Late Quaternary fluvial sequences of southern Mainland Kachchh, western India

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The Late Quaternary sequences of southern Mainland Kachchh occur in two discrete patches – the eastern alluvial plain which merges with the Little Rann of Kachchh further east and the western alluvial plain mainly along the Naira river. These plains show three distinct geomorphic surfaces – the featureless alluvial plain (S₁ surface), the extremely dissected surface (S₂ surface) characterized by deep ravines and a low flat terrace surface (S₃ surface). The base of the exposed fluvial succession that makes up the S₁ and S₂ surfaces, is marked by a coarse gravelly facies. This is overlain by a thick buried soil with abundant pedogenic calcrete nodules. It is hosted in fluvial sands and silts. In the eastern part, this soil is a red soil while in the western part it is manifested as a brown soil. In both areas, the red and brown soils occur at the same stratigraphic level. Three radiocarbon dates of pedogenic calcretes from these soils indicate that the pedogenic phase is pre-LGM. The soil horizon is overlain by a planar to trough cross stratified sandy gravel followed by partially pedogenically altered fine sandy silts. The entire fluvial succession is deeply incised and shows deep gullies indicative of a post-depositional phase of severe erosion during Early Holocene. The decreasing intensity of gully erosion and the depth of incision towards south, conforming to the tilt block structure, suggest that fluvial incision and gully erosion was controlled by tectonics. A 2–5 m incised fluvial terrace (S₃ surface) encountered within the various river valleys is of Mid-Late Holocene age. The terrace sediments comprise coarse to medium fluvial sands and silts which are devoid of calcretes and pedogenesis. The incision of these terraces is perhaps contemporaneous with the drying up of the Little Rann of Kachchh during the last 2 ka. The fluvial geomorphology and exposed sequences in the various river valleys are correlatable, suggesting broadly coeval depositional and erosional phases, that may be linked to regional tectonic and palaeoenvironmental changes.

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Geomorphology

Tectonic geomorphology

Most parts of southern Mainland Kachchh comprise the rugged terrain of the Katrol Hill Range, which consists of southward dipping Mesozoic and Tertiary sequences (Figure 1 b). The Katrol Hill Range is delimited by the north-facing mountain front scarps of the North Katrol Hill Fault (NKHF) and the South Katrol Hill Fault (SKHF). The crestline comprising the highest summits of this range lies close to the northern edge. The drainage divide also lies very close to the crestline (Figure 2 b). The drainage consists of south-flowing parallel streams draining dipslopes¹. The rivers follow deeply incised courses and entrenched meanders. The presence of the crestline close to the North Katrol Hill Fault, gradual reduction in the ruggedness of the topography towards south, southward tilt of the plane surfaces, and southward dips of the Mesozoic and Tertiary rocks indi...
cate that the southern Mainland Kachchh represents a large tilt block, delimited by the North Katrol Hill Fault in the north and the Gulf of Kachchh Fault in the south (Figure 3a). The tilting is essentially attributed to the uplift of the block in the north due to differential movement along NKHF, while the Saurashtra block (horst) to the south of the Gulf of Kachchh Fault has been uplifted. The larger tilt block is sliced into two smaller tilt blocks by another major E–W trending fault (Figure 3a), the South Katrol Hill Fault (SKHF). Geomorphic expression of this fault is similar to that of the NKHF. This north facing and E–W trending escarpment is traceable from the Bhukhi river in the east to Kankawati river in the west (Figure 2b).

A remarkable correlation between the amount of river incision and the two tilt blocks is observed (Figure 3b). This is brought out well by the change in the depth of incision observed in the rivers of the eastern part (viz. Rukmavati, Nagwanti, Phot and Bhukhi). A marked decrease in the depth of incision is noted as these rivers flow southwards in the direction of the tilt (Figure 3b). An abrupt increase in incision is seen as the rivers cut through the second tilt block which is again followed by a decrease in the degree of incision in the direction of tilt. This suggests that continued tilting of the tilt blocks due to differential uplift along the E–W trending faults bounding these blocks has controlled the degree and rates of incision along the rivers of southern Mainland Kachchh (Figure 3a, b).

The exposed Late Quaternary sediments in the area occur in two discrete patches (Figure 1b), one in the east which merges with the Little Rann and the other in the western part mainly along the Naira river. We designate these areas as the eastern alluvial plain and the western alluvial plain. These are separated by the flat penneplained Tertiary rocks (Figure 1b), which are exposed along the cliff sections of the Kankawati, Chok, Sai and Vengdi rivers right upto the coast. This penneplained surface has been designated as the Early Quaternary surface by Biswas1, and apparently coincides with the Median high
the western part, the deposition occurred in a small basin possibly created by downfaulting along the Nain River Fault. In the eastern part, precise boundaries of the Late Quaternary depositional basin are not clear, although it could be a part of the larger basin, which includes the Little Rann of Kachchh.

**Fluvial geomorphology**

The drainage of southern Mainland Kachchh comprises southward flowing parallel drainage that debouch into the Gulf of Kachchh and the Arabian sea (Figure 2a, b). All the rivers are ephemeral and consistent flow of water is rarely observed even during the monsoon period reflecting the present hyper-arid climate. The present drainage is in an erosional phase at present as evidenced by their incised courses, more so in the upper parts of their courses where pre-Quaternary rocks are exposed all along their valley floors. Recent channel deposits are rarely seen in these reaches. Extensive gully erosion is an integral part of the fluvial geomorphology of the area. An intriguing feature of the rivers in Kachchh is that several rivers are given the same name. Two Rukmavati and two Khari rivers are present in the area included in the present study. Therefore, the Rukmavati and Khari of the eastern alluvial plain will be mentioned hereafter as Rukmavati (E) and Khari (E) while that of the western alluvial plain will be mentioned as Rukmavati (W) and Khari (W).

Geomorphic mapping of the eastern and the western alluvial plains has revealed the presence of three distinct geomorphic surfaces (Figure 4a, b). Geomorphologically, these areas comprise a flat alluvial plain surface having a gentle southward slope, which has been designated as S1. The alluvial plain surface shows extensive ravines (badlands), 12–15 m deep, near river valleys formed by severe gully erosion. We designate this surface as S2 as it indicates a significant episode of fluvial erosion and also to differentiate it from the undissected alluvial plain. A third surface S3 is observed within the various river valleys which occurs in the form of a terrace that terminates against the cliffs of S2 surface and shows incision of 3–5 m (Figure 5a, b).

The fluvial successions forming the S1 and S2 surfaces and exposed in the incised cliffs of 10–20 m height were mapped to develop a lithostatigraphic framework and reconstruct their morphostratigraphic evolution. The succession comprising the S1 surface could not be studied because of dense growth of thorny bushes (*Acacia arabica*), thereby making the task of preparing lithologs extremely difficult. Few sections free of vegetative cover, were located in the S3 surface and have been utilized to note the distinguishing characters of sediments.
Quaternary fluvial sediments

The eastern alluvial plain

The Late Quaternary fluvial sequences are most extensively developed in this part. Further east, the alluvial plain merges into the salt-encrusted surface of the Little Rann of Kachchh while to the north it is bordered by the Early Quaternary surface, and extends up to the coast in the south where they are covered by present-day coastal sediments. Good exposed sections are seen along the 10–20 m incised cliffs (Figure 5a, b) along the Rukmavati (E), Nagwanti, Phot and Khari (E) rivers (Figure 3a). In the northern part of the plains, the Quaternary sequences unconformably overlie the Tertiary rocks, or in places the Deccan Traps. A total of eight sections have been logged in this part – three each from Rukmavati (E) and Nagwanti river basins and one each from Phot and Kharod river basins (Figure 6).

At the base of the cliff succession, a coarse gravelly facies is exposed at almost all the locations. This basal gravel ranges in thickness from 1–3 m and shows a wide range of characteristics. In Rukmavati (E) basin, the basal gravel shows trough cross stratification while in Nagwanti basin planar cross-stratified gravel is observed. In Phot basin, an unsorted sandy gravel containing clasts of pebble and cobble size is observed at the base of the exposed sequence. The basal gravelly facies is overlain at places by planar cross-stratified or massive fluvial sand. At Samaghogha in Phot basin, the planar cross-stratified sand shows abundant rhizocoenconcretes.

A prominent red soil overlying these deposits is observed in all the four river valleys and is readily identifiable by its characteristic deep red colour (Figure 5c). This soil is well developed in the Rukmavati (E) basin where it shows a maximum thickness of 10–12 m near Mota Asambria village. In general, the red soil shows a uniform thickness of 4–6 m in most places. The soil shows profuse development of pedogenic calcite nodules and rhizoliths. The calcite nodules are more profuse in the upper parts of the soil profile. Small pockets showing cross bedding are recognized within the soil indicating that the parent material comprised fluvial sands. At Bhujpur, in Nagwanti basin, the red soil comprises angular grains of medium to coarse sand, which is a reflection of short transport and close proximity of the source area.

The red soil is overlain by a thick sandy gravel that very commonly shows trough cross stratification. The contact is erosional as seen from several channel scars at the base. The clasts consist of basalt pebbles and small amounts of Tertiary rock fragments in a sandy matrix. Calcrete nodules show random distribution with the sandy parts being relatively more enriched in calcium carbonate. The top of the succession is marked by a weakly pedogenically modified massive silty sand with occasional cross stratification. This horizon also contains nodular calcrites.

The western alluvial plain

The Late Quaternary sequences in the western part are well exposed along the incised cliffs of the Naira and Rukmavati (W) rivers, the latter is a tributary of the Khari (W) river. The Quaternary sediments show an erosional contact with the underlying Tertiary rocks. Four sections were logged in the Naira basin while one section was logged from the Rukmavati (W) river (Figure 7). As in the eastern part, the base of the Late Quaternary succession is marked by coarse gravelly facies which over-
lies the fossiliferous rocks of the Tertiary age. The basal gravelly facies comprises a semi-compact planar cross-stratified gravel. At some places, sandy to massive gravel overlies the cross-stratified gravel (Figure 5d). The overall thickness of the basal gravelly facies varies from 0.5–4 m.

The basal gravels are overlain by a 4–5 m thick brown soil. Intensive pedogenesis is indicated by the abundant nodular pedogenic calcrites and rhizoconcretionary structures. Relative abundance of the calcrete nodules increases upwards in the soil profile. The soil is particularly well developed at Bitta in Rukmavati (E) valley (Figure 5d) and at Kothana and Bhimpar in the Naira valley (Figure 7). The brown soil occurs at the same stratigraphic level as the red soil in the eastern alluvial plain. Towards the top, the succession is capped by another fluvial cycle that starts with a cross-stratified gravel and terminates with a weakly pedogenically modified silty sand (Figure 7). The base of the gravel is marked by channel scours carved into the underlying brown soil. The overlying silty sand, at places, shows planar cross-stratification. Calcrete nodules are evenly distributed throughout the horizon.
Lithostratigraphy

The exposed fluvial sequences forming the \( S_1 \) and \( S_2 \) surfaces in the eastern and western alluvial plains are correlative. A broad similarity and contemporaneity of aggradation phases and pedogenic phases is observed (Figures 6 and 7). The exposed succession starts with a cross-stratified gravel with clasts of trappean basalts and Tertiary rocks. In western Kachchh, this gravel consists of cobble to pebble-size clasts and is devoid of sedimentary structures. This is overlain by a thick buried soil, and is hosted in fluvial sands and silts. In the eastern alluvial plain, this soil horizon is a red soil, while in the western alluvial plain a brown soil is developed. The presence of a palaeosol midway in the exposed fluvial sequences has considerable stratigraphic implications as it is found to consistently occur at the same stratigraphic level. Owing to its ubiquitous occurrence and easily identifiable field characteristics, the palaeosol qualifies to be used as a marker horizon for stratigraphic studies of fluvial sequences in southern Mainland Kachchh. The soil horizon is overlain by a cross-stratified sandy gravel which exhibits planar as well as trough cross-stratification. The clasts include mainly trappean basalts and calcareous nodules presumably derived from the underlying soil horizon. The top of the succession is marked by a partially
pedogenized fine sandy silt which also shows presence of nodular calcrites but less abundant in comparison with the underlying red/brown soil. The sedimentation appears to have taken place in three phases. The first phase is indicated by the deposition of the basal gravelly sediments. Sands and silts comprising the palaeosol mark the second phase of deposition. The third phase deposited the sandy gravelly facies that overlie the palaeosol. The second and third phases of sedimentation are separated by an interval of pedogenesis. Though no detailed sedimentological and palaeoclimatic data are available as yet, the overall characteristics of the exposed sequences indicate deposition by shallow ephemeral streams in a largely arid climate.

Radiocarbon dating of pedogenic calcrite nodules was attempted to date the regional pedogenic event represented by the palaeosol and provide a geologic time frame to the exposed fluvial sequences. 14C age of pedogenic carbonate provide good minimum ages for a soil, which can be useful in providing relative age constraints on sedimentary deposits associated with the soil8. Samples of pedogenic calcrites were collected from the soil exposed at three locations – one from the eastern alluvial plain and two from the western alluvial plain. Calcrite nodules were hand picked from 1–2 m down the soil profile and after excavating about 0.5 m into the vertical cliff section. The radiocarbon dates obtained on these samples are presented in Table 1. The pedogenic calcrite nodules from the red soil at Gelada in Nagwanti basin (Figure 6) yielded a calibrated age range of 18,980–18,210 years BP. Two samples of pedogenic calcrites from the brown soil in western alluvial plain (Figure 7) have provided a calibrated age range of 22,210–21,320 years BP (Kothara section in Naira basin) and a 14C age of 24,360 ± 640 years BP (Bitra section in Rukmawati W valley). These ages suggest that the pedogenic phase in southern Mainland Kachchh is pre-LGM (Last Glacial Maximum) under the conditions of increasing aridity. The sediments overlying the buried soil perhaps represent phase of weakened fluvial activity during the LGM. The entire sediment succession of the S1 and S2 surfaces is deeply incised and shows deep gullies (Figure 5 a) which suggests a post-depositional phase of severe erosion during Early Holocene, which was possibly aided by tectonic uplift.

The sequences in the S3 surface occur within the various river valleys in the form of low 2–5 m incised terrace sections, which abut against the sequences that form the S1 and S2 surfaces. These terraces are thus possibly of Mid-Late Holocene age and occupy the incised fluvial valleys formed during the erosional phase of Early Holo-
cene. Well-developed Holocene terraces are seen in Rukmavati (E), Kharod, and Naira river valleys. The terrace sediments comprise coarse to medium fluvial sands and silts (Figure 5b). The sediments are devoid of calcrites and pedogenesis and consequently are in contrast with the sequences associated with S1 and S2 surfaces.

The deposition associated with the S2 surface may have continued up to 2 ka BP as it is suggested that the Little Rann of Kachchh further east was submerged under 4–5 m deep sea water until this time$. The uplift of the S2 surface therefore correlates with the drying up of the Ranns during the last 2000 year.

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**Table 1.** Radiocarbon dates* of pedogenic calcrites from palaeosol. For location of samples refer to Figures 6 and 7.

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Lab. no.</th>
<th>Age of the sample based on half life 5570 ± 30 years BP</th>
<th>Calibrated age range years BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSR-1</td>
<td>BS-1933</td>
<td>18320 ± 250</td>
<td>22210–21320</td>
</tr>
<tr>
<td>NWSR-1</td>
<td>BS-1932</td>
<td>15560 ± 230</td>
<td>18980–18210</td>
</tr>
<tr>
<td>RSR-1</td>
<td>BS-1933</td>
<td>24360 ± 640</td>
<td>Beyond calib. range</td>
</tr>
</tbody>
</table>

*Radiocarbon dating was carried out at Birbal Sahni Institute of Palaeobotany, Lucknow.
**Table 2.** Summary of Late Quaternary morphostratigraphic evolution of southern Mainland Kachchh

<table>
<thead>
<tr>
<th>Geomorphic surface</th>
<th>Lithology/event</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>S_1 Surface</td>
<td>Deposition of Holocene terrace sediments within fluvial incised valleys comprising Late Pleistocene sediments followed by incision after 2 ka</td>
<td>Middle to Late Holocene</td>
</tr>
<tr>
<td>S_2 Surface</td>
<td>Incision of Late Pleistocene sediments (S_1 surface) forming deeply incised fluvial valleys accompanied by extensive ravine erosion, formation of present channel belts</td>
<td>Early Holocene</td>
</tr>
</tbody>
</table>
| S_3 Surface        | * Deposition of sandy gravels and silts  
|                    | * Phase of intensive pedogenesis  
|                    | * Deposition of fluvial silts and sands  
|                    | * Deposition of coarse fluvial facies | Upper part of Late Pleistocene |

**Morphostratigraphic evolution**

The present study has revealed remarkable similarity of fluvial geomorphic features in the various river basins, including those in the eastern part and the western part. A comparable sequence of morphostratigraphic events in the eastern and western alluvial plains is suggested (Table 2). This, together with the lithostratigraphic studies, indicates that the phases of deposition and erosion have followed climatic and tectonic changes of regional dimension during Late Pleistocene and Holocene. Radiocarbon dates on pedogenic calcrites within the palaeosol suggest that the sequences comprising the S_1 and S_2 surfaces were deposited during upper part of the Late Pleistocene, while the sediments of S_3 surface were deposited during Mid-Late Holocene as fill in an incised valley.

The extreme gully erosion leading to formation of deep ravines appears to be a discrete phase of severe erosion as evidenced by the complete absence of gullies in the S_3 surface. Geomorphic evidences and lithostratigraphic studies indicate that this erosional phase occurred during Early Holocene. Tectonics is the primary factor responsible for the Early Holocene ravine erosion and fluvial incision. The depth, extent and intensity of ravine erosion and fluvial incision is observed to gradually decrease towards south, i.e. in the downstream direction. In fact, the ravines die out much before the coastline. This is in conformity with the tilted block structure of the area as discussed in earlier section (Figure 3a). The sediments of the valley fill terrace (S_3 surface) represents the aggradation phase, which followed the Early Holocene erosional phase. Indications of the high sea level are provided by previous work in the Little Rann of Kachchh which has pointed out that the Rann was submerged under sea until 2 ka BP. The formation of the terraces is thus correlateable with the drying up of the Little Rann during the last 2,000 years. Interestingly, the Late Quaternary geomorphic history and stratigraphic framework worked out in this study is broadly similar to that of the adjacent Gujarat alluvial plains. This warrants detailed palaeoclimatic and neotectonic studies to understand the Quaternary sequences of Mainland Kachchh in a regional context.

**Conclusions**

The present study has led to the following conclusions: The exposed Late Quaternary fluvial sequences of southern Mainland Kachchh form distinct geomorphic surfaces – the featureless alluvial plain (S_1 surface), the extremely dissected surface (S_2 surface) characterized by deep ravines and, essentially produced by gully erosion of the S_1 surface and a low flat terrace surface (S_3 surface). The successions comprising the S_1 and S_2 surfaces were deposited by ephemeral rivers in an arid-semiarid climate during the later part of the Late Pleistocene. The presence of a buried soil midway in the exposed sediment succession, red in the eastern part and brown in the western part is a useful marker for inter-valley correlation.


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