Active tectonic control on alluvial fan architecture along Kachchh mainland Hill Range, Western India

by

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with 11 figures and 1 table

Summary. The various north flowing rivers of Kachchh mainland have given rise to conspicuous semi-conical shaped alluvial fans at the base of the Northern Hill Range along the drainage divide of the mainland for south and north flowing rivers. These fans were deposited during the early Holocene, with their outer fringes overlying the younger sediments of the depression that intervenes the mainland uplift and the Banni Plains (MALIK et al. 1999). A striking feature of these fans is their formation by the very same rivers that were responsible for the deposition. The constituent material of the fans points to a variety of sediment-gravity processes, comprising debris flows (Gms), high density current deposits (Gm) and fluid-gravity processes giving rise to sheet flood (Sh) facies. These deposits are interbedded by channelized flows marked by Gt and St facies. Abundant angular to sub-angular bouldery fragments (150 cm) represent fault-generated debris. Frequent flash floods during late Quaternary, representing high energy flows, probably transported this colluvial material down the fault-controlled Northern Hill Range front to form alluvial fans. Successive uplifts along the various regional as well as local faults were responsible for (i) generating the colluvial debris, (ii) controlling the energy of the north flowing rivers, and (iii) forming and subsequently incising the alluvial fans.

Zusammenfassung. Aktive tektonische Kontrolle beim Aufbau von Schwellenfächern entlang der Kachchh Berge, Westindien. — Die verschiedenen Flüsse des Kachchh Region entspringen am Fuße der nördlichen Bergkette aus auffallend halbkonisch geformten, die Kachchh-Verwerfung kreuzenden Schwellenfächern. Die Verwerfung verläuft parallel zur nördlichen Bergkette und stellt die ideale geomorphologische Position für den Austritt der Flüsse aus der Kachchh Bergkette dar, die die Hauptwasserscheide der nach Norden und Süden entwässernden Flüsse bildet. Die Schwellenfächern wurden während des Holozän abgelagert. Ihre Ränder überlagern heute die jüngeren Sedimente der Depression, die zeitlich zwischen der Hebung des Festlandes und der Bildung der Banni Flächen liegen kommen (MALIK et al. 1999). Ein deutliches Merkmal der Schwellenfächern ist deren Zerfallsrichtung durch die gleichen Flüsse, die auch für deren Bildung verantwortlich sind. Die Materialzusammensetzung der Fächer läßt verschiedene Sedimentationsprozesse erkennen, die von Geröllflüssen (Gms) über hoch verdichtete Carpet-Ablagerungen (Gm) bis zu Schichtflut-
gie-reiche Sturzfluten während des Spätquartärs haben dieses kolluviale Material wahrscheinlich von der nördlichen Bergkette hinab transportiert und am tektonisch markierten Gebirgsfuß als Schwemmflächer abgelagert. Sukcessive Hebungsphasen entlang regionaler und auch lokal begrenzter Verwerfungen sind verantwortlich für (1) die Bereitstellung von kolluvial verlagerbarem Material, (2) die energetische Steuerung der nach Norden entwässernden Flüsse und (3) das spätere erosive Einschneiden in die Schwemmflächerkörper.

1 Introduction

The Kachchh region of western India is marked by areas of uplift (Kachchh mainland) and residual depression (Great Rann-Banni plains). Uplifts are oriented along and related to major sub-parallel E-W trending longitudinal faults (fig. 1), e.g. Katrol Hill Fault, Kachchh Mainland Fault, Banni Fault and Allah Band Fault (BISWAS & DESHPANDE 1970, BISWAS 1982). The landscape of Kachchh provides a good example of a terrain with neotectonics influenced landscape evolution and fluvial regime. The landscapes reflect both uplift and subsidence along well defined major faults, and the stream courses flow along the fault-related fractures and joints trending NNE-SSW, ENE-

![Map of Kachchh region](image)

Fig. 1. Structural framework of Kachchh (after BISWAS & DESHPANDE 1970). Inset show generalized geomorphic zones of Kachchh. Study area in shaded. NHR - Northern Hill Range, KHR - Katrol Hill Range, KMF - Kachchh Mainland Fault and KHF - Katrol Hill Fault. 1 Kaila fan; 2 Kaswali fan.
WSW, N-S and WNW-ESE. This structural control is reflected in their unusually straight courses, narrow deeply incised valleys and sharp high angle channel deflections.

The Katrol Hill Range forms the major drainage divide of the rocky mainland, and is characterised by numerous south and north flowing rivers. Various north flowing rivers on crossing the Kachchh Mainland Fault and debouching into the Great Rann-Banni depression have given rise to conspicuous semi-conical shaped alluvial fans. These fans comprise an important geomorphic element of the Great Rann-Banni area. The Banni depression is hypothesised to have come into existence with a concomitant uplift of the mainland, around 2.5 Ka when the northern Rann delta complex was partly destroyed (MALIK et al. 1999). As the outer fringes of the fans are seen to overlie the sediments of the depression that occurs between the mainland uplift and the Banni plains, these fans must have been deposited during the late Holocene after the formation of the depression. These fans point to an initial depositional phase followed by that of incision by the same rivers. Although, these alluvial fans occurring at the base of Northern Hill Range have so far received little attention, except for a passing reference made by KAR (1993a). The fans are unique in the sense that both their deposition as well as incision, are manifestation of a series of uplifts at successive stages of their deposition.

Formation of an alluvial fan is dependent on several essential conditions, the most important one being an abrupt change in geomorphic setting so that a river emerging from uplands is suddenly unconfined over a relatively flat lowland (BULL 1977, BLAIR & MCPHERSON 1994 a, b). The northern fringe of the Kachchh mainland marking the site of the Kachchh Mainland Fault has provided such a physiographic setting. The primary processes involved in the building up of the fan include rock falls, rock avalanches, gravity slides, debris flow, sheet flows and incised channel flows. The former four processes commonly produce angular to sub-angular fragments (LARSEN & STEEL 1978, BLAIR 1987, BEATY 1990, BLAIR & MCPHERSON 1992, BRIERLEY et al. 1993, CHAMYAL et al. 1997).

Though tectonism was the dominant factor, climate too must have played its due role in the formation of fans. Kachchh region falls under arid to semi-arid climatic zone with a mean annual rainfall of 300 to 400 mm (MERH 1995). Its ephemeral rivers periodically experience flash floods during peak monsoon, and such high magnitude floods of the past appears to have controlled the transportation and deposition of the debris.

The incised fan successions provide an opportunity in understanding the role of tectonic activity and climate in the formation and denudation of these fans.

Present studies are restricted to the Kaswali and the Kaila alluvial fans (fig. 2) and the scope of investigation aims at deciphering the distinctive morphometric elements of the two fans. The role of active tectonism that controlled the formation of the fans has been highlighted. The sedimentary facies, related fluvial processes and clast composition (size variations), length of the river channel and individual catchment and fan areas have also been described and estimated.

2 Tectonic setting

The Kachchh region forms a crucial geodynamic part of the western continental margin of India, and marks an intra-cratonic basin, which has been an important site of Mesozoic and Cenozoic tectonism and sedimentation (BISWAS 1982, 1987). The uplifts, exposing folded Mesozoic rocks (Middle Jurassic-Lower Cretaceous), how-
ever, are not simple broad-topped upwarps with a faulted margin. They are complicated by flexures along the bounding faults and by secondary upliftings along faults with accompanying flexures within them. The general form of the upliftings are marked by domes and asymmetric anticline which are confined to the south of the major faults (fig. 1). All the major upliftings are bounded, at least on one side, by a fault or a sharp monocline flexure, and on the other side by gently dipping peripheral plains, the strata (Tertiary) in which dip gently into the surrounding residual depression (Biswas 1980).

The northern fringe of the rocky mainland where the Northern Hill Range abuts against the Great Rann-Banni plains is marked by the Kachchh Mainland Fault. According to Biswas (1980) this fault is a vertical to steeply inclined normal fault, but changes upward into a high angle reverse fault. The central part of the rocky mainland, however, has been upthrown along the longitudinal Katrol Hill Fault, producing a sharp flexure with a chain of folds along it similar to those along the Kachchh Mainland Fault. The depressions or the low-lying areas between upliftings consist of Quaternary sediment successions marked by alluvial river terraces in the rocky mainland and the mud-flats and salt pans in the Great and Little Ranns and Banni Plains. The Kachchh region abounds in evidences of continued tectonism during the Quaternary times. Apart from the seismicity record, occurrence of paired fluvial terraces along various river valleys in the mainland, incised channels and recent gullying along the margins of the Banni Plains-Great Rann in the north and the Little Rann in the east point to the tectonic movements that took place in the region during Quaternary period and continuing even upto the present (Biswas 1974, Kar 1993b).

The Kachchh region has experienced several episodes of earth movements along the various major E-W trending faults all throughout the Cenozoic, and these have not only contributed to the evolution of the present day landscape, but have also accentuated the structural pattern (Biswas 1971, Kar 1988, 1993a, b). This continued tectonism is well reflected in the seismicity of the region. The Kachchh falls in the seismically active Zone-V of the Indian sub-continent and has a long history of earthquakes of varying intensities/magnitudes ranging between 3.5 and 7.8. The record of earthquakes that visited Kachchh from 1668 to 1997 reveals that the maximum earthquakes (3 to 3≥5 M) are confined along the Allah Band Fault, Kachchh Mainland Fault and Katrol Hill Fault (fig. 3). According to Sohoni et al., earthquakes occur more in the Katrol Hill Fault Zone, the principal drainage divide, than in the Kachchh Mainland Fault Zone, and is the active zone in Kachchh only next to the Allah Band region of the Great Rann.

Kachchh provide evidences of active tectonism. The rocky mainland drainage pattern, and behaviour of river channels ideally reflect this phenomenon. In the unconsolidated soft sediment of the Great Rann-Banni region on the other hand, the deformational structures like small-scale folding, micro-faulting, pseudo-sand blow, pseudonodules, sand dykes, intrusive flame structure, formation of craters (along en echelon faults) with no feeder dykes, contorted laminae and sediment plume are evidences of strong seismic activities in the region during the recent past (Sohoni & Malik 1998).

3 Geomorphology

Geomorphologically, the Kachchh can be categorized into four major E-W trending zones (1) coastal zone demarcating the southern fringe, (2) Kachchh mainland forming the central portion of the rocky uplands, (3) Banni-Plains marked by raised
mud flats and (4) Great Rann in the north and Little Rann in the east comprising vast saline-waste land. The boundaries of these geomorphic zones are bounded by major faults (fig. 1).

3.1 The Kachchh Mainland: Terrain morphology and drainage characteristics

Kachchh mainland is made up of two major hill ranges viz. the Katrol Hill Range and the Northern Hill Range. Both these hill ranges are flanked to their north by major E-W trending longitudinal faults, Katrol Hill Fault and Kachchh Mainland Fault respectively. These two faults have played a pivotal role in sculpturing the mainland landscape, mainly through differential uplifts. The mainland is criss-crossed by several sets of fractures and the hill ranges are characterised by domes, half domes, anticlines, monoclinal flexures and cuestas. Anticlines and domes ranging in elevation between 190 and 388 m are aligned along the southern flanks of the E-W trending faults. At places they are dissected by oblique cutting subordinate faults of varying trends (NNE-SSW, ENE-WSW, N-S and WNW-ESE). Since Tertiary onwards, the various fault-bounded blocks have shown periodic uplifts along their northern margin with concomitant southward tilt (Biswa 1971). Such fault related uplifts are the main cause for the development of cuestas, marked by steep northern escarpments (fig. 2).

Katrol Hill Range occupying the central portion of the rocky mainland is the major drainage divide that has controlled the development of the numerous north and south flowing rivers. The average altitude of the Katrol Hill Range varies between 148 and 348 m, whereas that of the Northern Hill Range is between 130 and 388 m and the area confined between these two forms the Bhuj lowland (80 to 100 m). A sudden altitude drop of 120 m marks the limit of Kachchh mainland where the Northern Hill Range abuts against the low-lying Banni Plains and the feature has controlled the sedimentation pattern resulting into development of alluvial fan lobes along its base (fig. 2, 4 a).

The present drainage network of the mainland as a whole is reflection of the uplifts along the Katrol Hill Fault, which were responsible for changes in the flow directions of the streams, including drainage reversal. The north-flowing rivers originating from the northern flank of Katrol Hill Range at altitudes of 187 to 348 m, debouch into the Banni depression, after flowing across the Bhuj lowland and Northern Hill Range. These rivers flow across hills and flexures forming incised channels and are seen cutting the uplifted areas marked by upwarps, flexures and half domes and maintaining their gradient. Such rivers according to Chorley et al. (1985) are typical examples of an antecedent drainage. Lineament analysis has revealed that smaller faults, oblique to the major E-W faults, trend N-S, NNE-SSW, ENE-WSW and WNW-ESE and these have controlled the flow trends of drainage network of the mainland both of the rocky upland as well as of the alluvial tracts (fig. 5 a, b). The streams are characterised by the straight channel courses, incised banks in alluvial as well as in rocky terrains, widening and narrowing of channels and valleys, high angle deflected channels and development of entrenched meanders, incised alluvial fan lobes and local braiding. Such features according to Schumm (1986) and Gregory & Schumm (1987) typically suggest active tectonism. Incisions of Mesozoic and Tertiary sedimentary succession in the rocky upland along the trunk streams have given
Fig. 2. Morphotectonic set-up of Northern Kachchh Mainland and Banni Plains. Map prepared from IRS-FCC satellite imagery, scale 1:250,000.
rise to 5 to 10 m wide and 20 to 25 m deep gorges or narrow valleys. These channels have not only incised the Quaternary sediment succession but also bedrock, and have formed paired terraces along the valleys. The paired terraces show steep banks with height ranging between 10 and 25 m. It is hypothesised that, the uplifts along the fault-bounded blocks during early and late Quaternary periodically rejuvenated these rivers resulting in negative base level change and downcutting in the rocky as well as alluvial terrain. The intensity of gully erosion near streams, also indicates uplift, which could be fault or flexure related.

The fan lobes along the Kachchh Mainland Fault are the most striking and prominent geomorphic features of active tectonism-related fluvial processes. So are the colluvial debris accumulations in the Bhuj lowland (fig. 2). Interestingly, a significant portion of the fan material is made up of the transported colluvial debris derived from the Katrol Hill Range as well as that from the numerous smaller fault escarpments that are found in the Bhuj lowland.

3.2 Morphology of Kaila and Kaswali alluvial fans

On crossing the Northern Hill Range, the rivers change their gradient and have built up fan lobes, where they end in the saline wasteland of Great Rann-Banni depression. The fans themselves are being dissected by the respective streams.

The Kaswali river emerges from an altitude of 298 m north of Baladaria and flows along a NNE-SSW trending fracture for 7 km (fig. 6 a, b), after which its channel is abruptly deflected northward along a N-S fracture (fig. 5 a, b). The total length of the
Fig. 4.  a S-N cross-profile along AA' across the Kachchh Mainland and Banni Plains (AA' shown in fig. 2). KHF – Katrol Hill Fault, KMF – Kachchh Mainland Fault. b Longitudinal profile of Kaswali river. c Longitudinal profile of Kaila river.
Fig. 5.  a Lineament map showing faults and fractures controlling the courses of various streams.  b North flowing rivers originating from the northern flank of Katrol Hill Range (KHR) that demarcates major drainage divide of the Kachchh mainland.

channel upto its mouth is about 20 km, and the stream has a drainage basin area of 66 km². It flows across a terrain made up of sandstone, shale and limestone of Mesozoic and Tertiary ages. The trunk channel is fed by several 1st and 2nd order streams originating from the Kas hill range and from the southern flank of Habo anticline. The main river, a 3rd order stream forms a prominent channel with a varying width
Fig. 6.  a Drainage basin of Kaswali river. b Morphology of Kaswali Fan.
of 100 to 600 m. The river flowing across the Northern Hill Range not only shows a sudden change in the gradient but also splits into several distributary channels. This feature is well reflected in the longitudinal profile (fig. 4 b). Kaswali fan has a radial length of 7 km and a maximum width of 6 km. It covers an area of about 35 km². Elevation of the fan lobe at the proximal end is 30 m near the base of the Kachchh Mainland Fault scarp and it decreases to as less as 5 m at the distal of its long axis where it merges with the surrounding saline wasteland of the Great Rann-Banni depression (fig. 6 b). Flowing northward across the fan, the trunk channel near the apex is 250 m wide and 8 to 9 m deep. Further north in the medial part of the fan, the channel is more than 150 m wide, and between 2 and 5 m in depth. Here that the river shows the maximum width of 600 m. The fan is considerably incised and the channel walls are marked by cliffs. The lobe surface near the fringe is characterised by numerous dry streams that appear to have been detached in the past from their major trunk channel, in all probability due to tectonic activity.

The Kaila river has built a similar fan. The river originates at an altitude of 198 m near Desalpur (figs. 2, 7 a) from the northern slopes of the Katrol Hill Range and flows in a NNE direction. The total length of the channel and the drainage basin area are about 40 km and 180 km² respectively. It flows across the rocky uplands of Mesozoic and Tertiary rocks. The trunk channel is of 4th order, and is joined by numerous tributaries emerging from the surrounding higher domes and ridges. In the southern upper reaches, where it flows in a rocky terrain, the channel is 50 to 100 m wide and shows entrenched cutting across upwarps, flexures, half domes and fault related uplifts giving rise to 10 to 18 m steep rocky paired terraces. The nature of the channel flowing across the upwarps and downwarps is well indicated in the longitudinal profile (fig. 4 c). At places the main channel as well as some of its tributaries flow along straight fracture-controlled courses and also show frequent high angle deflections in NNE-SSW, N-S and WNW-ENE directions (fig. 5 a, b). Just before crossing the Kachchh Mainland Fault scarp, the river turns sharply, with a 30 m steep escarpment indicative of tectonic uplift. The Kaila fan located at the base of the escarpment, has an average elevation from 20 to 25 m near the proximal end. The thickness reduces to almost 4 to 5 m at the distal end, gradually merging with the saline wasteland (fig. 7 b). The fan lobe covers an area of about 39 km² and has a radial length of 9 km and maximum width of 8 km. The channel near the fan apex is 50 m wide and has incised not only the fan material but also the underlying bedrock. It forms steep banks range between 15 and 25 m in height. The streams follows a straight course flowing along a NNE-SSW fracture (fig. 5 a, b, 7b). In the medial part of the fan the channel width is 250 m, but the main channel becomes narrower further downstream where it divides into multiple distributaries.

Sudden uplifts thus provided essential geomorphic setting for the formation of alluvial fans along the Northern Hill Range. Also the incision of the two fan sequences point to successive differential uplift along Kachch Mainland Fault during Late Holocene.

4 Sedimentary facies of the fans lobes

Exposed alluvial fan architecture along the Kaila and Kaswali rivers indicate various processes involved in building up of these fans (figs. 8–11). Four sites (1 to 4) along Kaila river and three sites (5 to 7) along Kaswali river were logged (fig. 6 b, 7 b, 8).
Plausible interpretations towards their mode of deposition were made on the basis of the categorisation of the lithounits as per lithofacies code scheme of Miall (1985). Five major sedimentary facies make up the Kaila and Kaswali fans and they include (i) debris-flow deposits (Gms), (ii) massive clast supported planar bedded gravel facies (Gm), (iii) trough cross-stratified gravel facies (Gt), (iv) trough cross-stratified sand facies (St), (v) horizontally stratified sand facies (Sh) (table 1).

The constituent clastics, a heterogeneous assemblage of the larger angular fragments and smaller rounded grains, typically point to a combination of transported sediments representing two distinct sources: primary colluvial material mixed up with reworked older sandstone fragments.

On the basis of the detritus characteristics, two categories of the constituents have been recognised:

One comprises unsorted, angular to sub-angular bouldery clasts having maximum size of 75 cm in Kaswali fan and 150 cm in Kaila fan with a variety of rocky types, represent tectonically-generated stream-transported colluvial material, derived from the steep face of Kator Hill Fault as well as from the hilly escarpments of the Bhuj lowland areas. This material was later subjected to a debris-flow process during heavy rain or flash floods, a phenomenon typical of ephemeral streams in arid to semi-arid regions (Costa 1984). The associated sub-rounded to rounded pebbles-cobbles are possibly the released clasts derived from the weathering and erosion of the pre-existing conglomeratic bedrock of Mesozoic age. Looking to the structural framework and history of active tectonism, the two aggradational events seen in the fan lobes reflect sudden uplifts in the provenance area. However, the role of flash floods in the development of fans cannot be completely ruled out. In this region, tectonism dominated over climate. The other category is that of consisting of coarse to fine sand grains, mainly quartz, well sorted and well rounded. It represents the released material due to weathering of the Mesozoic sandstones of the Bhuj lowland. Such a high degree of rounding cannot be achieved when transported over a short distance by rivers with rather small catchment areas.

5 Concluding discussion

Successive uplifts along the various regional as well as local faults during the late Quaternary (i) generated the colluvial debris in the catchment areas, (ii) controlled the northward flow of the rivers, and (iii) caused formation and subsequent incision of the alluvial fan lobes. We envisage that of the two factors (tectonic adjustment and climatic) responsible for the formation and incision of the Kaila and Kaswali alluvial fans, tectonism predominated. The entire Kachchh landscape exhibits influence of active tectonism during late Quaternary. The uplift of Kator Hill Range was responsible for the evolution of north-flowing rivers that followed the then existing fractures. The Kachchh Mainland Fault related Northern Hill Range demarcating the northern fringe of the Kachchh mainland provided ideal geomorphic setting for the development of the alluvial fans. The north flowing rivers emerging from the upland

Fig. 7. a Drainage basin of Kaila river. b Morphology of Kaila Fan. (refer to fig. 6 b for legend).
in the south after crossing the Northern Hill Range became unconfined over the flat low-lying Banni Plains and deposited semi-conical shaped alluvial fans at the base.

These fans were built by various sediment-gravity and fluid-gravity processes, along with intervening channelized flows (table 1). In the Kaila fan debris-flow facies is identified at two distinct stratigraphic levels, whereas in the Kaswali fan only one such unit is observed. The Gms-facies at different levels in Kaila fan are separated by Gt, Sh and St lithofacies indicating intervening channelized flows followed by each debris-flow events. This is in contrast to Kaswali fan deposition, where only one debris-flow event is recorded, the Kaila, thus point to two fan aggradational phases.

The Kachchh mainland is characterised by ephemeral rivers that currently carry only sand and gravel as bedload, and have incised the older (? late Quaternary) fan deposits forming steep banks ranging in height from 10 to 25 m along their valleys in the lower reaches in the fan lobe areas.

The present day channel courses of the Kachchh mainland are controlled by NNE-SSW, ENE-WSW, N-S and WNW-ESE trending fractures which are periodically activated. These features are reflected in their straight courses and entrenched valleys, widening and narrowing of channels and valleys, and abrupt high angle deflections in the channel courses. Incision of Mesozoic and Tertiary sedimentary succession in the rocky upland along the trunk streams giving rise to 5 to 10 m wide and 20 to 25 m deep gorges or narrow valleys. Incision of the Quaternary sediment succession along with the bedrock resulting into formation of paired terraces (10–25
Fig. 9. a Incised alluvial fan succession exposed along the left bank of Kaila river showing debris flow (Gms-facies) (Height of JRF 1.66 m). b Close-up view of Gm-facies at site 4 along Kaila river.

m high) suggest, uplifts in region during early and late Quaternary. The uplifts (vertical slips along the fractures as well as flexuring of fault-bounded blocks) are associated with the E-W trending major Katrol Hill Fault and Kachchh Mainland Fault and along the oblique faults (NNE-SSW, ENE-WSW, N-S and WNW-ESE) during late Quaternary. Continued tectonism is reflected in the dissection of the fan lobes. Post-depositional tectonism is also indicated by conspicuous local braiding of the trunk channels within the fan lobes.

Abundance of angular to sub-angular cobbly-bouldery fragments in the Kaswali and Kaila fans suggest very high energy carrying capacity, in contrast to the present-day conditions prevailing in the two rivers. At present, the Kaila and Kaswali are ephemeral streams and is limited to bedload size of sand and gravel (4 to 20 cm) even during the periods of peak floods. We therefore suggest that major tectonic uplifts along the faults could have probably caused sudden change in gradient resulting flows of magnitude higher than that occurring at present in order to explain the transportation and deposition of the colluvial debris comprising large angular fragments. Thus, the large remnant clasts reflect the net response of the fault generated topographic displacement. Seismic events of late Quaternary played important role in producing sandstone cobbles and boulders along the faults, fractures and joints. Even today, the major fault zones are seismically active (fig.3). Finer sediments, sub-rounded to rounded grains within the succession on the other hand are released material derived from the weathering of older sedimentary deposits.
Fig. 10. Photo-mosaic of Quaternary alluvial fan succession exposed along the left bank of Kaswali river showing angular unconformity with respect to the underlying inclined beds of Mesozoic rocks. Gms – debris flow facies and Gm - Massive gravel facies representing traction carpet deposits.
### Table 1: Description of lithofacies and their interpretation (after Miall 1985)

<table>
<thead>
<tr>
<th>Facies Code</th>
<th>Description</th>
<th>Interpretation</th>
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<tr>
<td>Gms</td>
<td>Poorly sorted, inversely graded, matrix supported with subordinate clay, pebbles, cobbles and boulders, sandstone and limestone clasts dominant, sub-angular to sub-rounded clasts having mean average size 25 to 90 cm along with common occurrence of angular to sub-angular boulders with maximum clast size up to 150 cm, imbrication WSW-SW (smaller discoidal clasts), 2 to 4 m thick pinches out in lower reaches with finer facies, non-erosive convex upward lower and upper bounding surface</td>
<td>Deposition under debris-flow-process during flash floods typical of ephemeral streams in arid and semi-arid regions (Blair &amp; McPherson 1994a, Larsen &amp; Steel 1978, Blair 1987, Brierley et al. 1993, DeCelless et al. 1991, Costa 1984)</td>
</tr>
<tr>
<td>Gm</td>
<td>Matrix supported moderate to poorly sorted pebbly-gravel, sub-rounded to rounded sandstone and limestone clasts dominant, mean average clast size 8 to 15 cm, imbrication ENE and ESE, .5 to 2 m 1 thick, individual layers within the lithounit are 10 to 20 cm show normal to inverse grading, sharp non-erosive basal surface</td>
<td>Deposition under high-density traction carpet by bedload dominated ephemeral streams during flash floods in alluvial fan setting (Mall 1985, Todd 1989)</td>
</tr>
<tr>
<td>Gt</td>
<td>Trough cross-stratified pebbly-gravel with average size 4 to 9 cm dominated by sandstone and limestone clasts, 0.5 to 3 m thick, normally graded, occur as solitary and cosets, at places marked by lensoidal geometry, foresets dips 8° to 12° due NNW and NNE, erosive basal surface</td>
<td>Channel-fill deposition representing intervening channelized flows during the fan aggradation (Miall 1985)</td>
</tr>
<tr>
<td>Sh</td>
<td>Horizontally stratified medium to fine sand, 0.5 to 2.5 m thick, laterally extensive without any distinct channel margins</td>
<td>Unconfined sheet flow deposition over a gently sloping fan surface (Blair &amp; McPherson 1994a, Friend 1983)</td>
</tr>
<tr>
<td>St</td>
<td>Trough cross-stratified medium to coarse sand, 0.5 to 1.5 m thick, occasional occurrence pebbly-gravely clasts, non-erosive basal surface</td>
<td>Channel-fill deposition representing intervening channelized flows during the fan aggradation (Brierley et al. 1993)</td>
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Fig. 11. Horizontally stratified sheet flow facies (Sh) along Kaila river occupying the upper portion of the succession.

One fact that needs to be highlighted is that whereas the fan areas of both the rivers are similar i.e. the Kaswali fan is 35 km$^2$ and the Kaila fan 39 km$^2$, the drainage basin area of Kaila river (180 km$^2$) is much larger than that of the Kaswali river (66 km$^2$). The rivers flow across identical terrains made up of Mesozoic and Tertiary rocks. It is likely that the Kaswali fan was produced by a bigger river with a catchment further south, quite close to Katrol Hill Range, and the present day Kaswali river is a truncated remnant of this older channel which stands obliterated today on account of tectonic movements.

The Kaila and Kaswali fans are comparable to the other fans occurring at the base of Northern Hill Range in the Kachchh region. Uplift along the Kachchh Mainland Fault was the common factor that provided unconfinement to all north flowing rivers over the low-lying Banni Plains and controlled the alluvial fan architecture. The alluvial fans of Kachchh are typical example of fans that are reported from the tectonically active regions with arid to semi-arid climatic conditions.

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