LATE CENOZOIC GEOMORPHIC EVOLUTION OF THE KIM RIVER BASIN, WESTERN INDIA

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By
Naresh H. Mulchandani

Department of Geology
Faculty of Science
The Maharaja Sayajirao University of Baroda
Vadodara-390002
Gujarat, India.

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SUMMARY

The Kim river basin is located at the western extremity of the seismically active SONATA zone which is a well known E-W trending zone of crustal instability since the Archaean times. The Kim River basin is unique in the sense that it has formed an independent drainage basin in an area where all the other rivers join either Narmada or Tapti. The river follows a conspicuous meandering course which is controlled by the diverse nature of the landscape configuration and tectonic pattern it traverse before meeting the Gulf of Cambay. Previous studies in the area have been mainly on sedimentary and stratigraphic aspects of the Tertiary sequences. The main objectives of the study, have been to characterize the varied landscape of the Kim river basin and to delineate Late Cenozoic geomorphic evolution of the Kim river basin. Detailed mapping of various geomorphic features and surfaces was carried out in the field for this purpose. The study has also dwelt on the stratigraphic aspects of the exposed Late Quaternary sediments which had remained uninvestigated so far to reconstruct the morphostratigraphic evolution. A critical evaluation of the existing data on the surface and subsurface structural aspects of the Tertiary rocks in the Kim basin was also done. The Kim river basin falls within the Narmada block of the N-S trending Cambay rift graben. The present study reveals that the geomorphological history of the Kim river basin has been controlled by the tectonic activity which includes the Post-Pliocene phase of basin inversion.

The Kim river basin has been divided into three morphostructural domains. The trappean highlands in the east has been designated as morphostructural domain I. The central part of the basin forms the morphostructural domain II while morphostructural domain III includes alluvial plain to the west. The morpho-structural domains delineated are characterised by a typical morphological configuration within a particular tectonic context such as lithology and degree and type of deformation. The Kim River arises in morphostructural domain I consisting of the trappean highlands in the east. The trappean rocks comprise mainly basaltic flows of varied chemical nature and associated dykes. These form the northwestern fringe of the vast Deccan Volcanic Province of Peninsular India. The trappean rocks terminate abruptly against the Tertiary rocks in the west along the N-S trending Rajpardi Fault. Within the Kim basin, the trappean rocks present a rugged topography with linear basaltic ridges. The associated dykes are mainly oriented in ENE-WSW direction and show a strong morphological expression as linear ridges which continue for several kilometers. These structurally emplaced dykes control the landscape and the drainage configuration in the trappean highlands.

The central part of the Kim River basin forming the morphostructural domain II, is occupied by the Tertiary rocks with intervening alluvium. The exposed Tertiary sequence comprises Dinod, Kand and Jhagadia Formations of Miocene to Pliocene age. On a regional scale the area is the part of the Cambay rift basin and lies within the uplifted block to the south of the Narmada river known as the Narmada block. The Tertiary rocks have been folded into several ENE-WSW trending anticlines separated by synclinal lows. The southern limbs of these folds are displaced by ENE-WSW trending reverse faults. These structures are manifestation of a post depositional phase of intense deformation. A complex morphological pattern is seen in this part which has been dominantly influenced by the post Pliocene tectonic deformation. The relief shows a remarkable correspondence with the structural features in the area which suggests that the erosion processes operating over the folded and faulted Tertiary rocks were also tectonically controlled.

The lower part of the Kim river basin constitutes the morphostructural domain III and consists of surficial cover of the Late Quaternary sediments that increases in thickness towards the west. The river follows an incised meandering course in this part which is characterized by a wide estuarine mouth. The Tertiary rocks are buried under a thin cover of alluvium which continue to increase towards west. However, the structures developed in Tertiary rocks continue to exert a strong control on geomorphology as evident by close correspondence of the subsurface structural features with the course of Kim River. The channel of the Kim River in this domain circles around the subsurface structural highs

The present study has delineated four geomorphic surfaces which have been formed during the Late Cenozoic. These are – Early Pleistocene Erosional Surface (EPES), Late Pleistocene Depositional Surface (LPDS), Early Holocene Erosional Surface (EHES) and the Late Holocene Depositional Surface (LHDS). The Early Pleistocene Erosional Surface (EPES) occurs exclusively within the morphostructural domain – II and is the oldest geomorphic surface mapped in the Kim river basin. This surface is developed over the deformed Tertiary rocks and occurs as discontinuous patches with intervening alluvium. The surface occupies topographic highs which correspond to tectonic highs within the Tertiary rocks. The surface shows a gentle inclination towards WSW. The maximum elevation of the surface is ~80 m in the east near the Rajpardi Fault which drops down to ~40 m in the downstream direction. Beyond this, the EPES disappears below the alluvial plain in morphostructural domain III.

The EPES is a gently hummocky surface and is not of so spectacular occurrence in the field owing to its discontinuous nature. Nevertheless it marks a significant prolonged phase of tectonically controlled erosion of the deformed Tertiary rocks. The erosional phase closely followed a phase of severe deformation due to N-S directed compressive stresses during the initiation of the basin inversion. The deformation produced ENE-WSW trending topographic highs along the anticlines and lows along the synclines. The crustal shortening associated with this deformation was partly adjusted by the development of the reverse 'thrust' faults in the southern limbs of the anticlines. The deformation took place during Late Pliocene to Middle Pleistocene which resulted in the basin being exposed to erosion. The erosion was tectonically controlled as revealed by the close relation between the topographic relief of the EPES with the structural elements.

The Late Pleistocene Depositional Surface (LPDS) comprises the flat surface developed over the Late Pleistocene alluvial sediments. The LPDS occurs in the morpho-structural domains II and III. In morphostructural domain-I it shows a very limited occurrence (eg. at Punjabnagri, Daulatpura and Pansim) along the river channels. In the central part of the Kim basin i.e. morphostructural domain-II, the LPDS occurs in patches within the topographic lows, while the topographic highs are occupied by the EPES as described earlier. However, almost the entire lower part (morphostructural domain III) of the Kim basin is a part of the LPDS where it assumes the form of a true alluvial plain. The Kim river has incised the LPDS by about 10-15 m all along its course. The alluvial sediments forming LPDS unconformably overlie the deformed Tertiary rocks. The sediments are well exposed in the vertical cliff sections. The fluvial sediments forming the LPDS represent a depositional phase which followed the prolonged phase of intensive tectonically controlled erosion. This indicates the waning intensity of tectonic activity during the Late Pleistocene. In morphostructural domain II, the deposition was confined within the topographic lows created during Early Pleistocene. Near the mouth the LPDS is superimposed by the coastal features such as mudflats.

The Late Pleistocene Depositional Surface (LPDS) show extensive dissection adjacent to the various river courses This erosional surface has been designated as the Early Holocene Erosional surface (EHES) and is uniformly seen in the vicinity of various river channels in all the three morphostructural domains wherever the Late Pleistocene Depositional Surface (LPDS) occurs. Deep gullies and ravines are seen in the Late Pleistocene sediments which indicate a distinct post-depositional phase of severe erosion and incision in the entire Kim river basin.

The Late Holocene Depositional Surface (LHDS) is a low valley fill surface which occurs about 5-8 m above the river bed This surface is most well developed in morphostructural domain III followed by II and finally by I. The sediments comprising the LHDS belong to two distinct depositional environments – fluvial and tidal-estuarine. The fluvially formed LHDS are found in all the three morphostructural domains whereas the tidal-estuarine LHDS occur in the estuarine reaches only. The deposition of the sediments of the LHDS correlate with the Mid-Late Holocene high sea. The fluvial sediments are mostly sands and silts with the coarser fractions dominating in the upstream reaches. The tidal-estuarine sediments show alternating sequence of fluvial sands and tidal organic rich clays which typically record the corresponding dominance and waning of fluvial and tidal conditions.

The sediments forming the Late Pleistocene Depositional Surface (LPDS) and Late Holocene Depositional Surface (LHDS) were studied in detail to reconstruct their lithostratigraphy and delineate their depositional environments during the present study For this purpose, vertical sediment profiles were prepared, the lithofacies were identified, their association and stratigraphic relations were established This was done mainly to understand the genesis of the depositional surfaces and reconstruct the morphostratigraphic evolution. The sediments of the LPDS are exposed in the incised cliffs of 10-15 m along the Kim river and overlie the trappean rocks in morphostructural domain I and the Tertiary rocks in morphostructural domain II. Lithologically, the sediments of LPDS consist of semiconsolidated to unconsolidated fluvial sands, silts and gravels with an intervening buried soil towards the top of the exposed sequences. The gravels mainly comprise Gms, Gh, Gp and Gt facies and is approximately 1m in thickness and suggest deposition mainly by sheet flows and occasional debris flows as dominant aggrading processes. These mostly show erosional bases and represent channel deposits. The clasts are dominantly of trappean rocks with a small percentage of Tertiary rocks. The gravels are overlain by a thick horizon of sands and silts. The sands and silts show varied facies from massive (Sm), planar cross stratified (Sp) and horizontally stratified (Sh) to finely laminated forms. At places the horizon shows calcrete development along vertical and diagonal cracks. These mainly represent overbank to channel or near channel sedimentation by flows carrying mostly sand as suspension load. Towards the top occurs a prominent deeply pedogenised brown coloured buried soil. The soil shows abundant nodular pedogenic calcretes throughout the horizon, however, the abundance is seen to increase towards the top. The soil is laterally persistent, easily identifiable and has therefore been used for correlating the sediments exposed at different locations At places, the buried soil is overlain by a cross-stratified gravel horizon with a distinct erosional contact. The gravel bed is overlain by a thick silty sand horizon which is overlain by top soil horizon. The overall sediment characteristics, presence of a conspicuous soil horizon and a marked prolonged erosional interval represented by an unconformity at the base of the sequence indicates that these sediments are of Late Pleistocene age and are comparable to similar sediments of lower Narmada valley which have been shown to be of Late Pleistocene age.

The LHDS is developed within the river channel in all the three morphostructural domains. This forms a series of discontinuous elevated surfaces which terminate abruptly against the incised cliffs of LPDS. These sediments comprise tidal-estuarine facies in the lower reaches and fluvial sand and gravel deposits in the upper reaches. In morphostructural domain-I the sediments of LHDS comprise sands and silts only, however, in morphostructural domain-II several gravel horizons are observed in the exposed sections. This suggests neotectonic activity along the N-S trending Rajpardi Fault. In morphostructural domain-III, the sediments comprise alternate layers of sands, silts and clays of estuarine origin. Carbonaceous muds dominate the tidal estuarine deposits with intervening fine to medium sands showing parallel lamination. The sands show presence of herringbone structures, ripple and cross laminations. Stratigraphically comparable estuarine-tidal and fluvial sediments have been reported from the lower Narmada valley to the north of the Kim basin.

Morphometric analysis of drainage of Kim river basin was carried out to characterize the drainage parameters sensitive to tectonic activity. The high bifurcation ratios in all the three morphostructural domains indicate a highly dissected terrain due to rejuvenation of the area. The stream orientation analysis shows that the higher order streams are controlled by the structural framework while the lower order streams are slope controlled. High sinuosity values in morphostructural domain-II is attributed to structural complexity of this domain. Overall, the Morphometric analysis substantiates the field studies.

The present study has interesting sequence of geomorphic evolution of Kim river basin controlled essentially by varying intensity of tectonic activity during Late Cenozoic. The Tertiary period is recorded as a period of almost continuous sedimentation as revealed by the various exposed formations. The sequence was uplifted, deformed and exposed to erosion due to inversion of the sedimentary basin since Late Pliocene. The Late Pliocene-Early Pleistocene is the period of transformation of the subsiding sedimentary basin into in uplifting one. The overall uplift and style of tectonic deformations was governed by regional N-S directed compressional stresses. The deformation resulted in the development of ENE-WSW oriented anticlines, which were subsequently reverse faulted in the southern limb. The Late Pliocene-Early Pleistocene is therefore a period of net erosion and extensive deformation which formed the Early Pleistocene Erosional Surface (EPES) seen in morpho-structural domain II. The tectonic deformation of this period marks the first major and most intensive tectonic phase of the basin inversion. The erosion was controlled by the structure as evidenced by the topography, which confirms to the structural highs and lows. The shallow morphostructural lows thus created between the anticlinal high provided for the site of fluvial sedimentation during Late Pleistocene.

The Late Pleistocene is a period of fluvial sedimentation within the structural lows created along the Late Pliocene Early Pleistocene phase of structural deformation. The Late Pleistocene sediments unconformably overlie the eroded topography developed over the Tertiary sequences. Within the morphostructural zone II, the fluvial sedimentation was confined in the structural lows while in the morphostructural zone III the deposition resulted in the burial of the Early Pleistocene Erosional Surface (EPES) and the formation of the Late Pleistocene Depositional Surface (LPDS) over it. The continuous sedimentation and presence of buried soil indicates a significant weakening of tectonic activity during this period.

The Early Holocene is again a period of erosion aided by tectonic uplift. The tectonic uplift of the basin at this time led to the erosion and incision of the Late Pleistocene Depositional Surface (LPDS) in all the three morpho-structural domains. The incision of ~15 m possibly reflects the total amount of uplift that occurred in the Kim basin during Early Holocene. This phase of tectonic activity marks the second phase of tectonic uplift of the Late Cenozoic basin inversion.

This period also marks the aggradation phase which corresponds with the Mid-Late Holocene high sea which led to the formation of the Late Holocene Depositional Surface (LHDS). The upliftment of the LHDS during Late Holocene represents the third and final phase of basin inversion which is still continuing.

The present study has revealed that the Late Cenozoic tectonic activity related to sedimentary basin inversion has exerted a major influence in controlling sedimentation pattern and development of topographic relief within the Kim River basin. The inversion was initiated in the Late Pliocene due to N-S oriented compressive stresses. This resulted in the development of ENE-WSW trending folds, reverse faulting and uplift of Tertiary rocks and tectonically controlled erosion which continued up to the Middle Pleistocene. The tectonic activity almost ceased during Late Pleistocene leading to fluvial sedimentation in structural highs while the anitclinal highs remained as geomorphic highs. Resurgence of tectonic uplift during Early Holocene led to the erosion and incision of Late Pleistocene sediments. This phase correlates with the initiation of inversion of the area to the north of Narmada suggesting northward propagation of inversion of the Cambay basin. The last phase of uplift during Late Holocene uplifted the Mid-Late Holocene sediments. The early inversion of the area to the south of Narmada is attributed to the thinner crust. Occurrence of low to moderate seismic activity in the recent past and the thermo-mechanical instability of the crust suggests that various faults countinue to be tectonically active.