4. **PETROGRAPHY**

1. **Metavolcanics**

   **A. Basic**

   The basic metavolcanics have an extremely fine grained groundmass of devitrified glass with dominantly tremolite needles and blades, subordinate amounts of plagioclase microlites, chlorite flakes, epidote granules, a little quartz and variable amounts of carbonate. Within the groundmass, plagioclase and tremolite occur as phenocrysts. Larger grains of chlorite, epidote and rarely muscovite also occur as metamorphic alteration products.

   Plagioclase: The lamellar twinning identifies the extremely fine grained plagioclase in the groundmass. Their extreme fine grain-size and the high degree of alteration in most of the larger grains make their specific identification difficult. In a few, relatively fresh felspar grains, the refractive indices are almost equal to that of Canada Balsam, thereby suggesting a composition near to oligoclase. The long slender laths of felspar microphenocrysts forming banded structure with tremolite blades may represent quench-crystals (Pearce and Birkett, 1974).

   Tremolite: It usually occurs as thin, slender laths or blades, often feathery in form or as radiating clusters. It is colourless, with positive sign of elongation; extinction angle is 22° with elongation. No relict of pyroxene from which the amphibole might have been derived could be found.
Chlorite : It is pale greenish coloured, feebly pleochroic in shades of pale green, with straight extinction, negative elongation and low birefringence; sometimes abnormal interference colours are also seen.

Epidote : It usually occurs as aggregates of small, colourless granules with high refractive index and high birefringence.

The basic volcanics are mostly massive showing a texture resembling intersertal texture in which large tremolite needles take the place of felspar laths and have decussate arrangement within a glassy groundmass (Fig. 4.1). The microphenocrysts of plagioclase laths also show random orientation. At many places, the tremolite shows clusters of radiating needles, often skeletal or feathery (Fig. 4.2). A series of parallel, alternating layers of tremolite and felspar forms a number of interfering bundles (Fig. 4.3), which resemble primary quench structures as described by Viljoen and Viljoen (1969b) and Pearce & Birkett (1974). Pearce and Birkett (1974) interpreted this type of structure (clusters of radiating hornblende crystals, locally skeletal, in an otherwise equigranular hornblende-plagioclase basalt) in Archaean metabasalts of Thackerey Township, Ontario, as a product of quenching in which rapid growth rate of crystals from the liquid due to quick cooling causes skeletal or feathery form of crystals. While Pearce and Birkett definitely expressed view against the metamorphic origin of these radiating amphibole, Viljoen and Viljoen (1969b) mentioned two
possibilities about the origin of the coarsely crystalline amphibolites containing large actinolite needles in Barberton type basaltic komatiite of Onverwacht Group — growth during the period of regional greenschist metamorphism under condition of greater volatile activity or growth during subaqueous extrusion of the lava due to rapid cooling or quenching in presence of water. It is not possible to choose between the two alternatives for the present area on the basis of textural criteria only.

The massive type, at places contain well developed spherules consisting of radiating aggregates of very fine fibrous antigorite with a little altered felspar and epidote granules (Fig. 4.4). The spherules are set in a very fine grained cryptocrystalline mosaic of slightly devitrified glass. Vesicles filled with quartz and epidote granules have been noted both within the spherules and the host rock.

The pillowed types have the same petrography and texture as the unpillowed massive type. In one case, the rim of the pillow has been noted to have a more felsic composition consisting of relatively coarse grained aggregates of quartz and felspar within a devitrified glassy matrix of dominantly epidote and chlorite.

The massive volcanics, at many places contain pea-shaped spherical nodules or varioles. These varioles are composed of randomly oriented microphenocrysts of dominantly tremolite needles and subordinate plagioclase laths set in a very fine
grained devitrified glassy groundmass showing granular aggregates of epidote, tremolite and a little carbonate. The varioles are set in a matrix which is dominantly made of tremolite needles and blades, a little chlorite, epidote and fine-grained intergranular quartz. The varioles have a more glassy base while the matrix of the rock is more tremolite-rich. The varioles often show a tremolite-rich concentric layer (similar to the matrix-composition of the rock) near their peripheral rim (Fig. 4.5). These varioles may represent initially spherical volcanic lapilli.

Due to metamorphism and deformation, the various basic volcanic rocks have been converted into chlorite schists, consisting almost entirely of thin chlorite flakes and films with a little quartz, sphene, rutile and opaques.

The schistose and the massive types of basic rocks are impregnated with carbonate to various degrees in different places. Intensely carbonated rocks contain only carbonate with a little chlorite.

**B. Acid**

Some lighter coloured rocks occur associated with the schistose metavolcanics. In these, the proportion of chlorite is comparatively small and within the fine grained groundmass of quartz, devitrified glass, chlorite flakes and patches, and sericite films, occur coarse lath-shaped pseudomorphs, probably after plagioclase, of muscovite and a little chlorite. Rarely relatively less altered
feldspar grains are also present (Fig. 4.6). These laths have a sub-parallel arrangement. This type probably represents original acid or intermediate volcanics. They could not be mapped separately in the field and constitute a small proportion of the metavolcanics which are dominantly of basic type.

C. Pyroclastics

Based on the size of the volcanic fragments the pyroclastics can be divided into two groups — (i) Lapilli tuff (fragments < 4 mm.) and (ii) Agglomerate (fragments > 4 mm., < 32 mm.).

(i) Lapilli tuff: Lapilli tuffs in this area are generally vitric tuff as the ejected fragments are essentially devitrified glass-pieces. In many areas, it is welded vitric tuff and coarse, angular, spindle-shaped to irregular fragments and shards of volcanic glass are welded together by a matrix of similar glassy material. Under microscope, the fragments are seen to be composed essentially of devitrified glass with epidote granules and some fine fibres of chlorite/amphibole. The fragments and glass shards are set in a groundmass of similar composition in which there are chlorite flakes, epidote granules, glassy material and a little quartz. The groundmass shows flow texture and the glass shards show a sub-parallel alignment (Fig. 4.7). Rarely, a few fragments having cryptocrystalline mosaic of quartz-felspathic material show concentric rims or bands formed by green chlorite flakes (Fig. 4.8) or by slightly devitrified buff-coloured glass (Fig. 4.9).
Though the fragments in the tuff are dominantly glassy, subhedral crystals of felspar and epidote have also been noted in some of the tuffs along with glass-fragments (Fig. 4.10). However, as the proportion of crystal-fraction compared to the glass-fragment is low, the term crystal tuff cannot be used for these rocks.

At places, the fragments in the tuff are accretionary lapilli having small spheroidal or ellipsoidal shape with thin light coloured peripheral rims. The lapilli are glassy, devitrified into fine grained aggregates of quartz and chlorite with long slender laths of plagioclase. The central part of the lapilli shows alternate laminations consisting of slender laths of plagioclase and chlorite aggregates (Fig. 4.11). The long slender laths of plagioclase probably represent quench-crystals. The light coloured outer rims are more felsic in composition and at times these are found to be richer in carbonate and epidote grains. These might have formed by accretion of material on the surface of lapilli-nuclei during their rolling over fresh ash-surface (Pettijohn, 1975, p. 304). Rims of green chlorite have been noted occasionally, around the outer rims of some of the lapilli (Fig. 4.12). The matrix of the rock is similar in composition to the core of the lapilli.

Due to effect of deformation and metamorphism the fine grained pyroclastics have been converted to tuffaceous schists. These are essentially chlorite schists with small ellipsoidal or irregular devitrified glassy fragments and amygdules (Fig. 4.13). The groundmass of the rock is made up dominantly of chlorite flakes, with subordinate quartz, epidote granules and a little biotite flakes.
(ii) Agglomerate: It is made of large, circular, spindle-shaped, discoidal or irregular light coloured fragments which probably represent original volcanic bombs. The fragments are composed of glass, either partially or fully devitrified, crypto-crystalline aggregates of quartz and chlorite with sphene and zircon as accessories.

The proportion of quartz to chlorite in the fragments are variable. The abundance of quartz is probably due to extreme silicification during devitrification and these bombs may represent materials from acid or intermediate type of pyroclastic ejecta in which such silicifications are usually common (Williams, Turner and Gilbert, 1969, p. 157). In rare instances, smaller fragments are contained within a large fragment. This indicates polyphasic eruptions of volcanic materials in the present area. Rarely, chlorite rims have been noted around the quartz-chlorite mosaic of the fragment. This probably represents differentiation of the ejected fragments in fluid state. The matrix of the rock is chlorite schist and is subordinate in proportion to the fragments present in the rock.
2. Metasediments

A. Conglomerates

The K.M.Kere conglomerate represents an epiclastic deposition of largely volcanic materials. The chief pebbles of this conglomerate are volcanic bombs and lapilli which are typical of the nearby agglomerate beds (pyroclastic deposits). The presence of detrital fragments of b.f.q., basic rocks, quartzite, clastic grains of quartz and the pelitic nature of the matrix help to establish their epiclastic rather than pyroclastic origin. Though most of the earlier workers (Srinivasan & Sreenivas, 1968; Zianddin, 1975; Iyengar, 1976) including Naqvi and Hussain (1972) did not report the presence of a large amount of volcanogenic material in the conglomerate, Swami Nath et al. (1976), identified the tuff-admixed nature of parts of the K.M.Kere conglomerate.

Under the microscope, the following types of fragments have been recognised:

(i) Volcanic bombs and lapilli having rounded, oval, spindle or irregular shape. They are composed essentially of a fine grained aggregates of quartz and chlorite with a little sericite, biotite flakes and films, sphene, rutile and opaque ore. The proportion of chlorite varies greatly in different fragments and it occurs as fine flakes, patches and thin films; quartz grains have sutured outline. The opaques are concentrated in small zones in some of the fragments. In one fragment, fine grains of rutile are found to form lenticular streaks.
(ii) Quartzite fragment with a mosaic of polygonal quartz grains.
(iii) Single crystals of quartz
(iv) Fragments essentially composed of chlorite with a little quartz
(v) Partially devitrified glass.

The matrix of the conglomerate is generally an aggregate of chlorite, sericite, biotite with a little quartz. At places, the matrix is a bit arenaceous being composed of a fine grained quartzose mosaic with a little chlorite and sericite. Clots with radially arranged chlorite are sometimes present in the matrix. Schistosity and later crenulation cleavage are well developed in the matrix. The matrix shows lamination only where the proportion of fragments is low.

The conglomerate lenses, south of the U-shaped closure of southern ferruginous quartzite band are slightly different from the linear K.M.Kere conglomerate, east of K.M.Kere village. The former lacks any glassy fragments and bedding is very conspicuous in the outcrops. There is no pyroclastic horizon nearby and therefore they probably represent true sedimentary conglomerate beds.

B. Argillites, Slaty rocks, Pelitic and Semipelitic schists

The argillites associated with the banded ferruginous quartzite consist of sericite, clay minerals and very fine grained quartz. At places, it is rich in ferruginous material containing
chiefly iron and clay minerals. In the slaty rocks, the proportion of quartz is relatively high and the slaty cleavage is better developed than those in the argillites.

The more schistose varieties of the metasediments can be broadly grouped into two types on the basis of relative abundance of chlorite, sericite and quartz. In one type, (chlorite-quartz schist or phyllite) the chief constituent is chlorite followed by quartz, sericite and muscovite. Films of biotite also occur parallel to the schistosity. Clastic grains of quartz and aggregates of quartzose mosaic are common. In one instance, coarse chlorite patches encircled by sericite films are found.

The variation in the proportion of the constituent minerals gives rise to a fine lamination in the rock. In many cases, alternate dark and light coloured bands are found; the dark bands are made mainly of chlorite with subordinate quartz and sericite while light coloured bands are composed of a fine grained quartzose mosaic with sericite and a little chlorite. The abundance of chlorite probably points to the presence of basic volcanic debris in the depositional basin and the rocks may represent largely volcanogenic sediments.

The D.T.A. of six samples of this schistose rock show large endothermic peak at temperatures between 120°C to 130°C (see Table 4.1). This, together with staining test using three different coloured dyes, malachite green, crystal violet and benzidine, (Table 4.2), confirms the major clay mineral to be
Table 4.2

Results of staining test of the samples studied

by D.T.A.

Nature of treatment of the samples with different dyes:

1. To a few mgs. powdered, acid (dil. HCl)treated sample, after heated to dryness, added a few drops of Malachite green dye.

2. To similarly treated sample, added Crystal violet dye separately.

3. To a few m.gm. powdered, raw sample, added a few drops of benzidine (10% solution in alcohol)

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Type of dye used.</th>
<th>Change in colour of the dye.</th>
<th>Inference</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>Malachite green</td>
<td>(a) Yellowish brown with</td>
<td>Montmorillonite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Bluish green spots ...</td>
<td>Kaolinite</td>
</tr>
<tr>
<td>247</td>
<td></td>
<td>Greenish yellow ...</td>
<td>Montmorillonite</td>
</tr>
<tr>
<td>257</td>
<td></td>
<td>Light blue ...</td>
<td>Montmorillonite</td>
</tr>
<tr>
<td>343</td>
<td></td>
<td>same as sample No. 257 ...</td>
<td></td>
</tr>
<tr>
<td>456</td>
<td></td>
<td>same as sample No. 257 ...</td>
<td></td>
</tr>
<tr>
<td>7C</td>
<td></td>
<td>same as sample No. 257 ...</td>
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</tr>
</tbody>
</table>
montmorillonite. The presence of dominantly montmorillonite clay suggests derivation of the material from a basic source.

In another type, the proportion of quartz and sericite is greater than that of chlorite. These are essentially quartz-sericite schists; some biotite also occur as thin films; opaques are almost invariably present; clusters of rutile have been noticed. The quartz-sericite aggregate usually forms a fine grained mosaic, but in a few cases, the grains are coarser. The relative proportion of quartz and sericite varies and some rocks are almost quartzitic while others are sericite-quartz schists. This variation is responsible for the compositional banding in the rock. Coarse clastic quartz grains and lenticular quartzose aggregates have also been found as in other types.

C. Banded Ferruginous Quartzite

The silica bands are composed either wholly of quartz or mixed with variable proportion of iron-minerals. The quartz is fine grained, elongated with sutured to polygonal outline. The ferruginous band is made of iron oxide mixed with various proportion of quartz grains. In the ferruginous band, the following mineral assemblages have been recorded:

i) Magnetite (martite) - lepidocrocite/goethite - quartz

ii) Specularite - quartz

The earliest iron mineral has been identified as magnetite. Most of the ferruginous bands are composed of euhedral to subhedral
and anhedral grains of magnetite (Fig. 4.14). Finer grains have euhedral shape and the outline usually gets irregular with increasing coarseness, the coarser grains being usually anhedral. The magnetite grains are altered to martite in various degrees along the octahedral planes (martite appearing as needles within unaltered magnetite) or along the grain boundaries. Sometimes, through core-replacement of the grains, a central patchy martitized part is seen to be surrounded by the marginal unaltered magnetite. The conversion of magnetite to martite is usually partial. However, in some cases, the martitisation process is so extensive that only a few relict patches of magnetite are present.

At places, there are ferruginous bands composed wholly of specularite without any remnant magnetite or martite (Fig. 4.13). The specularite is fine grained, lath shaped. Rarely stout squarish forms have also been noticed.

Secondary iron-minerals include goethite and lepidocrocite. In many instances, the martite has been hydrated to form goethite.

The variation in the oxidation states of the iron-minerals in different bands (Ferric in the specularite band and Ferrous in the magnetite band) can be attributed to either of the two reasons:

(1) The specularite bands and the magnetite bands represent original variation in oxidation state of the original sedimentary precipitate.
(2) Alternatively, the specularite may be formed later from the magnetite during metamorphism in presence of water vapour. In a water bearing system, the original mineral magnetite will change to hematite according to the following reaction:

\[ 2 \text{Fe}_3\text{O}_4 + \text{H}_2\text{O} \rightarrow 3 \text{Fe}_2\text{O}_3 + \text{H}_2 \]

In a closed system, where the hydrogen formed by this reaction cannot escape, the \( \text{PH}_2 \) will go on increasing (i.e., \( \text{PO}_2 \) decreasing) and soon equilibrium will be attained after conversion of requisite quantity of magnetite into hematite. But if the \( \text{H}_2 \) escapes out of the system, conversion of magnetite to specularite may proceed to completion. So presence of certain specularite-bands free from any magnetite grains within magnetite-bearing bands may suggest movement of fluid phase along certain layers producing specularite layers, while in other bands water was deficient and magnetite remained unaltered. The haphazard or random orientations of the laths of specularite, suggests that crystallization of specularite took place in post tectonic stage.

**Mafic Intrusives:**

These are medium grained dolerite or coarse grained gabbro. Those consist dominantly of pyroxene and plagioclase.

**Plagioclase:** Coarse, euhedral to subhedral, laths to tabular shape; lamellar twinning, symmetrical extinction angle ranging from 22° to 28° indicates composition in labradorite-andesine range. In many cases, the plagioclase is partly to completely altered to saussuritic materials and epidote, muscovite etc. In gabbroic rock, the very coarse grained felspar phenocrysts are completely altered.
Clinopyroxene: Subhedral, pale yellowish coloured, non-pleochroic; Interference Colour second order green, extinction angle 34° to 42°. The pyroxene is, in many cases, altered partly or completely into tremolite, chlorite or aggregates of chlorite and biotite.

Small amount of fresh quartz as intergranular anhedral grains is present. In one instance, the quartz and the felspar form intergrowth texture.

Epidote, carbonate and opaques (including leucoxene grains) occur as accessories.

The plagioclase laths are partially or completely enclosed by pyroxene blades and plates (or by its altered pseudomorphs) giving rise to sub-ophitic texture.

In one specimen, coarse blades and plates of clinopyroxene are set porphyritically in a chloritic groundmass. Felspar is absent but a few quartz grains are present. Pyroxene is altered into tremolite and chlorite. This represents an ultramafic variation of the intrusive gabbro-dolerite family.

Felsite:

Under the microscope it shows a groundmass of essentially quartzose mosaic with chlorite flakes and patches, sericite, muscovite, epidote, calcite (at times in abundance) and opaque ores.
Within the groundmass, there are lath shaped pseudomorphs formed by chlorite or chlorite-sericite aggregates. These probably represent original felspar laths in the rock (Fig. 4.16). In a few cases, comparatively unaltered plagioclase laths (albite) have also been found. The sub-parallel arrangement of the flaky minerals and the laths has given rise to a crude planar fabric in the rock.