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Neogene Stratigraphy of The Daud Khel Area, Mianwali District, Pakistan

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Abstract: The Neogene fluvial sequence northeast of Daud Khel, Mianwali District, is over 3,400 meters thick. The thin Murree (?) Formation underlies the well-developed Siwalik Group which contains locally the Kamlial, Chinji, Nagri and Dhok Pathan Formations. This group nomenclature contrasts with that used in the central and eastern Potwar Plateau. With the exception of the Kamlial Formation, the lithologies of the formations at Daud Khel closely resemble the lithologies of their stratotypes.

* * *

INTRODUCTION

Field groups jointly sponsored by Howard University and the Geological Survey of Pakistan have been examining Neogene sedimentary rocks at the western end of the Potwar Plateau since 1974 (Fig. 1). This work is complementary to an intensive restudy of the Siwalik Group stratotypes and their associated faunas in the central and southern Potwar Plateau by field groups from Yale University and the Geological Survey of Pakistan (Pilbeam *et. al.*, 1977).

The area northeast of Daud Khel (32°54′ - 33°01′N and 71°35′ - 71°44′E) contains a continuous Neogene section from the Murree (?) Formation at the base into the Dhok Pathan Formation at the top (Fig. 2). This report considers the detailed stratigraphy of this area; a preliminary report was published by Hussain *et al.* (1977). Vertebrate faunal lists are being published elsewhere (Hussain *et al.*, 1979), and fossil rodents and insectivores from the Daud Khel Neogene will be analyzed separately.

Stratigraphic nomenclature of Siwalik rocks has been expressed in various ways since Pilgrim (1913) first used the terms Chinji, Nagri, and Dhok Pathan. Subsequent usage has confused the lithologic, paleontologic, and temporal implications of these terms. Lewis (1937), Hussain (1971), and Fatmi (1974) have restricted the usage of Pilgrim's terms to litho-

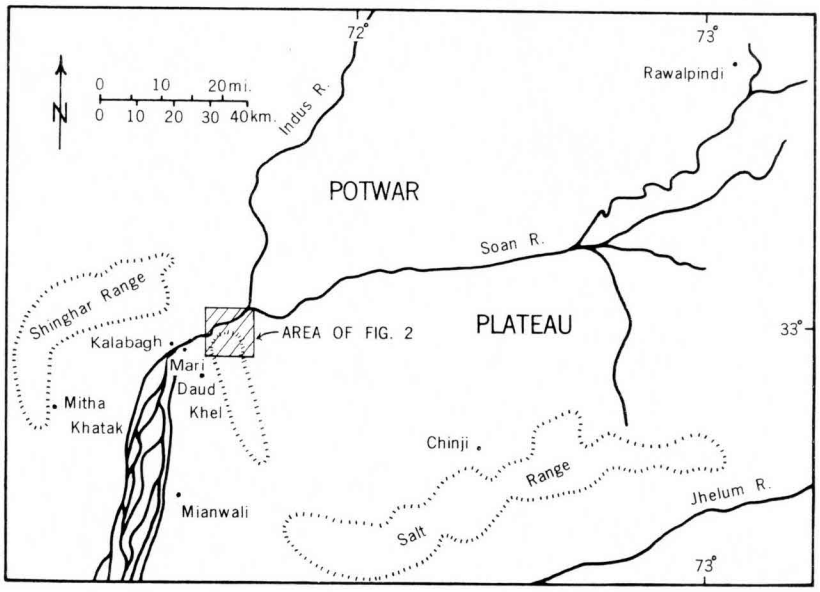

Figure 1. — Index map of the western part of the Potwar Plateau; the area covered by the geological map of Daud Khel is outlined.

logic units as formations. In the recent restudy of the stratotype region, Pilbeam *et al.* (1977) have followed the above authors in restricting Pilgrim's terms to lithologic units and proposing the establishment of new nomenclature for biostratigraphic and chronostratigraphic units. We agree with these recommendations and, for reasons detailed below, use the established lithostratigraphic names of the central Potwar Plateau with slight modifications.

Previous Studies

Several generalized descriptions of the geology of the Daud Khel area have been published. The salt mines at Kalabagh and Mari, near Daud Khel, were mentioned as early as 1815 by Elphinstone (1815, pp. 48-49). Other travelers, such as Oldham in 1864 and Warth in 1871, also gave cursory descriptions of Kalabagh (see citations in Wynne, 1880, pp. 211, 214), but they did not comment on the geology of the Siwaliks.

Andrew Fleming, a British officer who wrote early descriptions of Kalabagh in 1848 and 1849, was commissioned to study the geology and mineral resources of the Salt Range in 1851. His assignment included not only the entire area presently called the Salt Range, and the western Potwar Plateau, but also the Trans-Indus ranges in Mianwali District. Fleming apparently explored the Tertiary fluvial deposits rather extensively and collected a number of vertebrate fossils. He was able to conclude, correctly, that the deposits are mostly of Miocene age and that "they are merely the western extension of the strata of the Siwalik Range, which in the annals of geology have been rendered famous by the researches of

Cautley and Falconer" (1853, p. 357). His geological map includes the area of this paper and shows the Eocene and Neogene outcrops near Daud Khel.

Wynne (1877) summarized the geology of the entire Potwar Plateau and Trans-Indus ranges. The Daud Khel area is mentioned only very briefly in the text and the information upon which Wynne's mapping of this area was based was imprecise. Although most of the area is correctly shown as "Lower Siwalik" on Wynne's map, an important fault block, which we map as Nagri Formation, was considered by Wynne to be Silurian.

In his 1880 monograph on the ranges to the west of the Indus, Wynne discussed the Kalabagh area in some detail. Unfortunately for our present purpose, he confined his remarks to the area north of the Indus. Still, his Kalabagh map (facing p. 44) does show the geology of the area on the south side of the Indus for approximately two miles to the south and four miles to the east of Mari. Wynne recognized that the major fault along which Lunai Nala is developed extends to the south of the river, effectively separating the Siwalik rocks on the east from the earlier deposits to the west. He also noted the major faults west of Ainwan Nala and at Dhingot although he was not aware that they extend as far as Jaba Nala.

Observations made during a float trip down the Indus were reported by Waagen in 1884. The downstream portion of the resulting cross-section, between the Soan River and Kalabagh, corresponds to the north edge of the area mapped here. However, although Waagen's cross-section is drawn as indicating the geology of the east (or south) bank of the Indus throughout, he apparently combined geologic observations from both banks. Waagen's unusual perspective allowed him to note most of the faults crossing the Indus in this area, but his representation of the "Orange Series" (approximately equal to the rocks we map as Nagri and lower Dhok Pathan Formations) immediately upstream of Mari and "Dungote Sandstone" in the area of "Dungote" (Dhingot) Hill is clearly taken from the north bank. The lower part of this multi-storied sandstone unit is very high in the section south of the Indus and is best developed immediately north of the river.

Pascoe (1920) surveyed areas south and west of Daud Khel, but did not comment on the region discussed in this paper. Anderson (1927) did not mention the Daud Khel area in the text, but indicated the general Tertiary geology on the periphery of his map (1927, p. 668). He showed only "Nummulitic," "Lower Siwalik" and "Upper and Middle Siwalik" (undivided) approximately as we have mapped them here (Fig. 2).

Cotter's (1933) careful study of western Attock District included only the eastern margin of the Daud Khel area. His report indicates that the Gaud Nala area (32°50′ - 33°00′N and 71°47′E) is within the outcrop area of the Dhok Pathan Formation. This is significant in that Fatmi (1974, pp. 63-64) has designated the section along Gaud Nala a "principal reference section" for the Dhok Pathan Formation and indicates that thick Chinji and Nagri Formation sections are also exposed there. Fatmi does not comment on the upper or lower contacts of the Dhok Pathan Formation in this section. Our mapping and that of Cotter suggests that neither the top nor the bottom of the formation is present along Gaud Nala.

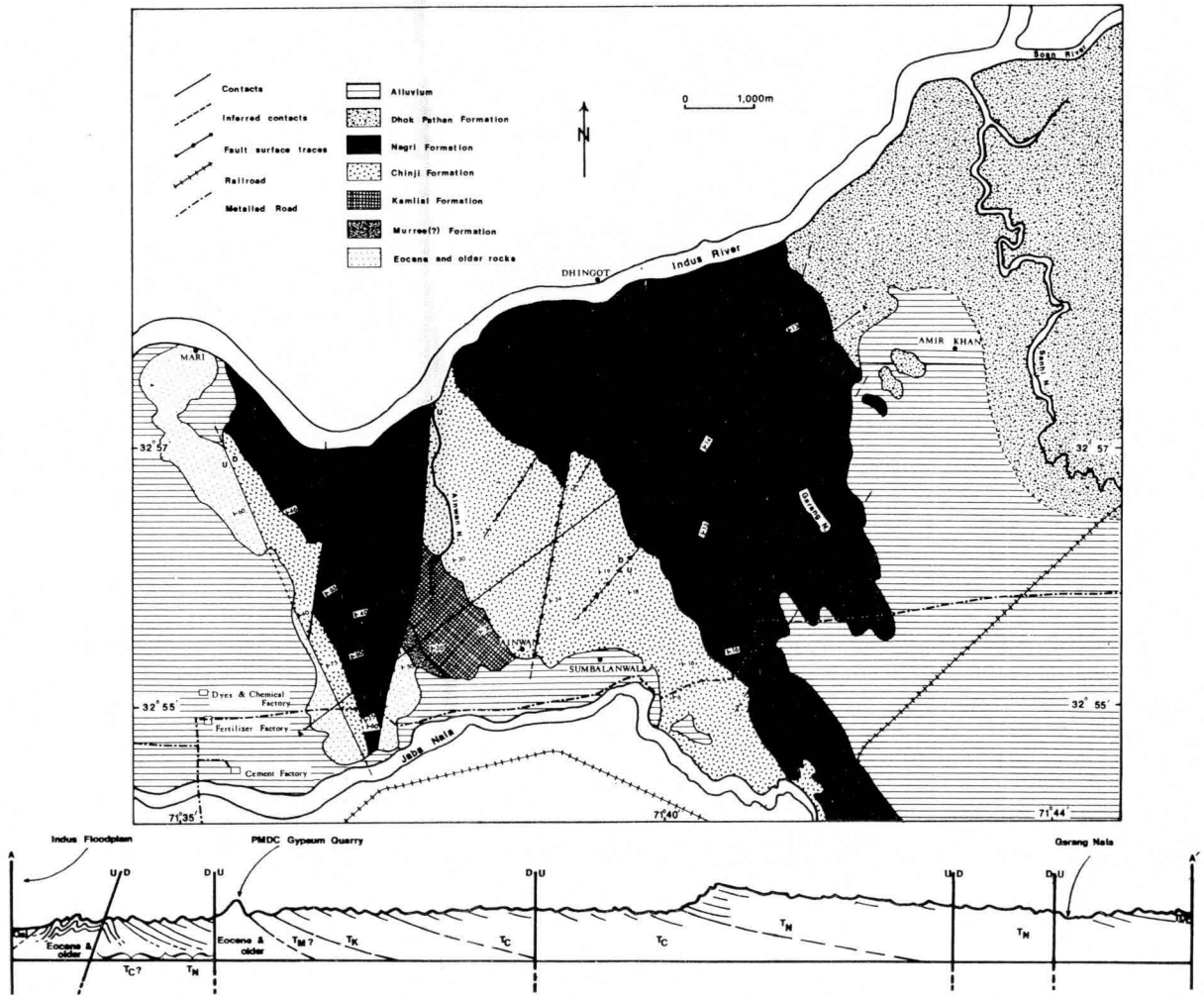

Figure 2. — Geological map of the Daud Khel area.

The Daud Khel area is not mentioned in the text of Morris' (1938) paper on the Bain Boulder Bed, but it is included in his geological map. His mapping of the Siwaliks in this area is quite accurate. It is not at all clear how he obtained the data on which this mapping is based. None of the papers he cites contain nearly as accurate a representation of the Daud Khel geology as does his map and he makes no mention of having done any field work in the area. In any case, it is clear that by 1938 the existence of a very thick exposed Siwalik section northeast of Daud Khel was known. This knowledge has never previously been exploited, however, for either stratigraphic or paleontologic purposes.

Gee (1947, pl. 2, 3) mapped part of the Daud Khel area in considerable detail. He recognized that extensive late Tertiary and Quaternary tectonism must have taken place in the area to account for the emplacement of the Saline Series within much younger rocks. Gee (1947) was not primarily concerned with the Siwaliks around Daud Khel and our mapping of the Siwalik units differs from his in a number of important features related to the complex fault network and the differentiation of the Siwalik formations.

The Daud Khel area is shown on Danilchik's (1961) map, but the geology, and especially the Tertiary geology, is very generalized. The 1:2,000,000 Geological Map of Pakistan (Bakr and Jackson, 1964) represents the area's geology in even more general terms. The Hussain *et al.* (1977) preliminary report on the Daud Khel area includes a geologic map which has been refined in the present paper.

Regional Setting

Middle and late Tertiary clastic sedimentary rocks are exposed throughout the map area with the exception of small areas of economically important exposures of Eocene and earlier rocks along the mountain front facing the Indus, parts of the floodplains of the Indus River and Jaba Nala, and agricultural lands in the plateau areas to the east. As is clear from earlier small-scale geologic mapping of the Potwar Plateau (e. g. Morris, 1938, pl. 35), the stratigraphy of the area described here is a westward and northward extension of typical Salt Range stratigraphy. The Daud Khel area is the northernmost and westernmost extension of the southern Potwar Plateau stratal succession, and although the structure of the area is complicated by faulting, the steep dips of the essentially monoclinal structure and the virtually continuous exposure provides a more comprehensive section of Siwaliks than is present at any one point in the southern Potwar Plateau.

The Tertiary units exposed intermittently over a broad east-west band in the southern Potwar Plateau (the "Soan synclinorium" and "Salt Range monoclinal zone" of Anderson (1927, p. 691)) are structurally compressed into a narrow badland area immediately south and east of the Indus River. These units are more extensively disturbed north and west of the river (Danilchik and Shah, 1976) and the Tertiary fresh-water section of the Shinghar Range is not at all similar to that at Daud Khel or the Potwar Plateau.

Small-scale normal faulting, trending approximately N30E, is common

in the Siwaliks northeast of Ainwan (Fig. 2). Three relatively major parallel faults, striking almost due north, have produced major offsets in the Siwaliks between Mari and Dhingot. A more recent reverse fault, which strikes approximately N30W and extends at least from Jaba Nala to Mari and probably controls Lunai Nala north of the Indus, is the dominant structural feature in the map area. Although obscured by locally contorted bedding and Recent alluvium, vertical displacement along this fault is apparently responsible for the present monoclinal structure of the Tertiary section to the east. Steep eastward dips (50°-80°) are typical of rocks near the fault; gentle northward dips (5°-10°) characterize the Dhok Pathan Formation along the eastern margin of the map area.

Daud Khel Neogene Lithostratigraphic Units

Lithologic descriptions below are based on a measured section through the Daud Khel area. This section is on file with the authors and is to be published in its entirety by the Geological Survey of Pakistan (Hussain *et al.*, 1979). Fig 3 is a diagrammatic condensation of the measured section. The region examined, between Jaba Nala and the Indus River, averages about 5,000 meters in width; this severely limited observations on regional lateral variation. Thus the descriptions focus on the line of section. The formations are distinguished on the basis of percentage differences in grain sizes, other grain characters, development of conglomerate clasts, and color. Fossils are also considered, but only as sedimentary particles. Temporal significance of fossils is not a criterion for defining or recognizing formations. Heavy mineral suites and other factors determinable only by means of petrographic studies are not utilized.

Murree (?) Formation: A thin formational unit which is tentatively identified as lower Murree Formation is exposed in the map area only within one minor wedge (at 32°55′N, 71°37′E) bounded by its contacts with the overlying Kamlial Formation and underlying Eocene unit, a major fault, and alluvial deposits of Jaba Nala.

This formation is 80 meters thick. Approximately 30% of this thickness consists of conglomerate, while 70% is claystone. The conglomerate beds are well-indurated and weather to a moderate yellowish brown.* They have silt to medium-grained sand size matrix and small pebble size clasts. The clasts are fragments of earlier Tertiary sediments, including very frequent reworked Eocene foraminiferans. Because specimens of the Foraminifera weather out of the shales, marls, and limestones in which they were originally contained quite intact, many do not appear redeposited. Although not particularly fossiliferous, the conglomerate beds do contain a few water-worn fragments of bone. In this, as well as in color, thickness and general composition, these conglomerates resemble some conglomerates which occur low in the Murree Formation in the central and northern Potwar Plateau. The claystone units are siltly and show the dusky red color typical of fine-grained Murree Formation sediments else-

*We have found color quite dependable in the recognition of formational units. Standardized according to the Geological Society of American Rock Color Chart, we believe that color is as useful and objective a lithologic feature as, for example, grain size in descriptions of Siwalik units.

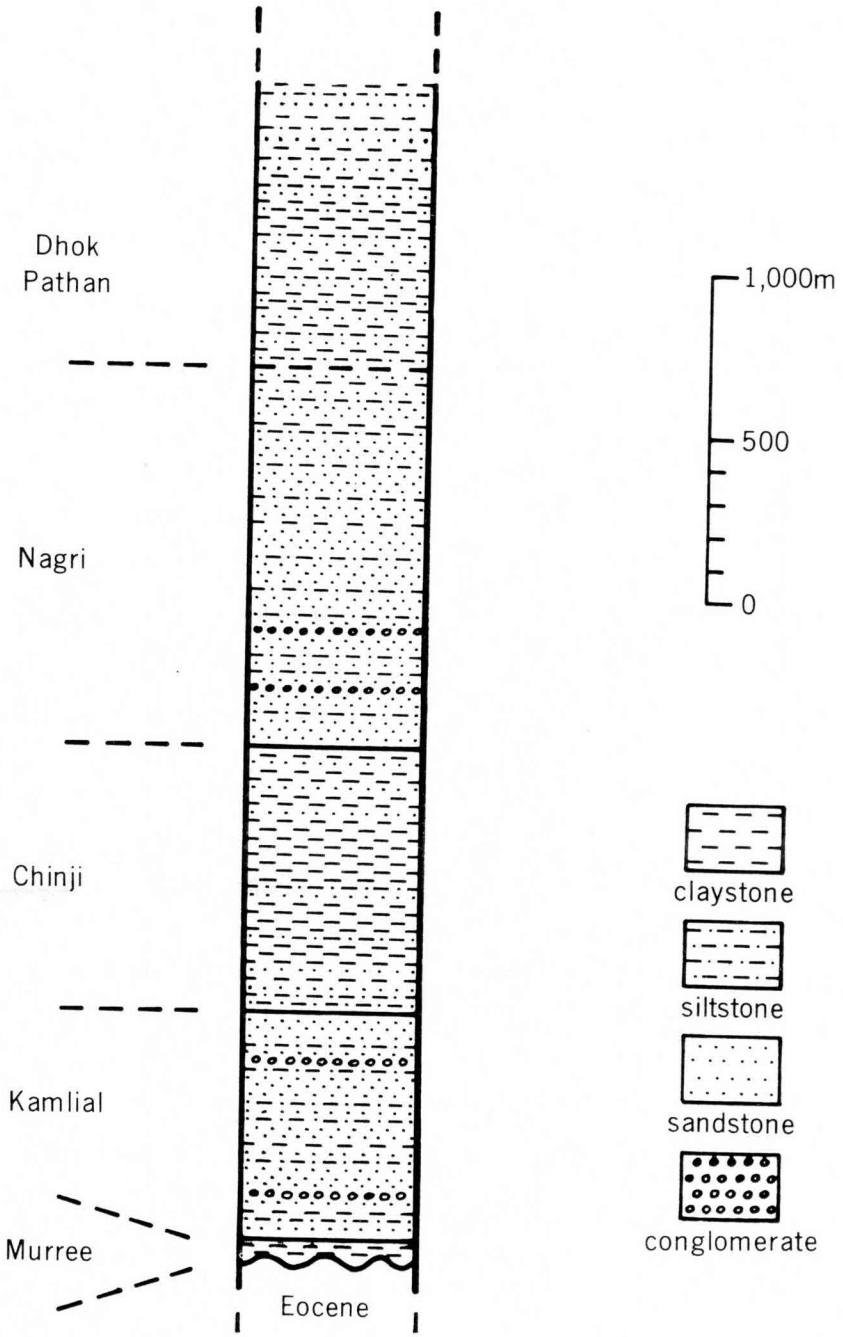

Figure 3. — Diagrammatic columnar section of the Daud Khel Neogene rocks.

where. There are abundant, irregularly oriented gypsum veins in the claystone beds, particularly in the lower units where gypsum may have been derived from the subjacent commercially developed Eocene gypsum deposits.

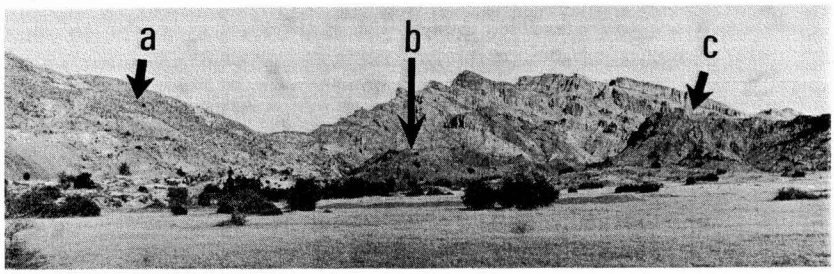

Figure 4.—Lower part of the Neogene section immediately northwest of the PMDC gypsum quarry. a = gypsiferous Eocene limestone; b = (?) Murree Formation; c = Kamlial Formation. The craggy ridge in the background is made up of Nagri Formation on the southwest side of the Ainwan Nala fault.

The single outcrop of this unit (Fig. 4) forms a small hill which is held up by a thick, resistant conglomerate unit. Therefore, both the upper and lower contacts are found in nala bottoms flanking this hill. The lower contact is sharp and unconformable. The top one meter of the underlying Eocene unit is weathered, apparently subaerially, and it contacts the Murree Formation with considerable angular discordance. The upper contact is obscured by alluvium, but the sudden change in color suggests a sharp contact. For reasons given below, we feel that this contact may be a paraconformity; we did not detect angular discordance.

This thin section may be representative of Wadia's (1975, p. 330) lower part of the Murree Formation and possibly of the "Fatehjang Member" (Fatmi, 1974). The presence of foraminiferans as clasts in the conglomerates, dark red clays, and mammal bone, together with the absence of poorly indurated sandstones and plant fossils, suggests that this section was laid down early during the period of Murree Formation deposition and that the upper parts of the formation typically exposed to the northeast were either never deposited at Daud Khel or were removed by erosion prior to the onset of Siwalik deposition. The very limited stratigraphic and areal extent of this unit at Daud Khel preclude extensive comparisons with Murree Formation exposures elsewhere.

Siwalik Group

The Siwalik Group in the Daud Khel area comprises the Kamlial, Chinji, Nagri, and Dhok Pathan Formations. This differs from the grouping of Fatmi who placed the Kamlial Formation together with the Murree Formation in the Rawalpindi Group (1974, p. 57). This arrangement allowed the Kamlial and Murree Formations, which grade into each other in the northern and eastern Potwar Plateau, to be set apart from the Siwalik Group. It has been suggested that there is an unconformity between the Kamlial and Chinji Formations and that this is the only significant unconformity within the units producing the "Siwalik fauna" (e.g. Colbert, 1935,

pp. 9-10). If this were true, it would make Fatmi's separation of the Rawalpindi and Siwalik Groups clear, but such an unconformity does not seem to be present in some places and Fatmi considers the two groups to be conformable.

Although the Rawalpindi and Siwalik Groups provide a lithostratigraphic division for the Tertiary fluvial strata of the central and northern Potwar Plateau, it is not possible to separate the units exposed at Daud Khel in this way. At Daud Khel the only break in the sequence is the possible paraconformity between the Murree (?) and Kamlial Formations. There is clearly no unconformity between the Kamlial and Chinji Formations. In fact, their contact is transitional and must be selected arbitrarily.

When the Daud Khel stratigraphy is placed in a broader regional perspective, it becomes even more difficult to utilize the Rawalpindi Group. Wynne (1880, pp. 229-230) suggested that the dramatic thinning of the Murree beds in the Trans-Indus area might be related to pre-Siwalik disturbance. Wynn probably incorrectly identified dark mudstone beds, which we consider Chinji Formation, as Murree beds throughout the Trans-Indus area and as far southeast as Mari. He also considered the Murree beds to be intimately associated with the nummulitic limestones (apparently *sensu* Anderson, 1927, p. 675), and since the limestone units thin to the west this may have influenced his thinking on the Murree beds. Nevertheless, the Murree Formation does thin abruptly to the southwest of its area of maximum thickness in the northern Potwar Plateau and the unit we tentatively identify as Murree Formation is only 80 meters thick at Daud Khel. It evidently is absent immediately to the north and to the west of Daud Khel. On the other hand, the Kamlial Formation is very thick here. This indicates that the Murree (?) and Kamlial Formations were deposited quite independently of each other and should not be placed within the same group in this area.

We consider the Kamlial Formation as part of the Siwalik Group in the Daud Khel area, but recognize its assignment to the Rawalpindi Group in the northeastern Potwar Plateau. This procedure is not considered by the Stratigraphic Nomenclature Committee of Pakistan (1962), but it is not excluded. The procedure is in accord with the recommendations of the International Stratigraphic Guide (Hedberg, 1976, p. 34) and the American Commission on Stratigraphic Nomenclature (1970, Article 9b,c).

The formations included within the Siwalik Group at Daud Khel were deposited in a relatively uniform episodic depositional regime. They are all conformable; all contacts within the group are transitional and, therefore, placed arbitrarily. The entire sequence is fluvial in origin and consists of alternations of sandstone and finer-grained overbank deposits.

Kamlial Formation: The Kamlial Formation is exposed in one block west of Ainwan. It is bounded by a major fault on the northwest, by contact with the Murree (?) Formation on the southwest (Fig. 4), by a transitional contact with the Chinji Formation on the northwest, and by alluvial deposits of the Jaba Nala floodplain on the south. Throughout this area, the Kamlial Formation is composed of sandstone beds forming long strike

ridges separated by nalas eroded into the intervening soft mudstone beds. A few water gaps are eroded through these ridges.

The Kamlial Formation is 648 meters thick in the Daud Khel area and is 83% sandstone, 17% mudstone. The sandstone units, which are similar to Potwar Plateau Kamlial Formation units described as "gray schist arenites"[1] by Krynine (1937, pp. 427-442), frequently weather to a distinctive dull greenish gray. They are very fine to fine-grained and usually medium bedded. Grain characters are quite variable, but commonly the sandstones consist of moderately to well-sorted and subangular to subrounded grains. Conglomerate beds, mainly incorporating autochthonous clasts[2], are very frequently interbedded with the Kamlial Formation sandstone units. They are not all confined to basal portions in the sandstone sequences and exist both as laterally persistent ridge-forming units and as local pods and lenses. They are seldom more than a few meters thick, and the thicker conglomerate beds tend to be the better indurated units at the top of a number of strike ridges. The clasts are uniformly sedimentary, mostly sandstone, and range in size from small pebbles to cobbles. Most of the clasts are rather well-rounded, apparently having been transported under high-energy conditions. The clasts are frequently weathered and limonitic, giving many of the conglomerate beds a pale yellowish brown color.

Kamlial Formation deposition was basically cyclical, with the conglomerate-sandstone parts of the fluvial cycles dominant over the fine-grained parts. Frequently only sandstone and conglomerate units are present in a well-defined cycle of the Kamlial Formation. This is in marked contrast to the condition seen in the Chinji Formation and, to a lesser extend, to that seen in the Nagri and Dhok Pathan Formations in the Daud Khel area. In this respect, the Kamlial Formation appears to have been deposited under higher energy conditions than the other Siwalik units exposed at Daud Khel.

The fine-grained rocks within the Kamlial Formation section are dominantly siltstones, but there are claystones and some shales. These units are generally grayish red-purple in color. They are slope-forming and are frequently masked in part by talus blocks of the overlying and better indurated sandstones and conglomerates. Gypsum stringers are present in the siltstone and claystone beds. The fine-grained units frequently lack lateral persistence, and slopes between ridge-forming conglomerate units are often composed of laterally altering lenses of siltstone and poorly indurated very fine-grained sandstone beds.

[1]Virtually all of the sandstone in the Daud Khel Siwalik section are sufficiently well sorted and mineralogically limited to be classified as arenites. Wackes are very rare or absent in the section and the only rock name used herein is the simple "sandstone." As detailed petrography is not part of this study, different petrological types of arenite are not referred to here, but "schist arenite" probably does describe most of the sandstones in this section.

[2]These are presumably "pseudoconglomerates" of the type discussed by Krynine (1937, p. 434) which appear frequently in the literature on the Siwaliks. They are true conglomerates, but their clasts are clay-pebbles or other apparently autochthonous sedimentary particles. Conglomerates higher in the Siwalik section tend to have increasing numbers of clearly autochthonous well-rounded igneous and metamorphic clasts. These are sometimes referred to as "true conglomerates" in the literature on the Siwaliks.

The Kamlial Formation rests in apparent paraconformity on the underlying Murree (?) Formation and is conformably overlain by the Chinji Formation at Daud Khel. The lower contact is at the base of the first grayish red purple claystone unit, which contrasts strongly with the upper dusky red claystone unit of the Murree (?) Formation. The mudstone beds above the contact are generally thin, while those below are thick. This contact is obscured by vegetation and alluvium in a nala bottom, but it is apparently sharp and paraconformable. The upper contact with the Chinji Formation is transitional and is arbitrarily placed at the top of the last greenish laterally-persistent sandstone-conglomerate stratum. Above this contact the mudstone beds thicken dramatically and take on a moderate red color and the sandstone units become thin and lenticular.

The Kamlial Formation at Daud Khel is not similar to the stratotype in the Khaur Dome. The stratotype contains approximately 20% sandstone, and 80% mudstone. This stratotype contrasts rather strongly with the usual concept of the Kamlial Formation (e.g. Fatmi, 1974, p. 59) and with the deposits at Daud Khel. The Daud Khel section is very thick for the western Potwar and may, in fact, be the thickest Kamlial Formation section exposed anywhere.

Chinji Formation: The Chinji Formation is exposed in a broad northwest-southeast trending band between Ainwan Nala and the cliffs east of Sumbalanwala (Fig. 2). The formation forms a low-lying badland topography which extends from the Jaba Nala floodplain to the Indus. Another thin wedge of upper Chinji Formation is exposed immediately south of Mari, where it forms the west-facing slope of the nala running southeast from Mari, possibly as far as the north bank of Jaba Nala.

The Chinji Formation section in the Ainwan area is 881 meters thick. This section is 27% sandstone and 73% claystone and mudstone. The sandstone beds, which are more frequent and thicker near both the upper and lower contacts, are generally lenses extending for only a few hundred meters laterally in the middle of the formation. The sandstones are typically very fine-grained with moderately to well-sorted, subangular to subrounded grains. They are usually medium bedded and often show crossbedding. They weather to a pale yellowish brown or gray in contrast to the greener Kamlial Formation sandstones. The sandstone beds in the middle part of the formation are locally indurated and form low ridges.

Where they are well exposed, the sandstone units frequently contain conglomerate beds with sedimentary clasts near their bases. Clay-pebble conglomerate beds and sandstone units with claystone or siltstone pebbles are present. Conglomerate lenses of the "pellet-rock" type are present, in some of the mudstone units. These are quite distinct from the conglomerate lenses in the sandstone beds, being made up of calcium carbonate cemented pellets very similar in lithology to the clay or silt matrix. These deposits tend to be hematitic, very limited in extent (a few meters to a few tens of meters in lateral extent), and fossiliferous. Fossil locality H-GSP 18 (Hussain *et al.*, 1977) is a "pellet-rock" bed. Although the appearance of some "pellet-rocks" suggests an entirely diagenetic origin, the concentration of fossils and contact relations with surrounding mudstones clearly

indicates that these rocks have a distinct mode of deposition.

The sandstone units grade upward into the much thicker siltstone and claystone beds. In most cases, a fining-upward fluvial succession can be followed from a basal conglomerate bed with sedimentary clasts or fine-grained sandstone unit resting on a scoured surface through progressively finer grain sizes into a thick red mudstone bed. The mudstones are most frequently siltstones with minor amounts of silty claystone. They are usually poorly indurated, but calcite veins are locally common and calcium-carbonate cementation results in nodular mudstone and the "pellet-rocks" discussed above. Bedding is obscure in most of the mudstone beds. Although termed "bright-red" or "brick-red" by previous authors who have discussed the Chinji Formation, they are in fact generally moderate red or 5R 5/6 on the Geological Society of America Rock Color Chart (1975) at both Daud Khel and the Chinji stratotype south of Chinji Village.

The Kamlial-Chinji Formation contact is conformable and transitional. It is artitrarily placed at the base of the lowest thick, moderate red mudstone unit. The thinner mudstone beds below are duller in color. The sandstone beds below the contact are better indurated, more laterally persistent, and greener than those above. Sandstone beds become less frequent, thinner and more lenticular above the contact.

The Chinji-Nagri Formation contact is also conformable and transitional. It is arbitrarily placed at the top of the highest thick, moderate red mudstone bed (Fig. 5). The mudstone beds above again become thinner

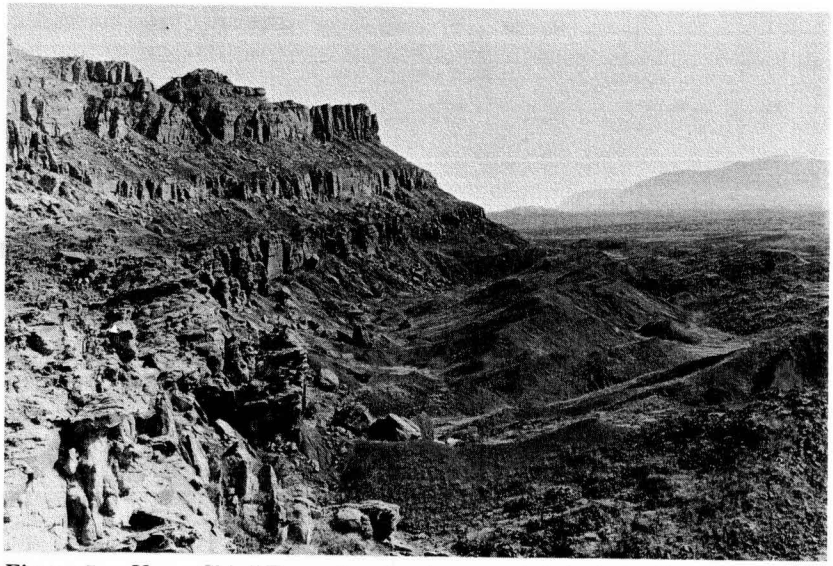

Figure 5. — Upper Chinji Formation claystones overlain by lower Nagri Formation sandstones northeast of Sumbalanwala. Each Nagri Formation cliff-forming unit is one fining-upward fluvial cycle.

and duller in color. Sandstone beds in the upper 200 meters of the Chinji Formation are thicker and more laterally persistent than those below, but they become quite thick, massive, and cliff-forming above the contact. Grain size within the sandstone units increases above the contact, and there is some decrease of sorting and extent of rounding.

The Chinji Formation is the most distinctive and readily identified of the Daud Khel Siwalik units. It is in all respects very similar to the Chinji Formation at its stratotype (Fatmi, 1974, p. 61), which is the most easily recognized of the formations of the Siwalik Group.

Nagri Formation: The Nagri Formation is exposed over much of the central part of the map area between Sumbalanwala and Amir Khan, in the fault-bounded block west of Ainwan Nala, and on the northeast-facing slopes between that fault block and Mari. The latter two outcrop areas have not been studied in detail, although a section has been measured in the block west of Ainwan Nala. The Nagri section in this area has not been correlated with the more complete Nagri section to the east because of its structural complexity. The Nagri exposures immediately southeast of Mari are composed of the lowest part of the formation and show the same transitional contact with the underlying Chinji Formation which is seen northeast of Sumbalanwala (Fig. 5).

The Nagri Formation is 1025 meters thick between Sumbalanwala and Nagha Khel, of which 56% is sandstone and 44% is claystone and mustones. The sandstone units are thick, particularly in the lower part of the formation where they form major cliffs. They are medium to thick bedded and often intensively crossbedded. These sandstone beds are like those of the Chinji Formation in usually being moderately to well-sorted and having subangular to subrounded grains. However, the average grain size is greater in the Nagri Formation, with many beds being medium-grained, especially in the lower part of the formation. The color is generally greenish gray. Except where the sandstone beds form major cliffs in the lower part of the formation, they tend to be variably indurated with a single sandstone unit being expressed topographically as a series of low ledges separated by slope-forming softer sands. As indicated by the overall sandstone-mudstone proportion, sandstone and mudstone units of approximately equal thickness alternate monotonously through the formation except near the base, where sandstone units predominate.

Conglomerates similar to those of the Kamlial Formation frequently are present as basal beds of the sandstone units, but they are not nearly as common in the Nagri Formation as in the Kamlial Formation. In addition, well-rounded igneous pebbles are fairly common in the upper third of the Nagri Formation, sometimes in sufficient numbers to constitute conglomerates.

The fine-grained rocks interbedded with the sandstone beds are mostly clayey or sandy siltstone units. There are no shales. The color of these units is variable, but they are red rather than orange and very dull in comparison with the Chinji Formation mudstones.

The upper and lower contacts of the Nagri Formation are conformable and transitional to the Dhok Pathan and Chinji Formations, respectively.

The lower contact is arbitrarily placed at the base of the first massive, cliff-forming, grayish green sandstone bed. The mudstone beds below this are thick and moderate red, while above they are thinner and duller in color. The contact with the Dhok Pathan Formation is difficult to place, as there is no obvious topographic break, nor is there a noticeable change in the proportions of sandstone and fine-grained rocks. There is, however, a striking color change; the mudstones in the Dhok Pathan Formation are definitely variations of orange in contrast to the red of the Nagri Formation mudstones. Therefore, the upper contact of the Nagri Formation is placed at the top of the highest sandstone bed underlying a distinctly orange mudstone bed.

The Nagri Formation at Daud Khel does not differ in any important respect from either the stratotype (Fatmi, 1974, p. 62) or other well-exposed sections in the southern Potwar Plateau. It contains somewhat less sandstone than some of these sections and is more difficult to separate from the Dhok Pathan Formation at Daud Khel than elsewhere (e. g. the Dhok Pathan Formation stratotype at Dhok Pathan Village where the lower part of the formation has been removed by the Soan River).

Dhok Pathan Formation: The Dhok Pathan Formation is exposed in the eastern part of the map area. It becomes nearly flat-lying along the eastern edge of this area and the top of the formation is not present. The Dhok Pathan Formation sandstone beds are not generally as well indurated as those in the Nagri Formation, with the result that the Dhok Pathan Formation, except for the valleys of Gaud Nala (immediately east of the area of Fig. 2) and Sahni Nala, forms low-lying badlands.

The Dhok Pathan is 778 meters thick in the map area, and is approximately 58% sandstone and 42% mudstone. The sandstone units, which are very similar to those of the Nagri Formation in the lower part, form a higher percentage of the section and tend to become lighter in color and less indurated upward. Conglomerate beds increase in frequency upward and there are well-developed pebble and cobble-beds in the upper part of the section. The fine-grained rocks are yellowish orange claystone and siltstone beds which become thinner and less frequent higher in the section.

The Dhok Pathan Formation rests conformably on the Nagri Formation. The contact is gradational and is best detected by a color change from red below to orange above. The base of the Dhok Pathan Formation is placed at the base of the first light orange mudstone unit. The top of the Dhok Pathan Formation is not present in the map area, and Dhok Pathan Formation exposures are frequently covered by alluvial gravels in the eastern part of the area. These deposits generally show 5° to 10° of angular discordance with the underlying Dhok Pathan Formation but may rest paraconformably on the Dhok Pathan Formation.

The Dhok Pathan Formation section at Daud Khel accords reasonably well with this formation as characterized by Fatmi (1974, pp. 63-64), although it is not as conglomeratic in the upper part nor are the sandstone beds as coarse-grained as Fatmi suggests is typical of exposures along the Indus. The section in our map area is laterally continuous with the section along Gaud Nala which Fatmi (1974, pp. 63-64) has designated as a "princi-

pal reference section" of the Dhok Pathan Formation. The section described here is much better exposed than the Gaud Nala section. Nevertheless, we do not consider it to be divisible into the members suggested by Fatmi for that section. The section at Daud Khel is considerably sandier than the type section at Dhok Pathan village, where only the lower 300 meters of the formation are exposed. The Dhok Pathan Formation is not nearly as coarse-grained at Daud Khel as Gill (1952, p. 389) found it to be along the Indus.

Discussion

The stratotypes of the Murree, Kamlial, Chinji, Nagri, and Dhok Pathan Formations are in the eastern and central Potwar Plateau, between 70 and 160 kilometers from Daud Khel (see Fatmi, 1974; Shah, 1977). Although a multidisciplinary project involving geological mapping, lithostratigraphic correlation and paleontologic correlation is currently underway in the central Potwar Plateau (e.g. Pilbeam *et al.*, 1977), it is not possible to demonstrate surface continuity between the formations at Daud Khel and their stratotypes to the east at this time. The work of Cotter (1933) and our field observations and studies of aerial photographs of the southern and western margins of the Potwar Plateau suggest that the Siwalik units can be traced at the surface throughout most of this region. Detailed mapping of this large area is not within the scope of the present study. Nevertheless, we feel confident in applying the formation names of the eastern and central Potwar Plateau in the Daud Khel area for the following reasons: 1) The formations we recognize at Daud Khel are homotaxial with the formations bearing the same names in the eastern and central Potwar Plateau. 2) Lithologic similarity (grain characters, bedding, color, induration, topographic expression, etc.) is in general quite close between the formations at Daud Khel and the stratotypes to the east. 3) With the exception of the Murree and Kamlial Formations, thicknesses of the formations we recognize at Daud Khel are comparable to thicknesses at the stratotypes.

Certain differences between the formations at Daud Khel and their stratotypes are worthy of note. The Murree (?) Formation, for example, differs markedly in thickness and lithology from both the bulk of the Murree Formation as it is exposed in the Potwar Plateau, and the Fatehjang Member of the Murree Formation, which is well exposed at Chharat Village (Pinfold, 1918). The Kamlial Formation at Daud Khel is quite different from the Kamlial Formation stratotype in its far greater thickness, higher percentage of sandstone, and purple mudstones. The Daud Khel rocks are similar to the Kamlial Formation as it is exposed elsewhere in the Potwar Plateau, such as south of the Chinji Formation stratotype at Chinji Rest House.

The upper part of the Nagri Formation is characterized by multistoried sandstone bodies in much of the central Potwar Plateau. It is easy to differentiate from the overlying Dhok Pathan Formation in this area because the Dhok Pathan contains a much higher percentage of claystone and siltstone. This distinction is not so obvious at Daud Khel, where the shift in sandstone-mudstone percentage is gradual throughout the upper

Nagri and lower Dhok Pathan Formations. The Nagri-Dhok Pathan contact is therefore placed arbitrarily and with less certainty at Daud Khel than in the central Potwar Plateau. Nevertheless, the homotaxial arrangement and overall lithologic character of the units at Daud Khel demonstrate that both formations are present. The Gaud Nala principal reference section of the Dhok Pathan Formation (Fatmi, 1974) is immediately east of our map area.

Analysis of Neogene sedimentary facies changes across the Potwar Plateau, which may yield important data for paleogeographic and paleoecologic studies, must await the completion of detailed studies of Neogene deposits in the eastern and central parts of the plateau. The Daud Khel section reported here provides a Neogene reference section for the western Potwar Plateau for future studies.

Conclusions

1. A 3400 meter thick section of Neogene rocks northeast of Daud Khel compose a westward extension of the Potwar Plateau sequence, with Murree (?), Kamlial, Chinji, Nagri and Dhok Pathan Formations present. Younger rocks apparently extend further northward; the measured section terminated at the Soan-Indus confluence.
2. In most respects Neogene rock units in the Daud Khel area closely resemble their stratotypes to the east. There is, however, some uncertainty in the identification of the Daud Khel Murree (?) Formation and the local Kamlial Formation is considerably sandier than is the Kamlial Formation stratotype.
3. Although the Daud Khel area is mappably contiguous with the Siwalik stratotype area of the central Potwar Plateau, the two areas have not yet been physically correlated. Thus, unexpected lateral variations may distort correlations made here based on physical stratigraphy.
4. The present work constitutes a foundation for subsequent detailed sedimentological studies. Genetic studies of the clastic sediments of the Daud Khel area will greatly enhance understanding of Neogene depositional regimes in Pakistan.

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