CHAPTER VI

PETROGRAPHY

A comprehensive petrographical account of the various rock types comprising the three lithostratigraphic units of the Siwalik Group exposed in the research area forms the subject matter of this chapter. Besides the hand-specimen and thin-section study, a sizable number of samples were subjected to modal analysis including maturity index; and determination of percentage frequency distribution of quartz having different types of crystallinity; extinction; inclusions; and rock fragments. The results are tabulated (Tables 4-8) and represented graphically (Figs. 21-32).

SAMPLING

The sections where the various lithostratigraphic units are exposed in their normal order of superposition were surveyed with the help of tape and Brunton compass. The beds were plotted on 1:2,500 scale. Systematic bed-wise sample collection was made from such measured sections. The collection was supplemented with random samples collected from other parts of the area so as to give the collection a representative character. The sample locations are marked on the geological map (Map 1).
The samples from the Nahan Formation were placed in the NNG (Nahan, Nahan Formation, Gill) and MNG (Morni, Nahan Formation, Gill) series. A total of 142 samples was collected from the measured sections (Maps 2A, 2B). Random samples from the Nahan Formation were placed in different series named after the important localities from the neighbourhood of which the sample collection was made, viz., BNG (Babarwali), GNG (The Ghaggar), JNG (Jauli), KNG (Katli), LNG (Lakes), RNG (The Run), SNG (Sainwala) and TNG (Tekri). The abbreviation 'N' stands for Nahan Formation and 'G' for Gill. In all, 95 random samples were collected.

Systematic samples from the Kala Amb Formation were placed in KKG (Kala Amb, Kala Amb Formation, Gill) and TKG (Kheri Tagrian, Kala Amb Formation, Gill) series. A total of 80 samples was collected from the measured sections (Maps 3A, 3B). The random samples collected from the Kala Amb Formation were placed in JKG (Jhanda, Kala Amb Formation, Gill) series.

The samples collected from the measured sections of the Saketi Formation were placed in KSG (Kala Amb, Saketi Formation, Gill), MSG (Morni, Saketi Formation, Gill), SSG (Sainwala, Saketi Formation, Gill) and TSG (Talokpur, Saketi Formation, Gill) series. A total of 138 samples was collected (Maps 4A, 4D). Random samples from the Saketi Formation were placed in the ASG (Asrewali),
BSG (Bhud), CSG (Churan), DSG (Dhandion), FSG (Ferozpur), GSG (Gobindpur), JSG (Jauli), LSG (Lagnasu), NSG (Nimbwala), PSG (Panchkula) and RSG (The Run) series. In all 156 random samples were collected.

Sample numbers and lithologic units are tabulated in Table 2.

CLASSIFICATION AND NOMENCLATURE

Classification of sedimentary rocks has been attempted either on the basis of petrographic characters (Krynine, 1948, 1950; Pettijohn, 1949, 1954, 1957, 1975; William, Turner and Gilbert, 1954, 1965; and Folk, 1956, 1961, 1968, 1974) or on the essentials of sedimentary structures (Packham, 1954; and Crook, 1960). The school led by Pettijohn and Gilbert considered the composition and the matrix content of sandstones as essential criteria for distinguishing one rock type from another. The view has been supported by Dapples, Krumbein and Sloss (1953), Bokman (1955), Fujii (1962), Dott (1964), Chab (1967), Marchese and Garrasino (1969), Okada (1971), Pettijohn, Potter and Siever (1973) and others.

The Krynine-Folk school proposed that only mineralogical composition is enough to classify sedimentary rocks. The view has been endorsed by Van Andel (1958), Fuchtbauer (1969), Hubert (1960), McBride (1963), Chen (1968) and most of the Russian workers.

No attempt is made in this chapter to suggest yet another classification or to propose another set of names to describe the various rock types. The classification and nomenclature proposed by Gilbert (1965) is adopted, in general, for the petrographic description mainly because it takes into account the entire composition of the rock including cement and matrix and gives due importance to the texture of the rock.
Gilbert (1965) proposed the term 'arenite' for well sorted rocks containing less than 10% of matrix. The rocks containing more than 10% of clay and silt matrix and having poor sorting were termed as 'wacke'. He further suggested that appropriate prefixes and suffixes be put with the above terms to signify the relative amount of quartz, rock fragments and type of cement.

PETROGRAPHIC DESCRIPTION

The various rock types recognised in the Siwalik Group of the research area include conglomerate, arenite, wacke, siltstone and clays/shales. The rocks containing a sizable proportion of worn out fragments coarser than 2 mm diameter are described as conglomerates. The sandstones containing less than 10 per cent of matrix are described as arenites while those containing more than 10 per cent of argillaceous matrix are described as wackes. The arenites have been subdivided into three main types namely quartz arenite, lithic arenite calcareous cement and lithic arenite ferruginous cement. Quartz arenite, as the name signifies, contains a high
proportion of quartz. Lithic arenites contain abundant unstable components and have been distinguished by appropriate suffixes signifying whether the cement is calcareous or ferruginous.

Wackes are subdivided into three main types namely quartz wacke, lithic wacke and lithic wacke pebbly. Wacke containing abundant quartz is designated as quartz wacke. The term lithic signifies that the rocks have a high modal percentage of rock fragments. The lithic wackes containing a significant proportion of coarser clastic fragments but lesser than those of the conglomerates are described as lithic wacke pebbly.

The petrography of siltstone and clays/shales has not been described in detail due to the limitation of the resolving power of microscope. X-ray diffraction study of clays forms the subject matter of the next chapter.

The various petrological types distinguished in the three formations of the Siwalik Group are tabulated in Text Table IV. The order of superposition of the various lithological units is given in Table 1.
## TEXT TABLE V

### LITHOLOGIC UNITS OF THE SIWALIK GROUP

<table>
<thead>
<tr>
<th>NAHAN FORMATION</th>
<th>KALA AMB FORMATION</th>
<th>SAKEHT FORMATION</th>
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<tr>
<td>Conglomerate</td>
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<td>shales</td>
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### NAHAN FORMATION

**Conglomerate**

**Megasconic characters:** In hand-specimens, the rocks exhibit various tints of earthy-pale-brown and pale-grey shades. Subangular to subrounded, granule and pebble-sized fragments of greyish-brown quartzite; pale-grey and greyish-brown sandstones; purple, pale-brown and pale-green shales; buff limestones; dark grey chert; dark grey slate and schists are seen embedded in ferruginous
matter. Presence of sand-sized detrital grains is conspicuous. The rocks show moderate induration. The fragments do not exhibit any preferred orientation.

Microscopic characters: The undecomposed fragments represent such parent rocks as quartz arenite, arenite calcareous cement, arenite ferruginous cement, wacke, siltstone, clays/shales, carbonaceous matter, limestone, slate, schists and polycrystalline quartz (Pl.V, A). The rock fragments constitute 49.3% to 54.1% of the modal composition.

The fragments of quartz arenite, arenite calcareous cement and arenite ferruginous cement make up a small proportion of the coarser clastic components (Table 8). Fragments of siltstones, clays and shales exhibit various tints of purple, pale-brown and pale-green and form the bulk of the sedimentary rock fragments. Carbonaceous matter is present as irregular grains. Rounded to subrounded fragments of limestone constitute 10.1% to 12.7% of the rock fragments (Table 8). Chert is present as coarse sand and granule-sized rounded grains.

Amongst the fragments contributed by metamorphic rocks, quartz-biotite schist, muscovite-biotite schist, carbonaceous schist and the polycrystalline quartz dominate over the other rock types. Purple and pale-grey slates fragments constitute only a small proportion of
the rock. Polycrystalline quartz constitutes 5.9% to 17.9% of the total rock fragments. Quartz-sericite schist and quartz-muscovite schist do not make up more than 5.8% and 3.6% respectively.

Quartz forms the main constituent of sand-sized detrital grains. The mineral grains exhibit angular to subangular outlines. Some of the grains bear inclusions of muscovite, tourmaline and opaque minerals. More than 50% of the quartz grains show undulatory extinction (Table 6A). Quartz and chert constitute a maximum of 33.8% of the rock composition (Table 4). Monocrystalline quartz makes up 82.1% to 88.4% of the medium sand-sized quartz content. Polycrystalline quartz made up of 2 to 3 crystals per grain forms 8.2% to 8.6% while the grains having more than 3 crystals per unit constitute 3.4% to 9.3% of the quartz content (Fig. 21).

Felspars form up to 1.4% of the modal composition and include altered orthoclase, microcline and plagioclase. Minor mineralogical components do not exceed 2.0% of rock composition and comprise zircon, tourmaline, rutile, garnet, epidote, biotite, muscovite, chloritoid, staurolite and dark opaque minerals.

The detrital fraction is impregnated with calcareous and ferruginous matter which make up a maximum of 13.1% and 3.4% of the rock composition respectively. The maturity index varies from 0.49 to 0.64.
Remarks: A high proportion of subangular to subrounded fragments of undecomposed parent rocks is suggestive of rapid erosion and quick and short transport of the detritus. The megaclasts and the sand-sized constituents were deposited in shallow clear waters as is evidenced by the absence of clay fraction and presence of chemical cement. The nature of the fragments indicates that sedimentary and metamorphic rocks were exposed to denudation in the distributive province. The fact is supported by the crystallinity, inclusions and extinction data of the quartz grains.

Quartz arenite

Megascopic characters: The rocks are medium to fine-grained and bear various tints of purplish-brown and greyish-purple. Weathered surfaces, at places, exhibit pale-brown hue. The rocks are well indurated and have sharp edges. Minute flakes of mica remain the only megascopically identifiable constituent.

Microscopic characters: Under the microscope, fine to very fine sand size, subangular to subrounded, well sorted, detrital grains are seen closely packed together imparting a mosaic texture to the rock (Pl.V, B). Most of the rocks have disrupted framework.
Quartz and chert constitute 84.9% to 97.0% of the modal composition (Table 4). A majority of the quartz grains are reorganised into clusters. A significant proportion of the mineral grains exhibit undulatory extinction (Table 6A). Monocrystalline quartz constitutes 61.7% to 73.4% of the quartz content. Polycrystalline quartz having 2 to 3 crystals per grain forms 16.6% to 17.9% and that with more than three crystals per unit makes up 10.0% to 21.2% of the quartz content (Table 5A). More than 89.0% of the quartz grains bear regular, irregular, acicular and globular inclusions of zircon, muscovite, tourmaline and dark opaque minerals (Fig. 27).

Felspars are represented by orthoclase, microcline and plagioclase which together constitute 0.6% to 1.8% of the modal composition. Some of the mineral grains are altered. Rock fragments make up 1.3% to 2.2% of the rock composition and include almost all the parent rocks referred to earlier (Table 8).

The minor mineralogical components make up 0.6% to 6.4% of the rock composition and include zircon, tourmaline, rutile, garnet, epidote, chloritoid/chlorite, biotite, muscovite, staurolite and dark opaque minerals.

Cement is almost negligible. Calcareous matter constitutes 0.5% to 1.6% while ferruginous cement does not exceed 3.0% of the rock composition.
The rocks have the highest maturity index as compared to that of the other lithologic units of the Siwalik Group. The values range between 24.78 and 51.05.

**Remarks:** The high proportion of detrital quartz is suggestive of stable paleotectonic conditions and a slow rate of denudation. The dominance of monocrystalline quartz indicates derivation of a part of the sediments from sedimentary and crystalline rocks. The mineral grains showing undulatory extinction and regular and acicular inclusions are suggestive of the fact that metamorphic rocks were also exposed in the distributive province. The sediments were deposited in shallow clear water as is evidenced by excellent sorting and total absence of clay matrix. The facts are supported by the high maturity index of these rocks.

**Lithic arenite calcareous cement**

**Megasopic characters:** The rocks are well indurated and exhibit greenish-grey, pale-grey and light-grey shades. Mica flakes and dark sand-sized grains can be seen in hand-specimens.

**Microscopic characters:** Medium to very fine sand-sized, subangular to subrounded, well sorted to moderately well sorted detrital grains are seen packed in calcareous
cement. Development of reaction rims at the junction of quartz and carbonate cement is a common feature. Most of the rocks show disrupted framework.

Quartz grains have angular to subrounded outlines. Some of the grains are wedge shaped (Pl.V, C). At places, carbonate cement has penetrated deep into the quartz grains. In some of the mineral grains, microcracks are seen filled with carbonate cement (Pl.V, D).

Quartz along with chert constitutes 44.1% to 67.8% of the rock composition (Table 4). Frequency of monocrystalline quartz varies from 49.5% to 73.4% of the quartz content (Fig. 21). Polycrystalline quartz having 2 to 3 crystals per unit forms 16.5% to 22.4% while that having more than three crystals per unit constitutes 8.8% to 32.1% of the medium sand-sized quartz grains (Table 5A). Quartz grains showing undulatory extinction on less than 5° rotation of the stage form 19.1% to 22.4% while those showing undulose extinction on more than 5° rotation of the stage make up a maximum of 46.1% of the quartz content (Table 6A). Nonundulatory quartz does not exceed 42.8% of the medium sand-sized quartz fraction.

Inclusion free quartz grains constitute up to 14.6% of the quartz content. Quartz grains having regular inclusions make up a maximum of 37.4% while those having irregular, acicular and globular inclusions constitute up to 37.2%, 19.1% and 10.9% of the quartz content respectively (Table 7A).
Felspars constitute 1.7% to 5.8% of the modal composition. The various minerals include orthoclase, microcline and plagioclase.

Rock fragments are coarser than the quartz grains. Subangular to subrounded fragments of undecomposed sedimentary rocks constitute 4.8% to 12.3% while those of metamorphic rocks make up 0.6% to 15.8% of the rock composition (Table 4). The sedimentary rock fragments represent such parent rocks as quartz arenite, arenite calcareous cement, arenite ferruginous cement, wacke, siltstone, clays/shales, carbonaceous matter and limestone. Fragments of purple, pale-brown and pale-green siltstone, clays/shales, carbonaceous matter and limestone constitute the bulk of the sedimentary rock fragments (Table 8). Amongst the fragments contributed by metamorphic rocks, slate is very poorly represented. Quartz-sericite schist, quartz-muscovite schist, quartz-biotite schist, muscovite-biotite schist and carbonaceous schist together form the bulk of the metamorphic rock fragments (Table 8). The fragments of polycrystalline quartz (Pl.V, E) make up 10.0% to 20.4% of the rock fragments (Table 8).

Minor mineralogical components constitute 2.8% to 5.6% of modal composition and include all the minerals referred to earlier. Micaceous minerals form a significant proportion and at places are seen bent along harder non-flaky components (Pl.V, F).
Cementing material is calcareous and forms 12.1% to 30.1% of the rock composition. Ferruginous matter and clay matrix do not exceed 1.4% and 8.0% of the modal composition respectively (Table 4).

Maturity index varies from 1.38 to 5.65.

Remarks: The angular and wedge shaped detrital grains and a high proportion of undecomposed rock fragments suggest closeness of the source rocks and the basin of sedimentation. Presence of carbonate cement indicates chemical weathering and slow rate of denudation which in turn reflects comparatively stable paleotectonic conditions. The nature of the rock fragments indicates that the sediments were derived from sedimentary and metamorphic rocks. The fact is supported by the optical characters of quartz. Development of reaction rims is a diagenetic change and indicates deep burial of the sediments.

Lithic arenite ferruginous cement

Megascopic characters: The rock bear various tints of purple, purplish-grey and greyish-brown. The pigment is distributed uniformly. In some of the samples, however, colour banding is conspicuous. Rocks are moderately indurated. Minute flakes of mica and dark opaque sand-sized grains can be identified megascopically.
Microscopic characters: Well sorted to moderately well sorted, subangular to subrounded, medium to fine sand-sized detrital grains are embedded in dense ferruginous cement. Some of the quartz grains exhibit etched outlines. Most of the rocks have disrupted framework (Pl.VI, A).

Quartz along with chert constitutes 48.4% to 71.8% of the modal composition (Table 4). Monocrystalline quartz forms 51.9% to 77.8% of the medium sand-sized quartz content. Polycrystalline quartz grains having 2 to 3 crystals per unit constitute up to 18.2% and those with more than 3 crystals per grain make up a maximum of 35.6% of the quartz content (Fig. 21). Majority of the quartz grains show strain effects (Table 6A). The amount of the quartz showing undulatory extinction within less than 5° rotation of the stage varies from 20.8% to 26.7% and that showing extinction on more than 5° rotation of the stage constitutes 30.1% to 46.4% of the medium sand-sized quartz grains (Fig. 24).

Only 8.0% to 16.8% of the quartz grains are without inclusions. Rest of the mineral grains bear regular, irregular, acicular and globular inclusions of zircon, tourmaline, muscovite, dark opaque minerals and liquid and gas bubbles.

Orthoclase and plagioclase felspars make up 1.2% to 4.4% of the modal composition. The undecomposed fragments represent the rocks referred to earlier (Table 8). The
sedimentary rock fragments constitute 3.6% to 14.5% while those of metamorphic rocks make up 3.5% to 12.5% of the rock composition (Table 4).

Minor mineralogical components make up 0.9% to 6.4% of the modal composition and include the minerals referred to in other units of the Nahan Formation. Micaceous minerals dominate the mineral assemblage.

Ferruginous cement forms 11.4% to 16.2% while clay matrix does not exceed 4.1% of the modal composition. Maturity index varies from 1.75 to 7.22.

Remarks: Well sorted to moderately well sorted detritus is suggestive of shallow to moderately deep environments of deposition. Presence of ferruginous cement indicates chemical decomposition of the parent rocks. Dominance of purple and brown sediments suggests the prevalence of oxidising environments. Etching of quartz grains is a diagenetic change.

Quartz wacke

Megasscopic characters: The quartz wackes of the Nahan Formation are well indurated rocks bearing purplish-grey, pale-grey and dark-grey shades. Minute flakes of micas and sand-sized dark coloured grains can be seen in hand specimens.
Microscopic characters: Medium to fine-grained, subangular to subrounded, well sorted, detrital grains are closely packed together. The rocks exhibit mosaic texture and disrupted framework (Pl.VI, B).

Quartz and chert constitute 75.8% to 77.9% of the modal composition. Monocrystalline quartz makes up 52.6% to 61.0% of the medium sand-sized quartz content. Polycrystalline quartz with 2 to 3 crystals per unit makes up a maximum of 24.5% while that with more than 3 crystals per grain forms up to 22.9% of the quartz content (Fig. 21). Quartz grains showing nonundulatory extinction make up 29.7% to 40.7% of the quartz content. Undulatory extinction within 5° rotation of the stage is shown by 14.4 to 23.4% while that with more than 5° rotation of the stage is shown by 44.9% to 46.9% of the medium sand-sized quartz grains. Inclusion free quartz constitutes 13.0% to 15.9% of the quartz content. The mineral grains bearing regular, irregular, acicular and globular inclusions make up a maximum of 36.8%, 33.6%, 13.4% and 7.8% respectively (Fig. 27).

Felspars do not exceed 1.2% of the modal composition and include orthoclase and plagioclase. Some of the mineral grains are altered.

The rock fragments in the quartz wacke are more or less the same as noticed in other petrological units described herein earlier. The modal percentage, however, is lower (Table 4). Sedimentary and metamorphic rock fragments do not form more than 1.6% and 0.9% respectively.
Minor mineralogical components constitute 2.3% to 3.8% of the modal composition and include all the minerals recorded in other petrological units.

The cementing material is predominantly argillaceous and constitutes 15.3% to 17.2% of the rock composition. Ferruginous cement forms 1.4% to 1.5% of the modal composition.

The maturity index varies from 22.97 to 33.87.

**Remarks:** Comparatively stable paleotectonic conditions are suggested by high percentage of quartz and maturity index. Crystallinity, extinction and inclusion characteristics of quartz are suggestive of sedimentary and metamorphic provenance. Disrupted framework of the rocks is a result of diagenetic and epigenetic changes.

**Lithic wacke and lithic wacke pebbly**

**Megascopic characters:** The lithic wackes and lithic wacke pebbly bear shades of purplish-grey, pale-grey, pale-green and greenish-grey. The rocks are medium to very fine-grained and show moderate induration. Mica flakes and dark opaque minerals constitute the megascopically identifiable constituents. In the hand-specimens of lithic wackes pebbly, granule and pebble-sized fragments of sandstones, clays and schists can also be identified.
Microscopic characters: Medium to fine sand-sized, well sorted to moderately sorted, angular to subangular detrital grains are packed in clay matrix. Presence of silica and carbonate veins is noticed in some of the sections (Pl.VI, C). Most of the rocks have disrupted framework. Mica flakes show a parallel linear arrangement (Pl.VI, D).

Quartz and chert constitute 43.1\% to 66.2\% of the modal composition (Table 4). Monocrystalline quartz forms 53.0\% to 62.0\% of the medium sand-sized quartz fraction. Polycrystalline quartz constitutes 38.0\% to 46.8\% of the quartz content (Table 5A). Non undulatory extinction is shown by 27.0\% to 44.2\% of the quartz grains while rest of the mineral grains show varying degrees of undulose extinction (Table 6A). Percentage of inclusion free quartz varies from 11.0 to 15.6. The mineral grains bearing regular, irregular, acicular and globular inclusions do not show any marked deviation in their percentage frequency distribution when compared with that of the other petrological units (Fig. 27).

Plagioclase felspars showing polysynthetic twinning dominate the felspars content of these rocks. In some of the rocks, the twin lamellae show microdisplacement (Pl.VI, E). Microcline and orthoclase constitute the other minerals of the felspar group. Most of the mineral grains are altered. Felspars make up 1.1\% to 4.0\% of the modal composition.
The sand-sized and coarser fragments of undecomposed parent rocks make up 9.7% to 32.0% of the rock composition. The sedimentary rock fragments constitute 6.9% to 20.8% while those of metamorphic rocks make up 2.8% to 12.3% of the modal composition (Table 4). Sedimentary rocks are represented by undecomposed fragments of quartz arenite, arenite calcareous cement, arenite ferruginous cement, wacke, siltstones, clays/shales, carbonaceous matter and limestones. Fragments of wacke, siltstone and clays form a significant proportion of the coarser clastic detritus (Fig. 30). The metamorphic rocks are represented by slate, quartz-sericite schist, quartz-muscovite schist, quartz-biotite schist, muscovite-biotite schist, carbonaceous schist and polycrystalline quartz. Fragments of muscovite-biotite schist and polycrystalline quartz dominate the assemblage (Table 8). Some of the schist fragments are seen bent along nonflaky detrital grains (Pl.VI, F).

Minor mineralogical components constitute 3.5% to 7.0% of the rock composition and include the various minerals recorded in the petrological units described earlier. The assemblage contains abundant flakes of muscovite and biotite. The flaky minerals show a parallel linear arrangement. Some of the flakes are bent along quartz grains (Pl.VI, D).

Mechanical clay matrix constitutes the cementing material. In most of the sections, the matrix is seen
reorganised into minute flaky minerals (Pl. VI, E). The matrix forms 10.8% to 20.3% of the rock composition. Ferruginous cement, wherever present, does not exceed 2.8% of the modal composition.

The lithic wackes and lithic wackes pebbly have the maturity index varying from 1.49 to 4.83.

Remarks: The dominance of undecomposed fragments of wackes, siltstones and clays indicates that a major part of the detritus was contributed by sedimentary rocks. Metamorphic rocks were also exposed in the distributive province as is suggested by the optical characters of quartz and presence of fragments of metamorphic rocks. Abundance of rock fragments and clay matrix is suggestive of a fast rate of erosion and short transport. The sediments were deposited in shallow to moderately deep waters. Author's contention is reinforced by the low maturity indices of these rocks.

Incipient development of micaceous minerals, bending of flaky minerals and schist fragments, parallel linear arrangement of micas, microdisplacement of lamellae in felspars and presence of veins are manifestations of the diagenetic and epigenetic changes.
Siltstone, clays/shales

Megascopic characters: The rocks bear various shades of purple, pale-brown, pale-green, greyish-green and grey. Some of the rocks have a patchy look due to irregular distribution of the pigment. Shales show fissility along the bedding planes. Some of the rocks bear laminations and colour banding. Minute concretions of ferruginous matter are noticed in a number of siltstone specimens. The rocks have moderate induration.

Microscopic characters: Under the microscope, most of the purple and brown coloured siltstones and clays show irregular distribution of the pigment. A majority of the rocks bear minute angular to subangular grains of quartz. Lamination is noticed in some of the thin sections. The clay fraction is frequently seen reorganised into minute flaky minerals.

The identification of various clay minerals has been carried out by X-ray diffraction technique (Chapter VII).

KALA AMB FORMATION

Various rock types identified in the Kala Amb Formation include conglomerate, lithic arenite calcareous cement, lithic arenite ferruginous cement, quartz wacke, lithic wacke, lithic wacke pebbly, siltstone and clays.
Quartz arenite is altogether absent in this lithostratigraphic unit of the Siwalik Group. A brief description of each of the petrological units is given herein. The similarities and differences in the petrographical characters of the rocks of the Kala Amb Formation and those of the corresponding units of the Nahan Formation are highlighted in order to make the study more subjective.

Conglomerate

**Megascopic characters:** The rocks bear greenish-grey, greenish-brown, pale-brown and pale-grey shades. Granule to pebble-sized, subangular to subrounded fragments of pale-brown and pale-grey sandstones; pink quartzite; grey and pale-brown shales; buff and pale-brown limestones; and grey schists make up the megaclasts of the conglomerates. The fragments of sandstones constitute a higher proportion than that in the conglomerates of the Nahan Formation. Corresponding decrease is noticed in the fragments of clays. The rocks have moderate induration.

**Microscopic characters:** Granule and pebble-sized fragments of sedimentary and metamorphic rocks are seen embedded in sand and clay-sized components impregnated with ferruginous cement. Fragments of sedimentary rocks constitute 34.5% to 35.0% while those of metamorphic rocks make up 18.1% to 21.3% of the modal composition.
The various types of parent rocks represented by the coarser clastic fraction are the same as noticed in the conglomerates of the Nahan Formation. The modal distribution and the percentage frequency of the fragments, however, show a little variation. Fragments of arenite calcareous cement, arenite ferruginous cement and siltstone constitute a higher proportion of the assemblage as compared to that of the corresponding units of the Nahan Formation. A slight decrease is noticed in the percentage frequency of wackes and clays/shales. So far as the fragments of metamorphic rocks are concerned, a considerable increase is noticed in the percentage frequency distribution of quartz-biotite schist and polycrystalline quartz (Table 8).

The modal distribution of fragments of metamorphic rocks is a little higher in the conglomerates of the Kala Amb Formation than that in the Nahan Formation (Table 4).

Sand-sized detrital grains and clay matrix form the cementing material. Quartz grains have angular to subrounded outlines and constitute 20.1% to 26.6% of the rock composition which is slightly less than the quartz content of the conglomerates of the Nahan Formation (Table 4). The proportion of monocrystalline quartz varies from 67.1% to 77.7% of the medium sand-sized quartz content (Table 5B). About two-third of mineral grains show undulatory extinction (Table 6B). The amount of inclusion-free quartz constitutes
up to a maximum of 15.7% of the quartz content. Majority of the mineral grains bear regular and irregular inclusions (Table 7B).

Felspars make up a maximum of 1.4% of the modal composition and include orthoclase, microcline and plagioclase. Minor mineralogical components do not show much variation. Addition of kyanite is rather significant. The modal percentage varies from 0.5 to 1.2.

Argillaceous matrix constitutes 15.3% to 18.0% of the rock composition. Calcareous cement, so very prominent in the Nahan Formation, is conspicuous by its absence in the conglomerates of the Kala Amb Formation. Ferruginous matter forms 3.1% of the rock composition.

The maturity index varies from 0.36 to 0.49 which is slightly less than that of the conglomerates of the Nahan Formation.

Remarks: The nature of the fragments of undecomposed parent rocks and optical characters of quartz indicate that the provenance of the megaclasts and sand and clay-sized detrital grains was the same during the Nahan (Lower Siwalik) and the Kala Amb (Middle Siwalik) time. As such, the observations made for the conglomerates of the Nahan sequence are broadly valid for those of the Kala Amb sequence. Dominance of clay matrix is suggestive of accumulation of the detritus in muddy environment.
Lithic arenite calcareous cement

**Megascopic characters:** The rocks are medium to fine grained and exhibit various shades of light-grey, greenish-grey, pale-grey and light green. Salt-and-pepper texture is conspicuous in some of the rocks. Induration is moderate to poor. Dark opaque grains and muscovite flakes remain the only megascopically identifiable constituents.

**Microscopic characters:** Angular to subrounded, well sorted to moderately well sorted, medium to fine sand-sized detrital grains are embedded in calcareous cement (Pl.VII, A). Some of the rocks exhibit partly disrupted framework. Development of reaction rims is a common feature to note (Pl.VII, A).

Quartz and chert constitute 48.9% to 67.0% of the modal composition. Some of the mineral grains are fractured. Occasionally, the cracks are filled with carbonate cement (Pl.VII, B). Monocrystalline quartz makes up 48.4% to 69.8% of medium sand-sized quartz fraction which is slightly lower than that of the corresponding unit of the Nahan Formation. Polycrystalline quartz with 2 to 3 crystals per unit constitutes 9.4% to 15.8% while that with more than 3 crystals per grain forms 16.2% to 36.3% of the quartz content. The percentage frequency distribution of quartz grains having 2 to 3 crystals per unit registers a
decline and a corresponding increase is recorded in amount of quartz grains having more than 3 crystals per unit (Figs. 21 and 22).

Inclusion-free quartz constitutes only 9.6% to 17.7% of the quartz content of these rocks. Mineral grains bearing regular, irregular, acicular and globular inclusions form a maximum of 38.0%, 34.5%, 14.5% and 12.4% of the quartz content respectively (Fig. 28).

Feldspars comprising orthoclase, microcline and plagioclase form 0.7% to 6.6% of the modal composition. Most of the mineral grains are altered.

The fragments of undecomposed parent rocks are the same as noticed in the conglomerates of the Kala Amb Formation. Sedimentary rock fragments constitute 2.4% to 19.8% while metamorphic fragments make up 4.3% to 14.0% of the modal composition. Fragments of siltstone, clays/shales, carbonaceous matter and limestone make up a major part of the sedimentary rock fragments. Amongst the fragments of metamorphic rocks, muscovite-biotite schist, carbonaceous schist and polycrystalline quartz form the bulk of the assemblage. A review of the Table 8 reveals that there is slight increase in the percentage frequency distribution of siltstone, clays/shales, carbonaceous matter and carbonaceous schist fragments as compared to that of the corresponding unit of the Nahan Formation.
Minor mineralogical components constitute 0.2% to 5.4% of the rock composition and have nearly the same composition as noticed in the conglomerate. Elongated flakes of muscovite show parallel linear arrangement (Pl. VII, C).

Calcareous cement constitutes 15.4% to 24.3% of the rock composition. Argillaceous matrix and ferruginous matter form a significant proportion of the cement.

Maturity index varies from 1.66 to 4.53.

Remarks: The nature and percentage frequency distribution of the fragments of undecomposed parent rocks is suggestive of the exposure of deeper seated metamorphic rocks having a higher grade of metamorphism to denudation. The fact is supported by the crystallinity, extinction, and inclusion data of the quartz grains. Development of reaction rims at the junction of quartz and carbonate cement indicates deep burial of the sediments. Filling of cracks by carbonate cement must have taken place during diagenesis of the rocks.

Lithic arenite ferruginous cement

Megascoptic characters: The moderately indurated rocks exhibit pale-brown, reddish-brown and purplish-grey shades. Some of the specimens have a patchy look due to irregular distribution of the pigment. Minute flakes of micaceous minerals can be identified in hand-specimens.
Microscopic characters: Moderately well sorted to moderately sorted, subangular to subrounded, medium to fine sand-sized detrital grains are seen embedded in ferruginous cement (Pl. VII, D). Most of the rocks have normal framework.

Quartz along with chert constitutes 55.9% to 68.9% of the modal composition (Table 4). Monocrystalline quartz registers a decline as compared to that of the corresponding unit of the Nahan Formation and makes up 45.3% to 64.5% of the medium sand-sized quartz content. Polycrystalline quartz constitutes a maximum of 54.7% of the quartz content. Quartz grains having 2 to 3 crystals per unit make up 12.3% to 16.7% while those having more than 3 crystals per grain form 22.0% to 38.0% of the quartz content (Fig. 22). Nonundulatory quartz forms 25.0% to 36.8% while the mineral grains showing extinction within 5° rotation of the stage constitute 17.2% to 27.8% and those showing extinction on more than 5° rotation of stage make up 41.0% to 47.2% of the quartz content. Inclusion-free quartz makes up 7.9% to 10.1% of the medium sand-sized quartz. The mineral grains bearing regular, irregular, acicular and globular inclusions form a maximum of 37.2%, 35.2%, 12.7% and 9.8% of the quartz content respectively (Fig. 28).
Felspars are represented by altered orthoclase, microcline and plagioclase. Microcline constitutes a significant proportion of the mineral assemblage (Pl.VII, E). Felspars make up 0.4% to 2.3% of the modal composition.

The undecomposed rock fragments constitute 5.6% to 16.3% of the rock composition. The sedimentary rock fragments make up 1.4% to 13.4% while the fragments of metamorphic rocks form 2.9% to 6.2% of the modal composition (Table 4). Slight variation is noticed in the percentage frequency distribution of the fragments of some of the rock types (Fig. 29). Fragments of arenite ferruginous cement, quartz-biotite schist and muscovite-biotite schist show an increase while those of purple clays, quartz-sericite schist and quartz-muscovite schist show a decline when compared with those of the corresponding unit of the Nahan Formation (Table 8).

Minor mineralogical components include more or less the same minerals as referred to earlier in the other rock types of the Kala Amb Formation. The modal percentage varies from 0.6 to 2.0.

Ferruginous matter makes up the cement and forms 20.9% to 26.1% of the rock composition. Clay matrix does not exceed 2.3% of the modal composition.

Maturity index varies between 3.05 and 9.70.
Remarks: The decrease in the percentage frequency distribution of monocrystalline quartz and the corresponding increase in polycrystalline quartz as compared to that of the corresponding lithologic unit of the Nahan Formation is suggestive of exposure of deeper seated metamorphic rocks to denudation in the distributive province. This is supported by the increased frequency of fragments of quartz-biotite schist and muscovite-biotite schist and a decrease in those of quartz-sericite schist. The pigment of the rocks is suggestive of oxidising environment. High quartz content, maturity index and chemical cement of the rocks indicate stable paleotectonic conditions.

Quartz wacke

Megascopic characters: Moderately indurated rocks exhibit pale-green, greenish-grey and purplish-grey shades. Mica flakes and sand sized dark coloured grains can be seen in hand-specimens.

Microscopic characters: Medium to fine-grained, moderately well sorted, angular to subrounded detrital grains are packed in clay matrix (Pl.VII, F). Some of the rocks have disrupted framework.

Quartz and chert constitute 76.4% to 82.8% of the modal composition. Monocrystalline quartz constitutes 45.4% to 53.0% of the medium sand-sized quartz fraction. In the polycrystalline quartz, grains having more than 3
crystals per unit dominate (Fig. 22). Non undulatory quartz forms 21.3% to 36.1% of the quartz content. Quartz grains showing extinction within 5° rotation of the stage constitute 16.8% to 32.8% while those showing more intense strain effect make up 44.9% to 47.1% of the quartz content (Fig. 25). Inclusion-free quartz make up 6.5% to 11.6% of the quartz contents which is lower than that of corresponding unit of the Nahen Formation (Tables 7A and 7B). Mineral grain bearing regular, irregular, acicular and globular inclusions constitute a maximum of 36.8%, 38.7%, 14.6% and 9.9% of the quartz content (Fig. 28).

Felspars constitute 0.4% to 0.6% of the modal composition and include orthoclase, microcline and plagioclase. Some of the mineral grains are altered.

Undecomposed fragments of sedimentary rocks make up 2.2% to 4.0% while those of metamorphic rocks constitute 0.4% to 3.7% of the modal composition (Table 4). The fragments represent the parent rocks referred to earlier (Table 8).

Minor mineralogical components constitute 2.9% to 3.2% of the modal composition and include almost all the minerals noticed in other petrological units of the Kala Amb sequence.
Reorganised clay matrix constitutes the cementing material and forms 10.0% to 11.2% of the modal composition. Ferruginous cement, wherever present, does not exceed 1.3% of the rock composition.

Maturity index varies from 9.43 to 27.60 and happens to be the highest in the petrological units of the Kala Amb Formation.

Remarks: High modal percentage of quartz and higher maturity index are suggestive of a slow rate of denudation and stable paleotectonic environments. The optical characters of quartz and nature of rock fragments are suggestive of derivation of a major part of the sediments from metamorphic rocks. Reorganisation of clay matrix is a manifestation of diagenetic and epigenetic changes.

Lithic wacke and lithic wacke pebbly

Megascopic characters: The rocks are medium to fine-grained and exhibit pale-grey, greyish-brown and greyish-green shades. Colour of the lithic wacke pebbly depends mainly on the colour of the megaclasts. Induration is moderate to poor. Megascopically identifiable constituents include granule and pebble-sized fragments of pink, purple and pale-grey sandstones, siltstone and clays; buff limestone; dark-grey slate; and light-grey to dark-grey schists. Minute flakes of muscovite and sand-sized dark coloured grains can also be identified megascopically.
Microscopic characters: Subangular to subrounded, well sorted to moderately well sorted, medium to fine sand-sized detrital grains are seen set in reorganised clay matrix. Most of the rocks show disrupted framework (Pl.VIII, A). In the lithic wackes pebbly, granule and pebble-sized fragments make up a sizable proportion of the rock constituents.

Quartz and chert make up 40.5% to 70.8% of the modal composition. Monocrystalline quartz forms 45.0% to 60.2% of the medium sand-sized quartz fraction. Polycrystalline quartz having 2 to 3 crystals per unit forms a maximum of 14.7% while that having more than three crystals per grain constitutes up to 40.3% of the quartz content which is higher than that of the corresponding unit of the Nahan Formation (Tables 5A and 5B). Quartz grains showing undulatory extinction within 5° rotation of the stage constitute 12.6% to 23.9% while those showing extinction on more than 5° rotation of the stage make up 44.0% to 54.2% of the quartz content. Mineral grains free from strain effect form 25.7% to 42.9% of the medium sand-sized quartz fraction. Only 4.4% to 10.6% of the quartz grains are free of inclusions (cf. Nahan Formation). Rest of the mineral grains bear regular, irregular, acicular and globular inclusions (Pl.VIII, B).

Altered microcline, orthoclase and plagioclase make up 0.4% to 4.5% of the modal composition of the rocks.
Undecomposed fragments of sedimentary rocks constitute 6.3% to 25.2% and those of metamorphic rocks make up 3.9% to 16.9% of the modal composition. Fragments of wacke, siltstone, clays/shales, muscovite-biotite schist and polycrystalline quartz are more than those in the corresponding unit of the Nahan Formation (Table 8).

Minor mineralogical components constitute 2.6% to 7.0% of the rock composition and include almost all the minerals noticed in other lithological units of the Kala Amb Formation. Mica flakes constitute a significant proportion of the assemblage and show parallel linear arrangement (Pl.VIII, C).

Cementing material is composed of mechanical clay matrix reorganised into minute flaky minerals. The clay matrix constitutes 10.6% to 18.5% of the rock composition.

Maturity index varies from 0.92 to 6.29.

Remarks: The increase in the amount of rock fragments suggests a faster rate of erosion and a short transport of the detritus. The optical characters of quartz and nature of the rock fragments indicate derivation of a major part of the sediments from metamorphic rocks. Bending of mica flakes, disrupted framework and reorganisation of clay matrix into minute flaky minerals are some of the more prominent diagenetic and epigenetic changes.
Siltstone and clays

Megascopic characters: The rocks have a lower degree of induration than that of the siltstones and clays/shales of the Nahan Formation. Fissility is almost lacking. The rocks bear pale-brown, chocolate, pale-green and pale-grey shades. Some of the rocks contain minute fragments of petrified vegetable matter. Lamination and colour banding is very rare. In some of the rocks, however, distribution of the pigment is irregular.

Microscopic characters: The most conspicuous feature of the siltstones and clays of the Kala Amb Formation is the arenaceous nature of the rocks. Clays invariably contain a sizable proportion of minute angular to subangular grains of quartz. In some of the rocks, clay minerals are seen reorganised into minute flaky minerals. Occasionally, concentration of pigment in irregular shapes is also noticed.

Mineralogy of clays is discussed in Chapter VII.

SAKETI FORMATION

In the Saketi Formation, presence of all the petrological rock types distinguished in the Kala Amb Formation is recorded. Quartz arenite remains conspicuous by its absence. A brief petrographical description of the conglomerate, lithic arenite calcareous cement, lithic
arenite ferruginous cement, quartz wacke, lithic wacke, lithic wacke pebbly and sandy clays is given herein vis-a-vis the corresponding units of the Nahan and the Kala Amb formations.

Conglomerate

Megascopic characters: The rocks are buff, pale-brown and purplish-brown in colour and have poor induration. Subangular to subrounded, granule to pebble-sized rock fragments constitute a significant proportion of the rock constituents. Various types of rocks represented by the coarser clastic components include pink and brown quartzites; pale-green, purple, greyish-purple and grey sandstones; pale-brown, purple and chocolate clays/shales; buff limestone and dark grey chert. The rocks are almost devoid of fragments of metamorphic rocks noticed in the corresponding unit of the older formations. Some of the fragments bear faint striations. Occasionally, the megaclasts show polished surfaces. The fragments are embedded in sand-sized detrital grains and clay matrix.

Microscopic characters: Under the microscope, granule and pebble-sized undecomposed fragments represent such parent rocks as quartz arenite, arenite calcareous cement, arenite ferruginous cement, wacke, siltstone, clays/shales and limestone. Sand-size fragments of slate, various types of
schists, polycrystalline quartz and traps (Pl.VIII, D) also constitute a sizable proportion of the rock fragments (Table 8). The fragments of sedimentary rocks constitute 24.5% to 31.1% while those of metamorphic rocks make up 26.8% to 27.4% of the rock composition. The fragments of basalt, which make their first appearance in this lithostratigraphic unit, constitute 0.4% to 1.6% of the rock composition (Table 4).

Quartz constitutes a sizable proportion of sand-sized detrital grains and make up 26.2% to 31.9% of the rock composition. Monocrystalline quartz constitutes 48.3% to 56.6% of the quartz content which is lesser than that of the conglomerates of the Nahan Formation and the Kala Amb Formation (Table 5). The same holds good for the extinction and inclusion characteristics of quartz grains of the three formations (Table 6 and Table 7).

Felspars constitute 0.9% to 1.9% of the rock composition and include orthoclase, microcline and plagioclase. Most of the mineral grains are unaltered. The minor mineralogical components make up 1.4% to 1.7% of the modal composition. The mineral assemblage comprises zircon, tourmaline, rutile, garnet, epidote, muscovite, biotite, chlorite, staurolite, kyanite, sillimanite and dark-opaque minerals. Kyanite was absent in the Nahan Formation while sillimanite was missing in the mineral assemblage of the Kala Amb Formation.
Sand-sized detrital grains and clay matrix act as cement. The matrix makes up 10.8% to 12.2% of the rock composition. Ferruginous matter, wherever present, does not exceed 1.2% of the modal composition.

The maturity index of the conglomerates varies from 0.44 to 0.61.

Remarks: Dominance of granule and pebble-sized fragments of quartzites, sandstones, clays/shales and limestone indicates a sedimentary provenance for the megaclasts. The sand, silt and clay-sized particles, however, were also contributed by metamorphic rocks as is evidenced by the presence of sand-sized fragments of schists and polycrystalline quartz. Traps were exposed to denudation in the distributive province of the sand-sized detrital grains. The source rocks had a higher grade of metamorphism as is evidenced by the presence of sillimanite. Unaltered felspars are suggestive of a climatic change during the deposition of the conglomerates of the Saketi (Upper Siwalik) Formation. Development of striations and polished surfaces of some of the megaclasts are indicative of glacial transport.

Lithic arenite calcareous cement

Megasopic characters: The rocks bear light-grey, greenish-grey and salt-and-pepper shades and show moderate to poor
induration. Micaceous minerals and dark coloured sand-sized grains constitute the megascopically identifiable constituents.

**Microscopic characters:** Subangular to subrounded, medium to fine sand-sized, very well sorted to well sorted detrital grains are seen closely packed in calcareous cement (Pl.VIII, E). Some of the rocks have disrupted framework (Pl.VIII, F).

Quartz and chert constitute 45.0% to 54.8% of the modal composition. Some of the mineral grains bear microcracks (Pl.IX, A). Etching of quartz grains and development of reaction rims at the junction of carbonate and quartz is a common feature (Pl.IX, B).

Monocrystalline quartz constitutes 47.1% to 65.3% of the medium sand-sized quartz fraction. Polycrystalline quartz having 2 to 3 crystals per unit and that with more than 3 crystals per grain form up to 12.5% and 44.0% of the quartz content respectively (cf. Nahan and Kala Amb formations). Quartz grains showing non-undulatory extinction do not exceed 31.4% of the quartz content. Mineral grains showing extinction within 5° rotation of the stage and more than 5° rotation of the stage constitute 21.7% and 68.1% of the quartz content respectively. A slight decline is noticed in the percentage frequency of non-undulatory quartz and a corresponding increase is recorded
in the frequency of the mineral grains showing extinction on more than 5° rotation of the stage when compared with the extinction characteristics of the quartz grains of the corresponding unit of the Nahan and the Kala Amb formations. Inclusion-free quartz grains make up 3.9% to 13.2% of the quartz content. The mineral grains bearing regular, irregular, acicular and globular inclusions constitute a maximum of 35.8%, 38.1%, 16.1% and 11.7% of the quartz content respectively.

Felspars are represented by orthoclase, microcline and plagioclase which together constitute 0.2% to 2.3% of the modal composition.

Sedimentary rock fragments make up 6.1% to 16.4% while those of the metamorphic rocks constitute 2.3% to 7.3% of the modal composition. Fragments of traps constitute a maximum of 2.8% of the rock composition. The sedimentary fragments represent such rocks as arenite calcareous cement, arenite ferruginous cement, wacke, siltstone, clays/shales, carbonaceous matter and limestone while those of metamorphic rocks include slate, quartz-sericite schist, quartz-muscovite schist, quartz-biotite schist, muscovite-biotite schist, carbonaceous schist and polycrystalline quartz.

Minor mineralogical components do not show much variation in the mineral assemblage when compared with that of the conglomerates of the Saketi sequence. Such
minerals make up 2.9% to 8.8% of the modal composition. Muscovite and biotite flakes show parallel linear arrangement. At some places, the flaky minerals show bending along non-flaky detrital grains.

Calcareous cement constitutes 20.9% to 30.8% of the rock composition. The cement, in some of the rocks, has penetrated deep into quartz grains. Development of reaction rims is frequently noticed.

Maturity index varies from 2.22 to 4.64.

Remarks: Dominance of carbonate cement is suggestive of moderate to slow rate of denudation and sedimentation. The nature of the rock fragments and optical characters of quartz are suggestive of derivation of a major part of the sediments from sedimentary and metamorphic rocks. Development of reaction rims at the contact of quartz and carbonate cement, etching of quartz by carbonate, parallel to sub-parallel alignment of mica flakes, bending of micas and disrupted framework of the rocks are manifestations of epigenetic and diagenetic changes the rocks have undergone.

Lithic arenite ferruginous cement

Megascopic characters: The rocks are medium to fine-grained and exhibit various tints of purplish-grey, greyish-green and pale-purple shades. The pigment, in
most of the rocks, is differentially distributed. Induration is poor. Minute flakes of micas and sand-sized opaque grains can be seen in hand-specimens.

**Microscopic characters:** Well sorted to moderately well sorted, subangular to subrounded, medium to fine sand-sized detrital grains are embedded in dense ferruginous cement (Pl.IX, C). In some of the rocks, especially those from the vicinity of tectonic junctions, brecciation and clustering of detrital grains is noticed (Pl.IX, D). Such rocks have disrupted framework.

Quartz and chert constitute 43.4% to 69.2% of the rock composition. Monocrystalline quartz grains make up 50.2% to 54.5% of the medium sand-sized quartz fraction. A maximum of 12.3% of the quartz grains are made up of 2 to 3 crystals per unit. Mineral grains having more than 3 crystals per grain make up 33.2% to 38.6% of the quartz content.

Quartz grains free from strain effects constitute 26.7% to 52.9% of the quartz content. The mineral grains showing undulatory extinction within 5° rotation of the stage form up to 20.1% and those showing extinction on more than 5° rotation of the stage make up a maximum of 56.6% of the quartz content. Inclusion-free quartz constitutes 4.1% to 10.2% of the quartz fraction. Mineral
grains bearing regular, irregular, acicular and globular inclusions do not exceed 34.6%, 38.1%, 16.2% and 10.2% of the quartz content respectively.

A comparative study of crystallinity, extinction and inclusions in quartz of the lithic arenite ferruginous cement of the three formations reveals that in the Saketi Formation, monocrystalline quartz constitutes a far lower percentage while polycrystalline quartz having more than 3 crystals per unit registers a corresponding increase. Non undulatory quartz also shows slight increase in the Saketi sequence. Inclusion-free quartz forms the lowest proportion in the lithic arenite ferruginous cement of the Saketi Formation (Figs. 21-29).

Felspars form only 0.3% to 1.8% of the modal composition. Microcline and plagioclase remain the more common minerals. Most of the mineral grains are fresh.

Rock fragments show better rounding and are coarser than the rest of the detrital components. Sedimentary rock fragments constitute 3.8% to 20.6% while the metamorphic rock fragments make up 1.3% to 10.0% of the rock composition. Fragments of volcanic rocks do not exceed 3.7% of the modal composition. The undecomposed fragments represent the parent rocks referred to earlier in other petrological units of the Saketi Formation. The statistical data reveals that the fragments of arenite
calcaneous cement, siltstone, clays/shales and polycrystalline quartz register a considerable increase in the Saketi Formation as compared to those of the corresponding lithological unit of the Nahan and the Kala Amb formations (Table 8).

Minor mineralogical components make up 1.7% to 4.4% of the modal composition and include more or less all the minerals mentioned earlier.

Ferruginous cement constitutes 16.2% to 26.4% of the rock composition. In some of the rocks, clay matrix is seen associated with the ferruginous cement. The matrix does not exceed 3.2% of the modal composition. In one sample, calcaneous cement forms 1.2% of the rock composition.

Maturity index varies from 1.67 to 7.13.

Remarks: The comparatively higher percentage of undecomposed rock fragments in the lithic arenite ferruginous cement of the Saketi Formation (cf. Nahan and Kala Amb formations) suggests a faster rate of denudation. The nature of the rock fragments and optical characters of quartz indicate sedimentary, metamorphic and volcanic provenance. The detritus, after short transport, was deposited in shallow oxidising environment as is evidenced by purple hue of the rocks. Brecciation of the detrital grains and disrupted framework are attributed to local slumping and faulting.
Quartz wacke

**Megascopic characters:** The quartz wacke are poorly indurated, pale-brown to pale-grey rocks. Weathered surfaces have a lighter hue. The rocks crumble down on application of a little pressure. Minute flakes of muscovite and dark-brown sand-sized grains can be seen in hand-specimens.

**Microscopic characters:** Medium to fine-grained, angular to subrounded, well sorted detrital grains are seen closely packed in clay matrix (Pl. IX, E). Some of the rocks have disrupted framework.

Quartz and chert make up 69.5% to 70.9% of the modal composition. Monocrystalline quartz forms up to 50.9% of the medium sand-sized quartz fraction. Quartz grains showing non-undulatory extinction form 14.3% to 22.1% of the quartz content. Mineral grains showing undulatory extinction within 5° rotation of the stage make up 17.9% to 19.8% while those showing extinction beyond 5° rotation of the stage constitute 58.1% to 67.8% of the quartz content. Most of the quartz grains bear inclusions of muscovite, biotite, tourmaline and dark opaque minerals.

Only 8.2% to 16.1% of the mineral grains are free of inclusions. Mineral grains bearing regular, irregular, acicular and globular inclusions make up the maximum of 37.1%, 33.4%, 14.2% and 10.5% of the quartz content respectively.
A comparative study of the crystallinity, extinction and inclusion of quartz constituting the quartz wacke of the three formations of the Siwalik Group reveals that monocrystalline quartz forms the lowest proportion of the quartz fraction of the Saketi Formation (Figs. 21-23). A considerable increase is noticed in the mineral grains showing extinction on more than 5° rotation of the stage (Figs. 24-26) and those bearing globular inclusions (Figs. 27-29).

Felspars constitute 0.5% to 1.9% of the rock composition and include microcline, orthoclase and plagioclase. A majority of the mineral grains are unaltered. Sedimentary rock fragments make up 6.6% to 8.2% while those of metamorphic rocks do not exceed 4.2% of the modal composition. Volcanic rock fragments make up only 0.2% to 0.4% of the rock composition. The decomposed rock fragments do not show much variation from those of the corresponding petrological unit of the Nahan and the Kala Amb formations in so far as the types of the parent rocks are concerned. Total absence of fragments of quartz arenite, limestone and slate and addition of fragments of volcanic rocks, however, is conspicuous. Some variations is noticed in the percentage frequency distribution of the fragments in the three formations. The fragments of siltstone, clays/shales, muscovite-biotite schist, and polycrystalline
quartz register an appreciable increase in the Saketi Formation while those of carbonaceous matter and quartz-biotite schist make up a lower proportion. Distribution of the fragments of other rock types does not show any marked change (Table 8).

Minor mineralogical components constitute 1.9% to 3.4% of the rock composition and include almost all the minerals recorded in the other petrological units of the Saketi Formation.

Clay matrix forms 10.5% to 17.0% of the modal composition. Ferruginous cement constitutes a negligible proportion of the rock composition.

Maturity index of the rocks varies from 3.87 to 6.65.

Remarks: Mineralogical characteristics of the detrital quartz grains and nature of the rock fragments are suggestive of derivation of a major part of the sediments from metamorphic rocks. Author's contention is supported by the statistical data such as lower percentage values of monocry stalline quartz, and a higher proportion of quartz grains showing extinction on more than 5° rotation of the stage. The higher percentage of quartz grains bearing globular inclusions indicate greater contribution of sediments by crystalline and volcanic rocks. The abundance of fragments of such fragile rocks as siltstone, cleys/shales indicates a short transport of the detritus.
Lithic wacke and lithic wacke pebbly

**Megascopic characters:** The rocks have moderate to poor induration and exhibit various shades of pale-grey, steel-grey, light-grey and pale-brown. Some of the rocks bear salt-and-pepper shade. In the lithic wacke pebbly, granule and pebble-sized fragments of pale-grey and purple sandstones and siltstones; disc-shaped fragments of purple, pale-brown and pale-green shales; dark-grey slates; light-grey to dark-grey schists; and milky white quartz can be identified in hand-specimens. Minute flakes of muscovite and dark-opaque grains remain the only identifiable constituents constituting the sand-sized fraction of these rocks.

**Microscopic characters:** Medium to fine-grained, well sorted to moderately well sorted, subangular to subrounded detrital grains are seen packed in clay matrix. Some of the rocks have disrupted framework (Pl.IX, P). Occasionally, parallel linear arrangement of micas is also seen.

Quartz and chert form 40.0% to 54.3% of the modal composition. Monocrystalline quartz constitutes 46.6% to 57.3% of the medium sand-sized quartz content. Rest of the mineral grains show varying degrees of polycrystallinity. Quartz grains showing undulatory extinction within 5° rotation of the stage do not exceed 21.2% while those showing more pronounced strain effects form 37.4% to
54.3% of the quartz content. Inclusion free quartz constitutes the maximum of 14.5% of the quartz fraction. Quartz grains bearing regular inclusions constitute 30.8% to 36.2%, irregular inclusions 30.9% to 34.1%, acicular inclusions 10.9% to 14.6% and globular inclusions 7.7% to 12.9% of the medium sand-sized quartz fraction.

A review of the optical characters of quartz grains reveals that non-undulatory quartz forms a higher proportion of the lithic wacke and lithic wacke pebbly of the Saketi Formation as compared to that of the corresponding lithological unit of the older formations (Figs. 24-26). This is attributed to the contribution of a part of the mineral grains by volcanic rocks.

Microcline showing cross-hatched twinning, plagioclase exhibiting polysynthetic twinning and orthoclase constitute 0.6% to 4.1% of the rock composition. A majority of the mineral grains are unaltered.

Sedimentary rock fragments constitute 8.2% to 18.5% while fragments of metamorphic rocks make up 6.0% to 19.6% of the modal composition. Fragments of volcanic rocks constitute only 0.3% to 3.0% of the rock composition. More common fragments of sedimentary rocks are those of arenite calcareous cement, arenite ferruginous cement and clays/shales. Muscovite-biotite schist and polycrystalline quartz are comparatively more prominent amongst the
fragments of metamorphic rocks. The volcanic rock fragments are represented by traps (Table 8).

Minor mineralogical components form 2.6% to 8.4% of the modal composition and include almost all the minerals noticed in other lithological units of the Saketi Formation. In some of the rocks, flaky minerals constitute a major proportion of the mineral assemblage. Occasionally, mica flakes show parallel linear arrangement. Some of the flakes are bent along quartz grains.

Clay matrix forms 10.0% to 16.6% of the modal composition. Incipient development of flaky minerals is a common feature. In some of the rocks, ferruginous cement makes up 1.2% to 2.8% of the rock composition.

The values of maturity index range between 1.19 and 2.74 (Table 4).

Remarks: The high proportion of undecomposed fragments of the parent rocks in the lithic wackes of the Saketi Formation coupled with higher modal distribution of clay matrix and low maturity index reveal mechanical mode of weathering of the source rocks and a fast rate of denudation. The dominance of the fragments of such fragile rocks as clays/shales and schists indicates a short transport. The grade of metamorphism of source rocks was a little higher as compared to that of the Nahan and the Kala Amb formations as is evidenced by the presence of sillimanite.
Disrupted framework, bending of mica flakes and their parallel linear alignment and reorganisation of clay matrix in to flaky minerals are manifestations of diagenetic and epigenetic changes.

Sandy-clays

_Megascopio characters_: The sandy-clays show the lowest degree of induration when compared with that of the siltstone clays/shales of the Nahan and the Kala Amb formations. The rocks are very poorly cemented and highly friable. The sandy-clays bear various tints of light-brown, pale-brown, greyish-brown, pale-green and pale-grey shades. Pigment distribution in some of the rocks is irregular. _Megascopically identifiable constituents_ include granule and sand-sized grains and minute flakes of micas.

_Microscopic characters_: Presence of angular to subangular, very fine sand and silt-sized grains of quartz remain the most conspicuous feature of these rocks. Some of the rocks contain coarse sand and granule-sized fragments also. Pigment distribution in most of the rocks is irregular. Clay minerals are generally devoid of incipient recrystallisation.

Mineralogy of the clays of the Siwalik Group is discussed in the next Chapter.