STRUCTURAL STUDIES ON CENTRAL KACHCHH MAINLAND WITH SPECIAL REFERENCE TO QUATERNARY TECTONISM

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Parag S. Sohoni

Department of Geology, Faculty of Science,
M. S. University of Baroda, Vadodara – 390 002

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SUMMARY

The thesis incorporates the results of the investigations carried out on the Central Kachchh Mainland of western India. The area studied is one of the highest portions of the Mainland Kachchh, and its landscape is a unique product of tectonic activity since the advent of Mesozoic Era. As Kachchh area as a whole continues to be tectonically and seismically active till date, its topography, drainage and landforms have preserved with them the evidences of an interesting tectonic history. The scope of studies has been essentially tectonism oriented and an attempt has been made to explain various aspects of Central Kachchh Mainland landscape, emphasizing on the structure, morphotectonics & active tectonics and palaeoseismicity.

Kachchh region located along the western continental margin of India forms an important peri-cratonic Mesozoic-Tertiary sedimentary basin. It is bordered by different tectonic elements viz. Nagar Parkar ridge in the north, Radhanpur Badmer Arch in the east and Kathiawar uplift in the south. The region provides a unique example of tectonically active landscape. Except for the major E-W faults and a few conspicuous meso-scale structures, little has been said about the deformational history of the area. Studies carried out by most previous workers have generally concentrated on lithostratigraphic, sedimentological, palaeontological and K-T boundary aspects of the area. Structural studies are few and only some workers have provided regional details of major faults,

folds and domes. It is with this background the present study was taken around Central Kachchh Mainland with the aim to analyse the influence of tectonic activity on the area.

Area around Central Kachchh Mainland consists mainly of Mesozoic rocks along with limited occurrences of Tertiary and Quaternary rocks. Mesozoic rocks in the area belong to Chari, Katrol and Bhuj series, and mainly comprise limestones, sandstones and shales of Mesozoic age. The area marks the site of one of the major faults of the region, the Katrol Hill Fault (KHF), along which the Mesozoic rocks are seen folded into monoclinal flexures. Tertiary rocks are less abundant with some occurrences recorded in the eastern part of the area. These mainly comprise of sandstones, siltstones and limestones and are relatively less deformed than the Mesozoics. Good exposures of Quaternary rocks (Miliolites) are found scattered within the intermontane depressions and valleys. Since the advent of Mesozoic, Kachchh has been tectonically active. Kachchh as a whole and the study area in particular has been visited by a number of earthquakes of varying magnitudes in the recent and historic past. The occurrence of several earthquakes in the recent times thus provides an evidence of continuous tectonic activity.

The thesis incorporates the results of the studies carried out with the following approaches:

a) A detailed fieldwork carried out to record different structural elements.
b) Structural analysis of the field data to decipher the structural history.
c) Qualitative tectono-geomorphic analysis with the help of satellite and field data.
d) Quantification of geomorphic data using different morphometric parameters.
e) Seismic studies of the Kachchh region as a whole including the statistical analysis of seismic data.

STRUCTURAL STUDIES

A record of different structural elements was made in the field. Well-exposed mesoscopic folds and faults were encountered throughout the study area. Detailed structural mapping has revealed that the rocks have undergone a complex deformation. Maximum deformation is seen along the major Katrol Hill Fault extending for almost 100 km in the E-W direction. This forms a zone of about 10 km south of KHF all along its stretch. However, it has been observed that rocks to the north and south of this zone are also deformed. Faults with strike slip, normal slip and reverse slips were encountered.

Table 1 Major deformational events of CKM

Age	Deformational Event/s	Mode of Deformation	Evidences	Source
Jurassic- L. Cretaceous	Rifting and Major normal faulting	Extension	Development of major regional faults; stratigraphic correlation indicating pattern of deposition under the rifting conditions.	Hardas, 1969; Biswas, 1982, 1987.
U. Cretaceous-Eocene	Major igneous activity and formation of domes	Extension	Formation of domes due to major igneous intrusions.	Hardas, 1969; Biswas, 1982, 1987; This study
Oligo-Miocene to late Tertiary	Major structural inversion and folding alongwith the formation of major strike-slip faults. --- Normal faulting related to the inversion	Compression, Transpression (?) Extension	Change over of regional rift related normal faults into reverse faults. Development of fault propagation folds.	This study
Post Early Pliestocene - Holocene	Two events of uplifts in the Central Kachchh Mainland.	Compression	Development of paired terraces within the CKM	This study
Recent	Many small and large magnitude earthquakes.	Compression and Extension	Generation of related faults; field evidences and fault plane mechanisms	Chung and Gao, 1995; This study

The faults with reverse slip are seen restricted only within Katrol Hill zone. Apart from folding and faulting in Mesozoic rocks, conspicuous folding is also observed in

Tertiary and Quaternary rocks. Structural analysis of the field data reveals that the fold axis orientation of all the folds occurring in area is generally identical (i.e. falling inbetween N60°E-N110°E). On the basis of this it is inferred that the stresses resulting in folding of strata have influenced the rocks right upto Quaternary (Table 1). The rocks in central Kachchh Mainland are highly jointed. Detailed mapping of joints also helped in setting up their relationship with some major structures. An attempt has been made to study them in relation to the successive events of deformation.

A part of the thesis deals with the lineament analysis, which was carried out to know the behaviour of the linear features of the area. Topographic sheets and satellite imageries were used to map the lineaments of the study area and the area surrounding it. It was found that the lineaments follow three general trends, a) E-W b) NE-SW and c) NW-SE.

MORPHOTECTONICS

In regions of active tectonism, topographic changes can be generated rapidly compared to the rates of erosion and deposition, so that the position of ridges and range fronts often offer a useful guide to locate active faults and folds. Drainage systems adapt to changes in the surface slope and thus have the potential to record information about the evolution of folds and faults. Field studies were carried out with the aim of locating geomorphic features caused and influenced by tectonic activity in recent times. It was found that the fluvial systems are the most affected by tectonic activity. Most streams within the Central Kachchh Mainland have preserved conspicuous uplift related terraces. Within Katrol Hill Zone (KHZ) three sets of terraces are seen. Although, terraces are also present to the north and south KHZ their number does not exceed two in any case.

Table 5.1. Terracing sequence of Central Kachchh Mainland, note the more number of terraces within the Katrol Hill Zone indicating the highest amount of tectonic instability within this zone as compared to the north and south of it.

Distribution of Terraces		Number of Terraces	Type of Terraces	Lithological and Morphological Description	Height in Meters	Probable Cause
Katrol Hill Range (Zone)		3	One Paired Strath Terrace and Two Paired Alluvial-Fill Terrace	Strath Terrace – forming the oldest rocky paired surface comprising Mesozoic sediment succession	Cliff height ranges from 25 to 35 m	Periodic uplifts related to Katrol Hill Fault
				Second Alluvial-Fill Terrace – Comprise valley fill miliolitic deposit	Cliff height ranges from 10 to 15 m	
				Lower most Younger Alluvial-Fill Terrace - comprise coarser colluvial material made up of angular to sub-angular boulders and cobbles representing tectonically generated fragments during strong seismic shaking	Cliff height ranges from 1.5 to 3 m	
North of Katrol Hill Range	Bhuj lowland	2	Paired Strath Terrace and Paired Alluvial Fill Terrace	Strath Terrace – comprise Mesozoic sediment succession, at places show capping of 2.0 to 3.0 m thick Quaternary fluvial sediment.	Cliff height ranges from 8 to 20 m	Incised due to uplift along fault-bounded blocks or due to fault related flexuring. These terraces are the manifestation of two individual event of uplift related down-cutting
				Alluvial fill Terrace – made up of trough to planar cross-stratified gravel facies along with silty and clayey litho units	Cliff height ranges from 1.5 to 3 m	
	Along the Northern Hill Range	1	Paired Alluvial Fan Surfaces	Dissected alluvial fan surface comprising debris flow facies, high-density traction carpet deposits, trough cross-stratified gravel and sand facies representing channel-fill deposits and sheet flood deposits.	Cliff height ranges from 20 to 25 m	Uplift along Kachchh Mainland Fault (KMF) was responsible for formation and incision of the alluvial fan lobes by the same newly developed north flowing streams originating from KHR after the main episode of drainage reversal
South of Katrol Hill Range		1	Paired Rocky Strath Terrace	The terraces in the central and lower segment consists Tertiary succession, at places capped by 3-4 m thick unconsolidated Quaternary fluvial material	Cliff height ranges from 20 to 35 m in upper reaches, 20 m in central and 5 m in lower reaches	Strath terrace along KHR is a result of KHF related flexuring, whereas terraces in central and lower portions represent younger tectonic event of fault related flexuring

On the basis of this field evidence it is inferred that maximum uplift took place within the KHZ and at least three uplifts were responsible for carving out these features. A detailed description of the terraces observed in the field is summarized in table 2. Besides

this, most of the streams are antecedent. The phenomenon of drainage reversal is seen both on local and regional scale. Good exposures of local scale reversal of drainage were found near Godpar and the area to the north of Bhuj where Stream ponding on account of reversal is seen. Drainage reversal on regional scale was confirmed by studying late Tertiary-early Quaternary sediments to the north of KHF, which show palaeocurrent directions against the present day flow.

Almost all streams show incision of 25 to 40 m, this indicates a slow uplift in the area. To check the extent of such features studies were extended to the Kachchh Mainland fault (at the northern margin of Kachchh Mainland). Along Kachchh Mainland Fault, several alluvial fans are exposed at the mouths of rivers debauching into the Great Rann-Banni depression. Two such fans (i.e. the Kaila and Kaswali river fans) were studied in detail. It was found that the present day channel cuts alluvial fans up to 25-35 m. A set of terraces is also seen along both these rivers indicating Quaternary uplift along this stretch.

To support observations resulting from the field investigations, a detailed morphometric analysis of a number of streams draining north and south of KHF was carried out. The parameters studied include the Gradient (G), Gradient Index (GI), Pseudo Hypsometric Integral (PHI), Sinuosity Fractal Dimension (SFD), and Drainage basin elongation ratio (R_e). The exercise reveals that there is more variation in Gradient Index for the rivers draining south. PHI was calculated for several rivers draining north and south of KHF. Although the rivers in the Kachchh Mainland flow through the identical lithologies along their courses, it was noticed that there is increased standard deviation in the range of PHI for the rivers draining south. SFD for 6 rivers (2 of which flow to the north of KHF and others to the south) indicate that there is no marked variation in the SFD values for both the north and the south flowing rivers except for the south flowing Bhukhi river which has SFD value of 1.11 indicating greater amount of deformation related

variation in sinuosity characteristics. R_e values indicate that the south flowing rivers have less R_e than the north flowing streams. On the basis of all these parameters it is envisaged that the area to the south of KHF has undergone greater degree of tectonic deformation than its northern counterpart.

Drainage spacing ratio was calculated to understand the influence of recent tectonic activity on different fault bounded ridges. The individual drainage outlet spacing was measured for an individual hill range where the similarity of this ratio is suggestive of active tectonic uplift along that range. About 6 different individual fault bounded hill ranges were studied and drainage spacing ratio was calculated for an individual drainage outlet. It was found that the standard deviation for individual drainage spacing is less than 55 % of the mean in all the cases. This indicates recent tectonic deformation along these fault segments.

Mountain Front Sinuosity: Mountain front sinuosity is one of the parameters that indicate the degree of tectonic activity on individual mountain front. More the activity lesser the degree of sinuosity. A value of 1 is achieved for the most active fronts. Several mountain fronts of the study area were investigated and the sinuosity ratio was calculated for every individual mountain front. It was found that several of the mountain fronts within Katrol Hill zone have the values less than 1.2. This indicates higher degree of tectonic influence along these fronts. Along with this several other elated parameters were also calculated viz. faceting percentage and valley floor to valley height ratio (V_{fw}). The results show higher degree of faceting with less degradation/erosion, thus indicating repetitive activity along the fronts. Also, values of V_{fw} fall in the range of .1 to 1.5 with typical values falling between .1 and .3. This points to V shaped valleys in the area.

PALAEOSEISMICITY AND SEISMOTECTONICS

Kachchh has been a region where a number of devastating earthquakes have taken place in recent and historic past. Records of earthquakes since 1668 are available. But in recent times two of these i.e. the 1819 AllahBand earthquake and the 1956 Anjar earthquake were the most devastating. Structures such as pseudo sand blows, crater with no feeder dykes, sand blows and micro faulting were observed in the trenches dug near Khavda and Bhirandiala and are related to one big earthquake exceeding magnitude 5. Since one of the recent (i.e. the Anjar, 1956) earthquakes falls within the study area, preliminary appraisal of earthquake related features was carried out in the region.

To understand the pattern of seismicity, the data compiled from different sources (i.e. IMD, New Delhi) was plotted on the Kachchh map. It was found that there are two zones (i.e. Allah band Fault zone and Katrol Hill Fault zone) where the population of earthquakes is maximum. Interestingly, the Katrol Hill Zone marks the site for maximum population of earthquakes. Earthquakes in this zone as well as Allah-Band zone follow regional strike of the two major faults and are aligned in E-W direction, and this fact suggests the influence of recent tectonic activity on these two faults especially the Katrol Hill fault. Apart from spatio-temporal plotting a detailed probabilistic assessment for earthquake occurrences was also made using Poisson's probability density function.

CONCLUSIONS

Some of the important conclusions are summarised in the following section.

1. Kachchh region in general and study area in particular has undergone structural inversion from extensional regime to compressional regime resulting into the formation of the reverse faults and the fault propagation folds.

2. Doming and folding in the area are genetically unrelated, wherein the doming in Central Kachchh Mainland appears to have been on account of igneous activity and the folding on account of horizontal shortening.
3. Most of the normal faults predate the phenomenon of structural inversion, however, some which essentially strike E-W and N-W in general are related to the extension related to horizontal shortening. The reverse faults are essentially found in Katrol Hill Range and are the result of the compressional stresses responsible for bringing out the reactivation of then existing normal faults. Most of the strike-slip faults essentially strike N-S, NNW-SSE, NNE-SSW, these are the part of the northeasterly directed compressional stresses.
4. The near orthogonal joint sets in Central Kachchh Mainland are related to major folding on account of fault propagation and sudden change in least principal stress axes in the perpendicular directions.
5. Katrol Hill Fault Zone (KHFZ) has experienced at least three events of uplift, one coinciding with the major inversion event which resulted in the large scale drainage reversal and the other two post dating it. The chronology of the later events is inferred on the basis of individual paired terraces exposed within the KHFZ.
6. Morphometric analysis of the Central Kachchh Mainland shows that the Katrol Hill Fault (KHF) is one of the most active faults of Kachchh region.
7. The drainage related geomorphic parameters indicate that the area to the south of Katrol Hill Fault is tectonically more unstable than its northern counterpart.
8. Integration of the structural, tectonogeomorphic and the seismic aspects indicate that the Kachchh region in general and the Central Kachchh Mainland in particular are traversed by several active faults viz. Kachchh Mainland Fault, Katrol Hill Fault, Allah Bund Fault, Mahadev Temple fault, Naira river Fault, Bhujpur Fault, Marutonk

Dungar Fault, Wadwa Fault, Godpar Fakirwari Fault, Sanosra Dungar Fault and Wagad Fault.

9. Presence of the soft sediment deformational structures in the Great-Rann sediments near Khavda indicate that an earthquake of Magnitude > 5.5-6 must have occurred in the recent past. The future work, however, would enhance the existing knowledge.
10. Studies related to the genesis of Allah Bund indicate that the faulting involved was of normal nature.
11. The seismic hazard analysis indicates the presence of four major seismo-active zones in Kachchh region.

(Candidate) (Supervisor)

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HEAD
GEOLOGY DEPARTMENT
M. S. University of Baroda