COARSE GRANOPHYRE

A coarse granophyre with well developed miarolitic cavities is the most extensive acidic rock in the present area of the eastern part of Bara hills igneous complex. The rock is creamy white, pale pink to pale brown in colour, whereas in fresh specimens it is light grey. The most characteristic feature of these granophyres is the presence of large miarolitic cavities with large crystals of quartz, alkali feldspar and dark brownish black magnetite projecting into them. Microscopically, the rock is poorly porphyritic with few phenocrysts of plagioclase and clinopyroxene, whereas quartz and alkali feldspar form abundant coarse micropegmatitic intergrowth in an extremely variable form. The micropegmatitic units are defined by unit extinction of alkali feldspar host, and are generally medium in sizes. Clinopyroxene grains are ferrosalite, ferroaugite and hedenbergite varieties with rims of alkali pyroxene of aegirine-augite type and they occur both as phenocrysts and as groundmass constituents. Opaque minerals occur as small octahedral phenocrysts to anhedral interstitial phases. Accessories in the miarolitic and submiarolitic areas, include fluorite, sphene, zircon, apatite, baryte, chlorite, alkali amphibole, green biotite, calcite, iron ores, muscovite, aegirine-augite and stilpnomelane.

This same granophyre, occurs in irregular patches, and along its contact against the basalts (both the stoped block and basaltic country rock), it does not show the well-formed granophytic intergrowth, which commonly grades into the felsitic or cryptographic intergrowths of quartz and alkali feldspar. It appears that during intrusion through the basaltic country rock, the acid rocks at the contacts are more quickly chilled (supercooled) than the
same away from the contact. Megascopically, this contact rock is finer
grain than the above mentioned miarolitic type; and shows variegated
colours, such as light grey, brown, green and white. The green variety is
most remarkable. Microscopically, the characteristic features of the rock
are the presence of microphenocrysts of $\beta$-quartz, rare clinopyroxene (mostly
replaced by iddingsite), spherulite and secondary euhedral epidote and zoned
plagioclase. This contact acid rock has not been mapped separately as it
occurs in irregular patches within the coarse granophyre.

**DISTRIBUTION**

Coarse granophyre is distributed in the area from Bhad village in the
southern part to Modhpur in the north, and Wansjalia-Sakhpur area in the east
to Bileshwar-Kasvirdi Nes and in the central part of the Barda hills which
forms the western portion of the area. The distribution of this rock type is
interrupted by the occurrences of other acid rocks, e.g., fine granophyre,
felsite and in a large area near Hanumangarh and Sajanwala Nes, a large patch
of basalt occurs as an inlier. The coarse granophyre shows contact against
the Deccan Trap basalt flows in the eastern flank of Barda hills near Wansjalia.

The important exposures of this rock type are found near Sakhpur,
Bordi, Bhad, in the area between Bordi and Ranawao, Wansjalia, Tarsai, Sajanwala,
Bileshwar, Kasvirdi Nes, Phatal talao (tank or lake) east of Talaro Talao and
east of Modhpur and are described briefly in the following paragraphs. The
course granophyre generally forms the plain areas with minor undulations, but
it is also occupies high lands in the western-most parts of the area.
1. The outcrops of coarse granophyre with strongly developed miarolitic cavities occur in the plain lands on either side of the railway line in between Sakhpur and Bordi and extend up to the crossing of the railway line and the Porbandar–Jamnagar highway. The rock type is coarse grained, creamy white to pale pink in colour, the characteristic joint sets in the exposures trend N 65°E and S 85°E. The Sakhpur–Bordi occurrences are covered by miliolitic limestone in the southern parts and are thus detached from felsite and fine granophyre of Naliadhar and Daulatgarh hills. The exposures of coarse granophyre also occur at Bhad village and east of Naliadhar hill, and these exposures extend over a large area along the flanks of Naliadhar, other parts of which area are covered by miliolitic limestone. The coarse granophyric rock is also exposed northwest of Naliadhar and in the areas between Ramgarh and Khambala village, and it occurs in the high hills adjoining Khambala but gives to felsite and fine granophyre in the adjacent western parts.

2. In the northeastern parts, the exposures of coarse miarolitic granophyre extend to the plainlands in between Talara talao and Modhpur village. The eastern contact of this coarse granitic granophyre, where it abuts against the Deccan Trap basalts, runs in a nearly straight line towards northwest. In the northwest and western part, the coarse granophyre grades into fine granophyre and felsite. The basaltic patch (stoped block) of Talara talao area is located in between coarse granophyre and felsite which predominate in the area to the west. The coarse granophyre of Talara talao and Modhpur shows the characteristic joint trends as S 5°E, N 80°W, S 40°W and S 65°E with mostly vertical dips.

3. The occurrences of coarse granophyre at Kasvirdi Nes and Phatal talao, are exposed mainly in the low grounds, whereas the felsite forms the adjacent high ridges.
4. The coarse granophyric rocks are also exposed in the gently undulating area in between Sajanwala and Wansjalia and these exfoliated exposures are characterised by well formed miarolitic cavities, and marked by a prominent joint set trending N 40° E. This granophyre abuts against the Deccan Trap basalt near Wansjalia and grades to felsite in the western part. In the eastern side of Bileshwar village and along the Bileshward river valley, the sheeted coarse granophyre with characteristic vertical joint sets with strike directions as N 10° E, N 60° W and N 35° E, are well exposed.

The contact granophyre has been traced as irregular patches, along the contact of coarse granophyre against the basaltic rocks. The main occurrences are along the contact of granophyre and the granodiorite porphyry of Sakhpur and as patches within granophyre against the basaltic rocks of Wansjalia area.

MODE OF OCCURRENCE

The coarse-grained granophyre was emplaced discordantly within the gently dipping Deccan Trap basalt flows. The coarse grain size of this variety, and the presence of large crystal-lined miarolitic cavities indicate that this body intruded and crystallized under a depth of cover and its crystallization took place at a comparatively slow rate. The close association of this rock type with rhyolite and felsite, its granophyric texture and homophanous character, and absence of pegmatite clearly indicate its epizonal character as classified by Buddington (1959).

This variety of granophyre generally forms the plain areas, and in a few places it forms the highlands. It commonly grades into fine granophyre and felsite with gradational or sharp contacts.
The coarse variety is characterised by more widely spaced, joints and bouldery outcrops compared to those of the fine granophyre and felsite. Exposures are almost always weathered and eroded to typical well-rounded surfaces. Exfoliation on spheroidal boulders, resulting in concentric shells is a common feature.

PETROGRAPHY

In hand specimen, the coarse granophyre is medium to coarse grained and commonly porphyritic with phenocrysts (maximum 5 x 3 mm) of altered (white) and unaltered (pink) feldspars and mafics (green and black) in a quartzofeldspathic groundmass. Other megascopically identified minerals include black opaques, brown limonite and green coloured epidote and chlorite. Commonly the rock has creamy white to pale pink and pale brown colours; the yellowish brown colour due to limonite (altered iron oxides) is found in specimens of Phatal talao and Wansjalia areas, whereas profuse greenish patches owing to epidote and chlorite are found in the specimen of granophyre at contact with basalt in the Kharipat Nes. Light grey colour is scarcely found in the rock specimens from Bardi area. Miarolitic cavities are conspicuously developed in the specimens of coarse granophyre and they are filled in with quartz and opaques; very coarse miarolitic cavities (Fig. 11) are found in the specimens from Kasvirdi Nes and Phatal talao areas.

The thin section petrography of a few typical specimens, collected from the different parts of this widely distributed rock type is given below, as an account of their textural and mineralogical characteristics and variations.
In thin section plagioclase phenocrysts are common and have tabular shape with a wide alkali feldspar rim which grades into granophyric intergrowth. The plagioclase phenocrysts are at places marginally corroded and replaced by granophyric material; they are untwinned, and have indistinct zoning.

Clinopyroxene grains in the form of coarse plates with schiller inclusions are common as phenocrysts, with faint pleochroism, \( X = \) light olive green, \( Y = \) olive green and \( Z = \) olive green, \( Z \wedge c = 43^\circ \), \( 2V_z = 58.5^\circ \), \( N_y = 1.722 \pm 0.002 \) and it is ferrosalite in composition \((\text{Ca}_{46}\text{Mg}_{14}\text{Fe}_{40})\) (in Table 7). Alkali-pyroxene rim is well observed.

Alkali feldspar \((2V_x = 65^\circ)\) is common in the groundmass as subhedral to euhedral plates, and it is heavily altered and kaolinised. Optical data of alkali feldspar indicates that these fall on the low sanidine-high albite series and transitional types towards low albite-orthoclase series of Tuttle and Bowen (1958).

Micropegmatitic intergrowths of quartz and alkali feldspars are abundant in the groundmass and occur in various forms (fine radial, cuneiform with coarse triangular, rhomboidal and irregular, and coarse granitic in miarolitic areas) grading from finer to coarse (Fig. 12), with slightly kaolinized and stained alkali feldspar patches and clear quartz parts.

Iron ores are common as subhedral to anhedral grains, replacing clinopyroxene.

In the miarolitic patches, coarse anhedral grains of quartz and subhedral to euhedral plates of alkali feldspar (orthoclase) are common in
association with irregular iron ores, fluorite, euhedral plates of baryte (colourless, with prominent sets of cleavages, and first order grey interference colour), fibrous olive green patches of chlorite and stilpnomelane (pleochroism from $X$ = brown, $Z$ = dark brown, $X\Delta c = 15^0$). Iron ores also occur as coating the outer wall of mierolitic cavity.

Sp. No. 13/20.2.71: Collected from near the crossing of Jamnagar metalled road and the railway in between Bordi and Ranawao.

Thin section shows that the rock has micropegmatitic groundmass composed of a coarse intergrowth of quartz and alkali feldspar, free grains of alkali feldspar and quartz, traces of clinopyroxene, iron ores and other accessories.

Alkali feldspar in large sizes and as individual grains are abundant; a few groundmass grains are euhedral.

Clinopyroxene grains occur in the form of fine, subhedral prismatic and needle shaped grains, pale green in colour, with weak pleochroism and $Z\Delta c = 46^0$, $2V_2 = 56^0$, $N_y = 1.717 \pm 0.003$. Composition is ferrosalitic, Ca$_{46.5}$ Mg$_{18.5}$ Fe$_{35}$ (in Table 7). Coarse micropegmatitic intergrowths of quartz and alkali feldspar are abundant in the forms varying from fine to coarse cuneiforms, with irregular quartz areas, grading to coarse granitic type.

A probable pseudomorph after fayalite, reddish brown in colour (altered to iddingsite) with high refractive index has been observed. Comparatively fresh olivine grains are found in the associated fine granophyre (Sp. No. 7/20.2.71 in the succeeding chapter) of the present location.
Some large skeletal crystals of zircon are common. Fluorite, in the form of fairly large sized crystals with distinct cleavage and isotropic character has been found. Irregular anhedral patches of iron ores occur in traces.

Miarolitic cavities are seen with chlorite, fibrous amphibole, anhedral grains of fluorite, zircon and quartz.

Sp. No. 3/11.269: Collected from 1.5 km southeast of Sakhpur Railway Station.

In thin section plagioclase phenocrysts are common, but small in amount and show zoning and incipient albite type twinning (Fig. 13) and they are rimmed by micropegmatitic intergrowth.

Micropegmatitic intergrowth of quartz and alkali feldspar are in various forms, such as, fine to coarse cuneiform, fine to coarse triangular, rhomboidal and irregular shaped quartz areas.

Minerals in the miarolitic cavities include coarse anhedral grains of quartz, euhedral to subhedral plates of alkali feldspar, fine granules of iron ores, zircon, sphene and a pale green micaceous mineral. Subhedral to euhedral plates of iron ores are common in the groundmass. Many limonitised iron ore patches are also common.

Sp. No. 30/3/93.8 Sakhpur: Collected near Sakhpur Railway Station.

In thin section plagioclase phenocrysts are common and form tabular to subhedral grains with poorly preserved twinning; some grains are strongly resorbed with corroded edges (Fig. 14), studded with dusty inclusions; coarse granophyric intergrowth of quartz and alkali feldspar forms a radiate pattern around some of the phenocrysts.
Fig. 11. Photograph of a hand specimen showing microlitic cavity (m) in coarse granophyre.

Fig. 12. Photomicrograph showing fine granophyric intergrowths grading to coarse granophyric intergrowths. Crossed nicols. x 28.

Fig. 13. Photomicrograph showing zoning in plagioclase phenocryst, with incipient albite twinning. Crossed nicols. x 23.
Individual alkali feldspar grains, which ultimately grade into the outer micropegmatitic intergrowth, commonly occur as rim around plagioclase phenocrysts. Abundant micropegmatitic intergrowth of quartz and alkali feldspar occurs in various forms of coarser pattern, e.g., radial to cuneiform (Fig. 15), sometimes separated by a well formed twin plane of feldspar.

Coarse miarolitic cavities are filled in with coarse anhedral grains of quartz, finer euhedral to subhedral plates of albite and potash feldspar (Fig. 16). Other accessories include zircon and sphene in traces lying in the groundmass.

**TALARA TALAO-KHAMBIYARA TALAO-KODHPUR AREAS**

Sp. No. 2/23.2.71: Khambiyara talao area.

In thin section plagioclase phenocrysts \(2V_z = 67^\circ\) are common and euhedral with faint zoning and indistinct Carlsbad twinning, with a clear core and altered border zone, rimmed by micropegmatitic intergrowth. Zonation in granophyric intergrowths (i.e. coarser intergrowths rimmed by finer intergrowths and vice versa) is common (Fig. 17).

Clinopyroxene occurs in the form of euhedral to needle-shaped prisms, their margins are studded with small inclusions of euhedral plagioclase and iron ores; they are pale green with feeble pleochroism: \(X = \) pale yellowish green, \(Y = \) brownish yellow and \(Z = \) deep yellowish green with \(Z \perp c = 45^\circ\), \(2V_z = 55.5^\circ, N_y = 1.722 \pm 0.002\). It is ferroaugite with a composition \(\text{Ca}_{43.5} \text{Mg}_{17.5} \text{Fe}_{39}\) (in Table 7). A few deep bright green patches of aegirine-augite, \((\text{Ca Mg Fe})^{++}_{31} (\text{Fe}^{++} \text{Na})_{19}\), have been traced.

Alkali feldspars form individual, large subhedral to euhedral plates and occur in the interstitial spaces of micropegmatitic groundmass.
Fig. 14. Photomicrograph showing resorbed and weakly twinned plagioclase phenocryst, rimmed by micrographic intergrowths of quartz and alkali feldspar. Crossed nicols, x 28.

Fig. 15. Photomicrograph showing granophyric intergrowth of quartz and alkali feldspar, fine radial to coarse cuneiform intergrowths separated by a twin lamellae of the host alkali feldspar, the host alkali feldspar is in extinction. Crossed nicols, x 82.

Fig. 16. Photomicrograph showing miarolitic cavity with fillings of quartz (white) and plates of alkali feldspar (grey); rimmed by granophyric intergrowths. Crossed nicols, x 23.
Micropegmatitic intergrowths of quartz and alkali feldspar are common in the forms of coarse cuneiform (triangular to irregular quartz areas) which grades to granitic patches in the submiarolitic areas.

Iron ores are common as interstitial ramifying patches and associated mostly with pyroxene. Titanomagnetite grains have been identified as the major opaque constituent of the rock. They occur as large to medium sized, euhedral to subhedral plates and also form porous incrustations in the miarolitic cavities. The titanomagnetite grains show poikilitic intergrowth with the silicates, which indicates that the crystallisation of titanomagnetite was, either simultaneous or after that of the silicates. Under the ore microscope maghemitisation in irregular patches are frequently observed. A few grains are martitised along octahedral planes. Oxidation exsolution lamellae of ilmenite within titanomagnetite in the forms of three to four sets (Fig. 18) are most frequent (indicating oxidation index-III after the method of Watkins et. al, 1970); the thicker lenticular lamellae cut across the finer lamellae. Non-opaque spinel lamellae in the form of three to four sets have been observed; the spinel lamellae cut across ilmenite lamellae. Sulphides are rarely represented by a few dot-like specks of chalcopyrite, chalcopyrite-bornite intergrowth, both of which occur as inclusions within silicates.

Amongst accessories, large euhedral grains of zircon and anhedral sphene occur in association with iron ores.

Sp. No. 4/17.2.69 Modhpur : Southeastern part of Modhpur village.

In thin section, plagioclase phenocrysts are common, euhedral tabular, and show resorption and they contain inclusions of pyroxene needles and iron ores.
Clinopyroxene grains form both the phenocrysts and groundmass grains; in places they are replaced by iron ores and also altered to micaeous minerals. The pyroxenes are aegirine-augite forming irregular prisms with deep bright green interference colour and $X^c = 20^\circ$, indicating a composition $(Ca Mg Fe)_2^+_6 (Na Fe^{+++})_4^+ (out of Di-Hed-Ac molecules taken as 100)$. A few patches of aegirine with deep bright green colour and $X^c = 0^\circ$, are common (in Table 7).

Micropegmatitic intergrowth of quartz and alkali feldspar in comparatively finer forms are abundant. Forms of quartz inclusions vary from fine lamellar to coarse cuneiform with some irregular areas.

Iron ores occur in the form of anhedral grains; they are associated with sphene and commonly occur in the groundmass. Zircon forms a few anhedral plates.

Miarolitic and submiarolitic areas have coarse-anhedral grains of quartz and independent alkali feldspar plates.

KASVIRDI NES - PHATAL TALAO AREAS

Sp. No. 1/20.10.70 Kasvirdi Nes : 0.5 km southwest of Kasvirdi village.

In thin section plagioclase phenocrysts occur in the form of euhedral tabular grains and show albite twins and composition based on maximum $X'010 = 11.5^\circ$ is An$_{29}$.

Micropegmatitic intergrowth is abundant as coarse intergrowth of quartz and alkali feldspar in the forms of fine to coarse elongated lamellae-shaped quartz and also as fine to coarse cuneiform and irregular quartz areas, to granitic textured type. It shows host of potash feldspar
having unit extinction. Individual grains of alkali feldspar are common, these are perthitic and show patchy extinction.

Iron ores occur in lath shaped and octahedral forms. Brown limonitic patches are present which presumably represent pseudomorphs after pyroxene grains; the latter are also replaced by iron ores.

Submiarolitic patches are entirely filled in with coarse anhedral grains of quartz, anhedral granules of sphene and iron ores.


The rock is porphyritic with phenocrysts of plagioclase in a groundmass, composed of micropegmatite, clinopyroxene, iron ores and free quartz in miarolitic cavities.

Plagioclase phenocrysts are euhedral tabular, zoned and rimmed by alkali feldspar which is also the host of micropegmatite intergrowth (Fig. 19).

Micropegmatite is formed by coarse intergrowth of quartz and alkali feldspar occurring in various forms, e.g., coarse cuneiform with irregular quartz areas in the groundmass (Fig. 20).

Clinopyroxene occurs in traces, as anhedral granules, mostly replaced by iron ores.

Iron ores are present, in the form of fine anhedral to subhedral grains. A few large crystals of titanomagnetite show poikilitic intergrowth the silicates. Under the ore microscope titanomagnetite grains are found to be highly martitized. Moderately coarser grains of titanomagnetite with abundant oxidation-exsolution lamellae of ilmenite (oxidation index = III) have
Fig. 17. Photomicrograph showing zonation in granophyric texture, coarser intergrowths around plagioclase phenocryst grades to finer and vice versa. Crossed nicols, x 28.

Fig. 18. Photomicrograph showing three sets of oxidation-exsolution lamellae of ilmenite within titanomagnetite. In reflected light, after etched by conc HCl, x 450.

Fig. 19. Photomicrograph showing zoned plagioclase phenocryst (partly resorbed), and rimmed by alkali feldspar which is also the host of granophyric intergrowths with quartz. Crossed nicols, x 94.
been traced. Ulvospinel lamellae within titanomagnetite have been traced in etched specimens. Primary intergrowths of titanomagnetite and ilmenite are also common (Fig. 21). A few needle-like ilmenite grains occur interstitially. Sulphides are rare and represented by dot-like specks of chalcopyrite as inclusions within silicates.

Coarse anhedral grains of quartz and subhedral to euhedral plates of alkali feldspars are present in the miarolitic cavities.

**SAJANWALA-WANBJALIA-TARSAIL-KHARIPAT NES AREAS**

**Sp. No. 3A/12.2 : 1.5 km north of Tarsai village.**

In thin section, the rock is poorly porphyritic; plagioclase phenocrysts are few in number, euhedral and zoned (Fig. 22).

Micropegmatite abundantly occurs in the groundmass, in fine to coarsely developed forms (fine lamellae with radiating to herring-bone types 'Fig. 23', fine to coarse cuneiform types with triangular and irregular quartz areas) that grades to granitic texture in the submiarolitic areas. A few large separate anhedral aggregate of quartz also occur in the groundmass.

Clinopyroxene grains are pseudomorphed by haphazardly oriented chlorite and green biotite (X = light greenish yellow and Z = deep yellowish green).

**Sp. No. 1/15.2.69 : Collected from 1.5 km. southwest of Tarsai village.**

In thin section, the rock appears porphyritic with microphenocrysts of plagioclase and β-quartz in a micropegmatitic groundmass including clinopyroxene and other accessories.
Fig. 20. Photomicrograph showing coarse and cuneiform granophyric intergrowths; quartz grains are clear and cuneiform; the host alkali feldspar (grey) is in extinction. Crossed nicols, x 94.

Fig. 21. Photomicrograph showing prism of ilmenite (II), occurring as primary intergrowth with martitized titanomagnetite (t). In reflected light, after etched by Conc. HCl, x 450.

Fig. 22. Photomicrograph showing zoning in plagioclase phenocryst, rimmed by fine micrographic intergrowths of quartz and alkali feldspar. Crossed nicols, x 23.
Plagioclase phenocrysts are common, euhedral tabular, showing Carlsbad twinning and indistinct zoning; plagioclase phenocrysts are rimmed by micropegmatitic intergrowth.

Microphenocrysts of β-quartz occur in a granophyric groundmass; β-quartz as euhedral grains are set in between graphic intergrowth areas (Fig. 24).

Micropegmatite is abundant, in the form of fine to coarse intergrowths of quartz and alkali feldspar. Distinct domains of granophyric intergrowth are seen. Intergrowths in various forms from very fine radiating quartz lamellae, to coarsely cuneiform with irregular quartz areas and that grading to granitic texture are common.

Clinopyroxenes in the groundmass are in the form of short stout prisms to prismatic needles, with distinct pleochroism (Z = green, X = olive green, Y = greenish yellow), and ferrosalitic composition (in Table 7). In association rare alkalic pyroxene grain has been traced.

Iron ores, in euhedral to subhedral grains, are common in the groundmass. Other accessories in the groundmass include zircon and sphene.

Submiarolitic patches are filled in with coarse anhedral grains of quartz, euhedral plates of alkali feldspar and traces of iron ores and sphene.

Sp. No. 70/15.2.69: Collected from the contact of granophyre against the Sajanwala-Hanumangadh basaltic stoped block at Kharipat Nes.

The thin section study shows that the coarse granophyre along the contact against the basalt stoped block, has undergone considerable modification in irregular patches. It contains quartz in subordinate amounts (7.2 per cent)
due to desilicification, indicating a syenitic composition. Other minerals include fine intergrowths of quartz with stained alkali feldspar, spherulitic intergrowths, epidote and traces of clinopyroxene (charged with iron ores), prehnite, actinolite and sphene. Epidote pseudomorph after plagioclase occurs in the form of euhedral tabular grains, strongly pleochroic in the scheme of $X = \text{colourless}, Y = \text{deep greenish yellow} \text{ and } Z = \text{greenish yellow}$. Actinolite is fibrous in form. Primary clinopyroxene grains are altered to reddish brown iddingsite.

Sp. No. 2/12.2.69: From the acid rock contact against the basaltic country rocks in the Wansjalia area.

Large euhedral plagioclase phenocrysts in thin section show the twinning of Albite and Carlsbad types and are partly resorbed. $\beta$-quartz grains occur in the form of euhedral microphenocrysts.

Granophyric intergrowths are in varying forms, from coarse to finer inclusions of quartz within alkali feldspar (Fig. 2f). Alkali feldspar parts are mostly altered.

Clinopyroxene grains are mostly leached and pseudomorphed by limonitic iron ores. Miarolitic cavities are filled in with coarser anhedral grains of quartz, iron ores, calcite and baryte.

MODAL DATA

The modal percentages (volume per cent) of constituent minerals in coarse granophyre, are shown in the following Table 3.
Fig. 23. Photomicrograph showing granophyric intergrowths (fine lamellar, with radiating to herring-bone type) of quartz and alkali feldspar. Crossed nicols, x 23.

Fig. 24. Photomicrograph showing β-quartz as euhedral phenocryst set in between graphic intergrowth areas. Crossed nicols, x 82.

Fig. 25. Photomicrograph showing granophyric intergrowths of coarse to fine inclusions of quartz (white) within alkali feldspar (grey), separated by a twin lamellae of host alkali feldspar. Crossed nicols, x 28.
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<th>Quartz</th>
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<th>Plagioclase</th>
<th>Clinopyroxene</th>
<th>Opaques</th>
<th>Accessories</th>
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<td>Nil</td>
<td>4.8</td>
<td>0.3</td>
</tr>
<tr>
<td>1/15.2.69 Tarsai</td>
<td>32.1</td>
<td>56.4</td>
<td>6.7</td>
<td>1.9</td>
<td>2.9</td>
<td>Nil</td>
</tr>
<tr>
<td>16/25.2.71 Modhpur</td>
<td>30.8</td>
<td>65.5</td>
<td>1.2</td>
<td>Nil</td>
<td>1.9</td>
<td>0.6</td>
</tr>
</tbody>
</table>

(All totals to 100)

| Average     | 32.25 | 58.50 | 3.37 | 1.32 | 3.86 | 0.66 |
Quartz contents vary from 30.1 to 34.6 percent, excepting two samples which showed the values of 38.3 and 25.8 percent. The alkali feldspar varies in amounts from 54.2 to 65.5 percent with one sample containing 49.6 percent. Plagioclase content ranges from 10.1 to nil (with an average of 3.37 percent) and varies inversely with the alkali feldspar content.

These modal percentages of the constituent minerals, particularly the plagioclase and alkali feldspar content, have similarity with the Tertiary granites of Skye. In the Skye granite (Tuttle and Bowen, 1958, p. 109), out of the 44 specimens studied one contained less than 20 per cent quartz and none carried more than 35 percent. In the same granite alkali feldspar is the most abundant mineral and it makes up 39 to 79 percent of the specimen studied. The plagioclase content varied from 19.2 percent to nil, with the average of 11.1 percent in the mode.

The variations in the three major constituents (namely quartz, alkali feldspar and plagioclase) in the mode of this coarse miarolitic granophyre have been shown in a triangular diagram (Fig. 26) and have been compared with similar plots for the granites of Skye. The similarity between these two groups is noteworthy. The plagioclase content of the coarse granophyre, reaching only upto 11 percent, are restricted to the quartz-orthoclase sideline of quartz-orthoclase-plagioclase triangular diagram. Similar dispersion patterns have been shown in the modal percentages of plagioclase, ranging upto 20 percent in the Skye granites. The trend of modal compositions of granites from the quartz-orthoclase side line towards the centre of the diagram represents a falling temperature trend of final crystallisation of granites (Tuttle & Bowen, 1958, p. 115). The present granophyre, the plots of which are restricted to the quartz-orthoclase sideline, may thus be considered to be of high temperature
MODAL PLAGIOCLASE, ALKALI-FELDSPAR
AND QUARTZ IN COARSE GRANOPHYRE
OF BARDA ACID IGNEOUS COMPLEX, IN
COMPARISON TO THAT OF SKYE GRANITE.

FIG. 26.

Quartz

Coarse Granophyre of
Barra Acid Igneous Complex.

Skye Granite.

Alkali feldspar
(Orthoclase)

Plagioclase
crystallisation, as it is shown for Skye granites.

In view of the high normative albite content (ranging between 30.41 and 30.8 percents in specimen number 21/9C and 31/12 as given in Table 4 in the granophyres), it is considered that the alkali feldspar is not pure "orthoclase" but contains a large amount of albite in solid solution. Hence the modal analyses only gives an apparent location of the rocks in the three component system; whereas actually the bulk composition of the rocks should lie more near the centre of the ternary Q-Ab-Or diagram.

The quartz-feldspar ratio (i.e. \( \frac{\text{Quartz} \times 100}{\text{Quartz} + \text{Alkali Feldspar}} \)) in the present granophyre ranges from 33 to 39 percent, with a few scatterings above and below the range. In any suite of rocks (Dunham, 1965) which have probably crystallised under similar water vapour pressures, the variation in the quartz-feldspar ratio should not be very great, if quartz and feldspar have crystallised simultaneously. The work of Tuttle and Bowen (1958) suggests that, the amount of quartz crystallising simultaneously with the feldspar under isobaric water pressure conditions can vary upto 10 percent and under non-isobaric conditions may vary by a greater amount.

CHEMICAL DATA

The chemical analyses of the following two samples of granophyre from the present area are tabulated below (in Table 4) as obtained from De and Bhattacharyya (1971).
### TABLE 4

Chemical Analyses and Norm in Coarse Granophyre

<table>
<thead>
<tr>
<th></th>
<th>Ferroaugite Granophyre (31/12)</th>
<th>Aegirine-augite Granophyre (21/9C)</th>
<th>C. I. P. W. Norm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>72.22</td>
<td>73.28</td>
<td>31/12 21/9C</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>11.36</td>
<td>10.95</td>
<td></td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.50</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1.94</td>
<td>3.88</td>
<td></td>
</tr>
<tr>
<td>FeO</td>
<td>3.64</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>0.07</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>1.94</td>
<td>1.16</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>0.14</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>3.61</td>
<td>3.54</td>
<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>3.97</td>
<td>4.32</td>
<td></td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.089</td>
<td>0.160</td>
<td></td>
</tr>
<tr>
<td>H₂O⁺</td>
<td>0.08</td>
<td>0.24</td>
<td>An/Ab+An 8.6</td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>0.40</td>
<td>0.88</td>
<td>3.7</td>
</tr>
</tbody>
</table>

99.97 100.00

Analyst - B.P. Gupta.

The following salient features have been observed from the chemical data.

(1) The normative quartz albite and orthoclase recalculated to 100 (as found 32.4; 39.2; 28.4 for ferroaugite granophyre and 33.5; 36.9; 29.6 for aegirine-augite granophyre) have their plots near the minima of experimental
Na Al Si$_3$O$_8$ - K Al Si$_3$O$_8$ - SiO$_2$ - H$_2$O system of Tuttle and Bowen (1958), that is expected from their undoubted igneous origin.

(2) The normative quartz, orthoclase and (albite + anorthite), recalculated to 100, as found 33.68, 27.22, 39.10 for ferroaugite granophyre and 35.46, 29.06 and 35.46 for aegirine-augite granophyre indicate the rock as adamellite in composition.

(3) The differentiation indices in the ferroaugite granophyre and aegirine-augite granophyre have been calculated as 86.68 and 89.24 respectively, which indicate them as felsic differentiates (Poldervaart, 1958).

(4) The ferroaugite granophyre has a low oxidation ratio of 28, which may be compared with the ratio of 20 as found in the Deccan Trap basalts in the stage of their maximum iron enrichment (De, 1964). The aegirine-augite granophyre indicates a very high oxidation ratio of 78, which may cause the formation of alkali pyroxene.

(5) The peralkaline tendency of aegirine-augite granophyre is indicated by the molecular proportion of Al$_2$O$_3$ which is only 0.005 higher than those of total Na$_2$O and K$_2$O. The absence of mica and hornblende and the presence of alkali pyroxene can be explained by this criteria.

(6) The low amount of modal plagioclase in coarse granophyre is reflected in the low amount of normative anorthite; whereas the large amount of normative albite can be explained by its presence of solid solution in the alkali feldspar.
SUMMARISED MINERALOGY

The observed variations in the mineralogy of coarse granophyres as revealed from petrographical studies of the thin sections, are summarised below.

Plagioclase:

Plagioclase is present in fairly coarse euhedral to subhedral tabular grains and occurs as phenocrysts of intratelluric origin forming on an average 3.3 percent in the mode. They are rimmed by alkali feldspar host of micropegmatitic intergrowth (Fig. 19). Plagioclase is generally clear and unaltered, and hence can be distinguished from alkali feldspars even when the twinning is lacking. Plagioclase phenocrysts are commonly resorbed at the borders (Fig. 14) but in some cases the resorption has also attacked the central part reducing the grains into skeletal forms. The signs of magmatic resorption and an outer rim of alkali feldspar around plagioclase phenocrysts are indicative of the presence of a reaction relation between the plagioclase, alkali feldspar and the residual melt (Tuttle and Bowen, 1958) as discussed detail in Chapter X. In some places, the plagioclase grains are saussuritised with the production of sericite, albite and Ca-rich secondary minerals. Plagioclase is seen to be enclosed in subophitic to ophitic manner by the coarser generation of clinopyroxene in glomeroporphyritic areas. Alteration to epidote is clearly seen in the plagioclase phenocrysts of granophyres at the contact.

Zoning is commonly detected in plagioclase phenocrysts (Fig. 13, 19, 22); but is generally indistinct. Zoning in plagioclase may be interpreted as a result of repeated movement of feldspar crystals from one part to another part of magma chamber; and (or) due to changes of pressures with consequent
loss of volatiles (Tuttle and Bowen, 1958). Twinning is polysynthetic, which is poorly and partially developed in most cases. Twin lamellae are generally thick. Simple Carlsbad type and combination of Carlsbad and albite type are found.

Albitic plagioclase in the late crystallised miarolitic cavities are minor in amounts, usually rimming alkali feldspar plates and show well developed twinning; it belongs to the late generations. At the final stages of crystallisation, the high concentration of volatiles may lower the liquidus temperature enough so that two feldspars would crystallise simultaneously in even a lime poor rock. In that case, alkali feldspar would show rims of plagioclase (Tuttle, 1952).

The following Table-5 shows the composition of plagioclase, calculated from maximum symmetrical extinction angle, measured on universal stage. The compositions range from 27.5 to 33 percent anorthite molecules, hence all the plagioclase is basic oligoclase to acid andesine. The optic axial angles of plagioclase phenocrysts measured as 67° indicate a high to transitional state (Tuttle and Bowen, 1958, p. 108) and hence they resemble the plagioclase feldspars from Skye granite, which are intermediate between those occurring in extrusive and plutonic salic rocks.
### TABLE-5

Composition of Plagioclase in Coarse Granophyre

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Maximum Extinction angle (X'(\overline{\alpha}010))</th>
<th>Refractive index in relation to Canada balsam</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.0/91 Sakhpur</td>
<td>14.5°</td>
<td>Higher</td>
<td>An&lt;sub&gt;32.5&lt;/sub&gt;</td>
</tr>
<tr>
<td>2/12.2 Tarsal</td>
<td>10°</td>
<td>Higher</td>
<td>An&lt;sub&gt;27.5&lt;/sub&gt;</td>
</tr>
<tr>
<td>1/20.10.70 Kasvirdi Nes</td>
<td>11.5°</td>
<td>Higher</td>
<td>An&lt;sub&gt;29&lt;/sub&gt;</td>
</tr>
<tr>
<td>4/17.2.69 Modhpur</td>
<td>12°</td>
<td>Higher</td>
<td>An&lt;sub&gt;29.5&lt;/sub&gt;</td>
</tr>
<tr>
<td>3/11.2.69 Sakhpur</td>
<td>15°</td>
<td>Higher</td>
<td>An&lt;sub&gt;33&lt;/sub&gt;</td>
</tr>
<tr>
<td>2/12.2.69 Wansjalia</td>
<td>10°</td>
<td>Higher</td>
<td>An&lt;sub&gt;28&lt;/sub&gt;</td>
</tr>
<tr>
<td>11/11.2.69 Sakhpur</td>
<td>12°</td>
<td>Higher</td>
<td>An&lt;sub&gt;29.5&lt;/sub&gt;</td>
</tr>
</tbody>
</table>

Average An<sub>30</sub>

**Alkali feldspar:**

Alkali feldspar (orthoclase–albite solid solution) is a major constituent of these rocks and generally occurs in two forms, one intergrown with quartz forming micropegmatitic unit and the other forms free grains. It varies in the mode from 49.6 to 65.5 percent. Coarse micropegmatitic
units tend to attain subhedral forms, like free alkali feldspar grains and indicate that alkali feldspar is the host containing intergrown quartz. This is clearly indicated in a very coarse grained specimen in which cleavages of alkali feldspar are seen to continue on both sides of the intergrown quartz area. Rectangular reticulation in many grains due to two sets of cleavage is characteristic. Individual grains of alkali feldspar occur in miarolitic and submiarolitic areas, in association with quartz, plagioclase and iron ores. Alkali feldspar grains while occurring adjacent to miarolitic cavities, have indistinct perthitic intergrowth and narrow rim of albite. The grains in the miarolitic and submiarolitic areas crystallised in the latest stage under volatile rich conditions.

The following Table 6 shows the composition and structural state of alkali feldspar, calculated from refractive index and 2V data. The alkali feldspar grains show transitional to high temperature optic axial angles (Tuttle and Bowen, 1958, p. 104), indicating that they belong to the low sanidine - high albite series of alkali feldspar, which are characteristically found in volcanic and subvolcanic rocks. The variation in the optic axial angles in the same rock type may be a result of partial inversion towards orthoclase-low albite series.

**TABLE 6**

Composition and Structural State of Alkali Feldspar in Coarse Granophyre

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Measured 2V</th>
<th>Refractive Indices (n₁)</th>
<th>Composition</th>
<th>Structural State</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/23.2.71</td>
<td>54°</td>
<td>1.530 ± 0.001</td>
<td>Or₅₆</td>
<td>Transitional</td>
</tr>
<tr>
<td>1/19.2.71</td>
<td>62°</td>
<td>1.527 ± 0.001</td>
<td>Or₆₄</td>
<td>Transitional</td>
</tr>
</tbody>
</table>
Quartz:

It is next in abundance to alkali feldspar and mainly occurs intergrown with the latter in various sizes and forms of intergrowths as triangular, rhombic, trapezoid, irregular, needle shaped or lamellar, granular, etc. Such variation in intergrowth pattern was generated in response to local variation in the concentration of the volatiles and the intergrowing components, i.e., quartz and alkali feldspar and on the nature of nucleation and rate of crystallization. The quartz grains formed as eutectic intergrowths with alkali feldspar, as indicated by the narrow range of variation of modal quartz content, which commonly varies from 30.1 to 34.6 percent. The rare euhedral phenocrysts of β-quartz have been preserved in the contact granophyre (Fig. 24). Miarolitic and submiarolitic quartz grains are usually very coarse and they form anhedral to euhedral aggregates. Small pockets of xenomorphic aggregates of interstitial quartz are common. It is always clear and unaltered unlike the alkali feldspar and plagioclase.

Clinopyroxene:

The clinopyroxene grains occur both as phenocrysts in the forms of subhedral bladed or tabular or euhedral elongated grains and also as groundmass constituents. Very long, narrow euhedral prisms and needle-like forms are also abundant. Grains are generally strongly resorbed showing corroded boundary which is mostly charged with small anhedral iron ores. In some cases phenocrysts of clinopyroxene are seen to enclose laths of plagioclase ophically.

In the coarse grained variety of granophyre, clinopyroxenes are mostly altered to iron ores, limonite, chlorite and biotite. Clinopyroxene ranges
between nil and 5.8 percent in the mode, the former value is a result of complete replacement by iron ores.

The clinopyroxene in the coarse grained granophyre from the southern part in the Sakhpur-Bordi and Wans Jal-Tarsai-Sajangwala areas is a ferrosalite. The clinopyroxene grains in the coarse grained granophyre of Modhpur-Khambiyara- Talara talao areas are varied in composition and they are ferrosalite, ferroaugite to aegirine augite and aegirine. The alkalie pyroxene also occurs as later formed rim around the primary pyroxene of ferrosalite or ferroaugite composition. The coarse grained granophyre of Kaswirdi Nes - Phatal talao shows no (or only a trace of) clinopyroxene, which is entirely pseudomorphed. The aegirine in the miarolitic cavities are formed at the late stage, as a result of an increase of oxygen fugacity by the dissociation of H₂ from water-rich fluid phase (De and Bhattacharyya, 1971). The alkalie clinopyroxene rims may have been formed by the gradual decrease of cooling temperature at constant oxygen fugacity condition (Buddington and Lindsley, 1964).
### TABLE 7

Clinopyroxene in Coarse Granophyre

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Shape, colour and pleochroism</th>
<th>Z &gt; c</th>
<th>2V&lt;sub&gt;z&lt;/sub&gt;</th>
<th>N&lt;sub&gt;y&lt;/sub&gt;</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 1/19,2.71 Bordi-Ranawao</td>
<td>Coarse pyroxene plates with schiller inclusions; Feebly pleochroic X = light olive green Y = olive green Z = olive green</td>
<td>43°</td>
<td>58.5°</td>
<td>1.722 ± 0.002</td>
<td>Ca&lt;sub&gt;46&lt;/sub&gt; Mg&lt;sub&gt;14&lt;/sub&gt; Fe&lt;sub&gt;40&lt;/sub&gt; (Ferrosalite)</td>
</tr>
<tr>
<td>2. 13/20,2.71 Bordi-Ranawao</td>
<td>Fine subhedral prisms and needle shaped grains; Pale green with very weak pleochroism. X = pale green Y = yellowish green Z = green</td>
<td>46°</td>
<td>58°</td>
<td>1.717 ± 0.003</td>
<td>Ca&lt;sub&gt;46.5&lt;/sub&gt; Mg&lt;sub&gt;18.5&lt;/sub&gt; Fe&lt;sub&gt;35&lt;/sub&gt; (Ferrosalite)</td>
</tr>
<tr>
<td>3. 2/23,2.71 Khambiyara-Modhpur</td>
<td>(A) Pale green, margin studded, inclusions of euhedral plagioclase and iron and granules; Feeble pleochroism X = pale yellowish green Y = brownish yellow Z = deeper yellowish green</td>
<td>45°</td>
<td>55.5°</td>
<td>1.772 ± 0.002</td>
<td>Ca&lt;sub&gt;43.5&lt;/sub&gt; Mg&lt;sub&gt;17.5&lt;/sub&gt; Fe&lt;sub&gt;39&lt;/sub&gt; (Ferroaugite)</td>
</tr>
<tr>
<td></td>
<td>(B) A few deep bright green patches, associated with iron ores.</td>
<td>68.5°</td>
<td>1.737 ± 0.002</td>
<td></td>
<td>(Ca Mg Fe)&lt;sup&gt;3+&lt;/sup&gt; (Na Fe&lt;sup&gt;+++&lt;/sup&gt;)&lt;sub&gt;81&lt;/sub&gt; (Aegirine-augite)</td>
</tr>
</tbody>
</table>
### TABLE 7 (Contd.)

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Shape, colour and pleochroism</th>
<th>Z &amp; c or X &amp; c</th>
<th>2V_z</th>
<th>N_y</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. 4/17.2.69 Modhpur</td>
<td>(A) Irregular prisms, deep bright green, studded with iron ores and having high order interference colour</td>
<td>X &amp; c = 24°</td>
<td>66°</td>
<td>1.732 ± 0.003</td>
<td>(Ca Mg Fe$^{++}$)$<em>{8/4}$ (Na Fe$^{+++}$)$</em>{16}$ (Aegirine augite)</td>
</tr>
<tr>
<td></td>
<td>(B) Deep bright green prisms</td>
<td>X &amp; c = 0°</td>
<td>-</td>
<td>-</td>
<td>Aegirine</td>
</tr>
</tbody>
</table>
| 5. 7/18.10.70 Talara talao | Short and stout prism; Feebly pleochroic  
X = pale green  
Y = deep green  
Z = olive green | Z \& c = 45°     | 58.5°  | 1.722 ± 0.002 | Ca$_{46}$ Mg$_{14}$ Fe$_{40}$ (Ferrosalite) |
Opaque minerals:

The opaque minerals in the coarse grained granophyre occur as coarse euhedral to subhedral plates, poikilitically enclosed in phenocrysts of clinopyroxene and plagioclase. Other forms include minute specks, needles and dendrites. Presence of anhedral grains of iron ores in spongy aggregates with interstitial quartz are common as apparent pseudomorphs after clinopyroxene. Interstitial opaques, which partially, or in rare cases completely fill up the miarolitic cavities are anhedral but rare euhedral forms are seen. The opaque minerals vary in modal amounts from 1.6 to 7.1 percent.

Ore microscopic study reveals titanomagnetite as a major constituent. Oxidation-exsolution intergrowth of titanomagnetite with ilmenite lamellae in three to four sets (Fig. 18) indicate the oxidation index ranging from III to IV following the classification of Watkins et al. (1970). Ulvöspinel and spinel lamellae within titanomagnetite have been traced in the etched samples. The ilmenite lamellae within magnetite are the result of unmixing and oxidation during the cooling of original magnetite-ulvöspinel solid solution (Buddington and Lindsley, 1964). Martitisation along octahedral planes and maghemisation in irregular patches have frequently been observed within titanomagnetite grains. The oxidation product titanomaghemite may be superimposed on the high temperature oxidation sequence. The oxidation of magnetite to maghemite has been reported to take place in the temperature as low as 200°C (Lepp, 1957, cited in Watkins, et al., 1970). Primary enclosure of titanomagnetite and ilmenite have also been observed (Fig. 21). A few discrete primary ilmenite grains are found in the groundmass. Sulphides are rare and represented by minute specks of chalcopyrite, and bornite, which occur as inclusions within the silicates. The minor sulphides are interpreted
to represent crystallisation of droplets of immiscible sulphide liquid within the silicates and iron oxides, such as observed in the Skaergard intrusion (Wager and Brown, 1967) and in the Deccan Traps (De, 1974).

Accessory and Secondary minerals:

Accessory and secondary minerals occur in minor amounts in the miarolitic and submiarolitic cavities and also interstitially in the groundmass. They include zircon, fluorite, apatite, baryte, sphene, chlorite, fibrous amphibole, green biotite, stilpnomelane, prehnite, calcite and iron ores. The modal amounts of accessory minerals vary from nil to 1.7 percent. At the later stage of crystallisation, under the high partial pressure of water, the pyroxene grains are altered in rare cases to biotite, chlorite and fibrous amphibole. Stilpnomelane and prehnite are hydrothermal alteration products from pyroxene. Zircon, fluorite, baryte, apatite and sphene may be considered as late magmatic to hydrothermal products. A probable fayalite pseudomorphed by limonite has been observed whereas fresh fayalitic olivine occurs in the associated fine granophyre and felsite. Limonite and iddingsite mostly occur as pseudomorphs after clinopyroxène.

TEXTURE

The texture of this rock type is dominated by coarse micrographic intergrowths of quartz and alkali feldspar in various forms. Plagioclase phenocrysts are always rimmed by alkali feldspar which grades into granophyric intergrowth of quartz and alkali feldspar (Fig. 19). The granophyric groundmass is composed of coarse to medium sized, micropegmatitic units, which are subhedral tabular and comparable in form to alkali feldspar host.
Plagioclase is in optical continuity with the bordering alkali feldspar including the part which is the host of micropegmatitic intergrowth (Fig. 19). The phenomenon of optical continuity of alkali feldspar with plagioclase phenocryst can be interpreted as a result of zoning in response to reaction relation between plagioclase, alkali feldspar and magmatic liquid as discussed in Chapter X.

The intergrowth pattern of the groundmass varies from coarse lamellar, feathery, herring-bone, cuneiform, irregular intergrowths to a coarse granitic textured type (Figs. 15, 20, 23, 25). Zoning (in the size of inclusions or of shape) in the micropegmatitic intergrowth is a common feature, indicating gradation in its formation, finer intergrowths may rim coarser intergrowths or vice versa (Fig. 17). Outward from micropegmatitic units, quartz and alkali feldspar are associated with pyroxene and accessories, but become very coarse and free from intergrowth as they approach the submiarolitic areas, where the interstitial grains show small patches with hypidiomorphic granular texture.

In the formation of granophyric texture, both the degree of supercooling and the composition of the magma, were important factors (Dunham, 1965). Granophyre and felsite originated from the same magma, but under contrasted environments. In one environment, under high degree of supercooling, the melt cooled quickly, chilling it to a glass, which later devitrified to form the microcrystalline groundmass of felsite. In the environment of granophyre formation, the supercooling was not so great and the groundmass has a bulk composition lying on the cotectic line of the system orthoclase-albite-silica-water (Tuttle and Bowen, 1958). The temperature and pressure would have to be maintained for a period of time for the formation of granophyric and granitic texture and water content would probably be near saturation (Lofgren, 1971). The latter would also help formation of larger crystals.
Miarolitic structure:

This variety of granophyre contains numerous large crystal-lined miarolitic cavities (Figs. 11, 16). The cavities are commonly visible to the naked eye, and may reach half-an-inch (1.2 cm) in diameter. They may be very large and only partially filled with late magmatic (or early hydrothermal) minerals.

The frequency of areal distribution of the miarolitic cavities measured in square cm of cavity area per 100 square cm of rock surface, hence equivalent to volume percent of miarolitic cavity in the rock as observed in a few specimens are given in the following Table.

**TABLE 8**

Volume Percent of Miarolitic Cavity in Coarse Granophyre

<table>
<thead>
<tr>
<th>Specimen No. &amp; location</th>
<th>Frequency of miarolitic cavity, measured in sq. cm. of cavity area per 100 sq. cm. of rock surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/12.2.69 Wansjalia-Sakhpur</td>
<td>5 sq. cm.</td>
</tr>
<tr>
<td>30.3/93.8. 11.2.69 Sakhpur</td>
<td>3 sq. cm.</td>
</tr>
<tr>
<td>1/19.2.71 Bordi</td>
<td>1.5 sq. cm.</td>
</tr>
<tr>
<td>14A/15.2.69 Phatal talao</td>
<td>6 sq. cm.</td>
</tr>
</tbody>
</table>
In the following Table 9, minerals from miarolitic and submiarolitic areas of a few specimens have been described as representatives from thin section studies.

**TABLE 9**

Texture and Mineralogy of Miarolitic Areas in Coarse Granophyre

<table>
<thead>
<tr>
<th>Specimen No. &amp; location</th>
<th>Minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>13/20.2.71 Bordi-Ranawao</td>
<td>Coarse anhedral grains of quartz, subhedral to euhedral plates of alkali feldspar, fine anhedral granules of iron ores, chlorite and fibrous amphibole (but not riebeckite), fluorite, subhedral zircon.</td>
</tr>
<tr>
<td>30.25/90.65 Sakhpur</td>
<td>Coarse anhedral grains of quartz, subhedral to euhedral plates of alkali feldspar, subhedral fluorite, calcite in patches, iron ores, sphene rimming around iron ores, zircon, muscovite and aegirine augite.</td>
</tr>
<tr>
<td>1/19.2.71 Bordi-Ranawao</td>
<td>Coarse anhedral grains of quartz, euhedral to subhedral plates of alkali feldspar, free irregular patches of iron ores, fluorite, baryte in euhedral plate (with prominent two sets cleavages), fibrous green patches of chlorite, stilpnomelane ($X^C = 15^\circ$, pleochroic with $X =$ brown and $Z =$ deep brown).</td>
</tr>
<tr>
<td>1/15.2.69 SW of Tarsal</td>
<td>Coarse anhedral quartz grains dominating, a few euhedral to subhedral plates of alkali feldspar, fine subhedral to anhedral granules of iron ores and sphene in traces.</td>
</tr>
<tr>
<td>1/20.10.70 Kasvirdi Nes</td>
<td>Coarse anhedral grains of quartz, euhedral plates of alkali feldspar, fine anhedral granules of sphene, anhedral to subhedral iron ores.</td>
</tr>
<tr>
<td>4/17.2.69 Modhpur</td>
<td>Coarse anhedral grains of quartz and independent euhedral alkali feldspar grains.</td>
</tr>
<tr>
<td>16/25.2.71 Modhpur</td>
<td>Fibrous chlorite, coarse anhedral quartz grains, subhedral to anhedral granules of iron ores and sphene.</td>
</tr>
<tr>
<td>30.3/93.8 Sakhpur</td>
<td>Aggregated quartz in the form of anhedral grains, euhedral fine twinned albite, euhedral to subhedral plates of alkali feldspar (orthoclase).</td>
</tr>
</tbody>
</table>
Previously it was thought that the miarolitic cavities in the granitic rocks are due to shrinkage incurred during freezing of the magma (Turner and Verhoogen, 1960). Lofgren (1970) experimentally found that miarolitic cavities formed in the devitrified samples, possibly resulting from the volume change on crystallisation. It is also known that the emission of gas toward the close of crystallisation may produce such cavities.

Formation of coarse grained hydrothermal minerals, chlorite, stilpnomelane, amphibole, alkali pyroxene, fluorite, baryte, calcite etc., indicate a development of a hydrous fluid phase - and this association suggests that miarolitic cavities formed from emission of a gas phase.

<table>
<thead>
<tr>
<th>Specimen No. &amp; location.</th>
<th>Minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>14B/15-2.69 Phatal talao east.</td>
<td>Coarse and euhedral tabular grains of quartz and free euhedral alkali feldspar plates.</td>
</tr>
<tr>
<td>3/11.2.69 Sakhpur</td>
<td>Coarse anhedral quartz grains, subhedral to euhedral alkali feldspar plates, in association with traces of zircon, pale green micaeous minerals and sphene.</td>
</tr>
<tr>
<td>2/12.2.69 Wansjalia</td>
<td>Coarse anhedral grains of quartz, patches of calcite, anhedral and skeletal iron ores, and baryte.</td>
</tr>
<tr>
<td>11/11.2.69 Sakhpur</td>
<td>Coarse anhedral grains of quartz, subhedral plates of alkali feldspar, anhedral epidote and spongy aggregated iron ores.</td>
</tr>
</tbody>
</table>
PETROGRAPHIC SIGNIFICANCE

The following features are of petrographic significance for the coarse granophyre.

1. A granophyric texture, formed by intergrowth of quartz and alkali feldspar is a noteworthy feature for high level intrusions of subsolvus granitic composition within which volatiles were retained (Buddington, 1959; Hughes, 1960). The grading of coarse granophyric texture to granitic texture in the interstitial miarolitic and submiarolitic spaces indicate that a progressive concentration of volatile constituents would depress the crystallisation temperature, and permit slower but gradual crystallisation in the interstitial coarser granitic fabrics. Scattered miarolitic and submiarolitic cavities are partially filled in with low (alpha) quartz (euhedral), baryte, fluorite, zircon, sphene, and they indicate the crystallisation products of trapped hydrothermal fluids. Besides lime, alkalies, iron and silicates, these fluids contain rare elements like barium, fluorine, zirconium, titanium etc. Presence of those minerals indicate that the interstitial hydrous fluids were at temperatures corresponding to early hydrothermal stage. The coarse granophyric rocks crystallised under greater hydrostatic pressure, which prevented the early escape of water vapour. Residual water in the granophyre would be expected to form a separate phase as the crystallisation from a water rich silicate melt progressed (Niggli, 1929 cited in Hughes, 1960). This would account for the miarolitic cavities as stated earlier in the granophyre. The alteration of plagioclase phenocrysts of granophyre in comparison to those of felsites and other fine grained acidic rocks can be ascribed to late stage deuteric activity by the volatile constituents.
2. The second boiling point of magma or the phenomenon of boiling due to increase in volatile concentration and vapour pressure during crystallisation of coarse granophyre was probably reached (De and Bhattacharyya, 1971). The water-rich phase which separates during the second boiling probably caused the larger crystal growth from the magma. The high water content decreases the viscosity and thus promoting more rapid movement of ions and help the growth of coarser crystals in the miarolitic areas.

3. The mineralogical characteristics like high to transitional state of plagioclase feldspar, low sanidine-high albite series of alkali feldspar and presence of β-quartz indicate the volcanic to subvolcanic nature.

4. The alkali pyroxene in the miarolitic cavities of coarse granophyre indicates that at the late stage of crystallisation there may have been a gradual increase of oxygen fugacity owing to the dissociation of $\text{H}_2$ from $\text{H}_2\text{O}$ molecules. As stated, the high oxygen fugacity and low temperature conditions are favourable for the formation of alkali pyroxene.

5. The high degree of oxidation-exsolution and maghemitisation in titanomagnetite of coarse granophyre also indicate indicate their crystallisation at a comparatively higher oxidation condition than the other varieties of acidic rocks.