CHAPTER 3

PETROGRAPHY

In order to understand the true petrological nature of the Jasrapura, Gorwala and Gothara granitoids, detailed megascopic and microscopic petrographic investigations have been carried out including the determination of their quantitative mineralogical compositions using a Swift Point Counter. The Amphibolites and metadolerites, that occur within these granitoids, have been included in such petrographic studies. Likewise, the country rocks in the immediate vicinity of the granitoids have also been examined in order to get a broad overview of their petrographic nature.

The chapter follows the layout and nomenclature of the lithological units already outlined in Chapter 2. However, in some cases, the lithological units comprise more than one petrographic entities, which have, therefore, been described as separate sub-units (Table 3.1).

3.1. Alwar Group

3.1.1. Mica schist

Mica schist, which forms the lowermost unit of the Alwar Group in the area, is medium to coarse grained, dark greenish black in colour and is well foliated.

In the thin sections, the rock is medium to coarse grained. Parallel to sub-parallel alignment of biotite and muscovite flakes, alternating with quartz rich layers define the foliation. The main minerals comprising the mica schist are quartz, biotite, muscovite and plagioclase while apatite, zircon, tourmaline and magnetite occur as accessories.
Table 3.1. Petrographic units of the rocks encountered around Khetri, North Khetri Copper Belt, Rajasthan

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Quartz occurs as xenomorphic to subidiomorphic grains. The smaller crystals are usually subidiomorphic, elongated in the direction of foliation and exhibit preferred optic orientation. The porphyroblasts of quartz are xenomorphic having serrated and fused outlines. These crystals exhibit wavy extinctions and at times the development of Bohem’s lamellae.

Biotite forms the main flaky mineral in the rock. It occurs in the form of lepidoblastic flakes defining the main foliation. It is greenish brown in colour and shows pleochroism from straw yellow (=X) to light brown (=Y) to brown (=Z) i.e. Z≥Y>X. Minor amount of biotite also occurs as porphyroblastic plates obliquely superimposed on the foliation.

Muscovite occurs as colourless, prismatic flakes defining schistosity along with biotite. It shows bright second order interference colour and straight extinction.

Plagioclase (An10-25) occurs in subordinate amount compared to quartz and micas. Subidiomorphic crystals of plagioclase occur along with flattened quartz grains defining arenaceous layers in the schist. Both untwinned and twinned crystals of plagioclase are observed and the twinning is largely based on albite law.

Apatite occurs in the form of idiomorphic, prismatic and basal grains commonly associated with micas. Zircon, occasionally zoned, occurs as colourless to honey yellow idiomorphic crystals with well developed crystal outlines showing high relief, straight extinction and high interference colours. Inclusions of zircon within biotite have well developed pleochroic haloes. A few scattered grains of blue coloured tourmaline and black magnetite are also observed in the mica schist.

3.1.2. Feldspathic quartzite

Megascopically, the rock is medium to coarse grained, hard and compact, cream to bluish grey in colour, highly recrystallised and vitreous.

Microscopically, the rock is medium to coarse grained and shows granoblastic texture. The quartz and feldspar grains are often stretched in the direction of subdued foliation imparted by minute flakes of sericite, muscovite and biotite. To the southern
side of Jasrapura granitoid, near the faulted contact between quartzite and schist and near the breccia zones surrounding the Gothara and Gorwala granitoids, the quartz grains in the quartzite exhibit granulation and fused grain boundaries. The main minerals of the rock are quartz, plagioclase, muscovite, sericite and biotite. The accessory minerals include zircon, apatite and iron oxide, which is mainly hematite.

**Quartz** is present as subidioblastic to xenoblastic crystals. The small, subidiomorphic grains, which form bands and layers, impart a banded appearance to the rock. These grains show clear extinctions and preferred optic orientation. The porphyroblasts of quartz, which are xenomorphic, exhibit serrated and fused grain boundaries and undulose extinction. Development of Bohem’s lamellae is quite common in porphyroblasts of quartz.

**Plagioclase** (albite-oligoclase) occurs as subidioblastic crystals, which are aligned in the common direction of stretching in the rock. Both twinned and untwinned crystals of plagioclase are present, the former grains most commonly exhibit albite twinning. Plagioclase at places appears cloudy due to alteration.

**Muscovite** and **sericite** are the main flaky minerals, although they are present in very small amount. They are interleaved with occasional flakes of **biotite**. Sericite is largely secondary having been formed by the alteration of plagioclase. Numerous idiomorphic prismatic and basal grains of **apatite** are dispersed throughout the rock. **Zircon** is present as idiomorphic crystals showing high relief, zoned interference colours and straight extinction. **Hematite** is the main opaque mineral, which often alters to brownish red and orange yellow secondary **limonitic** material.

### 3.1.3. Ferruginous quartzite

Depending on whether the dominant iron-oxide mineral in the rock is hematite or magnetite, two varieties of ferruginous quartzite have been recognised, i.e. hematite quartzite and magnetite quartzite (Chapter 2). Petrography of these two variants is described here together.
In the field and in handspecimens, the hematite quartzite is ochre brown in colour, medium to coarse grained and equigranular. It is characterised by alternate 1 mm to 2 cm thick quartz rich and hematite rich bands. The magnetite quartzite, occurring to the west of Gothara, is also medium to coarse grained and equigranular, but brownish black to dark black in colour and banding in it is less conspicuous. The former gives brown streak and the latter gives black streak. Quartz and hematite (in the former) or magnetite (in the latter) are the main constituents, besides minor amount of plagioclase and accessory tourmaline, apatite and zircon. The overall texture of the rock is granoblastic.

**Quartz** generally forms equant and polygonal, subidiomorphic, close-packed grains depicting a crude preferred optic orientation. Some large xenomorphic grains of quartz are strained and exhibit undulose extinction and occasional Bohem’s lamellae. Strain effects and marginal granulation of quartz are common in the magnetite quartzite near Gothara due to its proximity with the breccia zone.

**Plagioclase** (albite-oligoclase) occurs in very subordinate amount in the form of small subidiomorphic laths in the intergranular spaces between quartz grains. It is generally twinned on albite law or untwinned.

**Hematite**, in hematite quartzite, occurs as discrete grains, often concentrated in alternate layers. These opaque grains show feeble reddish brown fringes. **Magnetite** is the main iron oxide mineral in the magnetite quartzite. Its jet black, idiomorphic crystals are distributed throughout the rock. Both hematite and magnetite show minor alteration to orange yellow limonite, which fills the fractures and intergranular spaces. **Tourmaline, apatite** and **zircon** occur infrequently as accessory minerals.

### 3.1.4. Amphibole quartzite

The amphibole quartzite is a banded rock in which bands of leucocratic, feldspathic quartzite are interlayered with melanocratic, greyish green amphibole-chlorite-epidote rich layers. Due to alternation of leucocratic and melanocratic layers the rock often gives a gneissic appearance and where the layering is fine, it gives a
tuffaceous appearance to the quartzite. In samples from thick-banded rock, layering cannot be deciphered on microscopic scale.

In thin sections, the rock is medium to coarse grained and crystalloblastic in texture. The main minerals constituting the rock are quartz, plagioclase and amphibole, besides minor amounts of allanite, epidote, sphene, zircon and iron oxides.

**Quartz** is present as subidioblastic to xenoblastic, polygonal, closely packed crystals. The smaller, subidioblastic quartz grains form bands and are characterised by preferred orientation and uniform extinctions. The large crystals have xenomorphic outlines and exhibit undulose extinctions. Occasionally, inclusions of small quartz grains are also observed within the amphiboles.

**Plagioclase** of albite-oligoclase composition occurs as subidioblastic to xenoblastic crystals. Most of the crystals are untwinned but albite twinned crystals are also present. The plagioclase crystals generally occupy intergranular spaces between the quartz grains and exhibit preferred morphological alignment along with those of quartz. Some of the grains are sericitised.

**Amphibole** occurs as small to medium sized prismatic laths throughout the rock. Although the amphibole laths do not generally show any preferred orientation, some small prismatic crystals, aligned parallel to quartz rich layers, exhibit a crude foliation. Prismatic crystals, with one set of (110) cleavage show extinction (Z ^ C) in the 13°-30° range while basal sections, with two sets of rhombic cleavage, show symmetrical extinction. Pleochroism varies from bluish green (=Z) to green (=Y) to greenish yellow (=X), i.e., Z>Y>X.

**Epidote** occurs as rims around allanite, as discrete grains and clusters of grains in association with amphiboles probably forming therefrom, and as a few, small, grains associated with sericitised plagioclases resulting from its decalcification. **Sphene** and **zircon** form euhedral grains besides occurring as inclusions in the amphiboles. Some crystals of zircon are metamict and pleochroic haloes are well developed around allanite.
and zircon inclusions in amphiboles. Crystals of jet black magnetite are infrequently observed in the rock.

3.2. Ajabgarh Group

3.2.1. Metavolcanics

The mafic metavolcanics not only form a thick horizon at the Alwar-Ajabgarh interface, but they are also interlayered with the Alwar amphibole quartzite and Ajabgarh schists. In the present state they are of the nature of massive to crudely foliated amphibolites, which are fine to medium grained and dark green to greenish black in colour. However, at places they have been converted to actinolite-biotite schists.

In thin sections, these rocks are crystalloblastic and fine to medium grained. The prismatic laths of amphiboles form decussate structure without any preferred orientation. Relict ophitic to subophitic texture is quite common in which laths of plagioclase are wholly or partially enclosed within the amphiboles (Fig. 3.1a). The main constituents of the rock are amphiboles and plagioclase besides variable amounts of sphene, epidote and magnetite. Quartz occurs in very minor amount, apatite and zircon are the main accessories and minor sericite is the alteration product of plagioclase.

**Amphibole** occurs as prismatic laths and broad tabular crystals of actinolitic hornblende, showing one set of (110) cleavage. It commonly forms a criss-cross, decussate structure. Rhombic sections with two sets of (110) cleavage also occur less frequently. Pleochroism varies from X=light greenish yellow and Y=light green to Z=bluish green with absorption Z>Y>X. Interference colours are generally of middle to upper first order and extinction angles (Z \( \times \) C) range from 15° to 25°.

**Plagioclase** (An\(_{34-42}\)) occurs as subhedral laths and tabular crystals either partially or wholly enclosed within or in-between the amphibole crystals. Some of these are untwinned, but most of the crystals exhibit albite, albite-pericline and carlsbad-albite twinning and feeble zoning. Occasionally, plagioclase shows minor alteration to epidote and sericite.
Quartz is present in a couple of thin sections in extremely small or negligible amount. It occurs as small anhedral to subhedral grains in-between the plagioclase grains or as small inclusions in amphiboles. Some quartz grains show undulose extinction.

Epidote forms small euhedral to subhedral crystals showing medium to high relief and feeble pleochroism from nearly colourless to faint pale yellow. It shows anomalous lemon yellow and sky blue interference colours and inclined extinction. It generally forms clusters associated with amphiboles and are derived from the latter. However, minor amount of colourless epidote is also formed from plagioclase.

Independent grains or granular aggregates of sphene are associated with amphibole and epidote. It also forms trails along the cleavages of amphibole. Sphene shows very high relief, feeble pleochroism from colourless to light pinkish brown and high order interference colours. At times it contains small cores of magnetite. It is developed from amphiboles.

Magnetite is the common opaque mineral dispersed throughout the rock. At times it forms symplectic intergrowth with amphibole in which these two minerals are intergrown in parallel bands in two or three directions. Apatite and zircon occur as euhedral crystals in accessory amount and small flakes of secondary sericite occasionally form criss-cross pattern in plagioclase.

The marginal parts of the thick lenses and lenticular sheets of metavolcanics and their thin layers occurring within the Ajabgarh schists have often been converted to actinolite-biotite schist.

The schistosity in these rocks is well defined by the nearly parallel alignment of actinolite and biotite, but some transverse laths of actinolite are also present. The light greenish yellow to bluish green actinolite with $Z \wedge C=15^\circ-20^\circ$, has almost the same optical properties, as described above. The light brownish yellow to greenish brown biotite is an essential mineral in this schist. Chlorite, interleaved with biotite, is very subordinate. Quartz is also insignificant in amount, but plagioclase (An$_{28-34}$), though
Fig. 3.1a. Relict ophitic to subophitic texture in metavolcanics exhibited by laths of plagioclase enclosed in amphiboles (XN).

Fig. 3.1b. Relict andalusite crystal in an aggregate of sericite and quartz in andalusite schist (XN).

Fig. 3.1c. Long acicular and twinned laths of cummingtonite superimposed on chlorite imparting hornfelsic texture to the garnet-actinolite-biotite-chlorite schist (XN).

Fig. 3.1d. A cordierite porphyroblast containing inclusions of chlorite, quartz, magnetite and biotite in garnet-actinolite-biotite-chlorite schist (XN).

Fig. 3.1e. A staurolite crystal containing inclusions of quartz and magnetite (XN).

Fig. 3.1f. Development of tremolite-actinolite containing relict islands of carbonate, and of grossularite (isotropic) in marble (XN).
less than biotite and actinolite, is an important constituent. It forms untwinned as well as albite-twinned, subhedral, tabular crystals in which feeble zoning can be occasionally deciphered. At times, it is mildly turbid due to alteration. Magnetite is a common opaque mineral dispersed in the rock. Zircon andapatite occur as accessories, whereas sphene and epidote are sporadic and occasional.

3.2.2. Pelitic schists

Pelitic schists form a thick and conspicuous unit of the Ajabgarh Group of the Khetri Copper Belt. Different varieties of schists, encompassing the whole range of greenschist to amphibolite facies metamorphism, have been reported by the earlier workers (vide Chapter 2). Field observations and examination of samples collected by the author, however, revealed three main varieties of schists, namely, andalusite schist, mica schist and garnet-actinolite-biotite-chlorite schist. The slivers of garnet-actinolite-biotite-chlorite schist occurring within the metavolcanics at times contain sporadic cummingtonite, cordierite and staurolite.

3.2.2.1. Andalusite schist

The andalusite schist forms a conspicuous rock type in the pelitic schist horizon of the Ajabgarh Group of this belt. It is developed in the lower part of the pelitic schists often immediately overlying the metavolcanics or the amphibole quartzite.

The rock is medium to coarse grained and shows porphyroblastic texture due to the profuse development of andalusite crystals. Prismatic crystals of andalusite (chaistolite) generally range from 3 cm to 6 cm, at times up to 10 cm, in length and from about 1 mm to 3 cm in cross-section (Fig. 2.6f, Chapter 2). The squarish cross-sections exhibit dark crosses formed by carbonaceous and ferruginous inclusions, which run all along the axes of the prismatic crystals.

In thin sections, the rock is medium to coarse grained. Large crystals of andalusite, in the relatively finer matrix of quartz and micas, impart porphyroblastic texture to the rock. Schistosity is well developed due to parallel to sub-parallel alignment of biotite and muscovite and morphological and optic alignment of quartz.
grains. Andalusite crystals are mostly disoriented and transversely superimposed on foliation indicating their later development. The main mineral constituents of the rock are quartz, muscovite, biotite, chlorite and andalusite. Minor minerals include tourmaline, apatite, epidote, zircon, opaques and sericite.

**Quartz** occurs as subidiomorphic to xenomorphic crystals. The smaller grains are generally subidiomorphic, polygonal and close-packed in layers alternating with micaceous minerals. Larger crystals are xenomorphic having serrated outlines and showing undulose extinction.

**Biotite** occurs in the form of lepidoblastic, prismatic flakes defining schistosity and as broad porphyroblasts transversely superimposed on the main schistosity. It is pleochroic from greenish brown to brown and shows 2°-3° extinction.

**Muscovite** occurs as small prismatic flakes showing one directional cleavage associated with biotite and chlorite and contributes to the schistosity of the rock. However, some broad flakes of muscovite are also obliquely superimposed on the schistosity. Muscovite shows bright second order interference colours and strain extinction.

**Chlorite** occurs in the form of nearly colourless to light green flakes interlayered with biotite and muscovite parallel to the main foliation. Small quantity of chlorite occurs as an alteration product of biotite. It shows anomalous pale grey interference colours and 2°-5° extinction.

**Andalusite (chaistolite)** occurs as nearly colourless crystals. The squa

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more or less complete pseudomorphs giving only vague idea of the morphological outlines of the erstwhile andalusite crystals. Inclusions of carbonaceous/ferruginous material occur in the form of fine dusty aggregates. At some places the minute sericite flakes have recrystallised to larger flakes of muscovite.

Sericite is of secondary origin occurring in the form of minute flakes, which are mostly clustered together with quartz to form large pseudomorphs after andalusite. Green to greenish brown idiomorphic crystals of tourmaline, subidiomorphic, colourless to faint yellow crystals of epidote, euhedral grains of apatite and zircon and squarish grains of magnetite are dispersed throughout the rock.

3.2.2.2. Mica schist

Megascopically, the mica schist is medium grained, soft, dark greenish black in colour and foliated.

In the thin sections, the rock is medium to coarse grained, well foliated due to sub-parallel alignment of the flakes of biotite. The rock also shows porphyroblastic texture due to the presence of augen shaped aggregates of quartz and feldspar grains, which are often, arranged en-echelon with the schistosity. The essential mineral constituents are quartz, biotite and plagioclase while the accessory minerals include zircon, tourmaline and opaques.

Quartz crystals of two different types have been observed in the rock. The first type includes small equant grains with uniform extinctions. The second type includes large porphyroblasts of quartz with xenomorphic outlines and showing undulose extinction that have probably been formed due to recrystallisation of earlier smaller quartz grains.

Biotite occurs as lepidoblastic flakes and broader plates having brownish yellow colour. It is pleochroic from yellow (=X) to brownish yellow (=Y) to reddish brown (=Z) with absorption Z\(\geq Y > X\). Pleochroic haloes around inclusions of zircon in biotite are quite common.
**Plagioclase** (An15-20) occurs as subidiomorphic crystals in the rock. Some crystals are untwinned while others are albite-twinned. Most of the plagioclase grains are sericitised due to which twinning is partly obliterated. Plagioclase occurs in the matrix alongwith quartz and a few augen of plagioclase are also observed. It is quite subordinate to quartz and biotite in amount.

Idiomorphic crystals of zoned as well as unzoned **zircon** occur as inclusions in biotite showing well developed pleochroic haloes. Greenish brown stumpy crystals of **tourmaline** and euhedral grains of **magnetite** are present throughout the rock.

### 3.2.2.3. Garnet-actinolite-biotite-chlorite schist

This variety of schist is developed close to or in the slivers of pelitic schists occurring within the metavolcanics.

In hand specimens the rock is medium grained, greenish black to dark green in colour and foliated. Garnet crystals, sometimes up to 1 cm in diameter, impart porphyroblastic texture to the rock. In thin sections the schistosity is defined by biotite, chlorite and actinolite, while cummingtonite, when present, imparts hornfelsic texture to the rock in the form of radiating needles superimposed on foliation.

Actinolite and biotite are the main minerals in the rock followed by chlorite. Garnet is common. Cummingtonite and cordierite have been observed in a couple of thin sections and skeletal staurolite is present in one thin section alongwith cordierite. Feldspars and quartz are present in variable amounts, besides the common accessories. The assemblages vary and all the minerals described below are not necessarily present in the same sample or thin section.

Amphiboles form the main constituent of the rock. **Actinolite** or **actinolitic hornblende** occurs as prismatic laths aligned parallel or sub-parallel to the schistosity but some laths are also transversely oriented. Rhombic sections with two sets of (110) cleavage are also present. It is pleochroic from light yellow (X) to light green (Y) to bluish green (Z), shows middle to upper first order or lower second order interference colours and extinction in prismatic grains (Z C) varies from 10° to 18°.
**Cummingtonite**, when present, forms long to very long (breadth to length ratio up to 1:20), slender, acicular needles forming decussate or radiating arrangement. These are superimposed on the foliation and impart hornfelsic texture to the rock. It is generally colourless, but shows green to bluish green rims in both the prismatic and transverse sections. The birefringence in prismatic or acicular crystals is relatively higher (0.023) with interference colours going up to upper second order and extinction varying from 15°-25°. A very characteristic feature of cummingtonite is the prevalence of simple and lamellar twinning (Fig. 3.1c), which distinguishes it from anthophyllite and its biaxial positive character, which helps to distinguish it from actinolite. It may be mentioned that anthophyllite, gedrite, cummingtonite and cordierite bearing rocks have been reported (Lal and Shukla, 1975, 1978) from garnetiferous chlorite schist horizon to the west of Gothara.

**Biotite** is subordinate to amphiboles and in some cases it is negligible. Lepidoblastic flakes of biotite with light brownish yellow to greenish brown pleochroism (X<Y<Z) and straight extinction define the schistosity along with actinolite and chlorite.

**Chlorite** occurs as minute flakes interleaved with biotite and/or actinolite aligned parallel to the schistosity as well as clusters of twisted and waspy flakes. It is feebly pleochroic in light green, has low birefringence (0.002-0.003) giving anomalous grey to bluish grey interference colours and shows 0°-5° extinction. Polysynthetic twinning on mica law is observed in many flakes of chlorite.

**Garnet** is quite common, though not ubiquitous. In thin sections the feebly pink, skeletal and idiomorphic crystals of garnet are superimposed on foliation and contain numerous inclusions of quartz, actinolite, magnetite and occasionally plagioclase. The inclusions are not helicitic but disoriented.

**Cordierite** occurs as porphyroblastic crystals with irregular outlines in association with quartz-chlorite-biotite matrix along with amphiboles. It contains numerous inclusions of chlorite, quartz, magnetite and biotite (Fig. 3.1d). The mineral is colourless, with very low relief apparently similar to that of quartz. It shows faint one
directional cleavage, first order grey to greyish yellow interference colours and straight extinction.

**Staurolite** has been observed in one thin section in which cordierite also occurs. It is idiomorphic in shape and studded with inclusions of quartz. It shows orange yellow to brownish yellow pleochroism, straight extinction and biaxial positive character. Only a couple of small, skeletal crystals full of inclusions are present (Fig. 3.1e).

The amount of *quartz* is variable. It occurs as almost equidimensional, polygonal, medium sized grains that are closely packed in layers alternating with flaky minerals and depicting preferred morphological and optic alignment parallel to schistosity. It also occurs as inclusions in garnet and actinolite. Some larger grains are xenomorphic and undulose.

**Plagioclase** is subordinate and occurs as subhedral, lath shaped or tabular crystals. It is either untwinned or twinned on albite and albite-pericline laws. Sericitisation, leading to cloudy appearance and obliteration of twinning in plagioclase, is common.

**Epidote** is occasionally present, *zircon* and *apatite* are the common accessories, *magnetite* is the main opaque mineral and *sericite* is secondary after plagioclase.

### 3.2.3. Marble and Calc-silicate rocks

From petrographic point of view these calcareous rocks are divided in two categories, namely, marble and calc-silicate rocks.

#### 3.2.3.1. Marble

Megascopically, the marble is medium to coarse grained, equigranular, granoblastic in texture and greyish white to brownish white in colour. On weathered surfaces the rock appears saccharoidal. At places amphibole crystals can be seen in the hand specimens.
In the thin sections, the rock is medium to coarse grained, more or less equigranular and granoblastic. Slight inequigranularity is imparted to the rock due to the development of prismatic crystals of amphiboles and relatively smaller grains of quartz. The marble consists predominantly of carbonate (calcite/dolomite), tremolite-actinolite, scapolite and quartz. Development of phlogopite and garnet can be seen in some thin sections. Sphene and magnetite comprise the accessories in the rock.

Carbonate mineral constituting the rock are dolomite and calcite. They occur as subidiomorphic crystals showing perfect rhombic cleavage. Lamellar twinning in two directions parallel to short and long diagonals of the rhombs has been observed (Fig. 3.1f). They show high birefringence (0.18 to 0.19), which results into twinkling and pearly grey high order polarisation colours.

Amphiboles present in the rock are tremolite and actinolite. They occur in the form of prismatic crystals as well as rhombic sections. Tremolite is nearly colourless whereas actinolite is light green in colour. The extinctions in prismatic sections are 8°-18° whereas some sections give straight extinction. They do not show any preferred orientation. Development of small needles of tremolite and actinolite from dolomite can also be seen. Irregular patches and islands of relict calcite and dolomite are quite common in tremolite and actinolite (Fig. 3.1f) and suggest that the amphiboles are developed from dolomite.

Grossularite occurs in the form of colourless idiomorphic crystals having high relief. The mineral shows numerous cracks and it remains isotropic in crossed nicols (Fig. 3.1f). It occurs in association with calcite. Islands of calcite are well preserved in the aggregate of garnet crystals.

Phlogopite has been observed at a few places. It is yellow in colour, pleochroic from yellow to orange yellow and shows straight extinction.

Scapolite occurs as porphyroblastic, prismatic crystals having low to fair relief. It is colourless exhibiting one directional cleavage and transverse cracks. It is uniaxial negative and length fast. Some crystals give cloudy appearance due to numerous
inclusions of quartz and calcite. Islands of quartz and carbonate are preserved in some crystals indicating formation of scapolite from the carbonates.

Quartz occurs in minor amount in this rock especially in the intergranular spaces between calcite and dolomite and as inclusions in amphiboles and scapolite. Sphene and magnetite are present as accessories.

3.2.3.2. Calc-silicate rocks

In the field and in hand specimen the rock is medium to coarse grained and cream to brownish grey in colour. At some places, e.g. near Kharkhara, centimetric size knots of plagioclase and small criss-cross needles of amphiboles can be seen, in the rock.

In thin sections, the rock shows crude to well developed foliation which is defined mainly by stretching and parallel alignment of longer dimension of calcite similar to schistose rocks, but lacking in micas. The main mineral constituents of the rock are quartz, plagioclase, calcite, diopside, amphiboles and scapolite. Epidote and sphene are present as accessories.

Quartz occurs as subidiomorphic to xenomorphic crystals in intergranular spaces between the carbonates. The crystals are often traversed by cracks. Most of the grains show undulose extinction and development of Bohem’s lamellae.

Numerous ‘knots’ of plagioclase are sometimes developed in the calc-silicate rocks. The margins of plagioclase are well defined by carbonaceous material. Most of the crystals are untwinned and a few show albite and albite-pericline twinnings. Some of the plagioclase crystals are studded with carbonaceous inclusions and are altered to sericite. Inclusions of carbonate material are common in plagioclase.

Calcite and dolomite occur as elongated rhombs showing development of crude foliation. They show perfect rhombic cleavage and lamellar twinning in two directions. High birefringence of carbonate minerals results into twinkling and high order interference colours.
Fig. 3.2a. Scapolite developing from and forming pseudomorph after plagioclase in calc-silicate rock (XN).

Fig. 3.2b. A porphyroblastic crystal of scapolite superimposed on quartz-carbonate matrix in calc-silicate rock (XN).

Fig. 3.2c. Parallel to sub-parallel alignment of prismatic laths of hornblende imparting nematoblastic foliation to the Jasrapura amphibolite (PPL).

Fig. 3.2d. Ophitic texture shown by numerous plagioclase laths enclosed in relict diopsidic augite that is rimmed by amphiboles, in Gorwala metadolerite (XN).

Fig. 3.2e. Relict diopsidic augite showing two sets of right angled cleavage surrounded by a rim of acicular and prismatic laths of amphiboles (PPL).

Fig. 3.2f. Polysynthetic twinning in hornblende in Gorwala metadolerite (XN).
Tremolite and Actinolite are the characteristic amphiboles present in the rock. They occur in form of prismatic crystals as well as rhombic sections and do not show any preferred orientation. Tremolite is nearly colourless whereas actinolite is light green to green in colour. Tremolite and actinolite are often intergrown with each other with patchy development of green coloured actinolite in colourless tremolite. However, they also occur as independent prismatic and acicular crystals. The extinction angles (Z C) in prismatic sections range from 10° to 20°. Numerous inclusions of calcite and dolomite can also be observed in these amphiboles in form of irregular patches and islands indicating that the amphiboles are developed from dolomite.

Diopside forms short prismatic crystals having medium relief. It is nearly colourless to feebly light green in colour. It exhibits two directional, right angled, cleavage and parting forming a brick-work pattern. The interference colours range from grey of first order to greenish blue of second order. Extinction angle varies from straight on orthopinacoid (100) to about 40° on clinopinacoid (010). It is associated with carbonates and amphiboles and frequently contains relict islands of the former. At some places diopside appears to develop from tremolite-actinolite.

Small prismatic crystals of scapolite are often seen developing from plagioclase. At times scapolite forms more or less complete pseudomorphs after plagioclase (Fig. 3.2a). Besides these, large, prismatic crystals of scapolite form porphyroblasts superimposed on quartz-carbonate matrix (Fig. 3.2b). It is colourless, show one-directional cleavage, fair relief, first order orange yellow interference colours and straight extinction. The prismatic crystals have negative elongation and the mineral is uniaxially negative. Relict islands of carbonates are at times preserved in these large scapolite crystals. Sphene and epidote occur as accessories in the rock.

3.2.4. Micaceous quartzite

In the field and in hand specimens, the rock is medium grained. Due to larger proportion of flaky minerals, it is less close-packed, less vitreous and more foliated as compared to the Alwar quartzite.
Microscopically, the rock is medium grained and shows crystalloblastic texture. The rock appears to have been sheared as all the quartz-grains are stretched in the direction of foliation defined by flakes of muscovite and biotite. Both muscovite and biotite are concentrated in alternate layers. The main constituents of the rock are quartz, muscovite, biotite, iron oxides, tourmaline, and apatite. Feldspars are generally lacking.

**Quartz** occurs in the form of subidiomorphic to xenomorphic crystals. The small close-packed, polygonal crystals are often subidiomorphic in outline. However, most of the quartz grains constitute large crystals having xenomorphic, highly serrated and fused outlines and they are also stretched and elongated in the direction of foliation. These crystals show wavy extinctions and Bohem’s lamellae.

**Muscovite** occurs as colourless flakes, showing one-directional cleavage and at places interleaved with biotite. It shows bright second order interference colours and straight extinction.

**Biotite** is subordinate to muscovite. It is pleochroic from yellow brown (=X) to brown (=Y) to dark brown (=Z) i.e. Z≥Y>X.

**Hematite** is the main iron oxide mineral in the rock. It is dark brown in colour and usually concentrated in alternate layers along with biotite and muscovite. It also fills the intergranular spaces between quartz grains making their margins more prominent. Discrete crystals of **magnetite** and hematite are also dispersed throughout the rock. **Tourmaline** occurs as small stubby prismatic crystals, which show patchy yellow green colour in the plane polarised light with absorption O>E. Interference colours are masked by body colours. Extinction is parallel to prismatic outlines.

### 3.3. Amphibolites and Metadolerites

#### 3.3.1. Jasrapura amphibolite

Megascopically, the amphibolite is greenish black in colour, medium grained and crudely foliated.
In the thin sections, the rock is medium grained and foliated. The parallel to subparallel alignment of prismatic laths of hornblende impart nematoblastic foliation to the rock (Fig. 3.2c). The minerals present in order of abundance are hornblende, plagioclase, quartz, epidote, iron oxide, zircon and titanite.

**Hornblende** is the most abundant mineral constituent of the rock. It occurs chiefly as prismatic and rhombic crystals. It is green in colour and shows pleochroism from light green (=X) to green (=Y) to dark green (=Z) i.e. Z > Y > X. The prismatic sections exhibit one-directional cleavage, whereas the basal sections show rhombic cleavage. Extinction angle Z ^ C varies from 18° to 28°.

Anhedral to subhedral, mostly lath-shaped crystals of **plagioclase** are elongated in the direction of foliation. The composition of plagioclase varies from An_{35} to An_{40}. Most of the crystals show albite twinning whereas a few crystals are untwinned.

**Quartz** is present in very minor quantity in the form of small xenomorphic crystals. Most of the quartz grains are flattened in the direction of foliation and show undulose extinction.

Euhedral to subhedral crystals of **epidote** and **zircon** showing high relief are, often associated with hornblende. Zircon forms pleochroic haloes in the amphiboles. **Sphene** occurs as clusters of euhedral to subhedral grains. It is light pinkish in colour. **Magnetite** is present as small black grains, often widely distributed throughout the rock, but its association with sphene is quite prominent.

### 3.3.2. Gorwala metadolerite

Gorwala metadolerite is fine to medium grained, nearly black in colour and unfoliated in appearance.

In the thin sections, the rock is crystalloblastic and medium grained. Criss-cross and decussate arrangement of amphibole crystals is common without any preferred orientation. Ophitic to subophitic texture is quite prominent in the rock as numerous laths of plagioclase are completely or partially enclosed in pyroxene crystals (Fig. 3.2d). Pyroxene crystals exhibit alteration to radiating aggregates of hornblende all around...
their margins (Fig. 3.2e). The minerals constituting the rock are hornblende, plagioclase, pyroxene, sphene, iron oxide (magnetite) and minor secondary sericite.

**Hornblende** occurs as prismatic or lath shaped crystals. Both prismatic and rhombic sections are present. It is green in colour and shows pleochroism from light green (=X) to green (=Y) to dark green (=Z) i.e. Z>Y>X. Extinction angle Z^C varies from 18° to 30°. Polysynthetic twinning in hornblende is common (Fig. 3.2f) and symplectic intergrowth of hornblende and magnetite has also been observed at a few places. The frequent presence of relict pyroxene in the cores of hornblende indicates that the latter is the product of metamorphism of pyroxene.

The composition of **plagioclase** varies from An38 to An43. It occurs as lath shaped crystals most of which show albite, albite-pericline and albite-pericline-carlsbad twinning. Some crystals are untwinned as well. Compositional zoning is commonly observed in both twinned and untwinned crystals (Fig. 3.3a, b). Numerous laths of plagioclase are partially or completely enclosed within pyroxene crystals giving rise to subophitic to ophitic texture in the rock.

**Pyroxene** occurs frequently in cores of amphibole crystals as colourless to light green relics. The relict pyroxene is present as prismatic and basal sections. The prismatic sections show one directional cleavage whereas the basal sections show two sets of cleavage at right angles (Fig. 3.2e). The prismatic sections show extinction of 35° to 38° on clinopinacoids and interference figures are biaxial positive. On the basis of optical properties it can be identified as diopsodic augite. Hourglass texture is also observed in a few crystals of pyroxenes. On the margins, the pyroxene crystals exhibit moderate to extensive alteration to amphiboles indicating formation of the latter by metamorphism from the original pyroxenes in the rock.

A small amount of **sphene** occurs in the form of idiomorphic to subidiomorphic crystals, in association with hornblende and magnetite. Minor amount of **sericite** is present as an alteration product of plagioclase. Minute flakes of sericite form criss-cross pattern within plagioclase crystals and render the latter turbid with partial obliteration of twinning. **Magnetite** is dispersed throughout the rock as small grains. It also occurs in symplectic intergrowth with hornblende.
Fig. 3.3a. A phenocryst of plagioclase showing complex multiple twinning and compositional zoning in Gorwala metadolerite (XN).

Fig. 3.3b. A phenocryst of untwinned plagioclase showing compositional zoning in Gorwala metadolerite (XN).

Fig. 3.3c. Prismatic laths of plagioclase showing combined carlsbad-albite twinning and feeble compositional zoning in Gothara metadolerite (XN).

Fig. 3.3d. Oriented symplectitic intergrowth of magnetite and hornblende (PPL).

Fig. 3.3e. Plugs of albite encroaching cross-hatched microcline from margin inwards and producing myrmekitic intergrowth in Jasrapura granite (XN).

Fig. 3.3f. Microcline-perthite showing thin films of albite in Jasrapura granite (XN).
3.3.3. Gothara metadolerite

In the field and handspecimens, the rock is fine to medium grained, greenish black in colour and unfoliated.

Under the microscope, it is medium to coarse grained and shows crystalloblastic texture. Subophitic texture between plagioclase and hornblende has been observed. The minerals comprising the rock are hornblende, plagioclase, quartz and magnetite.

**Hornblende** occurs as clusters of prismatic crystals forming decussate arrangement. Relict subophitic texture, exhibited by laths of plagioclase partly enclosed in crystals of hornblende, indicates that the hornblende is the product of metamorphism of the original pyroxene. However, no relics of pyroxenes could be observed in the rock. The hornblende exhibits pleochroism from light green (X), to green (Y) to dark green (Z) with absorption Z>Y>X and it shows extinction (Z A C) from 18° to 30°.

**Plagioclase** varies in composition from An$_{32}$ to An$_{38}$. It often occurs in the form of laths, exhibiting albite and carlsbad-albite twinning and occasionally relict zoning (Fig. 3.3c). Apart from this compositional zoning, some crystals of plagioclase have developed rims of recrystallised sodic plagioclase around cores of calcic plagioclase.

Minor quantity of **quartz** occurs in-between the amphiboles and plagioclase as well as inclusions within plagioclase.

Euhedral crystals of black **magnetite** are dispersed throughout the rock. Some larger crystals of magnetite form symplectitic intergrowth with hornblende (Fig. 3.3d), which may be indicative of simultaneous or overlapping crystallisation of magnetite and original pyroxene. Minor amount of **sericite** is the result of alteration of plagioclase.

3.4. Jasrapura Granitoids

The Jasrapura granitoids occur in two forms. The main body of the lenticular sheet of the Jasrapura granitoids consists of foliated biotite granite with small, local pockets of granodiorite. However, small dykes of a later leucogranite, comprising both granite and trondhjemite, intrude the main granite. The classification and nomenclature...
of the Jasrapura granitoids based on the quantitative mineralogy (Table 3.2) will be discussed in a subsequent section of this chapter. The following petrographic description, has been divided into two categories namely, Jasrapura granite (including granodiorite) and Jasrapura leucogranite, which includes both the granitic and trondhjemitic varieties together.

3.4.1. Jasrapura granite

The Jasrapura granite is medium to coarse grained, grey coloured, foliated and leucocratic. At a few places it exhibits porphyritic character because of the presence of feldspar phenocrysts, which range from 1 cm to 2 cm and rarely up to 4 cm in length, and from half-a-cm to 2 cm in width. The granite is more foliated towards its outer margins as compared to the central parts of the lenticular body. The specific gravity of the rock varies from 2.67 to 2.79, with an average of 2.73 (Table 3.2).

In the thin sections, the rock is holocrystalline, medium to coarse grained and leucocratic. However, the phenocrysts of feldspar and quartz impart inequigranularity to the otherwise more or less equigranular rock. Parallel to sub-parallel alignment of biotite flakes together with the preferred morphological and optic orientation of quartz defines foliation in the rock. The alternating quartz-feldspar rich layers impart a gneissic character to the rock. The essential minerals, present in order of abundance are plagioclase, quartz, K-feldspar and biotite. The accessory minerals comprise allanite, epidote, zircon, apatite, titanite, magnetite, carbonates and secondary muscovite and sericite.

Two types of plagioclase are observed in the Jasrapura granite and granodiorite. The primary plagioclase ranges in composition from An28 to An46 in granite and An30 to An56 in granodiorite as determined by Michel-Levy method. It occurs as lath-shaped anhedral to subhedral crystals and phenocrysts in the quartzo-feldspathic layers. Generally, the plagioclase shows albite twinning, but albite-carlsbad, albite-pericline and pericline twinning are also developed. A few plagioclase crystals are untwinned. Some of the plagioclase phenocrysts are sericitised and clouded. At places the saussuritisation of plagioclase has led to the formation of epidote and calcite. The secondary plagioclase is mainly albite (An5-10) that occurs as films in microcline.
perthite. This sodic plagioclase is more fresh as compared to the primary calcic plagioclase. Recrystallisation of primary plagioclase has resulted in the development of albite rims all around it, which advance on to microcline to produce incipient myrmekitic intergrowths (Fig. 3.3e).

Three types of quartz are observed in this rock. The first type includes small, anhedral to subhedral grains aligned parallel to the foliation and showing uniform extinction. The second type comprises large elongated crystals of quartz that show undulose extinction. The third type constitutes small blebs and vermicules of released quartz in the myrmekitic intergrowths.

The K-feldspars are microcline (Fig. 3.3e) and microcline-perthite (Fig. 3.3f). Microcline occurs as xenomorphic crystals in the intergranular spaces as well as phenocrysts, most, of which are perthitic and contain thin films of albite. Two directional cleavage, cross-hatched and combined cross-hatched and carlsbad twinnings are well developed. Inclusions of plagioclase in microcline are common. Myrmekitic intergrowths are commonly observed along the boundaries of microcline with plugs of albite encroaching the microcline (Fig. 3.3e) from margin inwards.

Biotite is the principal mafic mineral in the rock. It occurs as lepidoblastic prismatic flakes aligned parallel or sub-parallel to the foliation of the rock. It is deep brown in colour, showing pleochroism from yellowish brown (=X) to brown (=Y) to reddish brown (=Z). Rarely minor amount of amphibole is observed in association with biotite.

Allanite occurs as euhedral to subhedral crystals, often aligned parallel to the foliation and surrounded by biotite (Fig. 3.4a). Two varieties of allanite are observed. One variety has a patchy brownish yellow core and deep orange brown margins in plane polarised light (Fig. 3.4a). Under the crossed nicols, the central part becomes patchy deep yellow and the marginal part becomes isotropic (Fig. 3.4b). The other variety has a colourless core and brownish yellow to orange yellow margins in the plane polarised light. Under crossed nicols the central colourless part becomes isotropic whereas, the outer part shows bright golden yellow interference colours. Both the varieties of allanite are rimmed by epidote.
Two types of **epidote** are observed in the rock. The primary epidote occurs as euhedral crystals enclosed in biotite (Fig. 3.4c) and as rims around allanite crystals (Fig. 3.4a, b). It is pleochroic from colourless to light lemon yellow and shows pale yellow to pink interference colours. The secondary epidote (clinozoisite) has formed by alteration of plagioclase. It is granular, colourless and shows typical ink blue polarisation colours.

**Titanite** forms euhedral to subhedral diamond or lozenge shaped crystals. It is pink in colour, shows high relief and is pleochroic from almost colourless to light pink. Polysynthetic twinning is well developed in titanite (Fig. 3.4d). It also occurs as inclusion in biotite. Euhedral crystals of **zircon** are characterised by high relief, bright interference colours and straight extinction. Zircon commonly forms pleochroic haloes in biotite. Metamictisation of zircon is common. **Apatite** occurs as euhedral to subhedral crystals in intergranular spaces and as inclusions in biotite. **Magnetite** occurs in granular form. It is black in colour and is often associated with biotite and titanite. **Sericite** is an alteration product of plagioclase. It forms minute flakes, oriented along the cleavage planes of plagioclase.

### 3.4.2. Jasrapura leucogranite

The petrographic description of both the granitic and trondhjemitic varieties of the leucogranite is discussed here together. The leucogranite is equigranular, fine to medium grained and creamy white to pinkish white in colour. However, it is considerably finer in grain size than the main granite. It shows a crude foliation resulting from sub-parallel alignment of micas. At places, the leucogranite becomes pegmatitic in character with the development of coarse crystals of feldspars, smoky quartz and tourmaline. The specific gravities of the two samples of the granitic and trondhjemitic varieties of the leucogranite are 2.63 and 2.65, respectively.

In thin sections, the leucogranite is fine to medium grained. Morphological and optic alignment of quartz, feldspars and micas define the foliation of the rock (Fig. 3.4e). Plagioclase, quartz, potash feldspar, biotite, muscovite and tourmaline are the principal mineral constituents whereas,apatite and magnetite are main accessories.
Fig. 3.4a. An allanite crystal rimmed by epidote, aligned parallel to the foliation and surrounded by biotite in Jasrapura granite (PPL).

Fig. 3.4b. The allanite crystal rimmed by epidote shown in Fig. 3.4a becomes isotropic at the margins and patchy deep yellow in the central part under crossed nicols (XN).

Fig. 3.4c. Euhedral crystals of epidote enclosed in biotite along with an inclusion of titanite in Jasrapura granite (PPL).

Fig. 3.4d. Polysynthetic twinning in titanite in Jasrapura granite (XN).

Fig. 3.4e. Morphological and optic alignment of quartz, feldspars and micas define the foliation of the relatively finer grained Jasrapura leucogranite (XN).

Fig. 3.4f. Domains of cross-hatched microcline in faintly albite twinned plagioclase, giving rise to antiperthite in the Gorwala granite (XN).
The composition of plagioclase is $\text{An}_{17}$ in the granitic variety and $\text{An}_{11.12}$ in the trondhjemitic variety. Plagioclase occurs as subhedral to anhedral grains. Most of the grains are twinned on carlsbad, albite and pericline laws. Some phenocrysts of plagioclase are sericitised.

Quartz occurs as small, subhedral grains, which define the quartzo-feldspathic layers and exhibit preferred optic orientation, besides larger, xenomorphic crystals having serrated margins that show undulose extinctions.

Microcline is present in significant amount in the granitic variety in the form of subhedral to anhedral grains. It is very subordinate in the trondhjemitic variety of leucogranite. Most of the grains exhibit cross-hatched twinning while a few are untwinned but contain patchy M-twin domains. Most of the grains are present in the intergranular spaces (Fig. 3.4e) alongwith quartz and plagioclase. Some larger crystals of microcline are also observed.

Tourmaline occurs as prismatic as well as basal sections. It shows medium to high relief and numerous cracks perpendicular to length. Its colour varies from yellowish brown (E) to bluish green (O) with absorption $O>E$. However, patchy development of colours is quite common as exhibited by domains of green in brown coloured tourmaline. At places, a crude compositional zoning can be deciphered with brown margins and green cores. Interference colours are upper first order to lower second order and extinction is parallel to the prismatic edges. The basal sections remain isotropic but yield good uniaxial negative interference figures. Inclusions of quartz, plagioclase and microcline are present in some tourmaline crystals.

Small amounts of biotite and muscovite are present in the rock. Prismatic and basal crystals of apatite and small squarish crystals of magnetite occur sporadically dispersed in the rock.

3.5. Gormala Granitoids

Two varieties of granitoids occur together in the Gorwala pluton. One variety contains alkali (i.e. K) feldspar, plagioclase and biotite without any amphibole while the
other contains albite and amphibole without K-feldspar and rare secondary biotite. The modal analyses of these two variants are given in Table 3.3 and their classification and nomenclature, based on modal mineralogy, will be discussed in a later section of this chapter. Both these varieties individually depict remarkable textural, qualitative and quantitative mineralogical homogeneity. The petrography of these two varieties of the Gorwala granitoids, has been discussed here separately as per this nomenclature.

3.5.1. Gorwala granite

The Gorwala biotite granite is medium to coarse grained, equigranular and compact. It is leucocratic and pinkish grey in colour. In the field and in hand specimens, the foliation can be deciphered by the parallel to sub-parallel alignment of biotite flakes, which also impart streaky and crudely gneissose appearance to the rock. The specific gravity of the rock varies from 2.70 to 2.74 (Av. 2.72, Table 3.3).

In thin sections, the rock is holocrystalline, medium to coarse grained, more or less equigranular, leucocratic and slightly foliated. The foliation is defined by parallel to sub-parallel alignment of biotite flakes, which are often concentrated in layers alternating with quartzo-feldspathic layers. Some larger crystals of feldspars and quartz tend to impart inequigranularity and pseudoporphyritic texture to the rock. The essential minerals present in order of abundance are quartz, plagioclase, K-feldspar and biotite. The accessory minerals comprise titanite, allanite, apatite, epidote, zircon and opaques.

Most of the quartz grains are anhedral to subhedral and closely packed in quartzo-feldspathic layers. They are generally equigranular and show uniform extinction. Some quartz grains are larger in size and have xenomorphic outlines. They show undulose extinction and impart inequigranularity and porphyritic character to the rock. A small amount of quartz, occurring in the form of blebs and vermicules in the myrmekitic intergrowths, is probably released during the replacement of K-feldspar by the plugs of sodic plagioclase.

Plagioclase occurs in the form of lath-shaped and tabular subhedral crystals. Some crystals also form phenocrysts imparting porphyritic texture to the rock.
Plagioclase (biaxial positive) ranges in composition from albite to low oligoclase (An$_{15}$) as determined by Michel-Levy method. Most of the grains show well developed albite, pericline, albite-pericline and albite-carlsbad twinning. Islands and lenticular domains of cross-hatched microcline in large phenocrysts of faintly albite-twinned plagioclase, giving rise to antiperthite, have also been observed (Fig. 3.4f).

**Microcline** is the prevalent K-feldspar in the Gorwala biotite granite. It occurs as medium sized xenomorphic crystals in the quartzo-feldspathic layers, besides phenocrysts like those of the plagioclase. The mineral shows well developed two directional cleavage. In most of the crystals, cross-hatched twinning is well developed but combined carlsbad - cross-hatched twinning is also quite common. Less frequently, microperthitic K-feldspar also occurs, showing thin films of albite transgressing microcline. Myrmekitic intergrowth has been observed along the margins of some grains of K-feldspar. Plugs of sodic plagioclase advancing and corroding the K-feldspar from the margin inwards seem to replace the host and produce vermicular intergrowths with released quartz (Fig. 3.5a).

**Biotite** is the principal mafic mineral in this rock, occurring almost to the exclusion of the amphiboles. It forms small prismatic flakes mostly concentrated in layers, alternating with the quartzo-feldspathic layers and aligned parallel to the foliation. It is pleochroic from light yellow (=X) to yellowish brown (=Y) to greenish brown/brown (=Z) i.e. Z≥Y>X. The interference colours are often masked by its dark body colour and extinction ranges from 0° to 3°.

**Titanite** is concentrated in the biotite rich layers forming aggregates of small, shapeless grains as well as some lozenge-shaped crystals. Polysynthetic twinning is well developed in some large lozenge shaped crystals of titanite. It is characterised by high relief, pinkish brown colour, high order interference colours and biaxial positive sign. Inclusions of magnetite, biotite, apatite and quartz are also seen in some larger crystals of titanite.

Small and stubby, euhedral to subhedral crystals of **epidote**, showing medium to high relief, feeble pleochroism from lemon yellow to light greenish yellow and anomalous blue yellow and low second order interference colours, are common in the
Numerous small crystals of epidote also occur as inclusions in plagioclase, which are probably formed from the latter. Greyish brown to orange coloured euhedral to subhedral crystals of **allanite** are also observed.

**Zircon** occurs as euhedral, prismatic and squarish crystals scattered throughout the rock. However, it is more concentrated in the biotite-rich layers and also occurs as inclusions in biotite showing marked pleochroic haloes (Fig. 3.5b). **Apatite** forms small idiomorphic grains especially in biotite-rich layers some of which occur as inclusions in the latter. **Sericite** forms small colourless flakes often forming criss-cross patterns along the cleavages and twin planes of plagioclase. **Calcite** occurs in a couple of thin sections forming clusters and irregular xenomorphic patches in the intergranular spaces between quartz and feldspars. **Magnetite** forms small, idiomorphic, discrete grains preferentially in the biotite rich layers.

### 3.5.2. Gorwala plagiogranite

On the outcrop and in hand specimens, the Gorwala plagiogranite is greenish grey to greyish white in colour, leucocratic, equigranular, medium to coarse grained, massive and unfoliated. The specific gravity of the rock varies from 2.64 to 2.75 (Av 2.69, Table 3.3).

Under the microscope, it is medium to coarse grained, holocrystalline and leucocratic. Generally the rock is equigranular but at places inequigranularity is seen in some thin sections due to the presence of somewhat larger crystals of quartz and albite. The Gorwala plagiogranite exhibits granophyric intergrowth between albite and quartz (Fig. 3.5c). The overall texture of the rock is hypidiomorphic granular. The essential minerals present in the rock are albite, quartz and actinolitic hornblende. Accessory minerals include titanite, allanite, epidote, zircon, carbonates, apatite, biotite, sericite and opaques.

**Albite** occurs in the form of subhedral crystals constituting the matrix as well as some larger lath shaped phenocrysts. The composition varies from An₄ to An₁₀ as determined by Michel-Levy method. A few grains of albite are untwinned whereas
Fig. 3.5a. Plugs of sodic plagioclase corroding the K-feldspar from margin inwards and producing myrmekitic intergrowths in Gorwala granite (XN).

Fig. 3.5b. Pleochroic haloes around zircon in biotite feldspar from margin inwards and producing myrmekitic crystals in Gorwala granite (PPL).

Fig. 3.5c. Granophyric intergrowth between chessboard albite and quartz in Gorwala plagiogranite (XN).

Fig. 3.5d. Colour variation in hornblende crystals in the form of green coloured cores and greenish blue margins in the Gorwala plagiogranite (PPL).

Fig. 3.5e. Dense pleochroic halo around deep orange allanite inclusion in hornblende in Gorwala plagiogranite (PPL).

Fig. 3.5f. Epidote developing from plagioclase in Gorwala plagiogranite (XN).
others show albite, pericline, albite-pericline, albite-carlsbad and albite-pericline-carlsbad twinning. At places the twin lamellae in albite show distortion and bending. Intimate intergrowth of albite and pericline twinning has resulted in the formation of chess-board pattern in some crystals of albite and micrographic (the granophyric) intergrowths are commonly developed between chess-board albite and quartz (Fig. 3.5c). However, such intergrowths are more common in the Gothara plagiogranite and will be discussed in greater detail along with its petrography.

Quartz is present as subhedral to anhedral crystals. The crystals are more or less equant except for blebs and vermicules in granophyric intergrowths. Three types of quartz can be deciphered. The first type of quartz occurs as small equigranular crystals, which exhibit uniform extinctions and form the major part of the rock. The less common, larger crystals of quartz having irregular grain boundaries and exhibiting undulose extinction constitute the second variety. The third type forms the rods, blebs and vermicules of different sizes in the granophyric intergrowths.

Amphibole is the most characteristic mafic constituent of the rock. It occurs both as prismatic and basal sections. The prismatic sections show one directional cleavage, whereas basal sections show development of two directional rhombic (110) cleavage. Dominantly the amphibole is olive green in colour and shows pleochroism from yellowish green (=X) to green (=Y) to olive green (=Z) with absorption Z>Y>X. In a few crystals, colour variation in the form of green coloured cores and greenish blue margins (Fig. 3.5d) has been observed. Extinction Z A C varies from 15°-30°, but the (100) sections show straight extinction. It is length slow in character. The optical properties suggest that the amphibole broadly corresponds to actinolitic hornblende or hornblende in composition.

Titanite occurs as clusters of euhedral to subhedral crystals often in association of amphiboles. The mineral shows high relief and pleochroism from light pink (=X) to pink (=Y) to pinkish red (=Z) i.e. Z>Y>X. It shows very high order interference colours.
Allanite forms euhedral to subhedral crystals associated with titanite, epidote and magnetite. It is pleochroic from reddish brown to orange yellow. It occurs in the cores of epidote and as inclusions in amphiboles forming dense pleochroic haloes (Fig. 3.5e).

Epidote occurs as lemon yellow euhedral to subhedral crystals, often forming clusters. It has high relief, feeble pleochroism and upper second order interference colours. It shows inclined extinction of 10°-15° and is biaxial negative. Occasionally, epidote shows simple twinning on (100). It is associated with titanite, allanite and amphiboles. Inclusions of epidote in titanite are also observed. In a couple of thin sections, epidote also appears to develop from plagioclase (Fig. 3.5f).

Zircon forms colourless, euhedral crystals showing very high relief and straight extinction. It is commonly associated with sphene, epidote and magnetite. The mineral is often in metamict state, showing cracks, and it forms pleochroic haloes in amphibole. Euhedral to subhedral crystals of apatite, showing medium to high relief, first order grey interference colours and straight extinction, also occur as inclusions in amphiboles. Opaques are generally represented by magnetite, which is black in colour. Carbonates occur as irregular grains with epidote and in-between the grain boundaries of quartz and albite. Deep reddish brown biotite and minute specs of colourless sericite occasionally occur in the rock as secondary alteration products of amphiboles and albite, respectively.

3.6. Gothara Granitoid

The Gothara granitoid pluton comprises a single albite-amphibole bearing plagiogranite phase that is very similar to the Gorwala plagiogranite.

3.6.1. Gothara plagiogranite

Megascopically, the Gothara plagiogranite is leucocratic, medium to coarse grained and equigranular. It is quite massive, hard and compact, homogeneous and unfoliated. The specific gravity of the rock varies from 2.62 to 2.74 (Av. 2.66, Table 3.4).
In the thin sections, the rock is holocrystalline, medium to coarse grained and leucocratic. It is equigranular, but occasionally large crystals of albite and quartz, set in relatively finer grained matrix of quartz, albite and mafic minerals, impart some inequigranularity to the rock. The overall texture is hypidiomorphic granular. Granophyric intergrowth between quartz and albite is quite prominently developed, particularly in samples from the southern and eastern parts of the body. The albite crystals show closely spaced chess-board pattern as a result of intimate development of albite and pericline twinning. The granophyric intergrowth is commonly observed in chess-board albite. The essential minerals present in order of abundance are albite, quartz and actinolitic hornblende. The accessory minerals include titanite, allanite, apatite, zircon, carbonates and epidote. Minor amounts of secondary biotite, chlorite and sericite are occasionally present while the opaques include mainly magnetite and minor amounts of hematite and limonite.

Albite occurs as subhedral to anhedral crystals as well as lath shaped phenocrysts. Its composition, as determined by Michel-Levy method varies from An$_3$ to An$_8$. Most of the crystals show albite, pericline, albite-pericline, albite-carlsbad and albite-pericline-carlsbad twinning, but some grains are also untwinned. Intimate intergrowth of albite and pericline twinning, giving rise to a chess-board pattern, is a very common and characteristic feature of albite in the Gothara plagiogranite. Chessboard pattern is developed in two different forms, (i) as irregular patchy domains within the simple albite- or albite-carlsbad-twinned crystals (Fig. 3.6a), (ii) as rims around the central albite- or albite-carlsbad-twinned crystals (Fig. 3.6b) without or with profuse development of granophyric intergrowth of the marginal chess-board albite with quartz that often extend all around like a cauliflower (Fig. 3.6c).

Three types of quartz can be identified in the rock. The first type of quartz includes medium sized anhedral to subhedral, more or less equigranular, independent grains or clusters of grains showing uniform extinction. The second type consists of large crystals having xenomorphic grain boundaries. These crystals show wavy extinction and often contain inclusions of albite. The third type constitutes the blebs and vermicules of quartz, which form part of granophyric intergrowth as a result of simultaneous crystallisation of quartz and albite. The size of quartz blebs progressively
increases from core to the margin of the albite crystals (Fig. 3.6d) maintaining the same optic orientation in the mushrooming granophyric intergrowth.

**Amphibole** forms the main and characteristic mafic constituent of the rock. Subhedral to anhedral, small stubby and long prismatic crystals of amphibole show one directional cleavage, while basal sections show rhombic cleavage. Two varieties of amphibole are observed. The dominant coloured variety, identified as **actinolitic hornblende**, shows pleochroism from yellowish green (=X) to green (=Y) to bluish green (=Z) with absorption Z>Y>X. The second, subordinate, variety of amphibole is nearly colourless to feebly pleochroic from faint greenish yellow to light green, which has been identified as **actinolite**. Both the varieties show extinction angles (Z A C) in the 17°-30° range, but some (100) sections exhibit straight extinction. The prismatic crystals show positive elongation. Both the actinolite and actinolitic hornblende often occur together in the same thin section. At places the bluish green actinolitic hornblende develops in the form of patches on colourless actinolite or on the margins of the latter depicting the development of crude zoning. The amphiboles are generally quite fresh but at a few places they are slightly altered to biotite or chlorite.

**Titanite** occurs as lozenge-shaped crystals or granular aggregates. It is commonly associated with the amphiboles, and it generally occurs as inclusions within the latter (Fig. 3.6e). It shows intense pleochroism from light pale pink (=X) to pink (=Y) to pinkish blood red (=Z). Lamellar twinning is also observed in some grains.

**Allanite** occurs as euohedral to subhedral crystals. It shows pleochroism from orange yellow to brown. Mostly the cores of the mineral are brown changing outwards into orange yellow colour (Fig. 3.6f). It commonly occurs as inclusions in amphiboles and in titanite. Thick pleochroic haloes are developed in amphiboles around allanite inclusions.

**Epidote** is generally associated with allanite, hornblende and sphene. It occurs as independent euohedral to subhedral crystals, granular aggregates and as rims around
Fig. 3.6a. Development of chess-board pattern within a phenocryst of albite-twinned albite in Gothara plagiogranite (XN).

Fig. 3.6b. Development of chess-board pattern and granophyric intergrowth around an albite-carlsbad twinned crystal of albite in Gothara plagiogranite (XN).

Fig. 3.6c. Chess-board albite with profuse development of granophyric intergrowth between albite and quartz, extending like a cauliflower around central albite in Gothara plagiogranite (XN).

Fig. 3.6d. Granophyric intergrowth between albite and quartz showing increase in the size of the quartz rods from the central to the marginal parts of the intergrowth in Gothara Plagiogranite (XN).

Fig. 3.6e. Lozenge shaped euhedral crystals and granular aggregates of titanite in association with actinolitic hornblende in Gothara plagiogranite (PPL).

Fig. 3.6f. Allanite showing patchy deep brown central parts and orange yellow marginal parts together with the development of pleochroic halo in the associated hornblende in Gothara plagiogranite (PPL).
allanite. It shows feeble pleochroism from nearly colourless to faint greenish lemon yellow, interference colours from greyish orange yellow of the first order to bright red blue and green of the lower second order and 10°-15° extinction.

Apatite forms euhedral to subhedral crystals with moderate relief. Both prismatic and basal sections are present. It often occurs as inclusion within albite and in intergranular spaces. Irregular grains and patchy aggregates of colourless carbonates (generally calcite) occur in subordinate amount in some thin sections. They are characterised by two directional rhombic cleavage, polysynthetic twinning and high order interference colours. Carbonates are generally associated with amphiboles, titanite and epidote. Euhedral, occasionally zoned crystals of zircon occur in association with titanite, allanite and amphibole. Minute flakes of sericite are occasionally developed as a result of alteration of albite. Similarly, yellowish brown to brown flakes of biotite are also rarely encountered as a result of minor alteration of amphiboles. Magnetite and hematite occur in the form of euhedral grains often in association with amphiboles, titanite and allanite. At places, symplectitic intergrowth between magnetite and quartz is observed. Limonite occurs occasionally as an alteration product.

3.7. Breccia

The field and megascopic characters of breccia that occurs at the margins of Gorwala and Gothara plutons have been discussed in Chapter 2. Due to the large size and different compositions of the clasts and the matrix, the thin sections do not provide a comprehensive picture of the breccia, which is best revealed in the field. The study of a few thin sections, however, confirms the field observations.

The clasts are largely of the Alwar quartzite, petrographically similar to the feldspathic and amphibole quartzite, the latter containing bluish green actinolitic hornblende. The clasts of the granitoids, though less frequent, are texturally and mineralogically identical to the Gorwala and Gothara granitoids, respectively, including the presence of amphibole, chess-board albite and granophyric intergrowth so typical of the plagiogranites of the two plutons. West of Gothara, the breccia also contains clasts of magnetite quartzite due to its proximity with the main breccia zone.
The matrix is dominantly that of the dark green to greenish black mafic material no different from the metavolcanics including such bands in the amphibole quartzite. In thin sections, it comprises actinolitic hornblende, chlorite and epidote, besides occasional plagioclase and sphene. However, the local pockets of breccia within the shattered Alwar quartzite have siliceous matrix. Similarly, the breccia in the proximity of magnetite quartzite of Gothara primarily contains altered ferruginous matrix. Other aspects of breccia have been discussed in detail in Chapter 2.

3.8. Pegmatites

The megascopic characters of the pegmatites have been described in Chapter 2. Because of the coarse to very coarse grain size, the thin sections are not representative of the whole rock. The most typical feature of the Gorwala pegmatite, that intrudes plagiogranite, is its graphic intergrowth between quartz and albite. In thin sections, this is exhibited in the form of rods or ribbons of polygranular quartz penetrating the albite and forming L-shaped patterns. The albite shows well developed albite and albite-pericline twinning, often giving rise to chess-board pattern. Microcline is subordinate and characterised by cross-hatched twinning and occasional albite lamellae. This pegmatite is composed of quartz, albite, subordinate microcline and tourmaline.

The pegmatites that occur in the country rocks to the east of Gorwala pluton are also coarse to very coarse and pegmatitic in texture. These pegmatites contain quartz, feldspars, tourmaline, beryl and apatite.

The Jasrapura pegmatite is only a local, coarse grained facies of the finer grained leucogranite. It comprises quartz, feldspar, tourmaline and subordinate biotite and muscovite. All these pegmatites have been described in greater detail in Chapter 2.

3.9. Quartz and Carbonate veins

The field and megascopic characters of quartz and carbonate veins have been described in Chapter 2.
3.10. Mineralogical Classification and Nomenclature of the Granitoids

Modal analyses of the forty-four samples of the Jasrapura (13), Gorwala (17) and Gothara (14) granitoids, expressed in terms of volume per cent mineral constituents, are given in Tables 3.2, 3.3 and 3.4, respectively. These modal data have been plotted in the QAP triangular diagrams (Figs. 3.7a, b and c) for the classification and nomenclature of the granitoids as per the IUGS recommendations (Streckeisen, 1976).

3.10.1. Jasrapura granite

Excluding the two samples of leucogranite, 8 out of the remaining 11 samples of the Jasrapura granitoids fall in the monzogranite field of the QAP ternary diagram (Fig. 3.7a) of Streckeisen (1976). These eight samples of Jasrapura granite, have modal quartz between 22.9% and 27.7% (Av. 24.29%), K-feldspar in the range of 19.8% to 22.0% (Av. 21.04%) and the plagioclase varies from 32.3% to 36.6% (Av. 34.06%). The composition of plagioclase as determined by Michel-Levy method varies from An$_{28}$ to An$_{40}$, whereas from the CIPW norms it is An$_{23-44}$ (Table 4.1, Chapter 4). Biotite is the main mafic mineral generally ranging from 18.5% to 20.3%, except for one sample (JS14) in which it is relatively less in amount (14.8%) with corresponding greater proportion of quartz and plagioclase. The colour index (M' = 19.4-21.3) closely follows the amount of biotite except in the sample JS14 (M' = 15.7).

However, three samples (JS9, 10, 16) mainly from the isolated, central parts of the granitoid body, having modal quartz 19.4%-25.2% (Av. 22.5%), K-feldspar 10.1%-13.2% (Av. 11.57%), plagioclase 43.7%-45.5% (Av. 44.47%), biotite 18.5%-23.1% (Av. 20.87%) and colour index (M' = 18.8-23.2, Av. 21.0), fall in the granodiorite field of the QAP triangle (Fig. 3.7a). The plagioclase composition ranges from An$_{36}$ to An$_{38}$ as determined by the Michel-Levy method, and from An$_{26}$ to An$_{38}$ in the CIPW norm (Table 4.1, Chapter 4). Thus, the Jasrapura granitoid sheet is dominantly of granitic composition, with minor amount of granodiorite.
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Table 3.2. Modal analyses and specific gravity of the Jasrapura granitoids.
### Table 3.3. Modal analyses and specific gravity of the Gorwala granitoids.

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| Sp. Gr.      | 2.70  | 2.74  | 2.74  | 2.70  | 2.70  | 2.71  | 2.72  | 0.02 | 2.71  | 2.64  | 2.68  | 2.75  | 2.68  | 2.65  | 2.69  | 2.73  | 2.72  | 2.68  | 2.71  | 2.69  | 0.03 |
### Table 3.4. Modal analyses and specific gravity of the Gothara plagiogranite

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Fig. 3.7. Classification and nomenclature of (a): Jasrapura; (b): Gorwala; and (c): Gothara granitoids as per the IUGS recommendation (Streckeisen, 1976). Fields labelled: 2 = Alkali-feldspar granite, 3a = Syenogranite, 3b = Monzogranite, 4 = Granodiorite and 5 = Tonalite. Numbers 12 and 13 in Fig. (a) refer to two varieties of Jasrapura leucogranite.
Two samples of the leucogranite contain different amounts of tourmaline as the main mafic mineral, but their Q-A-P proportions are quite different (Table 3.2, Fig. 3.7a). One sample (JS12) containing 24.8% of K-feldspar (microcline), 35.7% of plagioclase (An17) and minor biotite, corresponds to granitic composition. The other (JS13) is practically devoid of K-feldspar (0.4%) and contains (58.9%) plagioclase (An11-12) and corresponds to trondhjemitic composition.

3.10.2. Gorwala granite

The six samples of the Gorwala biotite granite have a very narrow range of modal quartz (32.3%-34.3%, Av. 33.27%), alkali (K) feldspar (19.4%-24.4%, Av. 21.62%), and plagioclase (29.3%-33.2%, Av. 31.78%). The anorthite content of the plagioclase as determined by the Michel-Levy method is An_{10.15} and the normative anorthite content is An_{7.5}. Biotite forms the only major mafic constituent (11.3% to 13.0%, Av. 12.02%) almost to the exclusion of amphibole. The colour index (M') varies from 12.5 to 14 (Av. 12.92). These six samples form a small cluster in the monzogranite field (3b) of the QAP diagram (Fig. 3.7b), and accordingly this variety has been appropriately named as ‘Gorwala Granite’.

3.10.3. Gorwala and Gothara plagiogranites

The 11 samples of the amphibole-bearing Gorwala plagiogranite have modal quartz in the range of 24.3% to 29.1% (Av. 26.69%), albite varies from 58.7% to 64.6% (Av. 61.9%) and amphibole, the principal mafic mineral in the rock, varies between 7.40% and 11.2% (Av. 8.91%). The mean colour index (M') ranges from 9.0 to 13.3 (Av. 11.12). Thus, like the Gorwala granite, the Gorwala plagiogranite also shows remarkable consistency in its modal mineral composition. The anorthite content of the albite is An_{10.15} by Michel-Levy method. In the CIPW norms, it is An_{11.5} for 7 samples and An_{6.5} for 4 samples (Table 4.5, Chapter 4).

This modal consistency is equally valid for the 14 samples of Gothara plagiogranite (Table 3.4) in which the modal quartz is in the range of 26.3% to 31.6% (Av. 28.47%) and the modal abundance of albite is from 60.5% to 66.4% (Av. 63.79%). The amount of amphibole is slightly lower and more variable (2.1%-8.2%, Av. 4.53%).
and the rock is more leucocratic ($M' = 4.8-9.8$, Av. 7.01) as compared to the Gorwala
plagiogranite. The anorthite content of the albite is $An_{1.4}$ by the Michel-Levy method
and $An_{2.5}$ from CIPW norms (Table 4.8, Chapter 4).

The classification and nomenclature of these amphibole-bearing Gorwala and
Gothara granitoids is not so straightforward. With practically no K-feldspar phase (the
extremely low $K_2O$ content apparently accommodated as solid solution in the albite),
the Gorwala and Gothara samples can be plotted on the QA join or QP join of the QAP
triangle and can be named accordingly either as alkali feldspar granite (field 2) or as
tonalite/trondhjemite (field 5). The swapping of plots from QA side to QP side and vice-
versa depends on the anorthite content of albite. The IUGS Subcommission on the
Systematics of Igneous Rocks recommended that albite with $An \leq 5\%$ should be treated
as alkali feldspar (Streckeisen, 1976). If the IUGS recommendations are to be followed
senso-stricto, seven samples of the Gorwala amphibole-bearing granitoids will plot on
the QA join, and the remaining 4 samples on the QP join of the QAP triangle. On the
other hand, all 14 samples of the Gothara will plot on the QA join. There seems no
justification for treating the four Gorwala samples separately, which have marginally
higher anorthite content ($An_{4.8}$) as compared to the majority (7 samples of Gorwala and
14 of Gothara). It is certainly more appropriate to plot all the samples on QA join rather
than QP join of the QAP triangle, so that a single name could be assigned to these
extremely homogeneous rocks. Accordingly, these rocks may be classified as alkali-
feldspar granite (Figs. 3.7b, c). However, the IUGS recommended that the term alkali-
feldspar granite be used as root name and the feldspar present in each should be
specified (Streckeisen, 1976, p. 13). Following this, these rocks may be termed as albite
granite.

Although, the IUGS classification distinguishes between ‘alkali granite’ and
‘alkali-feldspar granite’, the fact remains that most granites of field 2 of the QAP
triangle are true alkali granites including the peralkaline ones. They contain alkali-
amphibole and/or alkali-pyroxene, whereas the amphibole of the Gorwala and Gothara
rocks is a calcic-amphibole (actinolitic hornblende). Therefore, characterising these
rocks as albite granite would almost certainly lead to miscomprehension of the true
nature of Gorwala and Gothara rocks. Following the suggestion of Barker (1979), these
albite granites may be termed as trondhjemites. However, the textural, modal, mineralogical and chemical parameters of the Gorwala and Gothara rocks do not match with the original definition of trondhjemite (Goldschmidt, 1916) that contain oligoclase or andesine, little or no K-feldspar and biotite.

Two other names that have been used in the literature for rocks, which are more or less similar to those of Gorwala and Gothara, are 'alaskite' and 'oceanic plagiogranite'.

Alaskite has been described as a holocrystalline-granular plutonic rock characterised by essential alkali-feldspars, quartz, and a little or no dark component (Spurr, 1900; Johannsen, 1962; Streckeisen, 1976; Bates and Jackson, 1980). However, the alkali-feldspar of alaskite is mostly K-feldspar, but albite or anorthoclase may be present in small amount. Evidently the amphibole-bearing granitoids of Gorwala and Gothara are nowhere near alaskites.

Coleman and Peterman (1975) introduced the term 'oceanic plagiogranite' for medium to fine grained, hypidiomorphic-granular rocks consisting predominantly of quartz and zoned plagioclase (An\textsubscript{10-60}) with less than 10% ferromagnesian minerals (primary hornblende or pyroxene) that are characterised by granophytic intergrowth between quartz and plagioclase. It is a general descriptive and collective term that encompasses a large spectrum from diorite, tonalite and trondhjemite to albite granite, which are associated with ophiolites. In addition, the oceanic plagiogranites are characterised by extremely low K\textsubscript{2}O, Rb and high Na\textsubscript{2}O contents. The Gorwala and Gothara rocks also show granophytic intergrowth between quartz and albite, they also have extremely low K\textsubscript{2}O, Rb and very high Na\textsubscript{2}O contents (Table 4.5, 4.6, 4.8 and 4.9). Thus, in many respects, the textural, mineralogical and chemical features of these amphibole-bearing granitoids compare well with those of oceanic plagiogranites.

However, despite the obvious similarities of the Gorwala and Gothara rocks with the oceanic plagiogranites, two deterrents need further consideration. First, whereas the plagioclase in oceanic plagiogranites is described as zoned and ranges in composition from An\textsubscript{10} to An\textsubscript{60} (Coleman and Donato, 1979) or An\textsubscript{20} to An\textsubscript{50} (Barbarin, 1999), the albite of Gorwala and Gothara granitoids is unzoned and has a very restricted
composition, always less than $An_{10}$. However, if both albite granite and trondhjemite are part of the oceanic plagiogranite spectrum, then albite (by definition being $An_{0-10}$) is as much characteristic feldspar of this spectrum as the more calcic varieties. Plagiogranite can also be used as a synonym for the trondhjemite (Streckeisen, 1976) and it takes care of the samples plotting on the QA and QP sides of the QAP triangle.

Secondly, the oceanic plagiogranites have almost always been reported from the ophiolitic and Mid-Oceanic Ridge settings and less commonly from roots of island arcs or back-arc marginal basins (Saunders et al., 1979; Phelps and Ave Lallemant, 1980; Pitcher, 1983; Hyndman, 1985; Barbarin, 1999, and many others). Although, ophiolites per se have so far not been reported from the Khetri Copper Belt, it does not mean that they are absent. Metabasic rocks in the form of flows, sills and dykes, are extensively developed in this region (Chapter 2), which are yet to be characterised. Detailed investigation of these rocks is beyond the scope of the present work. Nevertheless, it is pertinent to mention here that isolated occurrences of pyroxenites and hornblendites have been reported from the Khetri Copper Belt in association with albitites (Basu and Narsayya, 1983; Ray, 1987, 1990; Yadav et al., 2000). Plagiogranites have also been reported from the Phulad Ophiolite Suite in the northern part of the South Delhi Fold Belt (Sinha-Roy and Mohanty, 1988). It is a well known fact that the complete sequence of ophiolite suites is seldom encountered, and is difficult to recognise in Precambrian rocks (Helmstaedt and Scott, 1992; Condie, 1997). Nevertheless, since oceanic plagiogranites always occur in association with ophiolite complexes, it is only appropriate at present not to use the qualifier ‘oceanic’ and name these rocks simply as plagiogranites, as has also been suggested by Phelps and Ave Lallemant (1980).