Geol. Bull. Univ. Peshawar, Vol. 26, pp. 103–112, 1993

Fluvial sole structures from the Siwalik Group, north Pakistan

IFTIKHAR AHMED ABBASI[1] & PETER F. FRIEND[2]

[1]Department of Geology, University of Peshawar, Pakistan
[2]Department of Earth Sciences, University of Cambridge, U.K.

ABSTRACT: *The Siwalik Group consists of over 6 km of fluvial clastic sediments. Fluvial cycles of thick sandstone (5-20 m) and siltstones (5-50 m) are common particularly in the Chinji Formation. Sole structures are well developed on the base of the sandstone bodies and represent an early phase of erosion of the overbank fines related to channel evulsion before deposition of major sandstone. Examples from the Chinji and Shakardarra formations include gutter casts, crescent marks, and flute marks all due to aqueous scour. Polygonal marks and pedestal structures, metres across, and locally metres in relief, may be subaqueous or sub-aerial in origin.*

INTRODUCTION

More than 5km of detrital molasse sediments of the Rawalpindi (late Oligocene to early Miocene) and Siwalik (Miocene to Quaternary) groups are widely distributed in the Potwar and Kohat area (Fig. 1). In the Kohat area, the molasse sediments are divided into A) a sand-silt assemblage, and B) a conglomerate assemblage. In the eastern Kohat area, the sediments of the Siwalik Group are divided into following formations a) Chinji Formation (Miocene), b) Shakardarra Formation (late Miocene) and c) Indus Conglomerate Formation (late Miocene-Pliocene) (Abbasi, 1991) (Fig. 2). The Chinji Formation is comprised of alternating dominant red silts and clay interbedded with subordinate sandstone. The multistoreyed sandstone bodies in the Chinji Formation are on average 5-20 metres thick, whereas, the red siltstone and clay are up to 50 metres thick (Fig. 3). The Shakardarra Formation is also comprised of thick overbank sediments interbedded with thick sandstone, particularly in its lower part (Fig. 3). Most of the erosional scour structures are present within the interbedded thick siltstone-sandstone sequences of the Chinji Formation and lower part of the Shakardarra Formation.

Erosional structures of a variety of sizes and shapes have been recognized in the interbedded sandstone and siltstone sequences of the Siwalik Group. The size and geometry of these structures appears to be a function of intensity of flow, nature of the underlying substrate and time available for erosion (Myrow, 1992). The common sole structures observed included, gutter casts, crescent and flute marks, polygonal marks and pedestal structures. The interbedded siltstone-sandstone sequences are steeply dipping at a number of places around Shakardarra area due to common imbricate thrusting in the area (Abbasi & McElroy, 1991). High tectonic dip in parts of the study area facilitates detailed study of these structures. This paper describes, for the first time, the sole structures and their mechanism of formation from fluvial sediments of the Siwalik Group in the eastern Kohat area around Shakardarra town (Fig. 1)

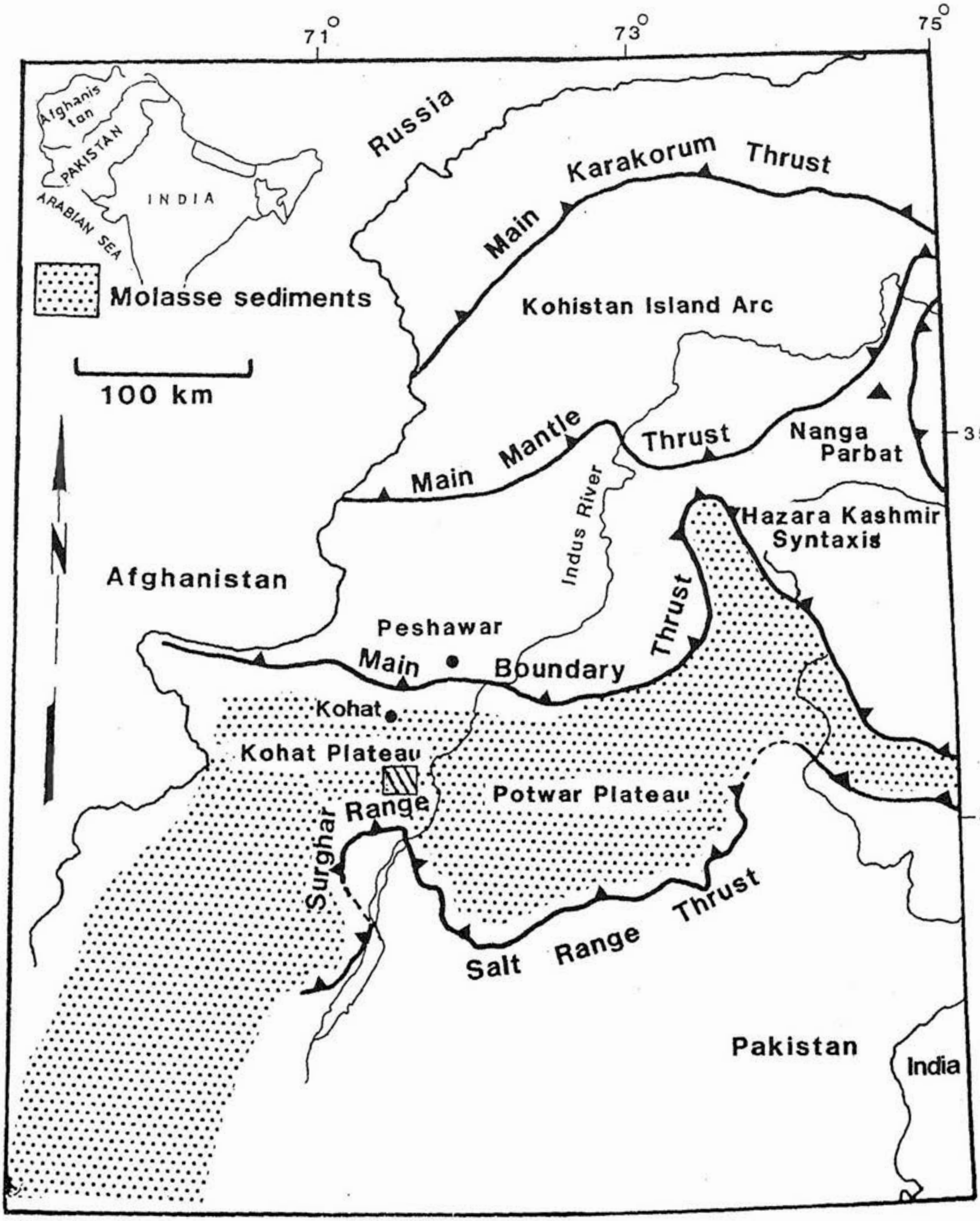

Fig. 1. Sketch map showing distribution of molasse sediments in the Kohat-Potwar area, the study area around Shakardarra town is marked by a rectangle.

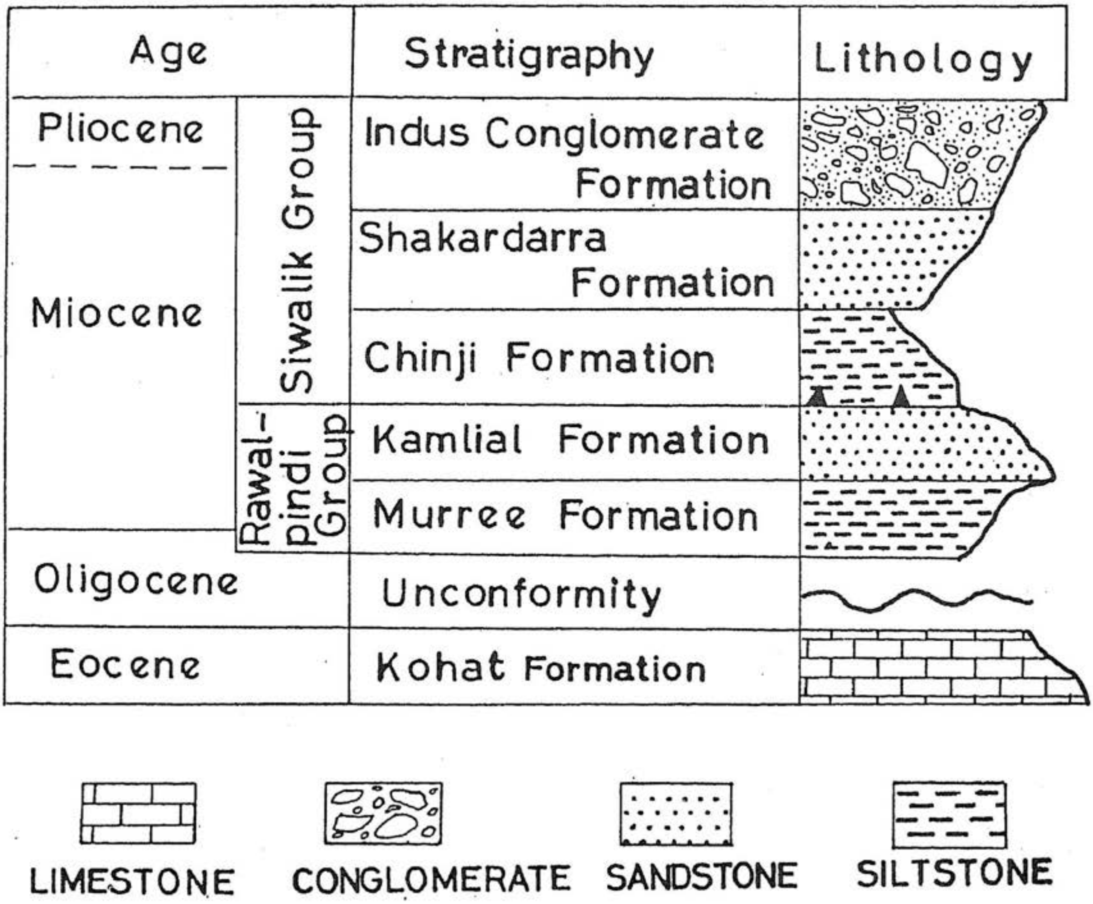

Fig. 2. Neogene stratigraphy of the molasse succession around Shakardarra area. The Shakardarra and Indus Conglomerate formations are stratigraphically equivalent to the Nagri and Dhok Pathan formations in the Potwar area, respectively.

GUTTER CASTS

Gutter casts are downward-bulging sole structures and isolated channels, formed by current erosion (Whitaker, 1973). The characteristics and scale of these structures is highly variable and have therefore been described in the literature using varied nomenclature, such as long welts (Friend, 1965), large groove casts (Whitaker, 1965), erosional furrows (Bridges, 1972), and gutter casts (Whitaker, 1973). The wide range of sizes, shapes, lithologies and internal structures suggests that they are polygenetic in origin (Myrow, 1992).

Gutter casts are common in sand-silt assemblages of the Siwalik Group. Gutter casts occur as elongated ridges separated by flat surfaces (Fig. 4a-d), at the base of the sandstone-bodies. These are composed mainly of fine-to medium grained sandstone, with occasional clasts of siltstone. The ridges are about 5-10cm across, 2-5cm in relief and a few centimetres to more than a metre long. They are commonly V-shaped, generally symmetrical, locally sinuous, but usually parallel to each other. Generally the narrow ones are more sinuous than the broader ones. Laterally they either die out with

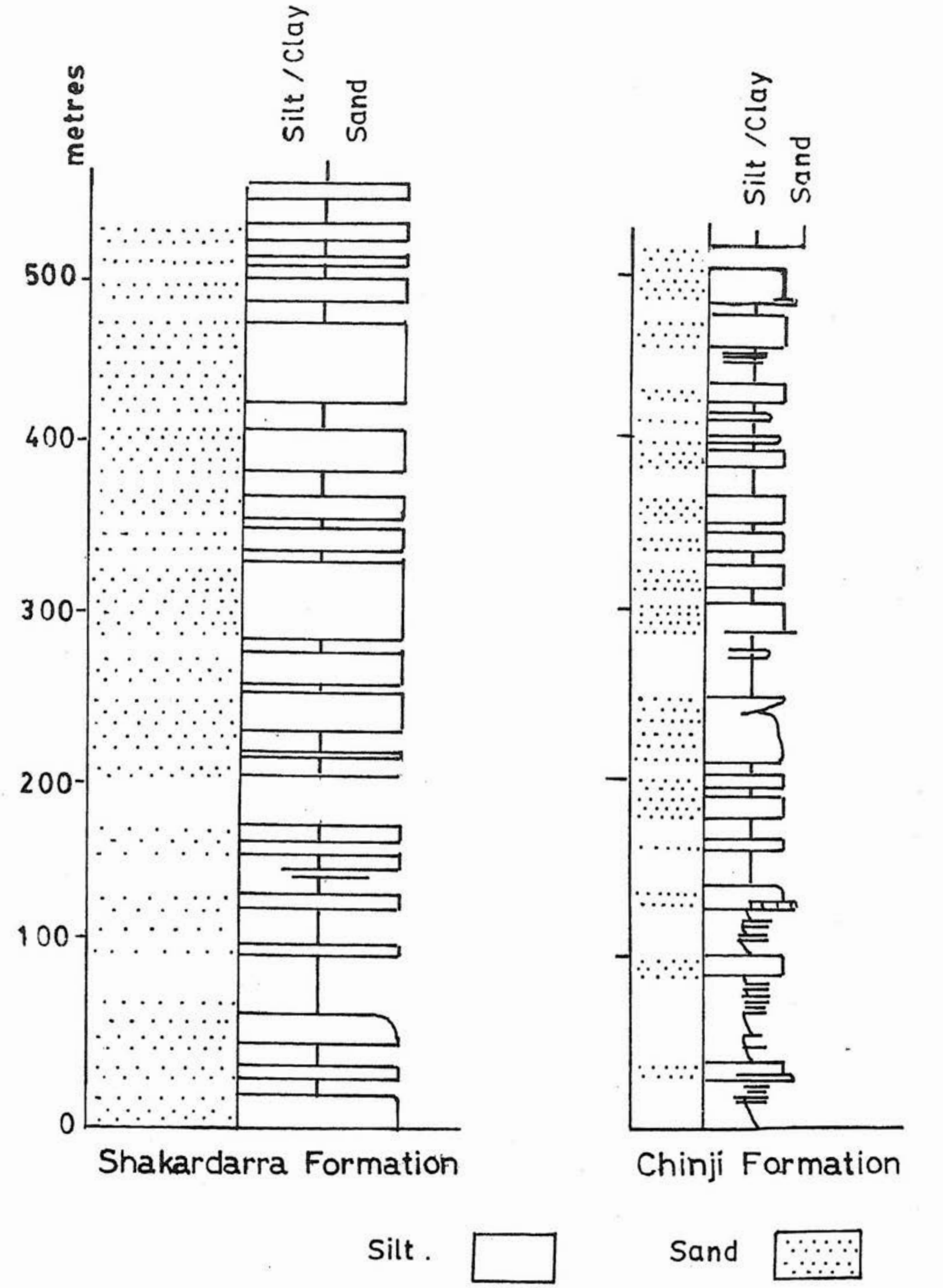

Fig. 3. Measured sections of the Chinji Formation and the basal 550 metres of the Shakardarra Formation from the study area.

a gently tapered end, or join an adjacent ridge. At places individual ridges change their trend at right angle to the overall trend of the gutter casts (Fig. 4b,d). The space between the ridges is either smooth or is covered by small scale flute marks (Fig. 4c). Mud clasts are scattered along the ridges. Most of these gutter casts are oriented parallel to the paleoflow direction as revealed by cross-bedding and ripple marks. Gutter casts are also found associated with crescent marks. The sandstone beds with gutter casts at their base are usually plane bedded or low-angle parallel-laminated and were probably deposited under oscillatory flow (Harms et al., 1982). The gutter casts are carbonate cemented as are their host beds which is an early stage digenetic phenomenon (Ahmed, 1989).

Whitaker (1973) suggested a clear relationship between the cast and the underlying mud bed. The mud was eroded, leaving small channels which immediately were filled with sand grains during the course of two phases of sedimentation. Downward bulging gutter casts at the base of thick beds are formed under conditions of higher sediment supply. The gutter casts are eroded by water moving along the helicoidal paths about a horizontal axis (Bridges, 1972; Whitaker, 1973). The steepened upcurrent end of the cast suggests that the vortices were initiated rather quickly but die out more slowly (Whitaker, 1973). Once initiated, horizontal helicoidal flows would move downstream, eroding the mud bed and under-cutting gutter walls. Fairly high velocities seem necessary to erode the cohesive mud, and to produce secondary vortices of large pitch (Allen, 1982). There is no special depth of water required for their formation.

CRESCENT MARKS

These are horseshoe shaped ridges on the sole surface of the sandstone-bodies (Fig. 4b) in the study area. These structures vary in size and shape. The smaller ones are about 5cm across and 30-40cm long, with a relief of about 1cm. The larger ones are up to 30cm across and 30-40cm long along their horns (Fig. 4b). They are both symmetrical (length of both horns is equal) and asymmetrical (one horn is longer than the other). They commonly contain mud balls in their centre. In a few cases crescent marks were found associated with the gutter casts (Fig. 4b). These are commonly oriented parallel to the regional flow direction.

Under fluvial conditions, crescent marks are formed by the differential scouring of cohesive mud around an obstacle (Friend, 1965; Allen, 1982; 1985), where the bed shear stress is increased up to 12 times that of the undisturbed flow (Russel, 1993). Due to increased velocities, rate of erosion enhances in front of and to the sides of the obstacle to carve out U-shaped scour marks. Current crescents are commonly associated with separated flows (Allen, 1985) which produce a zone in the obstacle lee, where shadow ridges may be deposited or preserved. Concretionary mud balls in the study area acted as obstacles for the flow separation which eroded a trough in the finer sediments, where later deposition formed the crescents (Allen, 1982). They are also interpreted in terms of the vortices and velocity defects created during flow around bluff bodies (Karcz, 1968). The current crescents are well preserved under high depositional rates (Allen, 1982).

FLUTE MARKS

Well preserved flute marks are found in the Chinji Formation and basal part of the Shakardarra Formation. Flute marks are particularly common where the sandstone bodies scour into the underlying clay or fine siltstone beds. In sandstone-mudstone assemblages, the basal contact of the sandstone bodies is usually erosional and irregular with some scouring of

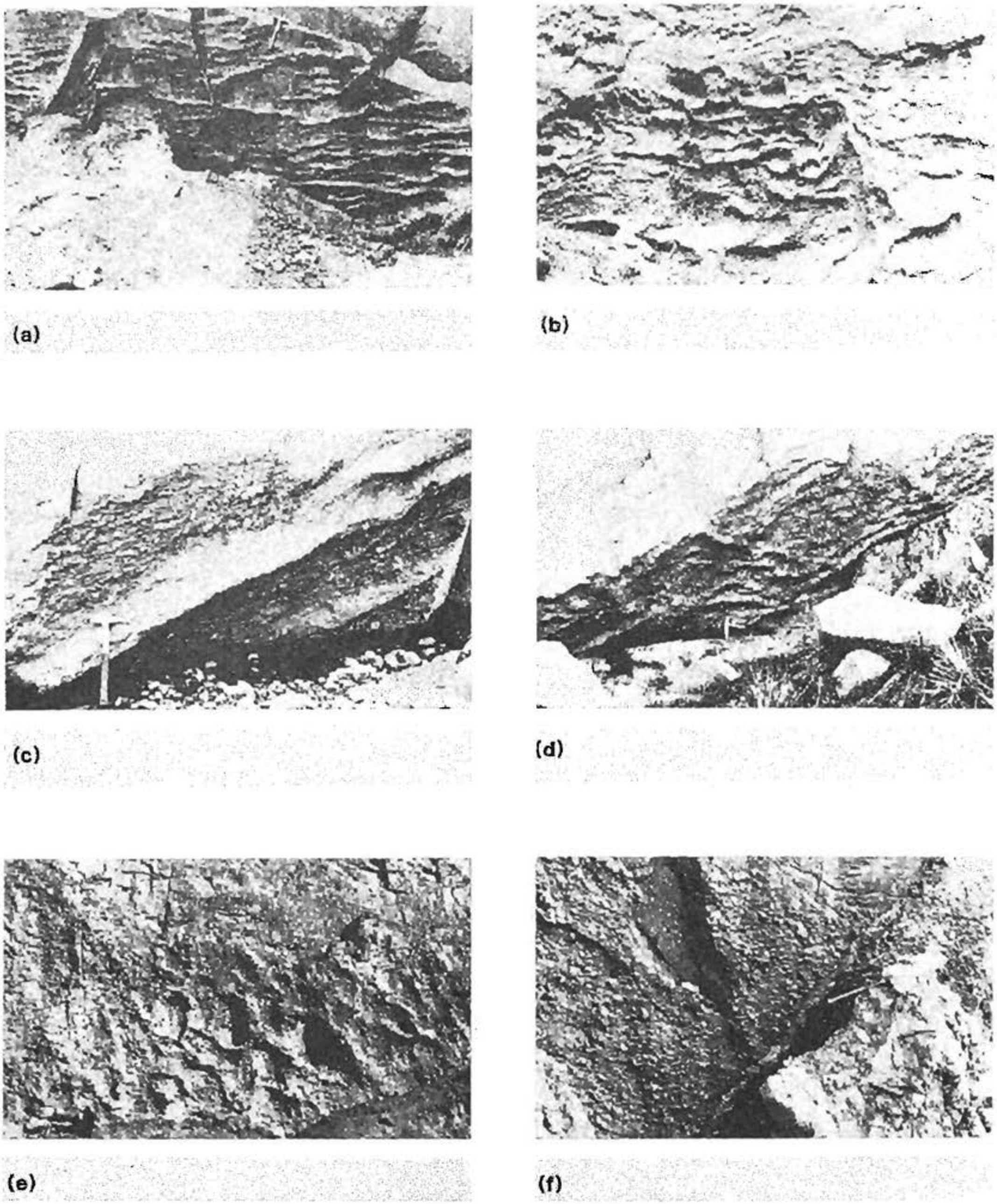

Fig. 4. Erosional structures at the base of the sandstone-bodies in the Chinji Formation and lower part of the Shakardarra Formation; a), b), c), d) gutter casts, b) also shows crescent marks along with the gutter casts, c) space between gutter casts is occupied by flute marks, e) polygonal marks, man as scale is 1.6m high, f) flute marks associated with a sand dyke.

the substrata. Most of flute marks are concentrated along the scoured parts of the sandstone bodies. The flutes are about 3cm across at the rounded end and about 1/2cm in relief (Fig. 4c, f). The flute bearing sole surfaces commonly contain mud balls of various sizes which were eroded from the underlying fine sediments.

Flute casts are commonly produced by the erosion of mud beds under powerful currents carrying sand in suspension (Allen, 1982). The flute casts are initiated and localized by prior inhomogeneities or defects in the eroded surface, and arise by the process of differential erosion due to flow separation of a mixing layer above the bed defect during the erosion of a mud bed (Allen, 1985). When a powerful sand-laden current flows on top of a smooth flat mud bed carrying small depressions, the current will separate along the sharp upstream edge of the defect and encroach at a steep angle down stream. As erosion proceeds, the flow separation increases and the mixed layer becomes more turbulent. The increased grain momentum due to strong transverse vortices increases the differential erosion, and the flute goes on expanding. Later deposition of sand in the hollow preserves the flute casts at the sole of the sand bed. Flutes can also be developed from bed defects such as irregular sheet of pebbles on the clay beds (Friend, 1965).

POLYGONAL MARKS

These are the largest sole structures in the study area, and are found in the basal part of the Shakardarra Formation. These are rectangular in outline, about 2-3 metre across and up to 5cm in relief (Fig. 4e). The sole surfaces of the sandstone bodies containing polygonal marks are extensively covered with mud clasts. Friend (1965) described these structures as polygonal types of welts. The polygonal marks are the casts of desiccation cracks in the underlying mud or siltstone, and are subaerial in origin. The cracks were preserved by infills of coarse silt or fine sand. Most of polygons from the study area are of quadrangle and triangle pattern.

Subaerial desiccation cracks develop in a dewatering mudy surface resulting an isotropic, horizontal, tensional stress field which is released by the development of vertical cracks (Collinson & Thompson, 1984; Allen, 1984). The depths of the cracks and diameters of polygons are directly related, the thicker the cracked layer, the larger the polygons. Thick mudstone beds (~20 m thick) in the Chinji Formation and lower part of the Shakardarra Formation were ideally suited for the formation of large desiccation cracks. Large polygonal marks were also formed from widening of the cracks by high velocity water flow associated with an active channel. The turbulence caused by high velocity flow above the cracks will move water in a helicoidal path. The horizontal helicoidal flow will erode and undercut the crack or gutter walls. Later deposition of sand in the cracks will form the cast.

PEDESTAL STRUCTURES

These are large scale erosional features common in the sandstone-siltstone interbeds and are also reported from the Potwar area (Behrensmeyer & Tauxe, 1982; Behrensmeyer, 1987; Friend et al., 1989). These structures resulted from the sharply defined local erosional relief on the flood plain and was preserved at the bases of some of the sandstones (Fig. 5). The overlying sandstone beds were deposited on surfaces formed by erosion of the underlying mudstones. The under cutting of the mudstone was mostly sharp with steep surfaces. These structures are up to 5 metre deep and many metres across. The sandstone deposited in the

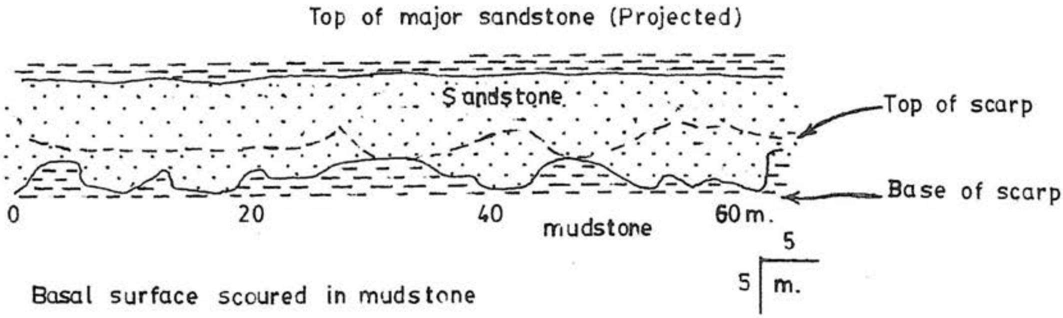

Fig. 5. Pedestal structures at the base of major sandstone bodies (after Friend, 1987). Sandstone-bodies scour into the underlying floodplain sediments

pedestal structures is plane-bedded suggesting high energy flow conditions. These structures were either formed due to subaqueous erosion by floods immediately preceding the sand deposition or due to gullying of the subaerial landscape, then followed by sand deposition after an avulsion event (Friend, 1987).

DISCUSSION

The sandstone-siltstone assemblages of the Chinji Formation and lower part of the Shakardarra Formation represent alternating flood-plane and in-channel deposition. The flood plane deposition prevailed for longer duration than the in-channel sedimentation during this time period (Johnson et al., 1985; Behrensmeyer, 1987). The overbank deposits are comprised mainly of red and brown coloured siltstone, clay, soil and occasional caliche horizons. The deposition of overbank fines is characterized by low rates of sedimentation and an aerial exposure for long time periods which resulted in the development of abundant soil and caliche horizons. Common red colouration of the overbank fines also suggest slow burial rates for the flood plain sediments (Bowen & Kraus, 1987). Long periods of exposure before burial facilitated the development of erosional features as erosional and depositional processes are consistent in most of paleoenvironments.

Fluvial deposits usually are formed in two phases of development, erosion followed by deposition. Localized early phase of erosion of floodplain sediments takes place before major avulsion events during which deposition commences. The nature and type of erosional features was determined by the factors, such as substrate type, digenetic history of substrate and prevailing flow conditions (Myrow, 1992). In the study area, the substratum in most cases was generally noncohesive to mildly cohesive siltstone. The linear structures developed in these sediments were usually straight furrows formed by horizontal helical flows. These were formed during the early erosive stage of the flow and were filled when the velocities dropped and deposition of fine to medium sand begun. Irregularity in shape such as bifurcation and pinchout in shape of the gutter casts may be due to local variations in the cohesiveness of the substratum (Myrow, 1992).

Large scale polygonal marks resulted from shrinkage cracks developed on top of overbank fines in floodplain sediments. The scale and character of shrinkage cracks depends on mineralogy and texture of the sediment, rate of water loss and nature of the underlying sediments (Allen, 1982). The shrinkage cracks in the Siwalik Group developed mainly in the fine silts or clays which were aerially exposed for a long period of time, and were later filled by in channel sediments.

Erosion has also played an important part in the overall construction of the architecture of the major sandstone-bodies. A number of sandstone-bodies in the Siwalik Group exhibit sharply defined zones of relief at their bases. They represent local zones of erosional relief on the floodplain which either existed prior to main avulsion event as part of floodplain landscape or developed subaqueously during high energy flood event. This indicates local topographic features on floodplain before deposition of major sandstone-bodies.

CONCLUSION

Erosional sole structures in the sediments of the Siwalik Group, such as gutter casts, crescent marks and flute marks were formed due to aqueous scouring around inhomogeneties or bed defects in the substratum. Large scale features like polygonal marks and pedestal structures have subaerial or subaqueous origin.

REFERENCES

Abbasi, I. A., 1991. Large scale vertical aggradation of sandstones in the Kamlial Formation of the Kohat Basin, Pakistan. Geol. Bull. Univ. Peshawar. 24, 33-44.

Abbasi, I. A. & McElroy, R., 1991. Thrust kinematics in the Kohat Plateau, Trans Indus Range, Pakistan. Jour. Struc. Geol. 13, 319-327.

Ahmed, I., 1989. Sedimentology and structure of the southern Kohat, Trans Indus Ranges, Pakistan. Unpub. Ph.D. dissertation, University of Cambridge. 231pp.

Allen, J. R. L., 1982. Sedimentary Structures: Their Character and Physical Basis. Vols. 1&2. Elsevier, Amsterdam, 593 & 663pp.

Allen, J. R. L., 1985. Principal of Physical Sedimentology. George Allen and Unwin, London. 272pp.

Behrensmeyer, A. K. 1987. Miocene fluvial facies and vertebrate taphonomy in Pakistan. In: Recent Developments in Fluvial Sedimentology, (F.G. Ethridge; R.M. Flores, & M.D. Harvey eds.) SEPM Sep. Pub. 39, 169-178.

Behrensmeyer, A. K. & Tauxe, L., 1982. Isochronous fluvial systems in Miocene deposits of northern Pakistan. Sedimentology, 29, 331-352.

Bowen, T. M. & Kraus, M. J., 1987. Integration of channel and flood plain suits, I. Developmental sequence and lateral variations of alluvial paleosols. Jour. Sed. Petrol. 57, 587-601.

Bridges, P. H., 1972. The significance of tool marks on a Silurian erosional furrow. Geol. Mag. 109, 405-410.

Collinson, J. D. & Thompson, D. B., 1984. Sedimentary Structures. George Allen and Unwin, London, 194pp.

Friend, P. F., 1965. Fluviatile sedimentary structures in the Wood Bay Series (Devonian) of Spitsbergen. Sedimentology, 5, 39-68.

Friend, P. F., 1987. Alluvial architecture in the Chinji Formation, Siwalik Group, Pakistan. an essay submitted for Sedgwick prize, University of Cambridge. 64pp.

Friend, P. F., Johnson, N. M. & McRae, L. E., 1989. Time-level plots and accumulation patterns of sediment sequences. Geol. Mag. 126, 491-498.

Harms, J. C., Southard, J. B. & Walker, R. G., 1982. Structures and sequences in clastic rocks: SEPM. Short course notes 9, 1-1 to 8-51pp.

Johnson, N. M., Stix, J., Tauxe, L., Cerveny, P. F. & Tahirkheli, R. A. K., 1985. Paleomagnetic chronology, fluvial processes and tectonic implications of the Siwalik deposits near Chinji village, Pakistan. Jour. Geol. 93, 27-40.

Karcz, I., 1968. Fluviatile obstacle marks from the Wadis of the Negev (southern Isreal). Jour. Sed. Petrol. 38, 1000-1012.

Myrow, P. M., 1992. Pot and gutter casts from the Chapel Island Formation, southeast Newfoundland. Jour. Sed. Petrology, 62, 992-1007.

Russell, A. J., 1993. Obstacle marks produced by flow around stranded ice blocks during a glacier outburst flood (jokulhlaup) in west Greenland. Sedimetology, 40, 1091-1111.

Whitaker, J. H. Mcd., 1965. Primary sedimentary structures from the Silurian and lower Devonian of the Oslo region. Nature, 4998, 709-711.

Whitaker, J. H. Mcd., 1973. Gutter casts, A new name for Scour-and-Fill structures: Examples from the Llandoverian of Ringerike and Malmoya, southern Norway. Norsk Geologisk Tidsskrift. 53, 403-417.