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Sedimentology and Tectonic Setting of Polymictic Conglomerates in a Rapidly Subsiding Miocene-Pliocene Foreland Basin: Kohat Plateau, Northern Pakistan

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ABSTRACT: *More than 6km of Neogene molasse sediments of the Rawalpindi and Siwalik Groups accumulated in the western Himalayan (Kohat) foreland basin, northern Pakistan, in response to active basin subsidence and orogenic uplift. In the Kohat Plateau, the Siwalik Group consists of a coarsening upward sequence of silt in the lower part (Chinji Formation), sand in the middle part (Shakardarra Formation) and conglomerate (Janak Conglomerate Formation) in the upper part. This formation was previously named as the Indus Conglomerate Formation by Abbasi and Friend (1989), but I now propose that it should be called the Janak Conglomerate Formation. This new name is proposed because of the danger that the previous name will be confused with stratigraphic terms used in the Indus Suture Zone of Ladakh, India, where the terms Indus Group, Indus Formation, Indus Molasse and Indus Flysch have all been used in recent years (e.g. Srivastava, et al., 1979; Searle et al., 1990; Searle, 1996). The name of Janak belongs to a village located on the northwestern edge of the outcrop area of the formation, at 71°38′30″E, and 33°14′30″ N (Fig. 2).*

The Janak Conglomerate Formation is exposed over an area of 400km², and is about 1500m thick. The conglomerate/sandstone ratio is 1:1 in the lower part and increases to 4:1 in the middle and upper parts. The formation is laterally variable but consists of three main lithofacies i.e., a) crudely stratified to horizontally bedded conglomerate (Gh), b) massive, clast supported conglomerate (Gm), and c) planar cross-stratified conglomerate (Gp). In lithofacies Gp, some of the cross-sets are up to 7m thick suggesting channels as deep as 14m or more. However, the average thickness of the cross-sets are 3-5m, suggesting channels 6-10 m deep.

The progradation of the conglomerates over the finer grained formations is probably mainly a response at this depositional site on the Indian plate, to the progressive movement of the plate towards the uplifted Himalaya. But in the Kohat area, the late Miocene progradation of the conglomerates is distinctly earlier than elsewhere in the western Himalayan foreland basin. The conglomerates pass laterally into the finer grained facies of the Nagri and Dhok Pathan formations to the east and south of the Kohat basin, and also pass into finer grained sediments to the west. This suggests that it was in this area that the largest river system entered the western foreland, about 10 ma, approximately along the course of the present-day Indus river.

INTRODUCTION

The detritus shed by the Himalayan deformation zones started accumulating in the Kohat-Potwar foreland-basin since late-Oligocene (Raynolds and Johnson, 1985). The molasse sequence in southeastern Kohat (Fig. 1) is comprised of two coarsening-up sequences, the Rawalpindi Group

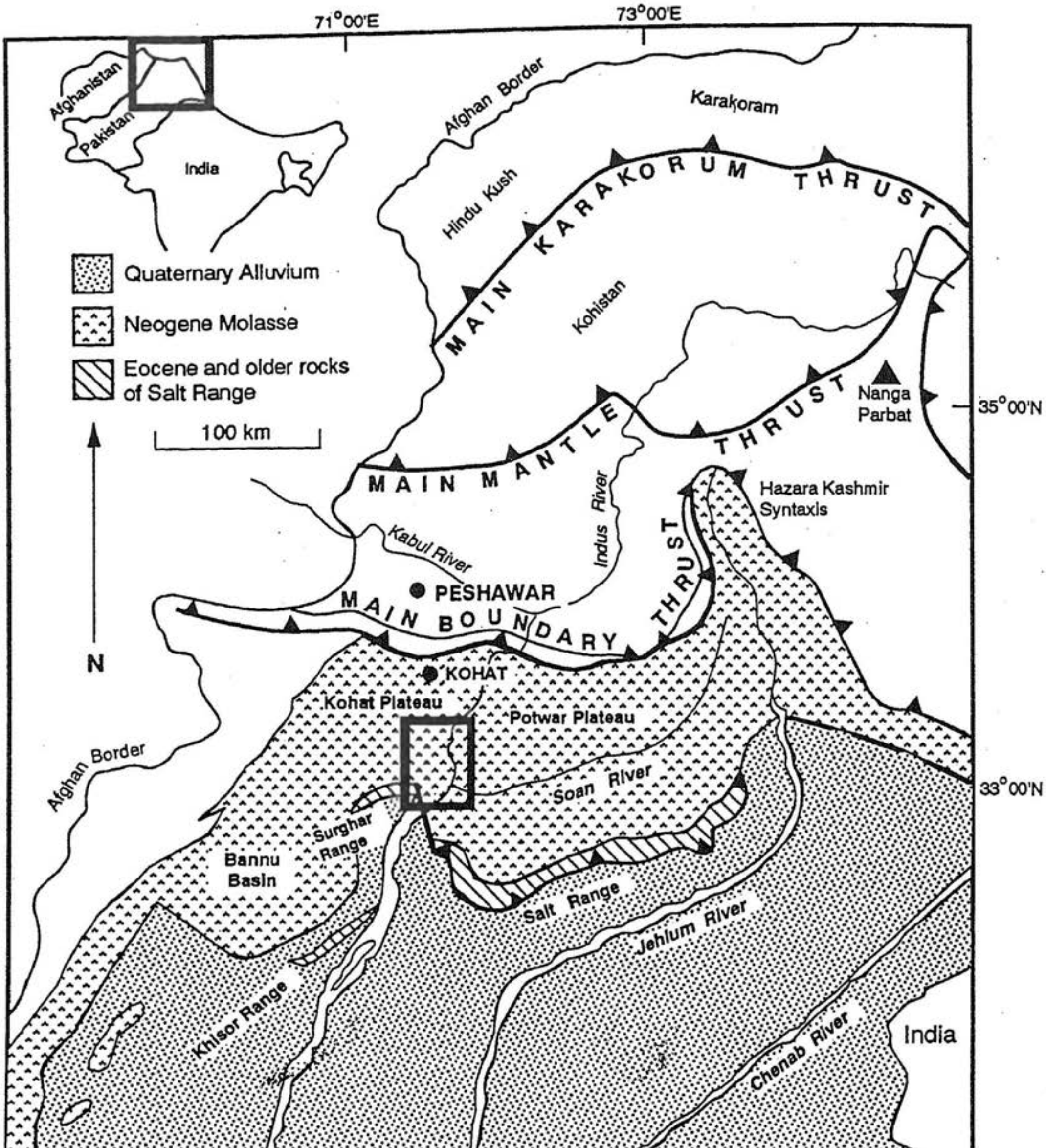

Fig. 1. Outline geological map of northwestern Pakistan, showing the main Himalayan lithotectonic units and the Quaternary alluvium south of the Salt Range (Frontal) Thrust. The box in the middle shows the location of Fig. 2. Modified from Abbasi and Friend, in press.

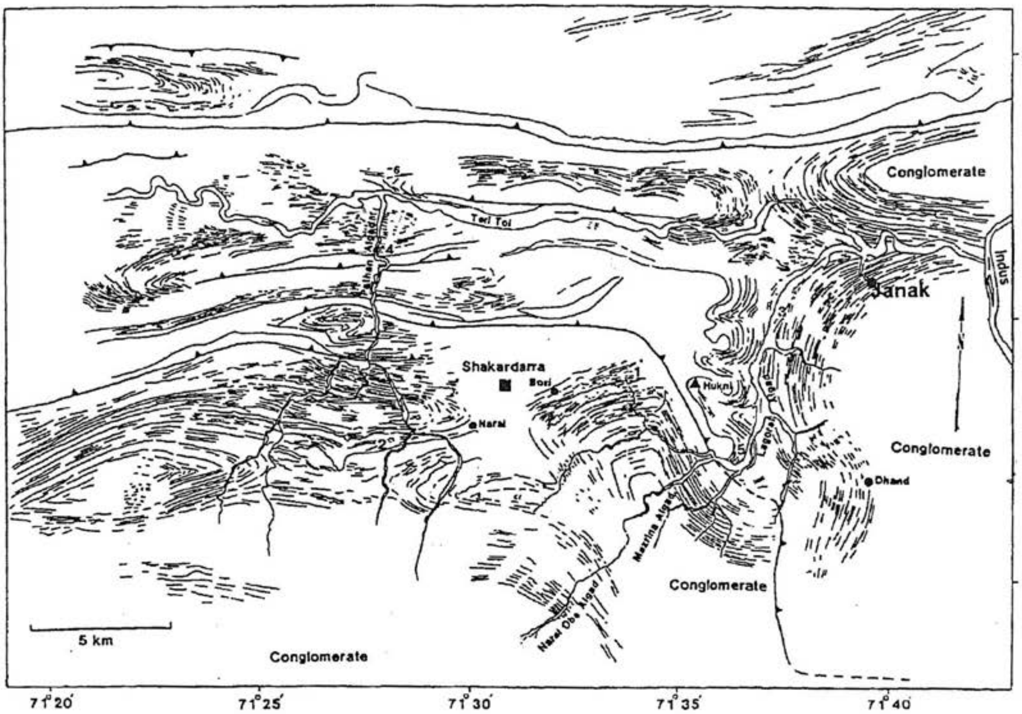

Fig. 2. Line drawing map of the study area based on the aerial photograph mosaic. Broken lines indicate sandstone-body distribution, solid lines with teeth show thrust faults.

and the Siwalik Group (Fig. 2). The Siwalik Group has dominant silstone in the lower part (Chinji Formation), Sandstone in the middle part (Shakardarra Formation) and polymictic conglomerates in the upper part (Janak Conglomerate Formation). The Miocene-Pliocene polymictic conglomerates (Janak Conglomerate Formation) of the Siwalik Group are confined only in the southeastern Kohat (Shakardarra area, Fig. 3) and adjacent western-most Potwar area (Gill, 1952).

The Janak Conglomerate Formation in the study area consists mainly of conglomerate units with subordinate sandstone. The succession coarsens up-section due to increasing thickness of the conglomerate units, without any noticeable change in the grain size of the pebbles. The conglomerates are exposed over an area of about 400km^2 in the Kohat and western Potwar Plateau (Meissner et al., 1974), and are stratigraphically equivalent to the Dhok Pathan Formation (Miocene) in the Potwar Plateau (Gill, 1952) and to the Nagri Formation in the Surghar Range (Makarwal Sandstone of Khan & Opdyke, 1993) (Fig. 4). The conglomerate sandstone ratio is about 1:1 in the lower part of the formation, where it has a transitional contact with the underlying Shakardarra Formation, and about 4:1 in the middle and upper parts. Overbank fines are absent in the formation except occasional beds in the lower part. The clast is derived mainly from the rising Himalayas (Abbasi and Friend,

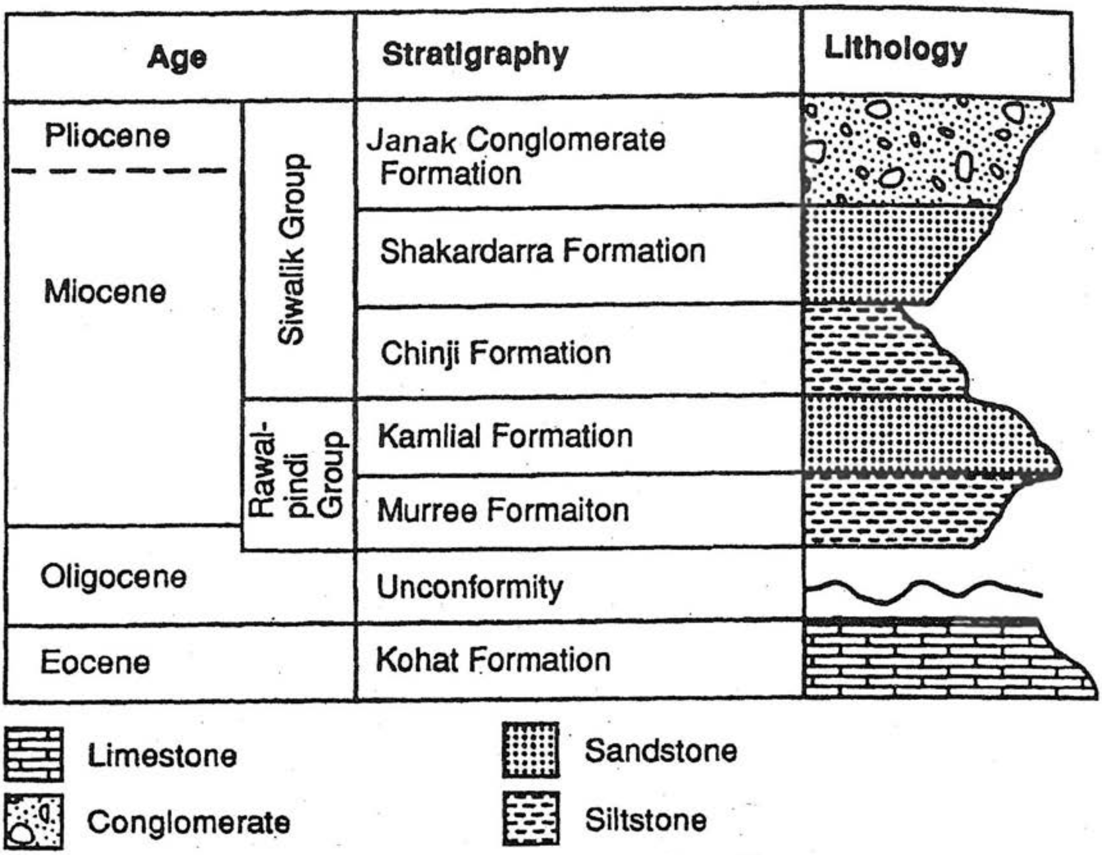

Fig. 3. Stratigraphy of the molasse sequence, southeastern Kohat Plateau.

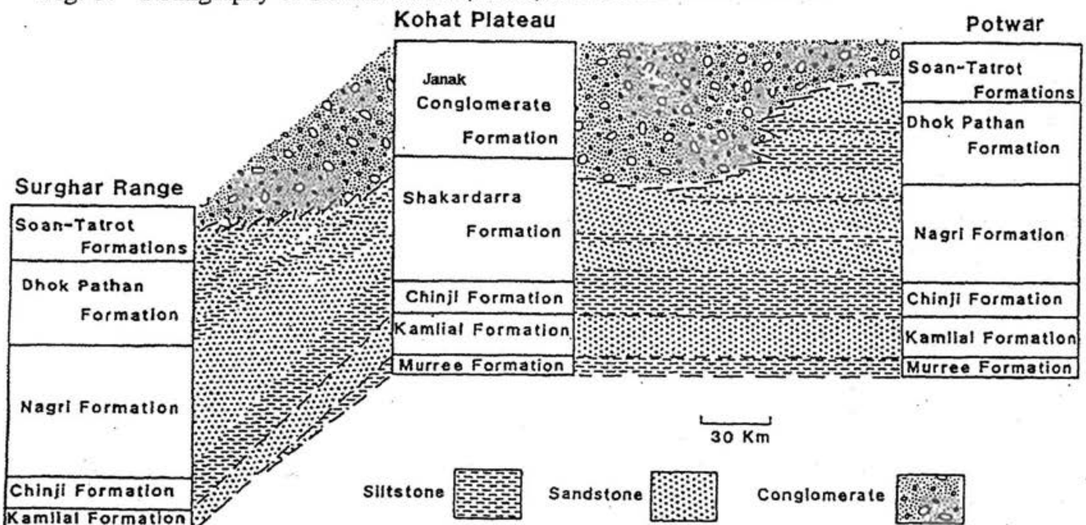

Fig. 4. Schematic stratigraphic sections of the Rawalpindi and Siwalik groups and equivalents from the Potwar area (east of Kohat Plateau), and the Surghar Range (south of Kohat Plateau). It shows large scale lateral lithological changes in the molasse sediments (after Gill, 1952; Meissner et al. 1974).

1989), being well rounded to discoidal in shape and moderately sorted. The grain size varies greatly with an average clast size about 10cm in diameter, however, clasts up to 30cm in diameter are also present. The conglomerates are composed of clasts of volcanics (av. 32%), quartzite (av. 27%), gneisses (av. 21%), limestone (av. 7%), sandstone (av. 6%), granites (av. 3%) and others.

Sedimentological studies of the formation were carried out around Shakardarra area in order to interpret the depositional system, tectonic setting, and lateral variation of conglomerates into finer grained facies.

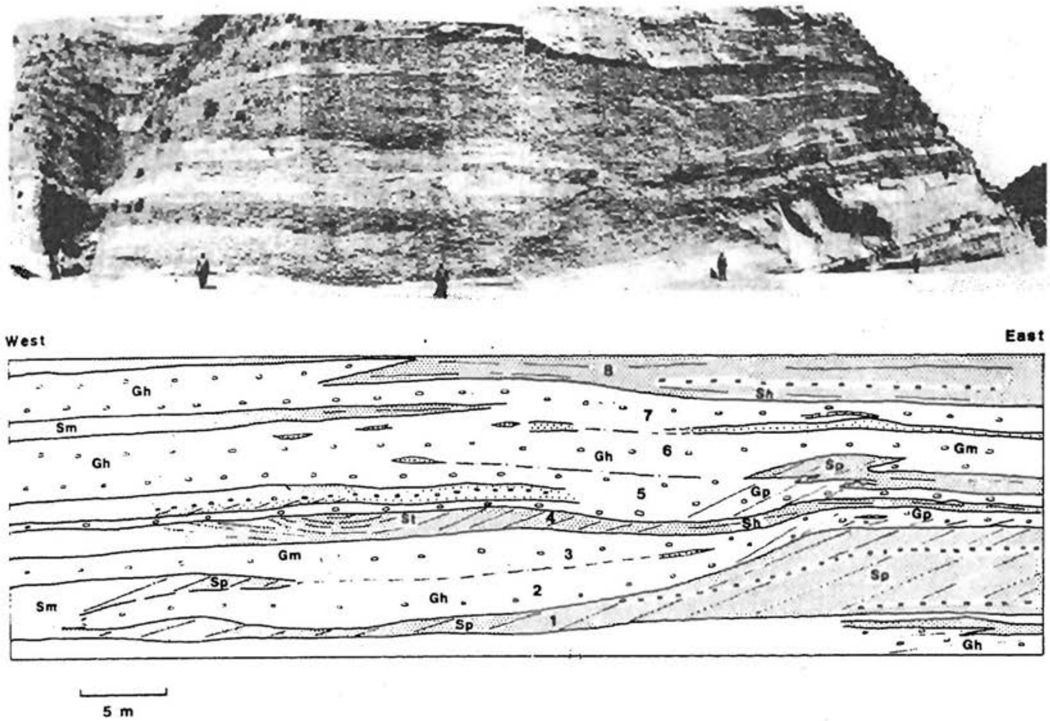

Fig. 5. Sketch of the interbedded conglomerate and sandstone lithofacies. Numbers refer to probable bars in the succession. Unit 2 erodes the underlying sandstone and passes laterally (westward) into the sandstone. The flow direction is out of page. Unit 4 shows channel-fill feature in sandstone. Facies Gp laterally pass into facies Gh.

FACIES ASSOCIATION

Although the conglomerates of the Janak Conglomerate Formation show much lateral variability, they have a simple association of only three major facies, a) crudely stratified to horizontally bedded conglomerates (Gh), b) planar cross-stratified conglomerate (Gp), c) massive clast supported conglomerate (Gm). Minor amounts of trough cross-bedded (Gt) and channel-fill conglomerates are also present. A modified version of the facies code scheme of Miall (1978) is used to describe the lithofacies in the formation. The massive conglomerates in the study area are different from the lithofacies Gms of Miall (1978) which have been interpreted as subaerial debris flow deposits. The massive conglomerates in the study area can easily be differentiated from the debris flow deposits on the basis of a) the moderate sorting and roundness of clasts, b) the conglomerates are commonly clast supported and, c) the clasts are polymictic and have been transported over large distances (> 300km). In the present study, the lithofacies Gm will therefore, represent massive gravel and Gh crudely stratified to horizontally bedded gravel. Sandstone facies, such as horizontally stratified sandstone (Sh), planar cross-bedded sandstone (Sp) and trough cross-bedded sandstone (St) are commonly interbedded with the gravel.

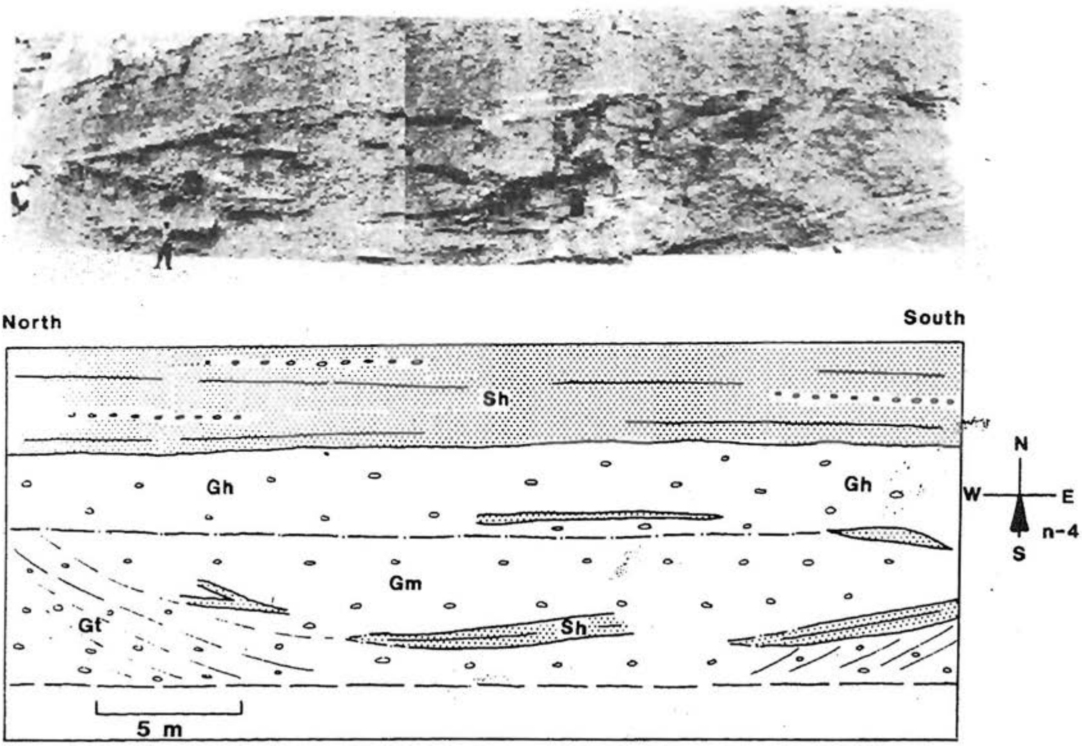

Fig. 6. Channel-fill feature occupied by lithofacies Gm. Lithofacies Gt on the northern margin of the channel-fill probably represent lateral accretion. The channel-fill is overlained by lithofacies Gh and Sh. The imbrication in facies Gh shows southward flow direction, whereas, channel-fill shows flow direction to the east. This suggests that it could have been a minor channel flowing at right angle to the major channel.

Crudely stratified to horizontally bedded conglomerate (Gh)

This is the most common and widespread facies constituting a major part of the conglomerate sequence in the study area. It corresponds to the facies Gm of Miall (1978, and most other studies in conglomerate sequences), except that it excludes the massive, clast supported conglomerate (termed here facies Gm). Sorting and roundness of clasts are generally high with average clast size between 5-10cm in diameter. Conglomerate fabrics are moderately organised with poor to moderate local imbrication. The fabric is clast supported, occasionally matrix supported, in a medium-grained sandstone matrix. The individual beds are 1-2m thick and are defined by the presence of sandstone lenses or moderate imbrication. Horizontally bedded or planar cross-stratified sandstone lenses or shadows are common and have strongly scoured upper surfaces. The facies Gh constitute most part of the conglomerate succession (Figs. 5, 6), and build multistoried sequences many metres thick. Internal grading is not common but when present, is usually normal. Imbrication indicates a flow direction to theSSE and SSW, so a mean southward flow direction is most likely. However, in many units the great degree of roundness of the clasts has prevented the development of imbrication. The lithofacies extends for hundreds of metres and laterally passes either into facies Gm and Gp, or into sandstone facies Sh and Sp, with well-developed bar-lee faces (Fig. 5). A distinct bar tail sequence may be present, composed of high angle facies Sp, in the lower part of the bar tail, and low-angle plane bedded sandstone (Sl), in the upper part.

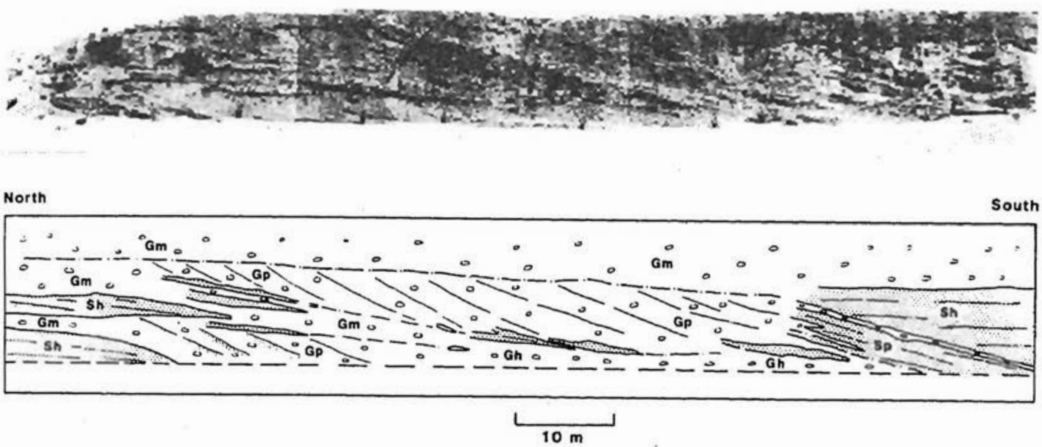

Fig. 7. Large scale planar cross-bedded conglomerate (Gp). The planar cross-sets at their thickest part are up to 7 metres thick. The conglomerates laterally pass into the sandstone lithofacies Sp and Sh. Small scale lithofacies Gp in the lower part shows fining upward trend and laterally pass into lithofacies Gh.

The dominance of facies Gh is typical in gravel of proximal braided rivers (Ore, 1964; Rust, 1978, 1984). It was deposited from shallow, high velocity flow over longitudinal bars and shallow intervening channels (Hein and Walker, 1977; Rust 1984). The facies Gh commonly develops in the cores of major bars, and finer material is deposited on top of the bars during waning flow conditions (Rust, 1978). The gravel-laden, high energy flows were probably channelised and strongly erosive (Fig. 5).

Planar Cross-bedded Conglomerate Facies (Gp)

This is the second most important lithofacies in the study area and makes up approximately 20% of the conglomerate succession. Thickness of tabular cross-sets varies from 1-7 metres (Fig. 7). The conglomerates are clast supported with medium grained sand as matrix. Its lateral transition to facies Gm and Gh (Fig. 5,7), and also to lithofacies Sp and Sh (horizontally stratified sandstone) (Fig. 7) is common. Cross-beds dip less than 30° and are marked by the presence of sand lenses, occasional downstream transition of gravel into sand, and normal grading. The cross-sets are usually enclosed by lithofacies Gh.

In Fig. 7, the lithofacies Gh laterally grades into facies Gp. The thickness of the facies Gp increases from 1 metre to over 7 metres, and then passes 70 metres downstream into fine grained facies Sp and Sh. The whole assemblage (Gh-Gp-Sp-Sh) probably represents a major bar with Gh as bar head, Gp as bar lee-face with angle-of-repose deposition, and Sp and Sh as bar tail. The steep angle of the foresets, laterally passing into sandstone, and interbedded with the facies Gh suggests that it was a major transverse bar.

A striking feature of many sets of facies Gp is normal grading in which coarse cobbles grade into medium sand. Occasionally, outsized pebbles are present in the upper sandstone cross-sets. In some cross-sets, sandstone dominates the bottom sets and lower part of the gravel foresets. This was probably due to periodical winnowing of sand (Rust 1975), or due to the avalanching of sorted gravel simultaneously with the erosion of sand from the underlying foreset, and re-deposition of the mixture as a sediment gravity flow (Steel and Thompson, 1983).

Lithofacies Gp was deposited from falling stage modifications of the downstream margins of longitudinal bars (Rust, 1978; 1984). The cross-stratification also develops in transverse bars in gravel streams when sediment and fluid discharge decreases rapidly and an angle-of-repose slip face develops downstream (Hein and Walker, 1977). According to Church and Gilbert (1975), the development of cross-sets depends on the availability of sufficient space (depth). This requires water depths considerably greater than foreset thickness, and rather persistent, non-ephemeral flow (Middleton and Trujillo, 1984). The great thickness of some of the cross-bedded conglomerate units, such as in Fig. 7 (over 7 metres set thickness), suggests about 14 metres deep channels in the paleoriver system. However, average thickness of the cross-sets are usually 3-5 metres, deposited by 6-10 metres deep channels.

Massive Conglomerate Facies (Gm)

The massive conglomerate facies (Gm) can be differentiated from the facies Gh by the paucity of any internal structure and imbrication, and are common in a number of sections (Fig. 5,6). The clasts are well rounded, and are moderately sorted. Grain size is generally uniform but occasionally large clasts (about 20-30cm in diameter) are also present amongst the major framework components. Internal grading and imbrication are rare. Massive conglomerates are predominantly clast supported with a matrix of medium sand filling the interstitial spaces. Lithofacies Gm usually grades laterally into the facies Gh or Gp.

The conglomerates of this type probably represent rapid deposition under high energy flow conditions (Bull, 1977), or stream flows with very high sediment concentrations and high current velocities (Morrison and Hein, 1987). In these situations rapid deposition of clast hinders the development of any gradation or stratification. The cores of large low-lying longitudinal bars may also appear massive where deposition takes place rapidly. Sheet-floods deposit massive conglomerates in the braid-plain setting particularly in the proximal reaches during the flood season. No sand shadows or sandstone beds were found in the lithofacies, probably because of the high energy flow conditions.

Finer Grained Facies

The conglomerate units are frequently interbedded with sandstone beds (Fig. 5). No siltstone or finer-grained facies are present. The interbedded sandstone is medium grained with occasional pebble layers marking erosional surfaces. The overall sandstone proportion decreases up-section as the formation coarsens upward. In the middle and upper parts of the formation, occasional beds of thick sandstone occur, particularly where they are laterally equivalent to conglomerates. The sandstone is both in the form of laterally extensive sheets and in thin laterally discontinuous beds. Thin lenses of sandstone are also present in the conglomerate beds as sand shadows.

FLUVIAL STYLE

The Janak Conglomerate Formation consists of conglomerates and sandstone (75%:25%), with conglomerate/sandstone ratio increasing up section. Lithofacies Gh and Gm are commonly interbedded (Fig. 5), and laterally pass into lithofacies Gp, Sp and Sh (Fig. 7). Channel-fill conglomerates are rare, and are usually massive internally (Fig. 6). Occasionally the conglomerates also show lateral accretion before passing into the channel-fill deposits (facies Gt in Fig. 6).

Lithofacies Gh and Gm were deposited as longitudinal bars in gravel streams similar to those formed in modern rivers (William and Rust, 1969; Rust, 1984). Lithofacies Gp was formed by the modification of the downstream margins of the longitudinal bars at low velocity flow (Rust, 1984), and also due to migration of transverse bars (Rust, 1972). Fining upward sequences are common particularly in the planar cross-stratified conglomerates, and are associated with channelised flow representing gradual decrease in the flow energy or abandoning and filling of channels. The presence of graded bedding implies that the transporting and depositing currents were strong enough to sort out the material, and clasts were free to move in the flow (Harms et al., 1982).

The average size (3-5 metres) of the cross-beds suggests channel depth between 6-10 metres, whereas, occasional very large size cross-sets (about 7 metres) suggest channels over 14 metres deep at places. The large size and great lateral extent of the cross-bedded conglomerates show a consistent high discharge, or at least, large migration distances for the bars.

The dominance of lithofacies Gh, Gm and Gp suggests that the conglomerates were deposited by high energy multichannel low sinuosity rivers. Deposition took place largely on mid-channel bars. The comparatively high proportion of lithofacies Gp (20% of the conglomeratic lithofacies) suggests that the flow was channelised and mid channel bars had high angle slip faces. These sediments were deposited in the proximal part of an alluvial braid-plain (Rust, 1984; Nemec and Steel, 1984; Haughton, 1989). The complete absence of debris-flow deposits, and large scale lateral and downslope continuity of the lithofacies distinguish these sediments from localized alluvial fan deposits.

STRATIGRAPHIC CORRELATION/DISCUSSION

The sediments of the Siwalik Group in the study area are characterized by coarse grained facies as compared to stratigraphically comparable successions from the adjoining Potwar Plateau and Surghar Range (Fig. 1). The Shakardarra Formation in the area consists of sand and silt in the lower part, mainly sand in the middle part, sand and conglomerate in the upper part (Abbasi, 1994). Stratigraphically equivalent Nagri Formation in the Potwar Plateau consists of sandstone and siltstone with subordinate conglomerate. A major difference in lithologies is evident at the time of deposition of the Janak Conglomerate Formation. The formation in the study area consists of thick polymictic conglomerate interbedded with sandstone, estimated to be about 1500m thick, and spread over an area of about 400-500km^2. Deposition of thick conglomerate beds started during upper part of the Shakardarra Formation which has preliminarily been dated about 10-8 Ma. (Beck, personal communication). Due to lack of overbank fines in the Janak Conglomerate Formation, chronological studies cannot be carried out. Nevertheless, based on the preliminary paleomagnetic dating of the underlying Shakardarra Formation (Beck, in prep), it is suggested that the conglomerates started depositing at about 8 Ma. This is consistent with ages proposed for stratigraphically equivalent the Dhok Pathan Formation in the Potwar Plateau (Johnson et al., 1985). The deposition of conglomerate continued until Pleistocene time, when deformational front rippled to the area (McDougal, 1989).

Further south of Shakardarra area, in the Surghar range (Fig. 1), a 3.5km thick sandstone sequence was deposited at about the same time (~8-3Ma) when thick conglomerate sequence was deposited in the study area (Khan, 1984; Khan and Opdyke, 1993). The thick sandstone sequence (Nagri Formation of Abid et al., 1983; Khan and Opdyke, 1993) is comprised almost entirely of sandstone with rare siltstone or clay interbeds. The sandstone has been dated on the basis of overbank fines present below and above the sandstone sequence (Khan, 1984; Khan and Opdyke, 1993). It is composed of medium grained, gray coloured sand derived from deep seated Himalayan terrains (Abid et al., 1983) and deposited by a paleoriver system flowing mainly to the south-southwest (Bonis, 1985). Detailed provenance studies (Abbasi and Friend, 1989; Abbasi and Khan, 1990) have revealed similar source terrain for the Janak Conglomerate Formation as that for the Nagri Formation of the Surghar Range. Paleomagnetic studies (Khan, 1983; Khan et al., 1988; Khan and Opdyke, 1993) have demonstrated a general younging of the onset of molasse sedimentation towards the south and west, i.e., Surghar and Marwat Ranges.

These studies suggest that both the Janak Conglomerate Formation in the Shakardarra area and the Nagri Formation in the Surghar Range were deposited at almost the same time by a similar paleoriver system. The paleoriver system deposited coarse grained gravels in the study area as its proximal facies, while thick sandstone of the Nagri Formation was deposited as medial to distal facies. The overbank fines were either not deposited or could not been preserved because of high energy flow conditions associated with the paleoriver system.

Deposition of thick Miocene-Pliocene coarse grained facies in the south-eastern Kohat area suggest that the major paleoriver system entered the Kohat-Potwar foreland basin almost along its present day coarse since at least 10-8 Ma. It was a braided gravelly system in the study area which passed further south into a braided sandy system. The paleoriver system in Kohat, western Potwar and Surghar Range was flowing mainly to south-southwest, while laterally migrating towards east in the central and southern Potwar. The active channel system and resulting channel belt facies were confined mostly to the Shakardarra area and Surghar Range, while occasionally shifting to the Potwar basin which became a major flood-plain area since about 8 Ma (Dhok Pathan time).

The timing of the appearance of gravels also corresponds to the observed higher uplift rates in the source terrain, especially in the Nanga Parbat and adjacent areas (Zeitler, 1985). The Nanga Parbat and adjacent areas have been uplifted more than 10km during last 10 Ma. The large scale uplift associated with thick-skinned thrusting (Main Mantle Thrust) caused increased subsidence in the proximal parts of the foreland basin, while active erosion contributed coarse grained sediments in large amounts to the basin of deposition. The gravels prograded over large distances despite the higher subsidence rates because of large sediment and water supply. The modern analogue of these conglomerates in the present day Indus River do not extend far south from the range front because most of the coarse grained detritus has been deposited in the intermontane-basins such as the Peshawar and Attock basins.

CONCLUSIONS

The Miocene-Pliocene Conglomerate deposits are confined mainly to the south-eastern Kohat Plateau and pass laterally into finer grained facies of Nagri and Dhok Pathan formations.

The conglomerates were deposited by a gravelly braided river system in the proximal reaches of a major braid plain. The paleoriver system had a flow direction fairly similar to the present day Indus river and can be regarded as the paleoIndus river system.

The paleoIndus river system entered the foreland basin along its present course for at least 8 Ma.

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