The Kathiawar peninsula is largely covered by extensive Deccan Trap basalts, with a few centres of acid igneous intrusions and Mesozoic-Tertiary sedimentary deposits. The present area of investigation involves a variety of acid igneous rocks, which have been intruded or extruded through the Deccan Trap basalts. Dykes and flows of more basic types, such as oceanite, ankaramite, picrite and limburgite are also known from Kathiawar from the work of Fedden (1884) and from detailed petrographic studies of Adye (1914, 1917) and West (1958). Fedden, however, did not study the details of the petrography of those lava flows. Adye, for the first time, described the petrography of basalts, along with the acidic rocks of the present area in some details.

The Deccan Trap basalts of Kathiawar, mostly belong to the upper sequence of Deccan Trap igneous province (Krishnan, 1958). West (1958) has studied in detail, the petrography of forty eight lava flows from the bore holes put down in three locations in Kathiawar, western India. He has studied, besides normal basalts, a few dykes and flows of more basic types, as mentioned in the previous paragraph. Washington (1922) called these as plateau basalts. Washington's study of twenty three samples of the Deccan Traps contained only one sample from the Kathiawar Peninsula.

Extensive flows of tholeiitic basalts, associated with infra-trappean and intertrappean beds, occupy low and flat lands in the northern and central parts of Saurashtra. The lofty masses of hypabyssal intrusives constituting the Barda and Alech group of hills are located in the western Saurashtra.
The infra-trappean and intertrappean sedimentary beds crop out mainly in the north-eastern parts of Kathiawar away from the present area, whereas the supra-trappeans representing the miliolitic limestone being exposed along the southern and eastern flanks of Barda hills, that constitute the present area of study.

**DISTRIBUTION**

Basaltic rocks in the present area, according to their distributions and modes of occurrence may be grouped as follows:

1. Basalts in the eastern part of the present area, adjacent to Wansjalia and Katkola occur as the country rock in between Barda and Alech hills, forming a flat low lying area. The occurrence is bounded to the western side by the lofty masses of acid igneous complex of Barda hills and to the eastern side by those of Alech hills. The exposures have mainly been covered by the cultivated lands. The basaltic area has been mapped from the exposures of nala (streams), Minsar river, dug well cuttings and black soil of cultivated land. The rock is well jointed with two most characteristic sets of joints which show strike N43°E, dip 88° towards south and strike N75°W, with vertical dip. In several places, acid dykes are found to cut the basaltic rocks.

2. Basaltic rocks, occurring in the low lying ridges and flat lands adjoining Verad Railway Station and in the western parts of Verad village, are located at about 7 miles (11.2 km.) northwest of Barda acid igneous complex. The basaltic rocks are well exposed along both the sides of Bhamwar-Verad railway line, and in the Minsar river valley. They are well sheeted by characteristic joints. The exposures in the flat lands are deeply eroded, and at a few places the upper part of the flow is lateritised.
3. A basaltic inlier within the acid intrusives of Tarsai-Sajanwala-Hanumangadh areas is considered to be a stoped block. The basalt crops out in the flat low lying lands, being exposed in river, nala and dug-well cuttings and is mostly covered cultivation areas. The basaltic block is bounded on all sides by granophyre and felsite. It is elliptical in shape, with a long dimension of 3 miles (4.8 km.) in northwest-southeast direction and width of 1 mile (1.6 km.). The contact of the basic unit against the acidic rock is clearly exposed in the Bileshawarl river cuttings located about 1 mile (1.6 km.) west-northwest of Tarsal village. The western and eastern contacts have the trends towards N53°W and dipping 85° north-westerly and towards N50°W dipping 85° easterly. Contact effects like epidotisation and desilicification in the acidic rocks have been found.

4. A similar basaltic stoped block, occurs adjoining Talara and Khambiyara talao areas in the form of an inlier within the acidic intrusives and exposed in the flat low lying lands. It is surrounded by felsite porphyry, rhyolite in the south and west and granophyre in the northern and eastern parts. Acidic plugs and dykes have been observed within this stoped block. It is comparatively smaller in dimension and has roughly a rectangular shape covering an area of around 1,2 sq. km.

5. Basalts along the north and north-eastern flank of Barda hills, adjoining Ghumli and Khambiyara Nes (village) areas, occurs as the country rock, along the NNW-SSE trending linear ridges and in the flat low lands. The basaltic rock has been mapped along the boundary of acid igneous complex whose contact trends north-west, extending from Khambiyara Nes to Ghumli. The basaltic rocks are exposed in the long ridges, elongated subparallel to the acidic complex, and have some mineralogical and textural differences compared to those occurring in the adjacent low lying lands. These petrographical differences appear to be due to thermal metamorphic effects caused by hot
acidic intrusions in the basaltic rocks. These rocks, particularly those in the Ghumli area, are highly sheeted or jointed on small scales (Fig. 3). The trend of major joint set has been measured as strikes N28°E with dip of 75° towards west.

The basaltic rocks, in general, have undergone a low grade thermal metamorphism, as a result of emplacement of the hot acidic magma, which formed the Barda acid igneous complex. The basalts of Ghumli-Khambiyara areas, as referred to earlier, have shown the maximum transformation and evidence of thermal metamorphism adjacent to the acidic rocks.

PETROGRAPHY

A detailed petrographic description of a few typical specimens are given below:

1. WANSJALIA-KATKOLA AREAS

Sp. No. 32.7/01.7 16.1.69 : From near Wansjalia Railway Station.

In hand specimen the rock is fine grained, grey coloured (with green and white patches), and porphyritic with feldspar phenocrysts embedded in fine grained, grey coloured amygdaloidal groundmass.

In thin section, the rock shows porphyritic texture with the phenocrysts of plagioclase in a fine grained groundmass with intergranular texture and amygdules.

Phenocrysts: Plagioclase commonly occurs as coarse and tabular phenocrysts some of which are clustered forming a glomeroporphyritic texture and show twins of albite type with rare zoning; plagioclase contains clinopyroxene (augite) grains formed from inclusions of glass. Composition measured is An_{58} to 64.5
with maximum \( X' \wedge 010 = 32^\circ \) to \( 36.5^\circ \).

Groundmass: Iron ores are abundant, granular with uniform grain size forming spongy mosaic in the groundmass. Clinopyroxene grains (augite) are also common and are fine grained with granular shape; the grains mostly altered to green chlorite. Plagioclase occurs in traces, and it is very fine grained and lath-shaped.

Amygdules: Recrystallized amygdules are irregular, subcircular to elongated and composed of quartz, green clinopyroxene prisms, chlorite and iron ores.

The thermal metamorphic effect in the rock specimen is evidenced by rarity of unaltered glass, even grained granular nature of pyroxene and recrystallization of amygdules.

Sp. No. 4/21.2.69: From a location to the east of Katkola Railway Station.

In hand specimen, it is fine grained, grey coloured and consists of fine feldspar laths and mafics.

The thin section shows the rock as aphyric, nonamygdaloidal with intergranular to subophitic ophitic texture and composed of plagioclase, clinopyroxene, iron ore and devitrified glass. Radial arrangement of plagioclase laths in association with pyroxene and iron ores are the noteworthy features.

Plagioclase occurs abundantly, mostly as lath-shaped or tabular, zoned and twinned grains. Composition is \( An_{46.5} \) to \( 48.5 \) with maximum \( X' \wedge 010 = 25^\circ \) to \( 26^\circ \). Clinopyroxene (augite) also occurs abundantly as subhedral prisms to anhedral granules in the interstitial spaces of plagioclase laths; some coarser euhedral grains enclose plagioclase laths. Glass (altered) is a common constituent and occurs in form of green patches, and shows recrystallized
aggregates of chlorite, green coloured clinopyroxene and plagioclase granules, as also micrographic quartz-alkali feldspar intergrowths. Iron ores are common, occurring as lath-shaped ilmenite and fine anhedral granules of titanomagnetite; the iron ores may be of both primary and recrystallization product after glass. The recrystallization of glass may be considered as a thermal metamorphic effect.

2. VERAD AREA

Sp. No. 2/22.10.74 : Collected from 1.5 mile (2.4 km.) west-northwest of Verad village.

In hand specimen, it is dark grey (with white patches), fine grained and amygdaloidal basalt. Visible amygdules are small with white coloured zeolite. A few thin feldspar laths may be seen.

In thin section the rock is very fine grained, aphyric and vesicular with fillings of zeolite. Groundmass is holocrystalline. It is difficult to distinguish the unaltered glass in the groundmass. The rock is composed of plagioclase, augite, iron ores and olivine pseudomorphed by iddingsite.

Plagioclase is very fine grained, lath-shaped, and clotted. Clinopyroxene (augite) is very fine grained, granular and highly studded with iron ore. Iron ore grains are very fine, equant and granular and they are evenly distributed. Coarse olivine grains are pseudomorphed by iddingsite. Irregular vesicles are filled in with dark brown glass and fibrous zeolite; coarse iron ores at places are distributed around vesicles.

The thin section does not appear to have any appreciable effect of thermal metamorphism.
3. TARSAI-SAJANWALA STOPED BLOCK
Sp. No. 8b/15.2 : From Bileswari river cutting at 1 mile (1.6 km.) west-northwest of Tarsai village.

It is a fine grained, grey coloured rock and consists of mafics, feldspars and quartz veins.

The thin section shows the rock as fine grained, and porphyritic, with phenocrysts of plagioclase in a fine grained groundmass; it is composed of clinopyroxene (augite), plagioclase, iron ore, epidote, chlorite and quartz.

Phenocrysts: Plagioclase phenocrysts are common; they are tabular in forms, and clotted, with poorly preserved albite type twinning.

Groundmass: Clinopyroxene (augite) occurs abundantly, mostly fine grained, euhedral to anhedral, occurring in the interspaces and clotted at places in association with plagioclase laths. Plagioclase occurs abundantly as fine laths with imperfect ill preserved twinning. Iron ore grains are common and occur as granules in association with augite, forming spongy mosaic in the groundmass. Chlorite occurs in shredded forms and green in colour, and it is derived from glass. Secondary quartz is occurring in traces. The absence of unaltered glass may be considered as an indication of thermal metamorphism.

4. KHAMIYARA-TALARA TALAO STOPED BLOCK
Sp. No. 9/18.10.70 : From central part of the Stoped block.

It is a fine grained, dark grey coloured porphyritic basalt. In thin section, the rock is porphyritic with phenocrysts of plagioclase within a fine grained groundmass which is characterised by intergranular texture formed by plagioclase, clinopyroxene and iron ores.
Phenocryst: Plagioclase is abundant as tabular grains which clotted in places (Fig. 5); altered and sericitised; cracks, cleavage and partings are common and they show twins on albite law. Composition is An$_{53.5}$ to An$_{60}$ with maximum $X'\Delta 010 = 29^\circ$ to $33^\circ$.

Groundmass: Plagioclase (An$_{50}$ to An$_{52.5}$ with maximum $X'\Delta 010 = 27^\circ$ to $29^\circ$) laths occur in varying sizes, forming triangular to subtriangular interspaces, in which granules of augite and iron ore occur. Iron ore and augite together form spongy aggregates.

5. KHAMBIYARA NES - GHUMLI AREAS

The basalts occurring in the Khambiyara Nes and Ghumli areas located in the northwestern part have shown numerous evidences of thermal metamorphism near contact of the felsite-granophyre body. However owing to the lack of basalt exposures in the other parts the contact aureole has been studied in detail (marked in Plate I) only along two field traverses in the Ghumli and Khambiyara Nes areas respectively. An attempt has been made to classify the contact metamorphic zone within basaltic rocks of the present area, based on the associated mineral assemblages as shown in the Table 2A and 2B.

The high grade zone (Pyroxene-hornfels facies of Turner, 1968 and Spry, 1974) lying close to the contact of acid intrusives is characterised by well recrystallised hypersthene, clinopyroxene and plagioclase with granular to blasto-intergranular texture (Harker, 1950). The recrystallised clinopyroxene grains in groundmass are commonly granular salite to ferrosalite and augite with numerous dotted exsolved inclusions of iron ores. Recrystallised plagioclase takes the granular form in the groundmass. The relict plagioclase phenocrysts in the higher grade zone have shown cloudiness and resorbed border as a result of recrystallization.
<table>
<thead>
<tr>
<th>Sp. No.</th>
<th>Distance from the contact of acid igneous body</th>
<th>Mineral assemblage</th>
</tr>
</thead>
</table>
| 1/20.10 | 5 metres                                    | Recrystallised: hypersthene + augite + plagioclase (granular) + iron ore (granular)  
Relict: plagioclase phenocrysts with irregular margin. |
| 2/20.10 | 15 metres                                   | Recrystallised: hypersthene + augite + plagioclase.  
Relict: plagioclase + augite + iron ore. |
Relict: plagioclase + augite + iron ore. |
| 5/20.10 | 75 metres                                   | Recrystallised: augite + hypersthene + plagioclase (minor) + iron ore + chlorite.  
Relict: plagioclase + augite + iron ore. |
| 6/20.10 | 100 metres                                  | Recrystallised: augite + hypersthene + biotite + iron ore + chlorite + amphibole.  
Relict: plagioclase + augite + iron ore. |
### TABLE - 2A (Contd.)

<table>
<thead>
<tr>
<th>Sp. No.</th>
<th>Distance from the contact of acid igneous body</th>
<th>Mineral assemblage</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/20.10</td>
<td>150 metres</td>
<td>Recrystallised: augite + iron ore</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relict: plagioclase + augite + iron ore.</td>
</tr>
<tr>
<td>8/20.10</td>
<td>200 metres</td>
<td>Recrystallised: chlorite + actinolite + albite.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relict: plagioclase + augite + iron ore.</td>
</tr>
<tr>
<td>9/20.10</td>
<td>250 metres</td>
<td>Recrystallised: chlorite + actinolite + tremolite + albite.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relict: plagioclase + augite + iron ore.</td>
</tr>
</tbody>
</table>

### TABLE - 2B

Mineralogical Assemblage along Khambiyara Nala Traverse-line in the Contact Metamorphosed Basalts.

<table>
<thead>
<tr>
<th>Sp. No.</th>
<th>Distance from the contact of acid igneous body</th>
<th>Mineral assemblage</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/25.2.71</td>
<td>Adjacent to the contact</td>
<td>Recrystallised: hypersthene + augite + plagioclase (granular) + iron ore (granular).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relict: plagioclase phenocryst with a rim of granular recrystallised augite.</td>
</tr>
<tr>
<td>Sp. No.</td>
<td>Distance from the contact of acid igneous body</td>
<td>Mineral assemblage</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------</td>
<td>--------------------</td>
</tr>
</tbody>
</table>

It is noteworthy that the contact metamorphism of the Deccan Traps has been detected here for the first time, as previous to the present investigation there is no report of any type of contact or regional metamorphism of the Deccan Traps which cover vast areas of India.
The low grade zone (Albite-epidote-hornfels facies of Turner, 1968 and Albite-actinolite-hornfels of Spry, 1974) lying away from the acid intrusive is characterized by its blasto-intergranular texture and composed of recrystallised chlorite and amphibole (actinolite-tremolite) from glass and pyroxene. The common relict minerals in the low grade zone include plagioclase, clinopyroxene and iron ores; the plagioclase phenocrysts are commonly recrystallized to form albite.

The high grade zone delineated by the recrystallised grains of hypersthene, plagioclase and augite with granular texture has the width of about 100 metres lying close to the Barda acid igneous contact in the Ghumli-Khabamiya Nes areas. The detailed petrography of a few typical specimens collected from those two different zones are described in the following pages.

Low Grade Contact Metamorphic Rock

Sp. No. 2/21.10.74 : Collected from 850 metres away of acid igneous contact on Khabamiya Nes traverse line.

In hand specimen, it is a dark grey coloured, fine grained and porphyritic rock.

In thin section, the rock is blasto-porphyritic with phenocrysts of plagioclase augite and olivine lying in a blasto-intergranular groundmass.

Phenocrysts : Plagioclase phenocrysts are glomeroporphyritic and they show patchy alteration of original labradorite to albite plagioclase along fractures. The albite plagioclase has higher birefringence (showing 1st order yellow interference colour). Olivine phenocrysts occurring as primary subhedral grains are entirely pseudomorphed by chlorite and amphibole aggregates.

Groundmass : Plagioclase laths in the groundmass are also transformed into patchy albite. Other minerals include augite, iron ores and altered glass. Glass is
entirely recrystallised into (a) randomly oriented flakes of chlorite with pale green colour and (b) amphibole (tremolitic) with $Z \wedge C = 19^\circ$ and faint pleochroism, in the shades of colourless to greenish grey. Groundmass pyroxene is also rimmed by amphibole in many cases. Iron ores are euhedral (octahedral) to subhedral.

The formation of chlorite and amphibole from glass and pyroxene and patchy alteration of plagioclase to albite are the thermal metamorphic effects.

Sp. No. 3/21.10.74 : Sample collected at 350 metres from acid rock contact on Khambiyara Nes traverse line.

It is a dark grey coloured, fine grained and porphyritic rock. In thin section, the rock is blasto-porphyritic with phenocrysts of plagioclase within blasto-intergranular groundmass.

Phenocryst : Plagioclase phenocrysts are patchy with transformation into albite along fractures and cleavage.

Groundmass : It is composed of unaltered and granular pyroxene, plagioclase laths with patchy alteration to albite, octahedral iron ores and altered glass. Glass is completely transformed into chlorite (green to colourless, and brownish green), amphibole (colourless bundles of fibres) and very few granular leucoxene.

Sp. No. 5/21.10.74 : Collected at 250 metres away from contact with acid igneous body on Khambiyara Nes traverse line.

In hand specimen, the rock is fine grained, grey coloured and porphyritic. In thin section, the rock appears blasto-porphyritic with plagioclase phenocrysts in a blasto-intergranular groundmass.

Phenocrysts : Plagioclase phenocrysts are glomeroporphyritic with patches of alteration to albite. Subpoikilitic inclusions of pyroxene and iron ores are common.
Groundmass: It includes altered laths of plagioclase, granular pyroxene, iron ores and altered glass. Glass is altered to chlorite and incipient amphibole. Amphibole also occurs as fibres rimming the relict pyroxene grains.

Medium to High Grade Contact Metamorphic Rock
Sp. No. 7/25.2.71: Collected from near the contact with acid igneous body in the Khambiyara Nes area.

In hand specimen, it is a dark grey coloured medium grained rock, containing coarse grains of feldspar in a granular groundmass.

The thin section study shows that the rock is blasto-porphyritic with relict phenocrysts of plagioclase and clinopyroxene in a granular groundmass (Fig. 4) composed of plagioclase, clinopyroxene and iron ores.

Phenocrysts: Plagioclase is common as coarse tabular grains, and it shows glomeroporphyritic texture at places; the grains are highly clouded (Fig. 4) with marginal resorption and contain inclusions of epidote, calcite, chlorite and clinopyroxene. Clinopyroxene grains occur as comparatively coarse anhedral prisms, clotted and have pleochroism from green to yellowish green, $2V_z = 53^\circ$, $N_y = 1.694 \pm 0.004$ and are ferrosalitic in the composition, $Ca_{44}Mg_{14.5}Fe_{44.5}$

Groundmass: Plagioclase is abundant, mostly as granular crystals of medium size, which rarely show twinning. Coarse plagioclase grains are recrystallised and form a mosaic texture. Clinopyroxene is common in minor amount; it is colourless and nonpleochroic with $ZAc = 44^\circ$, $2V_z = 47^\circ$, $N_y = 1.685 \pm 0.004$ and is an augite having the composition $Ca_{39}Mg_{47.5}Fe_{13.5}$

Clouding in relict plagioclase phenocryst, total obliteration of intergranular texture to form granular groundmass and formation of green pyroxene with a very large optic axial angle (ferrosalite) are the evidence for thermal metamorphism in this basalt rocks.
Fig. 3. Field photograph showing the sheeted joints in the basalts of Ghumli area.

Fig. 4. Photomicrograph showing clouded plagioclase phenocryst within granular groundmass of metamorphosed basalt; plagioclase phenocryst shows resorbed margin and inclusion of clinopyroxene. Ordinary light, x 94.

Fig. 5. Photomicrograph showing clotting of plagioclase phenocrysts within granular groundmass. Crossed nicols, x 23.
Sp. No. 10/25.2.71: Specimen collected from a spot adjacent to the contact with acid igneous body and located about 200 metres to the north-northwest of the previous sample.

It is fine grained, grey coloured and granular rock. In thin section, the rock shows blasto-porphyritic texture with phenocrysts of plagioclase and hypersthene within granular groundmass, composed of hypersthene, augite, plagioclase and iron ores.

Phenocrysts: Plagioclase occurs abundantly as tabular grains forming aggregates; few grains show strong zoning and contain inclusions of hypersthene; some grains are faintly clouded and show a granular recrystallised rim of pyroxene formed as a result of reaction with groundmass clinopyroxene and such reaction rims are recognised in contact metamorphosed hornfelses (Spry, 1974). Composition of plagioclase is An_{50} to An_{56.5} with maximum extinction angle $X' A 010 = 27^\circ$ to $31^\circ$. Hypersthene is abundant as coarse and clotted prisms, with strong pleochroism ($X = $ pink, $Y = $ pale green and $Z = $ pale pink), fractures and schiller inclusions of iron ores (Fig. 6); composition is measured as En_{68} with $N_z = 1.704 \pm 0.007$ and $2V_z = 65^\circ$.

Groundmass: Clinopyroxene in minor amount occurs in association with granular hypersthene; it is anhedral granular, colourless with $2V_z = 47^\circ$, $N_y = 1.685 \pm 0.004$ and is an augite having the composition $Ca_{39}Mg_{47.5}Fe_{13.5}$. This thermally metamorphosed mineral association of hypersthene (En_{68}) and augite contrasts with the hypersthene-pigeonite inversion point at Mg_{70}Fe_{30} molecular percent in basaltic rocks (Poldervaart and Hess, 1951). Iron ores are common as subhedral to anhedral granules and form spongy aggregate with recrystallised clinopyroxene (Fig. 7).
Faint closing and recrystallised rim around relict plagioclase phenocrysts schiller inclusions of iron ore within hypersthene, granular groundmass and recrystallised spongy mosaic formed of iron ores and pyroxene are the different evidences for thermal metamorphism of basaltic rock.

Sp. No. 14/25.2.71 : From a spot adjacent to contact with acid igneous body located about 500 metres north-northwest of the previous specimen.

In hand specimen, it is grey coloured, fine grained and granular. In thin section, the rock is blastoporphyritic with the relict phenocrysts of plagioclase within granular groundmass (Fig. 8) composed of recrystallised plagioclase, pyroxene and iron ores.

Relict plagioclase phenocrysts are usually clotted with resorbed margins and poikilitic inclusions of pyroxene; composition of plagioclase phenocrysts range from An$_{52.5}$ to An$_{57.5}$ with measured (X'$\Lambda$010) = 28.5° to 31.5°.

Groundmass pyroxene grains are mostly recrystallised to form pale green clinopyroxene with the pleochroic scheme : $X =$ pale green, $Y =$ yellowish green, $Z =$ green, $2V_X = 50^0$, $N_Y = 1.694 \pm 0.004$, and they are ferrosalitic in the composition, Ca$_{38}$Mg$_{18}$Fe$_{44}$. Twinned plagioclase grains in the groundmass have the composition, An$_{48}$ to An$_{51}$ with maximum extinction $X'$010 = 26° to 27°.

Formation of granular groundmass and recrystallised green ferrosalite is due to thermal effects in basic rock.

Sp. No. 15/25.2.71 : From the low lying area of basaltic exposures in Ghumli area.

In hand specimen, the rock is dark grey in colour, fine grained and amygdaloidal.
Fig. 6. Photomicrograph showing hypersthene prism with schiller inclusions of iron ores. Ordinary light, x 82.

Fig. 7. Photomicrograph showing recrystallised spongy mosaic formed by iron ore (black) and clinopyroxene in the metamorphosed basalt. Crossed nicols, x 82.

Fig. 8. Photomicrograph showing granular groundmass in the metamorphosed basalt, composed of plagioclase (white), pyroxene (grey) and iron ore (black). Crossed nicols, x 94.
In thin section, the rock is fine grained, amygdaloidal and contains augite, plagioclase, iron ores, green spinel, amphibole and scapolite. Relict intersertal to intergranular textures and recrystallised amygdules are preserved.

Augite (diopsidic) is abundant, occurring as fine granular to a few coarser grains which are densely aggregated at places. Plagioclase is very common, occurring as fine laths to form triangular to subtriangular interspaces; the grains are in many cases sericitised. Iron ores occur as granules to form spongy mosaic in the groundmass in association with pyroxene and spinel.

Under ore microscope, iron ore grains have been identified as titano-magnetite with two sets of oxidation-exsolution lamellae of ilmenite (Fig. 9).

Clots of green spinel (pleonaste) in association with iron ores are commonly observed in this specimen. The presence of green spinel is indicative of high temperature metamorphic effects (Williams, Turner and Gilbert, 1954).

Recrystallised amygdules (Fig. 10) include quartz, fibrous zeolite and plagioclase at core, which assemblage is followed by an inner rim composed of green spinel and brown amphibole and an outer rim with quartz and plagioclase.

Spongy mosaic in the groundmass formed by iron ores in association with green pleonaste spinel and brown amphibole, may be considered as evidences for thermal metamorphism in these basic rocks.

**DISCUSSIONS ON THERMAL METAMORPHISM**

The effects of thermal metamorphism caused by the intrusions of hot acidic magma are clearly marked in the basalts of present area. Basalts of Ghumli-Khambiyara Nes area have been intensely affected by the thermal metamorphic effects; the indications are also found in the basalts of
Fig. 9. Photomicrograph showing titanomagnetite grain with two sets of oxidation-exsolution lamellae of ilmenite. In reflected light, after etched by conc. HCl, x 450.

Fig. 10. Photomicrograph showing recrystallised amygdules in metamorphosed basalt. Ordinary light, x 23.
Obliteration of basaltic texture to form granular groundmass (Figs. 4, 6, 8) with granules of pyroxene, iron ores and plagioclase is clearly indicated in the basalts of Ghumli-Khambiyara Nes areas. Regarding the granular texture of metamorphosed basalts, we note the comment made by Harker (1950), who stated that in the highest grade of metamorphism of ordinary basic rocks, the basaltic texture is completely obliterated to form a granular mosaic of pyroxenes (augite + hypersthene), feldspar and iron ores. Augite in association with hypersthene is a remarkable mineralogical association. Harker also stated that when the recrystallization of feldspars sets in, the crystal may not at first lose their individuality in the process, and the phenocrysts or the scattered crystals may not be replaced by a granular mosaic. With advancing metamorphism, original outlines are lost and the whole rock takes on crystalloblastic type of structure.

Conversions of pyroxene (augite) to amphibole (in Sp. No. 2/21.10.74) and to pyroxene (augite and hypersthene in Sp. No. 10/25.2.71) in the high grades of metamorphism is also common feature in the present metamorphosed basalts.

The plagioclase in the present metamorphosed basalts is calcium-rich and labradoritic to calcic-andesine in composition. The labradorite-amphibole assemblage is a good indication (Miyashiro, 1968) for thermal metamorphic effects.

Clouding in the plagioclase phenocryst (Fig. 4) has been found in the metamorphosed basalts of Ghumli area. A peculiar cloudiness, found in the clear
plagioclase grains of more calcic varieties is the result of thermal metamorphism (MacGregor, 1931; Poldervaart and Gilkey, 1954; Armbreastwacher and Banks, 1974). This is due to the development of multitude of a very minute iron ore and probable pyroxene inclusions. Inclusions of pyroxenes and iron ores within the plagioclase is well seen in the present metamorphosed basalts (Fig. 4). The inclusions of iron ores may be formed as a result of thermal effects from the original iron content of the plagioclase. Pyroxene and iron ore inclusions may also be derived from the glass.

Rarity of an altered glass in the present basalt may be a result of thermal metamorphism. Basaltic glass contains the constituents for pyroxene and iron ores. The acidic magma has the intrusion temperature nearing 1000°C, which is much lower than the liquidus temperature for basaltic magma; hence it first affects the glass which becomes recrystallised forming pyroxene and iron ores. The clinopyroxene and iron ores along the rim of amygdules may also be considered as derived from glass.

Recrystallization of amygdules (Fig. 10) is also a common feature in the present metamorphosed basalts. Zeolite as vesicle fillings is derived from the plagioclase feldspar by simple reaction involving hydration. It is found, accordingly, the zeolites are found in the metamorphosed basalts, in association with crystalline aggregate of plagioclase feldspars, with or without other minerals. Harker (1950) represented the formation of zeolite, by the simple equations like (1) Albite + H₂O = Analcine + quartz and (2) 2 Albite + H₂O = Natrolite + 3 quartz. The equations are reversibles, which are driven towards the right during falling temperature of deuteric activity and towards the left with rising temperature of metamorphism. The amygdaloidal basalts of Ben More districts of Mull have shown their thermal metamorphism by subsequent granitic intrusions, and the reaction set up in metamorphism represent exactly the reversal of those which had taken place.
during the final stages of magmatic crystallization (McIntock, 1915 cited by
Harker, 1950).

**DISTRIBUTION OF CONTACT METAMORPHIC FACIES**

At the outer fringes of contact aureoles the temperature tends to be low, such that mineral assemblages correspond to those of albite-epidote-
hornfels facies as defined by Fyfe, Turner and Verhoogen (1958) and Turner (1968). It has been properly emphasized in the former reference that in such rocks "the paragenesis in the outer parts of the contact aureole is generally obscured by imperfect metamorphic recrystallization and by the persistence of unstable relics from the parent rocks". The recrystallised mineral assemblage recognised in this zone of the present area in the Barda Hills are as follows:
(a) albite-chlorite, (b) albite-chlorite-actinolite-leucoxene, developed mainly out of the metastable glass in the intersertal textured rocks, whereas in a little advanced stage fibrous amphibole develops out of the intergranular pyroxene; albite develops in ramifying manner in the phenocrysts and groundmass plagioclase. The outer fringe of contact aureole in the present area is rather extensive, but fibrous amphibole appears 1500 metres away from the probable vertical acid igneous contact.

The mineral assemblage typical for the hornblende hornfels facies is hornblende-plagioclase, and diopside may be present (Turner, 1968, p. 193). Unlike many other areas of the world this contact facies is not well represented in the Barda Hills area, as hornblende is absent, which may be ascribed to the initially water deficient nature of the unmetamorphosed and young Deccan Trap basalts. Moreover extremely reducing environment is indicated by these metabasalts which may favour pyroxene in lieu of hornblende whose field of stability is extended under oxidising condition (Turner, 1968, p. 246).
Spry (1974, p. 199) also recognises pyroxene-plagioclase hornfels with granoblastic texture occurring in association with hornblende-plagioclase hornfels in the hornblende-hornfels facies. It is noteworthy that the recrystallised clinopyroxene is a diopside-hedenbergite, and not augite or ferroaugite as in the unmetamorphosed basalts, as also discussed by Turner (1968, p. 203).

In the inner zone of contact aureole, i.e., within 150 metres from the contact with the acid igneous body the basalts give rise to a diopside-hypersthene-plagioclase assemblage developed in the Deccan Trap basalts. This assemblage is characteristic of the pyroxene-hornfels facies (Turner, 1968, p. 225). A comparable example is the innermost zone of the contact aureole of the diorite pluton of Comoroe, Perthshire, Scotland (Tilley, 1924 cited by Turner 1968, p. 228) where within about 150-200 metres of the contact, typical assemblage of the pyroxene-hornfels facies, i.e. diopside-hypersthene-plagioclase develops. Both the distance from the contact and the two pyroxene-plagioclase assemblage in the present area are clearly comparable to this famous Comoroe occurrence. It is noteworthy that biotite and a spinal (such as pleonaste in the present area) may develop in basic and silica-deficient rocks in the high grade contact metamorphic facies (Turner, 1968).