MORPHOTECTONIC EVOLUTION OF KHARI RIVER BASIN OF CENTRAL KACHCHH HIGHLAND

SUMMARY
of
The Thesis Submitted to
THE M. S. UNIVERSITY OF BARODA
for the Degree of
DOCTOR OF PHILOSOPHY
in Geology

BY

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1998

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SUMMARY

The Kachchh basin is an E-W trending rift graben located on the western Indian continental margin. The basin was formed due to the northward drift of the Indian plate during Late Triassic. Repeated tectonic movements along the various basinal faults have significantly affected the structural framework and sedimentation pattern in the basin. The Kachchh Mainland has evolved as a result of several tectonic events. The rocks of Mainland represent a complete succession from Middle Jurassic to Recent. The landscape shows remarkable correlation with the structural set up of the basin. Continuation of tectonic movements along various fault systems is evidenced by the seismic activity during recent geological past and historical times.

The present study is concentrated in the area around Khari river basin, a crucial part of Mainland Kachchh. The study records the tectonic and structural peculiarities and their implications on the pre-Quaternary and Quaternary tectonic evolution of the basin. Qualitative inferences on these features have been made by detailed analysis of different morphometric and morphotectonic parameters. The various fault systems and Quaternary deposits like alluvial and colluvial fans and miliolites have been investigated in the field in an attempt to understand the effects of continued tectonic movements along these faults in shaping the present landscape. Various gromorphic features like dissected drainage, Quaternary cliff cuttings in Mesozoic terrain, alluvial and colluvial fans assembled mainly at the northern

margin of the hill ranges, deeply cut gorges along the hard rock river beds, cuesta cliffs, conical hills and vertical scarps also suggest the ultimate contribution of active tectonism in the evolution of the Central Kachchh Highland. An evolutionary model of the present landscape has also been attempted with a view to construct the chronology of tectonic events that took place in the Khari basin.

The Khari river basin is triangular in shape, the base of the triangle being along the southern hilly range, spire towards north, it merges into the plain of Banni. The Pat and Pur Nadi, arising from southeasterly hill ranges are the two main tributaries of Khari river. The headward area constitutes the E - W trending Katrol hill range. General flow direction of the basin is towards north; while the main channel of the Khari river is flowing towards northeast.

Most part of the area is covered by the rocks of Jhuran and Bhuj Formations. The oldest formation on the Mainland is Jhurio Formation which occurs in the northwest part of the area. The maximum thickness of this formation is exposed as inliers in the Jhura hills northwest of Bhuj. The Jumara Formation occupies the core part of Habo hills. Within the Jhura dome they occur as ring shaped outcrops. The formation being soft, usually gives rise to a grey undulating country of low relief, resistant bands occasionally forming cuestas. Thin fossiliferous oolitic limestone (sandy oomicrites) bands are common all along the Katrol hill range. They are called "Dhosa Oolite Beds".

The Jhuran Formation rests upon the upper most member (Dhosa Oolite Member) of Jumara Formation and comprises a thick sequence of alternating beds of sandstone and shale. Southern flanks of Katrol hill range, and most of the northern part of Khari river basin are represented by Jhuran Formation. A major part of the central rocky plain around Bhuj is represented by the rocks of Bhuj Formation. The formation mainly consists of non-marine sandstones of uniform character deposited in a deltaic environment with occasional tidal influences. The Bhuj Formation is the youngest formation of Mesozoic rocks of Kachchh. The Mesozoic rocks in the area are intruded by a number of basic dykes trending mostly N-S or NW-SE. These occur in the vicinity of faults or along the faults, suggesting syntectonic nature of the intrusive rocks. The dykes occurring to the south and north of Katrol Hill Fault abruptly terminate against the fault. The area has a couple of patches of Madh Series of Paleocene age exposed north of Kukma village extending further north-eastward upto Paddhhar. The other important Tertiary unit is the Vinjhan Formation of Upper Miocene age which occurs in the form of scattered patches.

The Quaternary deposits are found to occur within the various river valleys and along major fault lines. An extensive tract of Quaternary deposits comprising the plain of Banni occur to the extreme north of the study area. Quaternary deposits in the study area occur mainly in the form of alluvial and colluvial fans, fluvial sandbars, valley fill miliolites and fluvio-aeolian miliolite patches. The Quaternary deposits directly overlie the Mesozoic or Tertiary rocks. The alluvial and colluvial fans mapped are associated with the Mainland Fault and Katrol Hill Fault.

The presence of colluvial fans at the base of fault scarps is a conspicuous feature of the area. The colluvial material is suggestive of degradation of the fault scarps. Majority of the colluvial fans recorded in the area are located along the E-W faults, notably the Katrol Hill Fault. The NNW-SSE, NW-SE, NE-SW and NNE-SSW trending transverse faults show very little or negligible colluvial material indicating a relatively fresh nature of these scarps. In contrast, the latitudinal faults, show huge colluvial debris at their base and gullied scarp face. The colluvial fans are incised by various streams and are overlain by miliolite deposits suggesting that these deposits are of Early Quaternary age.

Miliolites occur as small inliers within the rocky area as obstacle dunes and as sheet deposits. The sheet miliolites occurring extensively in the area are studded with cobbles and pebbles suggesting a fluvial component in the origin of these deposits. Alluvial deposits are found in patches within the various river channels. In the Katrol hill range, the alluvial deposits occupy valleys bounded by cliffs of sheet miliolites. This suggests that these represent a post-miliolite depositional phase. The sediments comprise mainly sandy structure less alluvium. The alluvial deposits at places show faulted contacts with the older rocks. Immediately to the north of Mainland Fault in the Banni plains, these deposits show incision of 1.5 to 3.0 m.

The structural history of the Khari river basin of Central Kachchh Highland is very interesting. Apart from the regional structures of Mainland Kachchh, the basin exhibits other local structural features of significance like faults, folds, domes, anticlines, synclines and dykes indicating that the area has a complex structural setting . The continued seismic activity in the area suggests that the area has not yet attained tectonic stability. The morphology of the area is very well conformable with the structure and lithology. Domes and anticlines usually stand out as areas with positive relief while synclines form valleys. Highly resistant rock units for example, dykes also stand out amongst the sorrounding area. Some of the scattered hills like Bhujiya hill and Kalitalawadi Hill are the results of basic intrusives in their core.

The E-W trending regional faults, the Katrol Hill Fault and the Mainland Fault are prominent structural features of the area. The Katrol Hill Fault and the Kachchh Mainland Fault are almost E-W regional faults. The Katrol Hill Fault has brought the older rocks in the south over the younger rocks to the north. The fault plane near Hamadra lake is inclined steeply (55-60^{o}) towards south and it is thus a reverse type of fault. The fault parallels the strike of the strata and is somewhat sinuous rather than straight. It marks the northern limit of the Katrol range and forms a major drainage divide of the Mainland. The northern faces of the fault scarps of the Kachchh Mainland Fault and the Katrol Hill Fault exhibit characters typical of a fault generated mountain front .

Significant features associated with the Katrol Hill Fault and the Kachchh Mainland Fault are half anticlines or domes. Structurally, the formation of the domes has influenced the geomorphology of the area. These domes constitute the northern hilly ranges - the Habo hills and the Jhura hills. Resembling the Habo dome, Jhura hills are also flanking at the Mainland Fault; but here the fault trends in NW - SE direction. Similar to the Mainland Fault, Katrol Fault also shows domes or half anticlines, but unlike those associated with Mainland Fault, here the extent of the domes is quite limited. The number of domes and flexures are more to the south than to the north of the Katrol Hill Fault. The various domes associated with the Katrol Hill Fault are Ler dome, Gangeshwar dome, ShivParas dome, Khatrod dome and

Chadwa dome. The northern limbs of the domes occurring to the south, are truncated by the Katrol Hill Fault. The southern limbs of the domes are gently inclined, as little as 5 -10° towards south while the northern limb is steeply dipping towards the north or is vertical. At places, the northern limbs are seen overturned with a steep dip due south. Some of these domes contain basic rocks in their central portions, several N-S dykes and plugs with occasional sills. The eastern and western limits of the domes are marked by N-S transverse faults. The central part of the domes is extensively cut by these transverse faults.

In addition to domes, numerous compressional structures seen in the area are anticlinal and synclinal flexures associated with the Katrol Hill Fault. These are Ratnal and Bharapar anticlines and Kukma and Pur River synclines. The axis of the anticlinal and synclinal flexures trend in E-W direction. These flexures are common in the vicinity of Katrol Hill Fault. Immediately to the south of the fault considerable drag effect is seen in the dips of the strata. Flexures resembling monoclines and overturned folds are associated with the southern hills where younger formations are exposed.

A numbers of transverse faults running NNW-SSE, NW-SE, NE-SW and NNE-SSW displace the Katrol Hill Fault at places. The large transverse faults are the striking features of the area. The fault planes are either vertical or steeply dipping. In general, the fault planes dip towards the domes. The sense of movement is always dominantly lateral, both sinistral as well as dextral slips are noted. The lateral movement along these faults is very conspicuous in the field. Effects of these faults are seen in the form of horizontal shifting of rocks and the Katrol Hill Fault. The N - S and NW - SE fractures are occupied by basic igneous dykes. The fact that some of the transverse faults cut across the Katrol Hill Fault is significant. The number of transverse faults is greater to the south of Katrol Hill Fault than in the north.

A significant feature of the faults is the fresh nature of the fault scarps. The Katrol Hill Fault scarp and the Mainland Fault scarp show close similarity to fault generated mountain fronts. The steep scarp marking the Katrol Hill Fault is a prominent geomorphic feature of the area. All along the base of the fault scarp several dissected colluvial fans are encountered. The NNE-SSW, NE-SW, NW-SE and NNW-SSE trending faults exhibit more younger fault scarp morphology. This is evidenced by very little or no colluvial deposits along these scarps and absence of gullies or projecting spurs. Moreover, these faults are continuous and never found to cut across by other faults unlike the Katrol Hill Fault which is divisible into several segments by transverse faults cutting across it.

Geomorphologically, the area is divisible into four major zones - the Katrol hill ranges in the south, almost flat, at places undulating rocky terrain in the central and eastern parts, western uplands and the northern hilly region comprising the Habo hills to the NE and the Jhura hills to the NW. The rocky terrain of Mainland Kachchh abruptly terminates against the Banni plain. The area is traversed by the Katrol Hill Fault and the Kachchh Mainland Fault in the south and north respectively. The Katrol Hill Fault delimits the Katrol range in the south while the Mainland Fault delimits the domal hills of Habo and Jhura in the north. In addition to the overall geomorphology, the other small scale geomorphic features like isolated hills and mounds are also tectonically controlled.

All lower order streams of the area arise from the hilly region of Katrol Hill range and are tectonically controlled. These lower order streams successively build higher order streams as they approach the piedmont zone and rocky surfaces around Bhuj. The pattern of the river on the rocky land surface around Bhuj shows anomalous meander development reflecting structural control. As these rivers flow on the Early Quaternary land surface indicating that they have evolved during Quaternary. Besides the deeply cut gullies and gorges along the main river channel show quite recent upliftment of the surface.

The present day landscape of the area is an end-product of various processes like sub-aerial erosion, pediplanation and tectonic activities. The series of erosional surfaces have constituted a stepped topography following the normal age sequence where the oldest surface occurs at the top and the youngest at the bottom. The erosional surfaces were identified on the basis of the occurrence of flat topped surfaces and accordant summits of a group of hills, ridges or plateaus over an extensive area.

A total number of six erosional surfaces E_1 to E_6 have been identified in the study area. These stand at an altitude of 260-300m, 240-260m, 160-200m, 120-140m, 80-120m, and 0-20m respectively. The general slope of these surfaces is towards south, suggesting a unidirectional tectonic movement from time to time causing periods of tectonic instabilities and stabilities leading to the formation of polycyclic landscape. These surfaces are correlatable with the unconformities in the sedimentary sequence exposed in the bordering coast land.

The pre-Quaternary erosional surfaces E_1 and E_2 occurring at an altitude of 300 m and 240 m are mostly seen within the Katrol hill range of the study area. A number of scattered hills ranging in altitude between 240-300m occur in the area. These are at places represented by discontinuous ridges and plateaus such as Khatrod ridge (280-342m) at Khatrod village, and Satpura plateau (260 m), south of Madhapar village. These landsurfaces in the Katrol hill range show steep mountain fronts.

The E_3 surface is distinguished from E_2 surface by flat hill tops, discontinuous ridges, plateaus and cuestas which generally fall between an altitude range of 160-200m. The youngest pre-Quaternary erosional land surface (E_4) is marked by gently sloping pediments, residual hills, flat stony surfaces, plateaus, cuestas, mesas and terraces. The surface is drained by the second and third order streams. All the pre-Quaternary surfaces show a southerly tilt which points to an unidirectional movement along E - W Katrol Hill Fault. The erosional surfaces show a wavy configuration which could be attributed to the differential movements along various fault systems and varying degree of erosional processes.

The two prominent Quaternary surfaces (E_5 and E_6) at an altitude of 80-120m and 0-20m are easily recognizable. The E_5 surface ranging in altitude between 80-120m is dominant in the central part of the basin. It is marked by low residual ridges, mesas, flat rocky and sandy pediments and rocky river terraces. This land surface slopes towards north opposite to dip, this phenomenon could be due to the vertical uplittment of the Central Kachchh Highland due to differential movement along katrol Hill Fault during Quaternary. A displacement of about 30-35m in the elevation of this surface on either side of the Katrol Hill Fault during Early Quaternary has been reported. The latest erosional surfaces (E_6) occurring at an altitude of 20m is marked by boulder and gravel beds in river valley terraces at levels higher than the valley floor, the depositional terraces within the Katrol hill range, the rubble deposit 1-15 m high above the valley floor, the clay and rubble terraces 8-9m above the river bed and the Banni plain. The Banni deposits at the mouth of Khari river near Sumrasar village are cut by streams and gullies up to a depth of 0.3-1.5 m. All these characteristics are indicative of Recent uplifts.

The study of drainage basin morphometry strongly suggests episodic upliftment of the landmass. Morphometric study of other related drainage basin parameters like longitudinal stream profile, valley height and width ratio and mountain front analysis was undertaken. The Khari river has been identified as a sixth order channel. Total channel length of all the stream orders indicate stream richness in the basin. Ruggedness number in the present basin is less than 1.00, which suggests low relief and moderate density and points towards semi-arid and arid climatic condition.

Each stream is divided into different segments from source to the base level for the study of different parameters. Highly concave upward profile suggests that the area is tectonically very active. The gradient index values of each segment of the streams have obvious similarity except in the Khatrod streams where each value is quite high. Such highly variable gradient indices are typical in areas experiencing an intermediate to high rate of uplift. It is in conformity with the field observations around Katrol hill where the tectonic uplift is indicated by fault scarps, triangular and narrow fans, fault breccias and synclinal troughs. The gradient value and gradient index values vary in different segments, but the corresponding segments in each stream has nearly similar values.

All the streams have very low Vf ratio near their source in the hilly region, while a few kilometers away from the source, the ratio is quite high due to the broad valley morphology. At places it becomes very low, as valley incision is quite high for a particular part of the area, indicating periodic tectonic activity during the Quaternary. The results of sinuosity parameters of the Khari river basin suggest that they are controlled dominantly by tectonism. The evolution of the Khari river basin in the later phase of tectonism is indicated by the sinuosity indices.

Most of the mountain front sinuosity values fall in the range between 1.0 to 1.6 in class-1, suggesting that the area has experienced active tectonism. Mountain fronts associated with Kachchh Mainland Fault trending in E - W direction show moderate values of Mountain front sinuosity falling in class-2 which indicates moderate to slightly active tectonism along the Kachchh Mainland Fault during Quaternary. The values of mountain front sinuosity associated with the transverse faults (NE-SW, NW-SE, NNW-SSE, NNE-SSW, N-S and WNW-ESE) are unusually low. Mountain front sinuosity values between 1.1 to 1.27 suggest the activeness of transverse faults. At places the values indicate that these have been more active than the Katrol Hill Fault. Overall, the mountain front sinuosity values indicate that the Khari river basin has been tectonically active during Quaternary.

The area around Bhuj in Mainland Kachchh reveals an interesting structural framework which has tremendous implications for tectonic evolution of Kachchh Mainland. The E-W trending faults are related to the origin of the Kachchh basin. The subsequent tectonic movements along these faults including the Katrol Hill Fault resulted in the present geologic and geomorphic configuration. North of this fault several similar faults including minor and major faults show step faulting towards north. These faults are responsible for the gentle anti-dip tilt of the area towards north.

The Katrol Hill Fault and the Mainland Fault are displaced by several NNW-SSE, NW-SE, NE-SW and NNE-SSW transverse faults. Close association of the transverse fault trends and the intrusive dykes of the area suggest that these events are related to each other and are coeval. The intrusives with the exception of plugs belong to a pre-Deccan trap phase. This seems to be distinct possibility since the area around Bhuj shows a large number of dykes, but no outcrop of Deccan traps is seen even though the Madh series of Palaeocene and Khari Series of Miocene age are preserved. This suggests that the transverse faulting and intrusion of dykes took place sometime after the deposition of Bhuj Formation but before the onset of Deccan trap volcanic activity. However, the presence of volcanic plugs related to the eruption of trappean lavas in the central portions of the domes indicate syntectonic volcanic activity.

The localization of folded zones along the Katrol Hill Fault and Mainland Fault points to the significant role played by these faults in the formation of the fold zones and suggests accumulation of compressive stresses along these fault planes. These compressive stresses possibly led to reverse movement along the Katrol Hill Fault. The formation of domes, folds and flexures is thus the result of intricate interplay of localized stresses in fault zones and simultaneous volcanism. This phase of tectonic upheaval ceased before the onset of Tertiary as evidenced by the very gently dipping Tertiary rocks which overlie the eroded Mesozoic folds elsewhere in Kachchh. The dykes do not cross the Katrol Hill Fault on either side whereas the transverse faults are seen displacing, both the Katrol Hill Fault and the Mainland Fault. The strata in the various domes also show lateral displacement along these faults. This suggests a later phase, sometime during Tertiary, of reactivation of transverse faults with dominantly strike slip movement as evidenced by the horizontally displaced fault scarps of Katrol Hill Fault and Mainland Fault. This event possibly took place during Eocene-Oligocene period when the final welding of Indian and Eurasian plate resulted in slowing down of the northward drift and anticlockwise rotation of about 9°. The abrupt slow down of the Indian plate after a very rapid northward movement and the anticlockwise rotation possibly realigned the tectonic stresses and reactivated the transverse fault systems resulting in strike slip movement.

The first order topography of the area indicates that tectonic movements along the various faults outpaced the erosional processes. Neotectonic uplift along various faults has been responsible for shaping the present landscape of the area . The youthful nature of the fault scarps and various other geomorphic evidences suggest tectonic instability of the area during Quaternary. The Quaternary deposits are significant for categorizing Quaternary tectonic activity. Two major phases of Quaternary uplift have been identified-a pre- miliolite phase and a post-miliolite phase. The pre-miliolite phase took place in Early Pleistocene while the post-miliolite phase occurred during Late Pleistocene which is perhaps continuing at present.

The Early Pleistocene tectonic activity took place along the E-W trending faults as evidenced by the huge colluvial deposits underlying the miliolites at the base of Katrol Hill Fault. The present geomorphic set up of the area thus originated during Early Quaternary due to neotectonic movements along E-W faults. The Late Pleistocene phase took place along the NNE-SSW, NE-SW, NW-SE to NNW-SSE trending transverse faults as suggested by faulting along this trend in fluvial deposits which are younger than miliolites. This is corroborated by undissected transverse faults with very little or no colluvial deposits. A displacement of atleast 30 m along the Katrol Hill Fault during Quaternary have been postulated earlier based on the occurrence of Early Quaternary surface at different levels on either side of the fault. A major portion of this displacement occurred during Early Quaternary which resulted in huge colluvial deposits and formation of alluvial fans. The present day tectonic instability of the area as evidenced by the high degree of seismic activity is possibly due to tectonic movements along these transverse faults.