table: 3).

6.2.2.3. Geometric co-efficient analysis:As the triangular shape is a common geometric shape of alluvial fans, so the first attempt has been taken to measure the triangular co-efficient of the fan. Triangular co-efficient is the ratio between the total area of the fan surface (TFA) and the area of the actual triangle (TA). The second is the Fan-shape co-efficient, that is the ratio of the area of serve zone (SA) to the area of half-circle (HCA)

Table- 3 (Fan shape co-efficient)	
Triangular Co-efficient = TFA/TA =57.98 sq k.m. / 16.63 sq k.m. =3.49 **When:** TFA = total area of the fan surface TA = area of an actual triangle	**Fan-shape co-efficient = (SA/HCA) x100** = (38.03 sq k.m. / 29.88 sq k.m.) x100 =127.28% **When:** SA= area of serve zone HCA= area of half circle
Source: Amron, T. Y. (2019)	

6.3. Vertical Geometry of the Fan:

To assume the vertical geometry of an alluvial fan the longitudinal and transverse profile is examined. Generally, longitudinal profiles of alluvial fans are concave and transverse profiles are convex. These profiles are constructed based on men elevations from mean sea level.

Three longitudinal profiles (Fig:4.) are constructed in a north-south direction across the study area to realize the break in slope, which will help us to detect the alluvial fan segments i.e., upper fan, middle fan and lower fan. The first profile (L1L1') is drawn over the Gorubathan Market, the second one (L2L2') passes through the middle portion of the fansurface and the last profile (L3L3') is constructed near the river Mal in the study area. Three prominent breaks in slope, at an average elevation of 400m, 320m and 220m, separate the study area into four segments i.e. mountain area, upper fan, middle fan and lower fan surface. The break-in slope at the elevations of 400m represents the mountain front, at 320m separates the upper and middle fan surface and at 220m divides the middle and lower fan segments.

Six sequential transverse profiles (Fig:5) are drawn along the study area based on tecto-litho- morphological significance to realize the gradual changes of topography from the upslope to the downslope area. These profiles depict the convexity of a transverse slope, drainage incision and escarpment of river terraces. The profile (C1C1') over the mountainous surface shows an asymmetrical open-folded structure of the topography. At the mountain front, the profile (C2C2') is showing a pic at the centre with a gentle slope.Here, the distance between the river Chel and Mal becomes minimum. Near RT or Gorubathan-Jity thrust (Mukul, M. et all. 2014)the transverse profile (C3C3') coversthe old fan surface, which reveals a flat top area with a convex slope. The remaining profiles (C4C4'; C5C5'; C6C6') over an upper-middle fan, lower-middle fan and lower fan surface interpret the gradual decreasing nature of fan convexity with the increasing nature of river incision.

7. DISCUSSION:

Analysis of the *conicality index* proves that the study area is an alluvial fan. However, the alluvial fan varies in shape i.e., triangular, circular, conical or typical (a combination of triangular and circular). To understand the shape the *geometric co-efficient* analysis has been done. The analysis of geometric co-efficient segment the fan area in different shapes of a triangle and half-circle (Fig: 3). The lithological survey in the field reveals that the *triangular part* of the study area represents an *old* fan surface and the *circular part* of the study area represents a *younger* fan surface. The RT (Fig: 2)is located at the junction of the triangular and circular parts of the study area, which means that the RT is separating the old and young fan segments. That indicates that after the formation of RT the propagation of the old fan surface has been stopped to the north of RT and the surface is restricted to a triangular shape with a high *Triangular Co-efficient* value of 3.49 (Table: 3). The co-efficient value 1 considers the appropriate triangular shape of the fan. When this value becomes less than 1, then it suggests that the fan is approaching the triangular shape. Alternatively, the greater than 1 triangular co-efficient value advocate for moving away of a fan from triangle to typical shape. Here the triangular co-efficient value 3.49 highly differs from the ideal value of 1. This value does not support the triangular shape of the alluvial fan and signifies the mean approach of that alluvial fan toward the typical shape.

The river Chel and Mal supply sediment continuously to the fan surface due to the presence of wet climatic conditions. The rivers continue their work of sedimentation to the south of RT. As a result, the extensive younger plain of an alluvial fan has been developed in the shape of a half-circle. However, the newly developed younger surface is not a proper half-circle (Fig: 3). Some part of this younger surface crosses the area of the half-circle to its south-eastern margin. That indicates the development of this younger surface is controlled by any other factor rather than RT. Because the long profile shows a uniform regional slope toward the south after RT, but the propagation of this southern edge is toward the south-east. It becomes possible when another different factor affects the local slope. The GTF (Fig: 2)is located along the river Ghiss, which causes the tilt-up of the western margin of the study area. As a result, the younger surface becomes sloped from the northwest direction to the southeast and the propagation of this surface follows this slope.

The triangular and circular geometric shape of the study area combinedly expresses the typical fan shape of the hole area. *Fan shape co-efficient* values are the measure of such typicality. The ideal-typical fan shape produces near about 100% fan-shaped co-efficient value. When this value becomes less than 100% then it interprets that the fan is presently moving away from the triangular shape toward a typical fan shape. However, a greater than 100% fan-shaped co-efficient value specifies the mean approach of the fan toward a triangular shape and it assumes that the fan shape right now is shifting away from its typicality (Amron, T. Y., 2019). Here the Fan-shape co-efficient of the fan understudy is 127.28% (Table: 3). This value is close to 100%, which advocates that right now the geomorphic surface under study is belonging to a typical fan shape and the slide variation of this fan-shaped co-efficient from 100% reveals the tendency of the fan understudy toward the triangular geometric shape.

The understanding of vertical geometry has been done with the help of long and cross profiles. The six-cross profile (Fig: 5) shows the variation of height from the upper area old fan surface to the lower area younger fan surface, which helps us perceive the direction of slope from north to south. The long profiles (Fig:4)of the study area depict the two breaks of slope between mountain area, old fan surface and younger fan surface. Between the old fan surface and younger fan surface, the RT is located, which means that the RT handles the break of slope between old and younger fan surfaces.

8. CONCLUSIONS AND RECOMMENDATIONS:

Both neotectonics and climate are the major controlling factors of alluvial fan development. At the foothill of the Eastern Himalayas, neotectonics is the dominant controlling factor over the climate. The tectonic movement of the Indian plate forms a major break of slope between Himalaya and its adjoining frontal part of the North Bengal plain. The break of slope provides an ideal environment to form the alluvial fans. Here the climate plays the role of an accelerator to produce a profuse amount of sediment by fluvial erosion, which helps develop the extensive alluvial fans along the eastern Himalayan foothills.

In the study area, tectonic movement controls the vertical geometry, directly and indirectly, control the aerial geometry by controlling the direction of the alluvial fan propagation. Analysis of aerial geometry shows that the fan area frequently changes its geometry. This change happens mainly under the control of neotectonics.

Lastly, it concludes that the effect of neotectonics in this area is still now present. Due to tectonic movements, the aerial geometry of the fan changes being studied according to the following stages- first, triangular; second is typical and presently is approaching from typical to triangular shape again.

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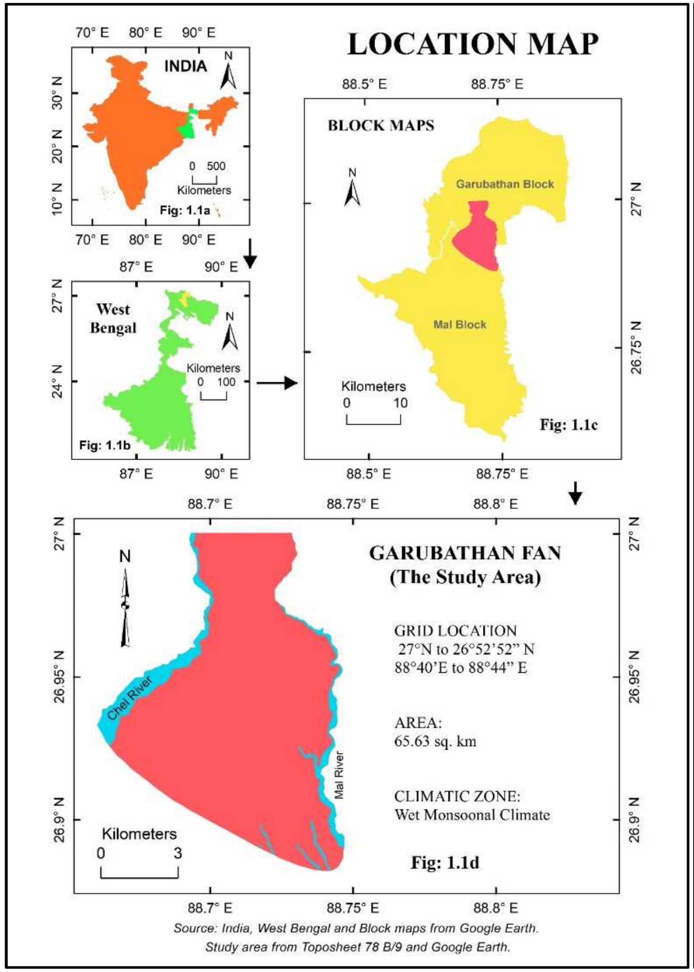


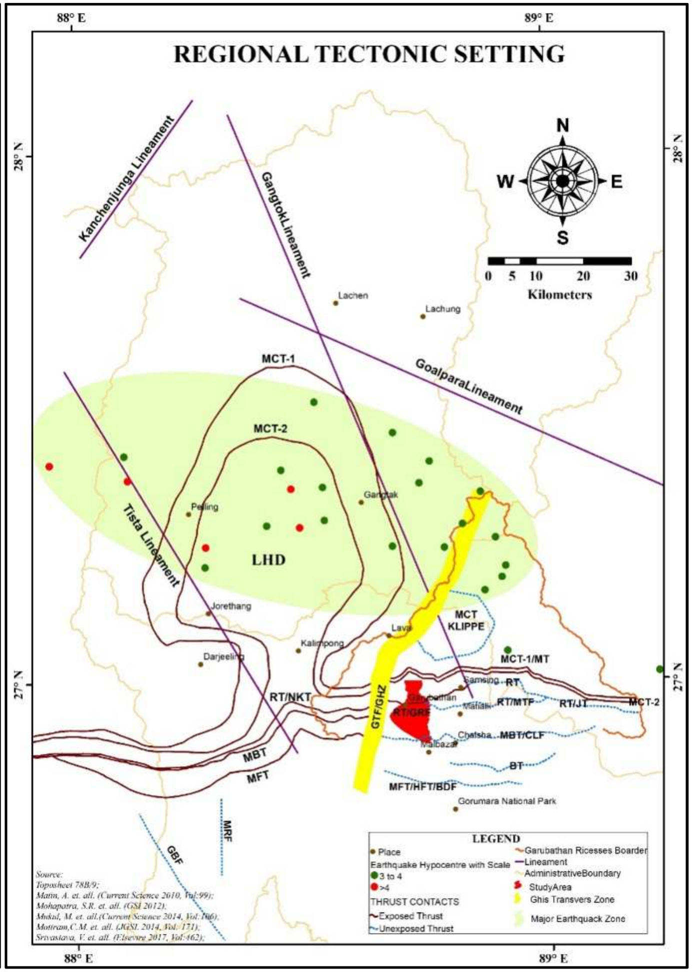


Fig: 1Fig:2

Fig:2:-MCT-Main Central Thrust, **RT**-Ramgarh Thrust, **NKT**-North Kalijhora Thrust, **MBT**- Main Boundary Thrust, **MFT**-Main Frontal Thrust, **MT**-Munsiari Thrust, **GRF**-Gorubathan Fault, **MTF**-Matialli Fault, **JT**-Jiti Thrust, **CLF**-Chalsha Fault, **BT**-Batabari Fault, **HFT**-Himalayan Frontal Thrust, **BDF**-Baradighi Fault.**GTF**-Ghish Transverse Fault

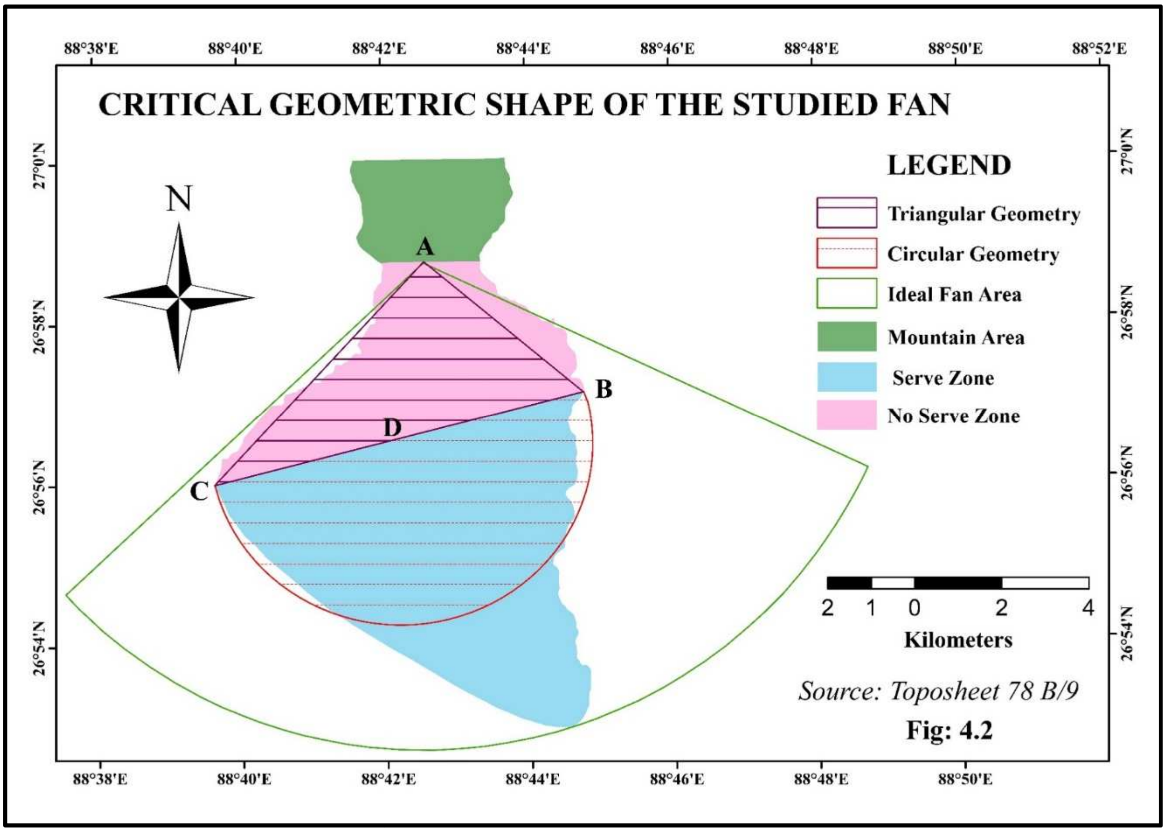


Fig:3

LOCATION:

Point	Latitude, N (in °)	Longititude, S (in °)
L1	26.999887	88.704092
L1'	26.898607	88.703879
L2	26.999929	88.714026
L2'	26.893087	88.714235
L3	26.999892	88.724251
L3'	26.887418	88.725236
C1	26.992060	88.697917
C1'	26.992161	88.733134
C2	26.978222	88.702778
C2'	26.978255	88.725372
C3	26.965947	88.700885
C3'	26.966060	88.740537
C4	26.944480	88.672204
C4'	26.944431	88.745553
C5	26.912976	88.681370
C5'	26.913059	88.742687
C6	26.893087	88.714235
C6'	26.893857	88.749761

Table:4.2

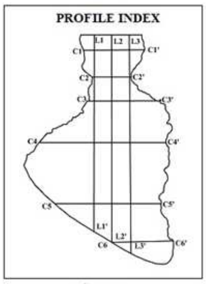
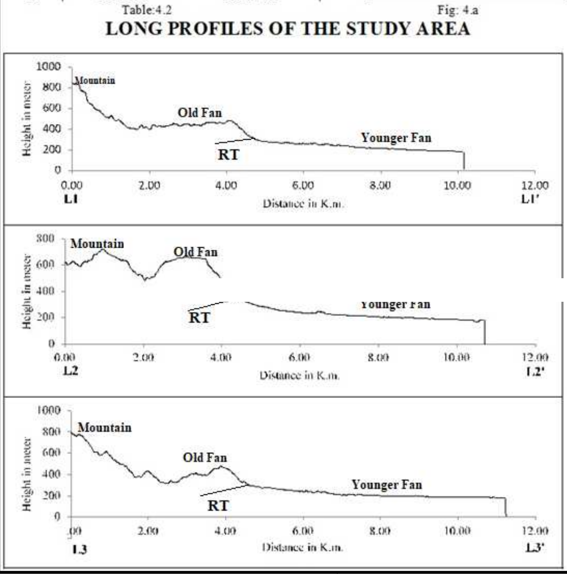
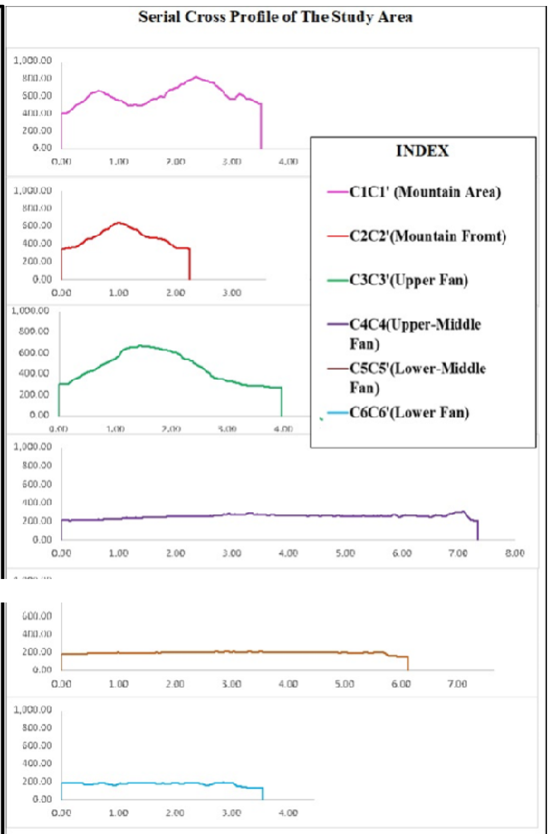


Fig: 4.a





SCALE Horizontal Distance in K.m. Vertical Distance in m; Fig:4.4

Fig:4Fig:5

(Source of Fig:4 & 5: Carto Sat DEM, Toposheet 78 B/9 and Field survey)