CHAPTER - III

TWO PYROXENE GRANULITES

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Under this group are included a set of rocks of charnockitic affinity. These hypersthenic rocks are most dominant amongst granulites and occupy a major part of the southern portion of the study area. The various types of pyroxene granulites are as follows.

1. Ultrabasic,
2. Basic (including norites and metanorites),
3. Intermediate and
4. Acid charnockite ("Charnockite")

The pyroxene granulites are massive in general appearance but at places banding is clearly seen due to variation in grain size and due to thin and tiny layers. In general, these are fine to medium grained granulitic to gneissic rocks with a characteristic greasy, grayish green appearance and look quite fresh on newly broken surfaces.

III.1 Ultrabasic Type

These have restricted occurrence as compared to other varieties and are confined to the area around Kanpura and Dhanpura villages. The minerals present in this variety are olivine, bronzite, hypersthene and calcic plagioclase. They show cryptic and rhythmic layering best seen in a freshly broken surface across the layers **(Plate-III.1A)**. Alternate layers are rich in felsic and femic content. The layers rich in olivine are seen as grooves with large pits parallel to layering while the olivine poor feldspar rich layers are seen as protruding bands (Plate-II 4A, Chapter-II) The plagioclase rich layers are leucocratic. The plagioclase content varies from layer to layer and is comparable to anorthosite. The layers rich in olivine, bronzite and hypersthene are comparable to troctolite and peridotite and obviously they represent the metamorphic equivalent of a layered troctolite-peridotite-anorthosite sequence.

III.1a *Petrography*

They contain following mineral associations : plagioclase - bronzite - diopside - olivine - spinel - phlogopite the petrographic features of which are described below :

Pyroxene :

Orthopyroxene is bronzite (2Vx = 78° - 80°). It occurs as matrix in which olivine and opaques are embedded. Smaller rounded grains of olivine enclosed within orthopyroxene suggests the possible derivation of orthopyroxene from the breakdown of olivine. Exsolution of pyroxene are seen **(Plate-III.1B)**. Similar exsolution lamellae have been described from basic granulites of (Sandiford and Powell, 1986a, Sengupta et al, 1996, Dasgupta et al, 1994).

Plagioclase :

Plagioclase is the dominant mineral in the rock constituting 20 - 45% by volume. Plagioclase is mostly calcic (with An content 60-70). Plagioclase occurs mostly as matrix enclosing olivine and spinels. Polysynthetic and lamellar twinning are conspicuous. Porphyroblastic plagioclase are generally very coarse (often 2.5 centimeters) and are completely recrystallised and are devoid of strain.

Olivine :

Olivine is Forsterite variety (2Vx = 74° - 88°). It is easily identified because of irregular cracks and alteration to serpentine along the fractures. Most of the olivines have rounded outlines. opaques are also seen to develop along fractures in olivine. Some of the olivine grains contain spinel inclusions. A few olivine grains are completely surrounded by orthopyroxene while others occur within the plagioclase **(Plate-III.2A)**.

Spinel :

It is greenish in colour. Its outlines are squarish when it occurs within olivine. The shape of the spinel surrounding the olivine grains is irregular - rather sickle shaped due to the rounded grain margin of the olivine with which it is in contact.

Phlogopite :

Phlogopite occurs either as laths with bent cleavage traces or as patches at the grain boundary of olivine and larger opaques particularly those which occur outside the olivine.

Modal composition of the ultrabasic type is as given below :

Sample No.	Femic layers			leucocratic layers	
Olivine	63.03	68.70	62.8	52.95	45.05
Plagioclase	22.32	20.70	22.4	40.62	44.50
Bronzite	8.04	5.17	11.4	0.35	2.18
Phlogopite	0.57	1.62	0.7	1.89	2.90
Calcite	4.54	2.60	1.8	3.61	4.36
Opaques	1.42	0.70	0.4	0.60	0.90

Plate-III.1A. Cryptic and rhythmic layering best seen in a freshly broken surface across the layers in ultrabasic granulite near Kanpura.

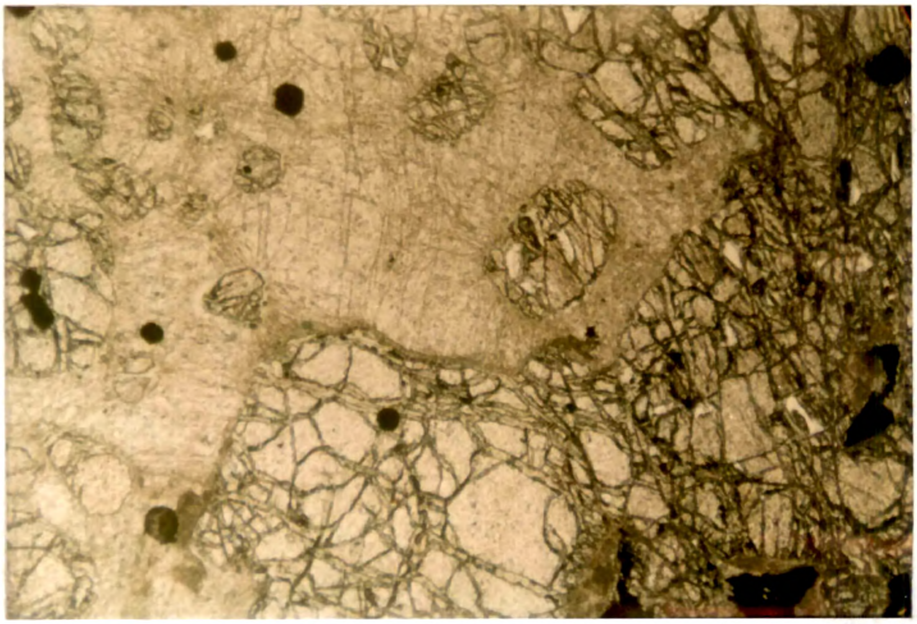

Plate-III.1B. Exsolution of pyroxene in ultrabasic granulite (PPL, 80X).

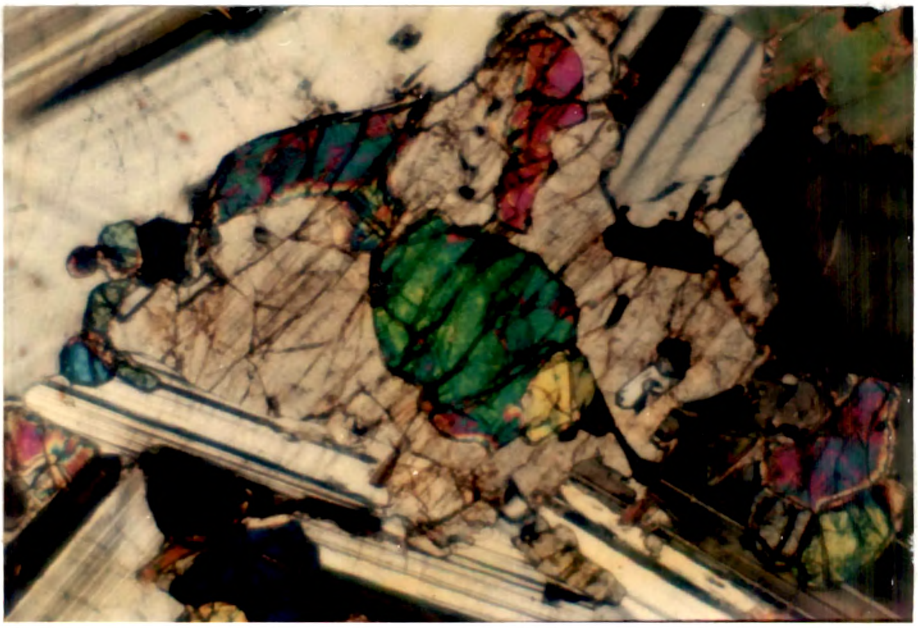

Plate -III.2A A few olivine grains are completely surrounded by orthopyroxene while others occur within the plagioclase in ultrabasic granulite (XPL, 80X).

III.1b *Mineral Chemistry*

Chemical composition of minerals were determined by a JEOL EPMA operated at 15 kv accelerating voltage and 2 - 5 μm beam diameter. Natural mineral standards were used and representative ZAF corrected analyses of coexisting phases are given in Tables - III.1 A-D.

Olivine :

Representative mineral composition of olivine is given in Table-III.1A. It is compositionally forsterite with XFo 0.83 and XFa 0.17. XFo decreases from core to rim. There is decrease in Si, Al, Fe, Mn, Ca and Ti from rim to core while Mg, K and Na increase. Ni content does not show any variation within the grain.

Plagioclase :

Representative mineral composition of feldspars is given in Table-III.1B. Anorthite content of plagioclase is approximately 54 - 69 mole%. Compositionally it is labradorite approaching bytownite with XAn varying from 54 - 69.11 %, XAb 30.31 to 45 39 % and XOr 0.38 - 0.57 %. XAn 54.08 % is from the rim of a plagioclase grain in contact with olivine. The same grain is XAn 65.32 % in the core.

Spinel :

Representative mineral composition of opaques is given in Table-III.1C. Spinels are predominantly chromite. Except Fe there is increase in the content of Cr, Al and Zn from core to rim; Mn and Mg too show slight increase while Ti and V decrease from core to rim.

Phlogopite :

Representative mineral composition of phlogopite is given in Table-III.1D. Biotite in the matrix is rich in phlogopite component where XMg (= Mg / (Fe^{2+} + Mg)) is 0..87 and XAlVI (= AlVI/ (Mg+Fe+AlVI)). There is decrease in annite content from core to rim (XFe decreasing from 12.9 to 12.53). Si, Fe, Ca and Na, K contents are seen to decrease from core to rim while Al, Mg increase from core to rim.

III.1c *Discussion*

Textural features such as olivine with a rim of hypersthene, depletion in An content in plagioclase near olivine as also segregation of purplish dust of rutile within the plagioclase laths indicate charnockitisation of olivine bearing rocks (Cooray, 1960). This is also evident from the recrystallisation of olivine, bronzite, and diopside to hypersthene.

Distinct compositional layering of plagioclase rich bands alternating with olivine and pyroxene rich bands with nodular structures and granoblastic texture suggest that the parent igneous rock was a layered anorthosite - peridotite - troctolite. Tilted nature of the relict original layers indicates its involvement in deformation. The southerly dipping nature of the banding suggests its deformation along E-W axis and these bands possibly represent one limb of the fold. A feebly pleochroic hypersthene (bronzite) obviously a primary mineral, is seen partly replaced by a more pleochroic hypersthene. This process is accompanied by (i) formation of diopside and (ii) marginal acidification of plagioclase. Sen (1959) has described a similar reaction from the charnockitic rocks of Singhbhum, Bihar as under :

$$\underset{Fs18}{\text{Bronzite}} + \underset{An72}{\text{Plagioclase}} \longrightarrow \underset{Fs53}{\text{Hypersthene}} + \underset{Di91}{\text{diopside}} + \underset{An64}{\text{plagioclase}}$$

TABLE-III.1A

Representative Microprobe Analysis of Olivine from Ultrabasic Type

Sample No.	KPR-A	KPR-A
Anal. No.	C1-1/1	C1-1/2
SiO_2	38.777	39.152
TiO_2	-	0.015
Al_2O_3	0.010	0.012
FeO	16.402	17.056
MnO	0.252	0.339
MgO	44.693	44.206
CaO	0.026	0.036
Na_2O	0.104	0.068
K_2O	0.011	0.003
Total	100.421	101.031

Number of ions on the basis of 4 oxygens

Si	0.9793	0.9848
Al	0.0003	0.0004
Fe	0.3464	0.3588
Mg	1.6826	1.6576
Mn	0.0054	0.0072
Ca	0.0007	0.0010
K	0.0004	0.0001
Na	0.0051	0.0003
Ti	-	0.0003
Ni	0.0029	0.0029
Total	3.0232	3.0164

TABLE-III.1B

Representative Microprobe Analysis of Feldspar from Ultrabasic Type

Sample No.	KPR-B	KPR-B	KPR-A	KPR-A
Anal. No.	C3-1/1R*	C3-1/2C	1/1	1/2
SiO_2	48.682	50.796	50.193	50.398
Al_2O_3	28.782	29.280	29.937	29.476
CaO	11.965	13.934	14.538	13.850
Na_2O	5.545	4.036	3.531	4.203
K2O	0.094	0.072	0.098	0.078
Total	95.067	98.118	98.343	97.999

* Near olivine

Number of ions on the basis of 8 oxygens

Si	2.339	2.359	2.329	2.346
Al	1.630	1.603	1.637	1.617
Ca	0.616	0.693	0.725	0.691
K	0.006	0.004	0.006	0.005
Na	0.517	0.364	0.318	0.379
Total	5.107	5.023	5.014	5.038

XAn	54.08	65.32	69.11	64.28
XAb	45.39	34.31	30.31	35.26
XOr	0.53	0.37	0.57	0.46

TABLE-III.1C

Representative Microprobe Analysis of Opaques from Ultrabasic type

Sample No.	KPR-B	KPR-B	KPR-A	KPR-A
Anal. No.	C3-1/1R	C3-1/2C	1/1	1/2
SiO_2	-	0.099	-	-
TiO_2	2.905	3.412	3.124	3.334
Al_2O_3	14.912	12.182	16.003	15.736
FeO	44.899	47.826	41.589	42.449
MnO	0.542	0.541	0.431	0.436
MgO	2.858	2.840	3.552	3.460
Cr_2O_3	33.507	31.905	36.719	35.369
ZnO	0.312	0.243	0.243	0.394
V_2O_3	0.028	0.035	0.033	0.047
Total	99.962	99.082	101.694	101.225

Number of ions on the basis of 6 oxygens

Fe	1.9937	2.1893	1.7806	1.8338
Ti	0.1160	0.1405	0.1203	0.1295
Mg	0.2262	0.2317	0.2711	0.2664
Al	0.9332	0.7859	0.9657	0.9581
Mn	0.0244	0.0251	0.0187	0.0191
Cr	1.4066	1.3808	1.4863	1.4445
Zn	0.0122	0.0098	0.0092	0.0150
Si	-	0.0054	-	-
V	0.0012	0.0015	0.0014	0.0020
Total	4 7135	4.7700	4.6531	4.6682

Species : Chrome-spinel

TABLE-III.1D

Representative Microprobe Analysis of Phlogopite from Ultrabasic type (between olivine and opaques)

Sample No.	KPR-B	KPR-B
Anal. No.	C1-1/1R	C1-1/2C
SiO_2	38.623	38.936
TiO_2	6.317	6.329
Al_2O_3	14.033	13.874
FeO	5.795	5.941
MnO	0.029	-
MgO	22.700	22.501
CaO	0.031	0.061
Na_2O	0.591	0.848
K_2O	9.716	9.894
Total	97.224	97.281

Number of ions on the basis of 22 oxygens

Si	5.423	5.459
Al	2.323	2.293
Fe	0.681	0.697
Mg	4.751	4.702
Mn	0.003	-
Ca	0.005	0.009
K	1.631	1.572
Na	0.161	0.231
Ti	0.667	0.667
Total	16.645	15.629

X_{Fe}	12.53	12.90
X_{Mg}	87.46	87.09

III.2 BASIC TYPE (INCLUDING NORITES & METANORITES)

These are dominant of all the pyroxene granulites. Most of the quarries around Chikanvas, Virampur, Khapa and Kanpura are seen to comprise the basic charnockites. On the surface, norites have a knotty appearance. The minerals present are calcic plagioclase, pyroxenes (diopside and hypersthene), hornblende, biotite and a little interstitial quartz. Sometimes small patches of felsic material are rarely seen in quarry faces (Plate-II.4B, Chapter-II). The intermediate as well as acid charnockite occur as bands in intimate association with the basic variety.

The feldspars and ferromagnesian minerals are nearly equal in proportion.

The presence of (i) ophitic textures in some cases, (ii) Schiller plates in the hypersthene of these rocks, and (iii) relict olivine , may suggest that igneous textures and minerals are mimetically preserved.

III.2a *Petrography*

These are medium grained, equigranular granulitic rock composed of hypersthene, diopside and plagioclase. Parallel arrangement of flattened mineral grains typically characterizes granulitic texture. In few thin sections, the mosaic of equidimensional grains (Plate-III.3A), with straight boundaries meet at triple junctions with ~120° (xenoblastic texture of Quensel, 1951; White, 1971). Hornblende and biotite are secondary minerals after the pyroxenes. Apatite and zircon occur as accessories. The important petrographic features are described below.

Pyroxene :

Hypersthene is free, devoid of inclusions and strongly pleochroic in shades of pink and green. It occurs along the edges of feldspar pools where it forms small grains moulded either into parallel lenticular layers or isolated coarse islands or pools, or as crescent shaped bits in a felsic mat. At places it occurs as vermicular bodies showing symplectitic intergrowth with plagioclase which it surrounds.

Diopside is green, non-pleochroic and occurs as isolated grains, clusters or as linear aggregates and is generally subordinate to hypersthene. Diopside and hypersthene show mutual intergrowths. Hypersthene is generally fresh, and is strongly pleochroic in shades of pink and green. This mineral also occurs at the edges of feldspar pools where it makes small grains moulded into either parallel lenticular layers or as isolated coarse islands or pools or as crescent shaped bits in a felsic base. Diopside and hornblende also tend to occur in a similar fashion. From the texture of the rock it appears that hypersthene formed later than diopside.

Often aggregates of amphibole - quartz replace orthopyroxene totally.

Plagioclase :

It occurs as idiomorphic plates or gathers into pools or channels a few millimetres across. Plagioclase is andesine to labradorite.

Antiperthite is rare.

Quartz :

Occasionally quartz forms tiny interstitial grains.

Hornblende :

It is a secondary mineral after pyroxene. The greenish hornblende is often seen surrounding hypersthene and diopside in crystalline continuity, generally along the margins and as patches following cleavages pointing to its later origin, a product of retrograde metamorphism. The presence of released calcite and iron ore as well as flakes of biotite are additional evidence of hornblende being of secondary origin.

Biotite :

Biotite, also a secondary mineral after pyroxene and or hornblende occurs along the cleavages within the latter or surrounding it, cross cutting the host grains. It is brown in colour.

Ilmenite/ Rutile :

Ilmenite and rutile occur as tiny grains or minute plates or needles commonly near or within the amphibole **(Plate-III.3B)**.

Apatite :

It is an accessory mineral and forms large platy grains or occurs as minute prismatic crystals in plagioclase **(Plate-III.3B)**.

Zircon :

This accessory mineral occurs as tiny grains in the main mass.

III.2b *Mineral Chemistry*

Chemical composition of minerals were determined by a JEOL EPMA operated at 15 kv accelerating voltage and 2 - 5 μm beam diameter. Natural mineral standards were used and representative ZAF corrected analyses of coexisting phases are given in Table-III.2 A-D.

Pyroxene :

Representative mineral composition of pyroxenes is given in Table-III.2A.

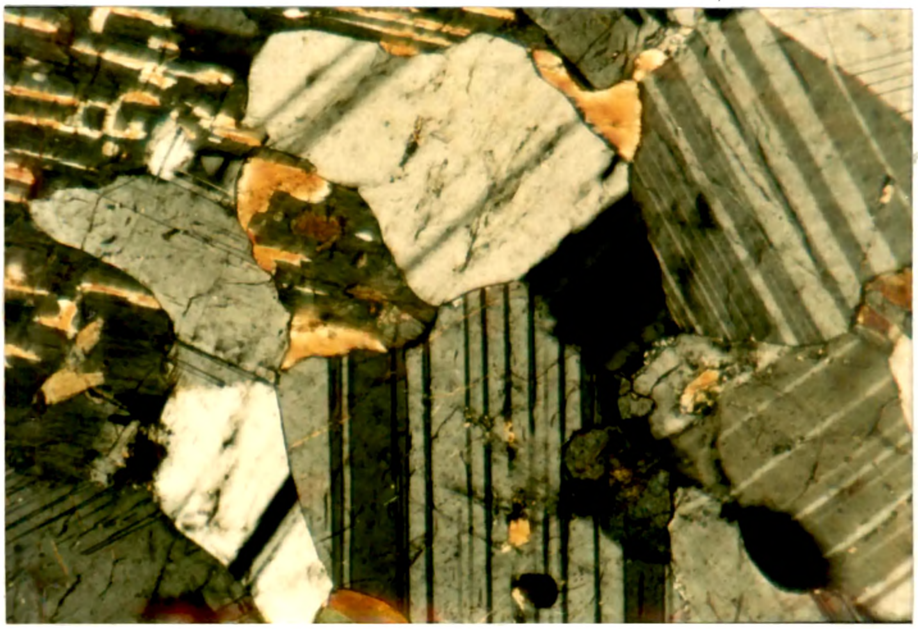

Plate -III.3A Mosaic of equidimensional grains, with straight boundaries meet at triple junctions with ~120° (xenoblastic texture) (XPL, 80X).

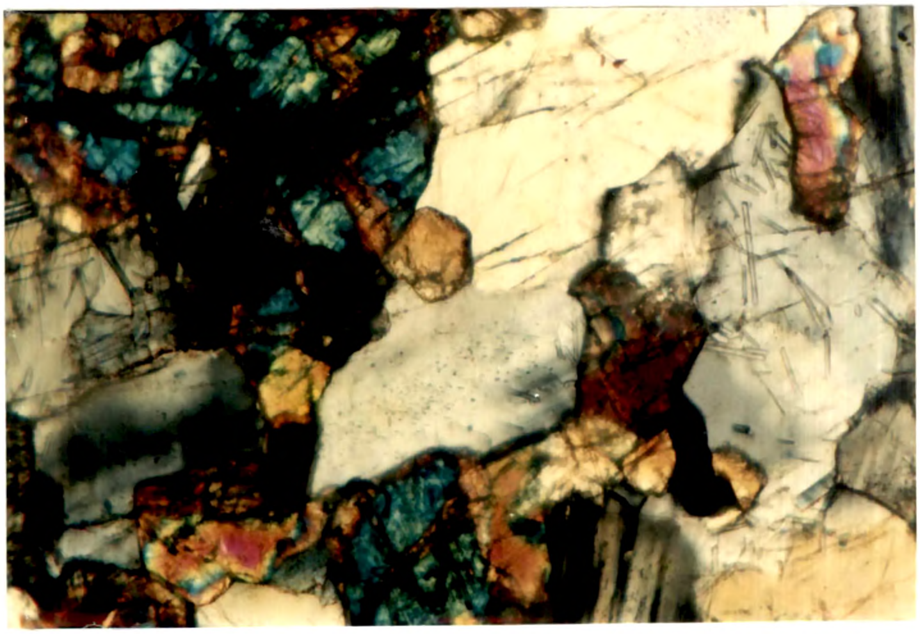

Plate-III.3B. Quartz with minute, opaque, dusty rod-like inclusions of rutile & apatite in basic type (XPL, 80X).

Orthopyroxene :

Compositionally,orthopyroxene of basic charnockite is ferrohypersthene (Deer et al., 1974) with XMg (= Mg /(Fe^{2+} + Mg)) 0.61 -0.62. Low XAlVI (Total Al/2) content (0.015) is characteristic of this orthopyroxene. Si, Al, Ca and K decrease from core to rim while Fe, Mg and Ti increase towards rim in orthopyroxene grains.

Diopside:

Compositionally clinopyroxene of basic charnockite is endiopside (Deer et al., 1974) with XMg (= Mg /(Fe^{2+} + Mg)) 0.836. Moderate XAlVI (Total Al/2) content (0.031) is characteristic of this pyroxene. XWo 40.2 mole %, XEn 40.9 mole % and XFs 18.59 mole %.

Plagioclase :

Representative mineral composition of feldspars is given in Table-III.2B.

Anorthite content of plagioclase is approximately 54 - 56 mole%, XAb 43 - 44.27 mole % and XOr 1.2 - 1.6 mole %. It is labradorite variety. There is a decrease in Si, K and Na content from core to rim while Al and Ca increase towards the rim.

Biotite :

Representative mineral composition of biotite is given in Table-III.2C. Biotite in the matrix is rich in annite component where XFe (= Fe^{2+}/(Fe^{2+} + Mg)) is 0.38 - 0.39 and XMg is 0.60 to 0.61. It is phlogopite. The Fe,Mn Ca, K, Ti and Si content decrease from core to rim with concomitant increase in Mg and Al.

Ilmenite :

Representative mineral composition of ilmenite is given in Table-III.2D.

Ilmenite porphyroblast is predominantly $FeTiO_3$ (96.3 mole%) with very limited amount $MgTiO_3$ (1.9 mole%) and $MnTiO_3$ (1.2 mole%). There is increase in Fe, Mn, Zn and Cr content from core to rim with corresponding decrease in Ti and Mg.

III.2c *Discussion*

Coarse granoblastic texture with development of large feldspar nodules with a rim of vermicular orthopyroxene has obliterated the original igneous texture to appreciable extent.

Amphibole and or amphibole-quartz corona restricted mainly to shear zones (SH2) and extensive replacement of orthopyroxene in an otherwise dry pristine assemblage of orthopyroxene - clinopyroxene - plagioclase - ilmenite - suggest amphibole and biotite formation in localized open hydrous conditions during retrogression.

NORITES AND METANORITES

Norites and metanorites occur in the unaltered cores of comparatively thick dikes and sills or intrusive bodies, most of which have been transformed into pyroxene granulites. Under the microscope,these rocks show an ophitic to subophitic texture and are mostly massive. They comprise olivine, clino- and ortho-pyroxenes, plagioclase, hornblende and biotite and show either plagioclase or olivine orthocumulate and olivine-diopside-plagioclase adcumulate structures. Iron ores, apatite and zircon occur as accessories. The mineral proportions vary widely and some varieties may be anorthositic.

Olivine : It is usually subrounded and altered along fractures to antigorite, chrysolite and penninite.

Clinopyroxene : Among these, diopside usually occurs, varying in colour from pale green to deeper green. It is non-pleochroic, usually fresh and has a large angle of extinction. In most cases, diopside appears in association with hypersthene which rims the diopside.

Orthopyroxene : Though it is usually fresh and clear, it is sometimes seen filled with purplish dust, similar to those in the feldspars of this series, crowded either at the borders, or at the center or along the cleavages. Schiller inclusions (bronzite) are common especially in grains which occur as coarse plates and it is possible that these places represent primary igneous pyroxenes. Generally extinction is straight.

A noteworthy and striking feature of these noritic rocks is the occurrence of a rim of pleochroic pyroxene around altered olivine which in turnis enveloped by radial (vermicular) arrangement of pyroxene bodies in plagioclase pyroxene symplectites. Some of these groups of vermicular pyroxenes have no central focus at all. This indicates that alteration of olivine to serpentine has taken place before the formation of hypersthene rim and vermicular pyroxene. The vermicular bodies are in optical continuity.

Plagioclase : It is labradorite or bytowinitic labradorite (An72) and is well twinned and not antiperthitic. The zoning (acid plagioclase rimming the calcic one) is marked and discontinuous. In slightly reconstituted rocks, where plagioclase occurs near the large crystals of pyroxene, it contains tear drop inclusions of pyroxene and olivine. Most of these included pieces are diopside surrounded by a pleochroic hypersthene similar to that of the pyroxene granulites. The feldspar from many exposures show dense segregation of purplish dust perhaps of rutile.

Hornblende : Three principal types of hornblende have been found :

(i) sometimes both olivine and pyroxenes have thin rims of light coloured hornblende (uralite) which also occurs along cleavages and fractures, as prismatic plates or folia.

(ii) green hornblende and

(iii) Blue or blue-green hornblende.

The green hornblende varies in colour from different shades of brownish green to olive or yellowish green and in some instances to emerald green. They are also highly pleochroic (X = pale brownish yellow, sulphur yellow, greenish yellow; Y = Brownish green, yellowish green; Z = deep brownish green, olive green, emrald green; Z^C = 15-24°)

This green hornblende is a secondary product derived from diopside, hypersthene and olivine.

The blue-green hornblende occur as marginal fringes to the yellow green amphiboles where they are bordered by sodic feldspars (perhaps indicating sodic metasomatism). These are also highly pleochroic (X = pale yellow to greenish yellow; Y = Greenish; Z = Bluish green or greenish blue).

The above two varieties may be sometimes idiomorphic or poikiloblastic, with inclusions of pyroxene, plagioclase, apatite, schiller plates and iron ores. They may be distributed throughout the rock or concentrated in foliae.

Biotite : It is seen to form at the expense of pyroxene and amphibole. Large biotite crystals may also be present and these frequently penetrate and traverse the hypersthene grains showingfollowing pleochroic scheme :

1. X = yellow, Z = dark greenish brown;
2. X = Pale yellow or colourless, Z = dark brown to reddish brown
3. Foxy red biotite showing reddish brown to dark red pleochroism.

Most frequent inclusions in biotite are zircon and rutile.

Iron ores occur as vermicular bodies within pyroxene. Apatite and zircon are the main accessories. Small patchesof calcite and chlorite are also present as alteration products. Apatite is present as small prismatic crystals enclosed in feldspars but more commonly as large platy grains which are frequently associated with ferromagnesian minerals.

TABLE-III.2A.

Representative Microprobe Analysis of Pyroxene from Basic Type

Sample No.	14Q	14Q	14Q
Anal. No.	1/1R	1/2C	2/1*
SiO_2	50.571	51.335	49.636
TiO_2	0.186	0.165	0.317
Al_2O_3	0.702	1.344	1.626
FeO	27.181	25.249	12.043
MnO	0.639	0.636	0.309
MgO	20.399	20.268	14.903
CaO	1.158	1.212	20.360
Na_2O	-	-	0.320
K_2O	0.002	0.031	-
Total	99.382	98.538	99.486

1/1R Near biotite, 2/1* Near plagioclase

Number of ions on the basis of 6 oxygens

Si	1.900	1.933	1.859
Al^{IV}	0.031	0.060	0.072
T site	1.931	1.992	1.931
Al^{VI}	-	-	-
Ti	0.005	0.005	0.009
Fe^{+3}	0.158	0.067	0.215
Fe^{+2}	0.696	0.728	0.163
Mn^{+2}	0.020	0.020	0.010
Mg	1.143	1.137	0.832
Ca	0.047	0.049	0.817
Na	-	-	0.023
K	-	0.001	-
M1,M2	2.069	2.008	2.069
X_{Fe}	0.378	0.39	0.164
X_{Mg}	0.622	0.61	0.836
X_{En}	55.92	57.40	40.92
X_{Fs}	41.78	40.13	18.59
X_{Wo}	2.30	2.47	40.19

TABLE-III.2B.

Representative Microprobe Analysis of Feldspar from Basic Type

Sample No.	14Q	14Q
Anal. No.	1/2R*	1/1C
SiO_2	53.002	53.293
Al_2O_3	28.096	26.939
CaO	12.074	11.612
Na_2O	5.134	5.242
K_2O	0.226	0.289
Total	98.533	97.376

* Near biotite

Number of ions on the basis of 8 oxygens

Si	2.441	2.480
Al	1.525	1.478
Ca	0.596	0.579
K	0.013	0.017
Na	0.458	0.473
Total	5.033	5.027

X_{An}	55.86	54.16
X_{Ab}	42.92	44.27
X_{Or}	1.22	1.59

TABLE-III.2C

Representative Microprobe Analysis of Biotite from Basic Type

Sample No.	14Q	14Q
Anal. No.	1/1R	1/2C
SiO_2	37.222	37.232
TiO_2	5.908	5.980
Al_2O_3	13.240	12.558
FeO	16.408	16.417
MnO	0.037	0.095
MgO	14.523	14.239
CaO	0.007	0.009
Na_2O	-	-
K_2O	9.716	9.894
Total	97.061	96.425

Number of ions on the basis of 22 oxygens

Si	5.520	5.571
Al	2.314	2.215
Fe	2.035	2.055
Mg	3.211	3.176
Mn	0.005	0.012
Ca	0.001	0.002
K	1.838	1.889
Na	-	-
Ti	0.659	0.673
Total	15.583	15.593

X_{Fe}	38.79	39.29
X_{Mg}	61.20	60.71

TABLE III.2D

Representative Microprobe Analysis of Opaques from Basic Type

Sample No.	14Q	14Q
Anal. No.	1/1R	1/1C
SiO_2	-	-
TiO_2	51.897	52.267
Al_2O_3	-	0.038
FeO	47.467	46.816
MnO	0.577	0.486
MgO	0.531	0.743
Cr_2O_3	0.130	0.076
ZnO	0.110	-
V_2O_3	0.280	0.268
Total	100.992	100.698

Number of ions on the basis of 6 oxygens

Fe	1.9914	1.9614
Ti	1.9579	1.9692
Mg	0.0397	0.0555
Al	-	0.0023
Mn	0.0245	0.0206
Cr	0.0051	0.0030
Zn	0.0041	-
Si	-	-
V	0.0113	0.0108
Total	4.0339	4.0228

Species : Ilmenite

III.3 INTERMEDIATE TYPE

These form transitional variety and on account of their restricted occurrence, it is difficult to demarcate them in field. It could be distinguished only in thin sections. These are medium to coarse grained rocks with distinct granulitic to gneissic foliation. The ferromagnesian bands form elongated clots and bands. The minerals are diopside, hypersthene, plagioclase and small quantities of k-feldspar and quartz. Hornblende and biotite occur as alteration products after hypersthene. The grains of diopside and hypersthene are smaller than those in basic charnockites. The plagioclase is less calcic and ranges from calcic oligoclase to sodic andesine. It is typically antiperthitic wherein K-feldspar inclusions occur as elongated homoaxial blebs aligned parallel or oblique to the twinning. The twin lamellae are variable - some well defined and sharp , others vague and diffuse and yet in others wedge shaped. The feldspars contain dusty and acicular inclusions which are purplish in colour and are similar to the rutile inclusions in acid charnockites. The optical characters of the constituent minerals in this type are similar to those described in basic and / or acid types and hence are not mentioned

III. 4 ACID TYPE

These pyroxene granulites (Charnockites- sensu stricto) are the major rock types exposed at the southern part of the area extending from Balaram in the west to north of Virampur in the east. These are very coarse grained rocks full of augens of feldspar. The trend of the long axis of augens is E - W. Narrow, centimeter(s) thick shear bands pass through this rock having a general E - W trend. .

Best exposures of these charnockite are seen to have restricted occurrence - near the Balaram Rest House and north of Virampur in the river section on way to Dhanpur where these are being quarried. In the Chitrasani quarry these are seen occurring as patches or tongues in the intermediate and basic charnockite. In the same quarry, the charnockite (acid) is also seen interbanded with basic variety.

III.4a *Petrography*

These are quartz rich hypersthene rocks, nearest in composition to the charnockite sensu stricto. They contain the following mineral association: Quartz - K-feldspar - plagioclase - orthopyroxene - biotite - amphibole, rutile, ilmenite and monazite. The important petrographic features are described below:

Quartz :

These grains are present in diverse sizes and shapes and occur in five distinct modes. (i) as elongate grains or quartz leaves parallel to the gneissic foliation, (ii) as small irregular grains in a quartz feldspar mosaic, (iii) as blebs and vermicular bodies in myrmekites, (iv) as pools or channels of interlocking granules filling the space between the feldspars and (v) as crescent shaped bits and irregular blebs, producing a sieve structure in hypersthene, amphibole and biotite. The mineral is often strained and shows wavy extinction and the included rods are bent or fractured when they cross the boundaries of the strain shadows. This mineral contains minute, opaque, dusty rod-like inclusions of rutile of the type described by Holland (1900, P.138) **(Plate-III.4A)** or of biotite (rarely).

Smaller quartz grains with polygonal outline and triple point junction indicate grain boundary equilibration **(Plate-III.4B)**. Often quartz grains are flattened to produce ribbons and occupy the interstices of porphyroblasts along with other smaller grains of feldspar and amphibole surrounding plagioclase and orthopyroxene respectively in association with orthopyroxene and plagioclase.

K-feldspar :

K-feldspar is also a dominant mineral in this rock constituting about 20% by volume. K-feldspar is both microcline and orthoclase and occurs in two modes; (i) as porphyroblast and (ii) as small grains. Potash feldspars are of two types : (i) those with undulatory extinction and only rarely show the characteristic microcline cross-hatching. This feature appears to be similar to that described by Eskola (1952) as a result of microclinization of orthoclase. (ii) Microperthitic microcline with abundant oriented spindles of plagioclase and associated with quartz and a lesser amount of hypersthene. Some of these types form large sub-idiomorphic grains showing patchy extinction, the patchiness corresponding to variations in the relative coarseness of the perthitic inclusions. A few grains show carlsbad twinning also. Embayment of alkali feldspar by patches of myrmekite is common. Porphyroblastic K-feldspar grains are fractured and subgrain formation is common. K-feldspar shows sutured grain boundary contact with quartz and plagioclase. Often K-feldspar porphyroblast contain oriented intergrowth of plagioclase feldspar and are thus perthitic. Different types of perthite include string perthite **(Plate-III.5A)**, bead perthite etc. Smaller grains of K-feldspar generally occur in aggregate with smaller grains of quartz and plagioclase along with biotite.

Plagioclase :

Plagioclase is the dominant mineral in the rock constituting more than 30% by volume. Plagioclase is mostly sodic (with An content 15-20). Plagioclase occurs in three modes; (i) as porphyroblast, (ii) as small grains and (iii) as included phases within K-feldspar. Plagioclase of the first two modes show medium refractive index and are biaxial positive. Polysynthetic and lamellar twinning are conspicuous. Porphyroblastic

Plate -III.4A

Rutile as fine needles or as dust in quartz. Different sets of rutile needles are seen as minute rods or dots oriented along different cleavages and intersected in thin sections at different angles in acid types (XPL, 80X).

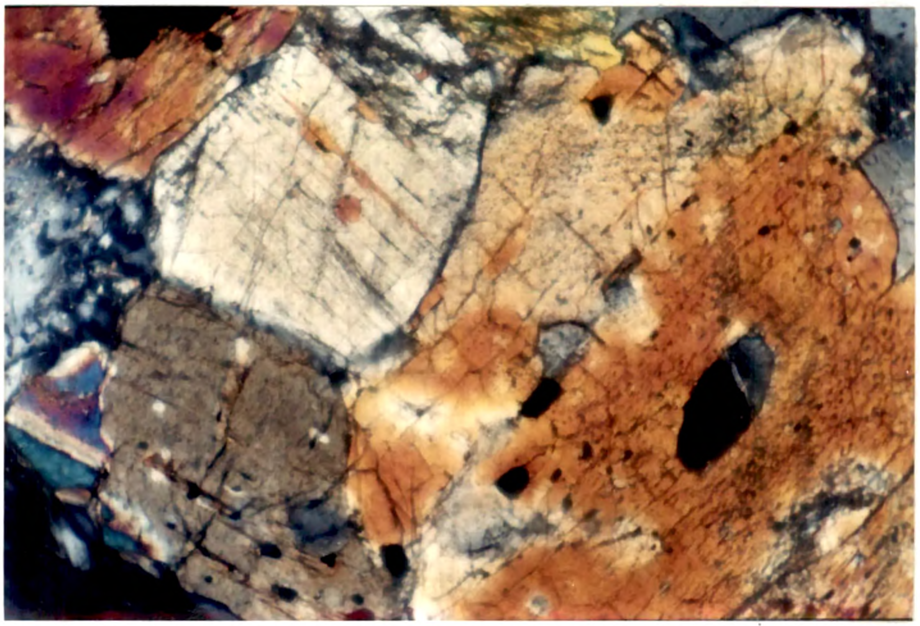

Plate-III.4B.

Smaller quartz grains with polygonal outline and triple point junction indicate grain boundary equilibration in acid types (XPL, 80X).

plagioclase are generally very coarse (often 3 centimeters). Often twin lamellae are bent to form kink bands. In the second mode, plagioclase is fine grained and occurs along with fine grained quartz. Such aggregates occupy the interspaces of porphyroblastic plagioclase, K-feldspar and orthopyroxene. Plagioclase in this mode is completely recrystallised and is now strain free. It exhibits polygonal outline. In the third mode, plagioclase occur as included phase within K-feldspar as perthite.

Orthopyroxene :

Hypersthene occurs as anhedral irregular clusters or as clumps or as isolated pools or crescent shaped bits in a felsic base **(Plate-III.5B)**. Pleochroism is moderate (X = pale pink, Y = pale blue green). This mineral also occurs in ragged or embayed grains.

In most of the cases orthopyroxene is replaced partially or completely by amphibole and/or biotite. Amphibole - quartz symplectite develops in between orthopyroxene and plagioclase **(Plate-III.6A)**. Often aggregates of amphibole - quartz replace orthopyroxene totally.

Biotite :

Biotite occurs either as laths with bent cleavage traces or as patches at the grain boundary of orthopyroxene, ilmenite and amphibole. Specs of amphibole remain as included phase within biotite.

Amphibole (Pargasitic Hornblende):

Amphibole in these rocks, a pargasitic hornblende, occurs either as aggregate of small grains or as symplectitic intergrowth with quartz. In both the occurrences, amphibole shows green to deep green to brownish green pleochroism. Amphibole alone or intergrown with quartz develops around orthopyroxene and ilmenite in association with plagioclase. A foliation represented by biotite and small grains of quartz and feldspar is conformable to the orientation of amphibole. Occasionally, amphibole occurs as included phase within biotite.

Ilmenite :

Ilmenite occurs in two modes; (i) as porphyroblasts and (ii) as smaller grains. (i) Anhedral porphyroblastic ilmenite is generally rimmed by amphibole. (ii) Smaller ilmenite grains occur along with small polygonal quartz, plagioclase grains at the interspace of porphyroblastic phases. Often ilmenite grains are flattened in this zone.

Rutile :

It occurs as fine needles or as dust in quartz. Different sets of rutile needles are

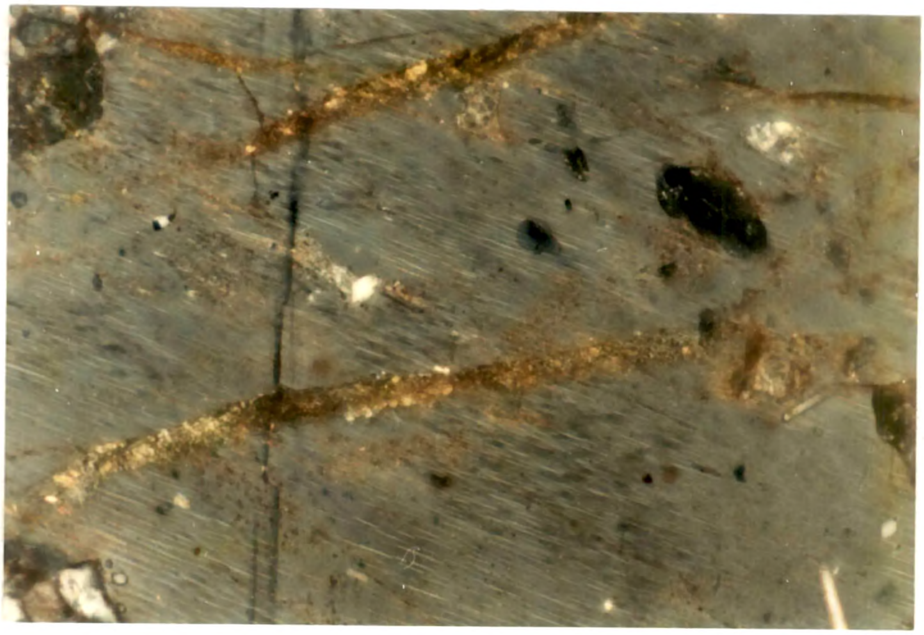

Plate -III.5A Often K-feldspar porphyroblast contain oriented intergrowth of plagioclase feldspar and are thus perthitic. Different types of perthite include string perthite (PPL, 40X).

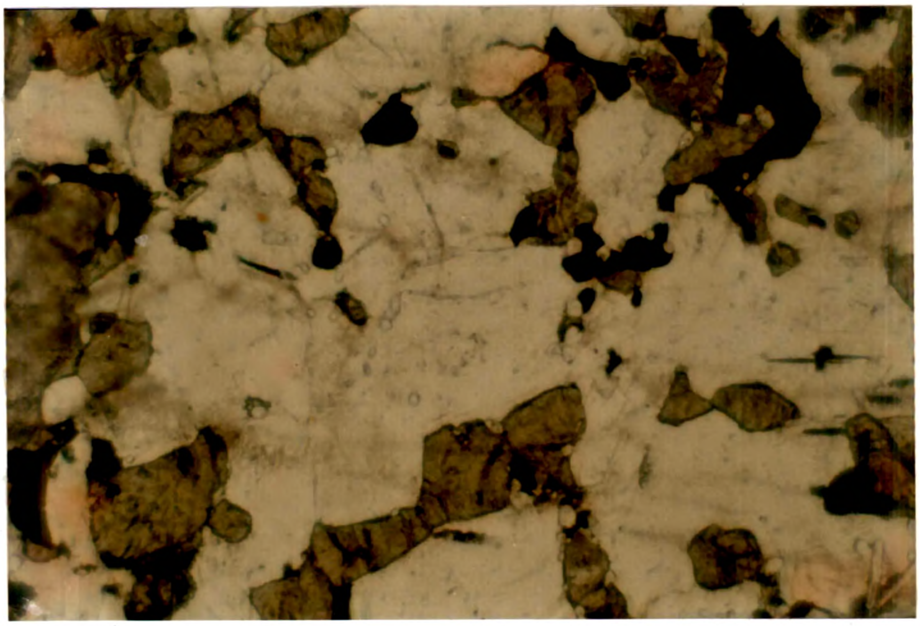

Plate-III.5B. Hypersthene occurs as anhedral irregular clusters or as clumps or as isolated pools or crescent shaped bits in a felsic base in acid types (PPL, 80X).

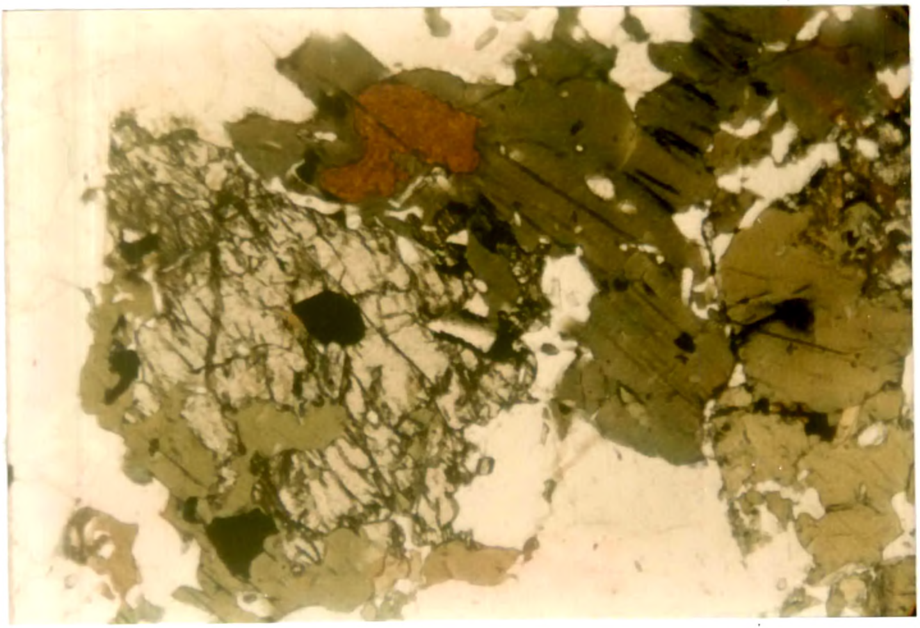

Plate -III.6A Orthopyroxene is replaced partially or completely by amphibole and or biotite. Amphibole - quartz symplectite develops in between orthopyroxene and plagioclase in acid types (PPL, 40X).

seen as minute rods or dots oriented along different cleavages and intersected in thin sections at different angles (Plate-III.4A).

III.4b *Mineral Chemistry*

Chemical composition of constituent minerals in acid charnockites were determined by a JEOL EPMA operated at 15 kv accelerating voltage and 2 - 5 μm beam diameter. Natural mineral standards were used and representative ZAF corrected analyses of coexisting phases are given in Table-III.4 A-D.

K-feldspar :

Representative analysis of K-feldspar from acid charnockite is given in Table-III.4A (sample No. B).

The Or content of the K-feldspar is 75 - 78 %. Ab content 21.5 - 23.2 % and An content 0.6 - 1.0%. There is increase in Si and K content from core to rim in k-feldspars with concomitant decrease in Ca, Na and Al. XOr increases towards the rim.

Plagioclase :

Representative analysis of plagioclase from acid charnockite is given in Table-III.4A.

Anorthite content of plagioclase is approximately 15 - 19 mole %, Ab 79 - 84 mole % and Or 0.5 - 1.8 mole % in general. In general, there is slight increase in XAn and XAb content from core to rim with appropriate decrease in XOr content. There are, however, some feldspar grains (OOC1) where the XOr varies from 86.45 % to 27.30 % from core to rim with corresponding increase in XAb 13.35 to 63.74 % and XAn 0.20 to 8.97 %. This anomaly is inexplicable.

Orthopyroxene :

Representative analysis of Orthopyroxene from acid charnockite is given in Table-III.4B.

Compositionally orthopyroxene of charnockite is ferrohypersthene (Deer et al., 1974) with XFe (= Fe2+ /(Fe2+ + Mg)) 0.76 - 0.80. Low XAlVI (Total Al/2) content (max. 0.012) is characteristic of this orthopyroxene. In these pyroxenes the XWo is low 2.1 - 11.12 % while XFs varies from 67 - 76 % and XEn varies from 17.- 21 %.

The other pyroxene is Ca - rich variety (which is strongly pleochroic. XFe in such pyroxenes is less as compared to the above variety - being 0.71 to 0.72. XWo in these is higher being 37.94 - 41.45. It is salite.

Amphibole :

Representative analysis of amphibole from acid charnockite is given in Table-III.4C. Its composition corresponds to pargasitic hornblende.

Ilmenite :

Representative analysis of ilmenite from acid charnockite is given in Table-III.4D.

Ilmenite porphyroblast is predominantly $FeTiO_3$ (98.15 mole%) with very limited amount of $MnTiO_3$ (1.85 mole%) and $MgTiO_3$ absent. Fe, Al and Mn content in ilmenite grains are seen to increase from core to rim while Ti, Cr, Zn and V contents decrease from core to rim.

III.4c *Mineral Reactions*

Textural features suggest that amphibole and quartz are secondary minerals and formed through the following reaction,

$$\text{Orthopyroxene} + \text{plagioclase} + \text{ilmenite} + H_2O \longrightarrow \text{amphibole} + \text{quartz} \quad \text{(i).}$$

III.4d *Discussion*

Coarse granoblastic texture with development of large feldspar augens completely obliterated its original igneous texture. Appearance of apparently intrusive nature of this rock is evident from its cross-cutting the foliation in the associated basic and intermediate charnockitic rocks but on a closer inspection it reveals a fine persistent banding in them thereby suggesting a metamorphic character of these rocks.

TABLE-III.4A

Representative Microprobe Analysis of Feldspar from Acid Types

Sample No.	B-2	B-2	OOC1	OOC1	OOC3	OOC3	B	B
Anal. No.	1/1R	1/2C	1/1R	1/2C	1/1R	1/1C	1/1R	1/2C
SiO_2	62.778	63.550	65.082	65.320	63.267	62.484	65.559	65.456
Al_2O_3	20.848	21.410	19.024	17.121	20.547	20.760	16.903	17.387
CaO	4.438	4.140	1.983	0.049	3.559	3.747	0.146	0.196
Na_2O	10.328	9.854	7.767	1.517	10.550	10.867	2.473	2.663
K_2O	0.307	0.340	5.060	14.943	0.128	0.108	13.565	13.252
Total	98.699	99.295	98.916	98.949	98.005	98.638	98.646	98.995

Number of ions on the basis of 8 oxygens

Si	2.831	2.838	2.947	3.039	2.867	2.836	3.046	3.029
Al	1.108	1.127	1.015	0.939	1.095	1.110	0.926	0.948
Ca	0.215	0.198	0.096	0.002	0.172	0.182	0.007	0.010
K	0.018	0.019	0.292	0.887	0.007	0.006	0.804	0.782
Na	0.903	0.853	0.682	0.137	0.921	0.956	0.223	0.239
Total	5.075	5.035	5.033	5.004	5.056	5.091	5.005	5.008

X_{An}	18.93	18.50	8.97	0.20	15.64	15.91	0.68	0.97
X_{Ab}	79.49	79.72	63.74	13.35	83.73	83.57	21.57	23.18
X_{Or}	1.58	1.78	27.30	86.45	0.64	0.52	77.76	75.85

TABLE-III.4B

Representative Microprobe Analysis of Pyroxene from Acid Types

Sample No.	B-2	B-2	OOC1	OOC1	OOC3	OOC3	B	B
Anal. No.	1/1R	1/2C	1/1R	1/2R	1/1R	1/1C	1/1R	1/2C
SiO_2	49.317	49.099	49.000	48.781	49.623	50.937	47.404	47.694
TiO_2	0.110	0.097	0.120	0.138	0.113	0.123	0.106	0.120
Al_2O_3	8.575	8.652	7.592	8.163	7.398	8.268	0.147	0.127
FeO	38.592	40.934	39.772	39.614	26.261	24.220	41.942	41.544
MnO	1.018	1.245	1.174	1.290	0.736	0.717	1.532	1.344
MgO	6.696	6.503	5.469	6.306	5.692	5.481	6.782	6.478
CaO	4.934	0.885	5.626	4.466	17.374	18.791	1.101	2.179
Na_2O	0.222	0.099	0.108	0.254	-	0.035	-	0.060
K_2O	0.007	-	0.011	-	-	0.008	-	0.023
Total	99.382	98.538	99.486	99.524	98.460	99.015	99.014	99.569

Number of ions on the basis of 6 oxygens

Si	2.004	2.057	1.998	1.993	1.984	2.018	1.989	1.988
Al^{IV}	-	-	0.002	0.005	0.016	-	0.007	0.006
T site	2.004	2.057	2.000	1.998	2.000	2.018	1.997	1.994
Al^{VI}	0.007	0.007	0.012	-	0.010	0.028	-	-
Ti	0.003	0.003	0.004	0.004	0.003	0.004	0.003	0.004
Fe^{+3}	-	-	-	0.021	-	-	0.008	0.016
Fe^{+2}	1.312	1.434	1.356	1.333	0.878	0.802	1.464	1.432
Mn^{+2}	0.035	0.044	0.041	0.045	0.025	0.024	0.054	0.047
Mg	0.406	0.406	0.332	0.384	0.339	0.324	0.424	0.403
Ca	0.215	0.040	0.246	0.195	0.744	0.797	0.050	0.097
Na	0.017	0.008	0.009	0.020	-	0.003	-	0.005
K	-	-	0.001	-	-	-	-	0.001
M1,M2	1.996	1.943	2.000	2.002	2.000	1.982	2.003	2.006
X_{Fe}	0.764	0.779	0.803	0.776	0.721	0.712	0.775	0.78
X_{Mg}	0.236	0.221	0.197	0.224	0.279	0.288	0.225	0.22
X_{En}	21.00	21.60	17.17	20.08	17.29	16.85	21.88	20.86
X_{Fs}	67.87	76.28	70.11	69.72	44.77	41.70	75.54	74.12
X_{Wo}	11.12	2.13	12.72	10.20	37.94	41.45	2.60	5.02

TABLE-III.4C

Representative Microprobe Analysis of Hornblende from Acid Types

Sample No.	B-2	B-2	OOC1	OOC1	OOC3	OOC3
Anal. No.	1/1R	1/2C	1/1C	1/2R	1/1R	1/1C
SiO_2	42.024	41.732	42.853	42.553	42.835	42.110
TiO_2	2.101	1.980	1.837	1.869	1.810	1.811
Al_2O_3	8.575	8.652	7.592	8.163	7.398	8.268
FeO	26.589	25.790	26.680	26.585	26.567	26.625
MnO	0.272	0.289	0.269	0.196	0.309	0.199
MgO	4.268	4.270	4.765	4.738	4.391	4.470
CaO	10.430	10.514	10.311	10.791	10.319	10.330
Na_2O	2.065	2.169	2.113	1.694	1.875	2.100
K2O	1.170	1.270	1.134	1.036	1.078	1.218
H2O	1.892	1.878	1.896	1.899	1.878	1.884
Total	99.382	98.538	99.486	99.524	98.460	99.015

Number of ions on the basis of 22 oxygens

Si	6.660	6.661	6.778	6.719	6.839	6.701
Al^{IV}	1.340	1.339	1.222	1.281	1.161	1.299
T site	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	0.261	0.289	0.194	0.237	0.231	0.251
Ti	0.250	0.238	0.223	0.222	0.217	0.217
Fe^{+3}	0	0	0	0	0	0
Mg	1.009	1.016	1.124	1.115	1.045	1.060
Fe^{+2}	3.480	3.443	3.460	3.425	3.507	3.472
Mn	0	0.015	0	0	0	0
Ca	0	0	0	0	0	0
M1,2,3	5.000	5.000	5.000	5.000	5.000	5.000
Mg	0	0	0	0	0	0
Fe^{+2}	0.045	0	0.069	0.085	0.041	0.072
Mn	0.036	0.025	0.036	0.026	0.042	0.027
Ca	1.771	1.798	1.747	1.825	1.765	1.761
Na	0.147	0.178	0.147	0.064	0.152	0.140
M4 site	2.000	2.000	2.000	2.000	2.000	2.000
Ca	0	0	0	0	0	0
Na	0.489	0.494	0.501	0.455	0.428	0.508
K	0.237	0.259	0.229	0.209	0.220	0.247
A site	0.725	0.752	0.730	0.664	0.648	0.755

Species Pargasitic Hornblende (?)

TABLE-III.4D

Representative Microprobe Analysis of Opaques from Acid Types

Sample No.	OOC3	OOC3
Anal. No.	1/1R	1/1C
SiO_2	-	-
TiO_2	52.872	52.668
Al_2O_3	0.040	-
FeO	46.941	43.875
MnO	0.864	0.747
MgO	-	-
Cr_2O_2	0.038	0.114
ZnO	-	0.015
V_2O_3	0.267	0.281
Total	101.021	97.699

Number of ions on the basis of 6 oxygens

Fe	1.964	1.881
Ti	1.989	2.031
Mg	-	-
Al	0.002	-
Mn	0.037	0.033
Cr	0.002	0.005
Zn	-	0.001
Si	-	-
V	0.011	0.012
Total	4.0038	3.9612

Species : Ilmenite

III.5 MYLONITES

The charnockitic basement is separated from the overlying sequence of pelitic and calc granulites by a well developed mylonite which occurs northwest of Kansara village. The mylonite represents the highly sheared basement - cover rock sequence which is due to the highly competent (brittle) charnockitic basement which resisted the deformation suffered by the incompetent cover rocks.

These mylonitic rocks are characterised by gneissic foliation and dark grey fine grained groundmass with ovoid patches of feldspar drawn out parallel to the foliation **(Plate-III.7A)**. In thin sections, these show typical mylonitic texture with coarse plates of feldspar full of dusty inclusions standing out like knots or augens around which the quartz flows in long, narrow ribbons of forms lenticular micro to crypto-crystalline aggregates **(PLATE-III.7B)**. The matrix is extremely fine grained dark glassy in which the stretched porphyroblasts of feldspar, pyroxene and garnet are embedded. Peripheral granulation of the porphyroblasts is seen resulting in fluxion structure. Numerous veins of chlorite are seen. Biotite, hornblende and calcite occur as alteration products. Similar mylonites have been described occurring in association with garnet sillimanite gneisses of the Bhilwara Supergroup of Rampura-Agucha area, Bhilwara district, Rajasthan (Gandhi et al, 1984).

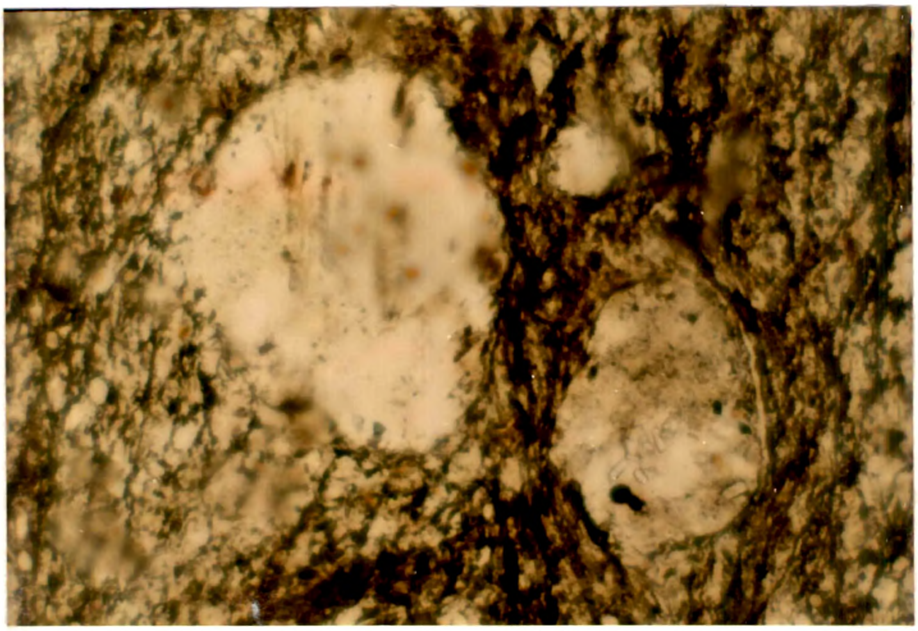

Plate-III.7A. Gneissic foliation and dark grey fine grained groundmass with ovoid patches of feldspar drawn out parallel to the foliation in mylonitic rocks (PPL, 40X).

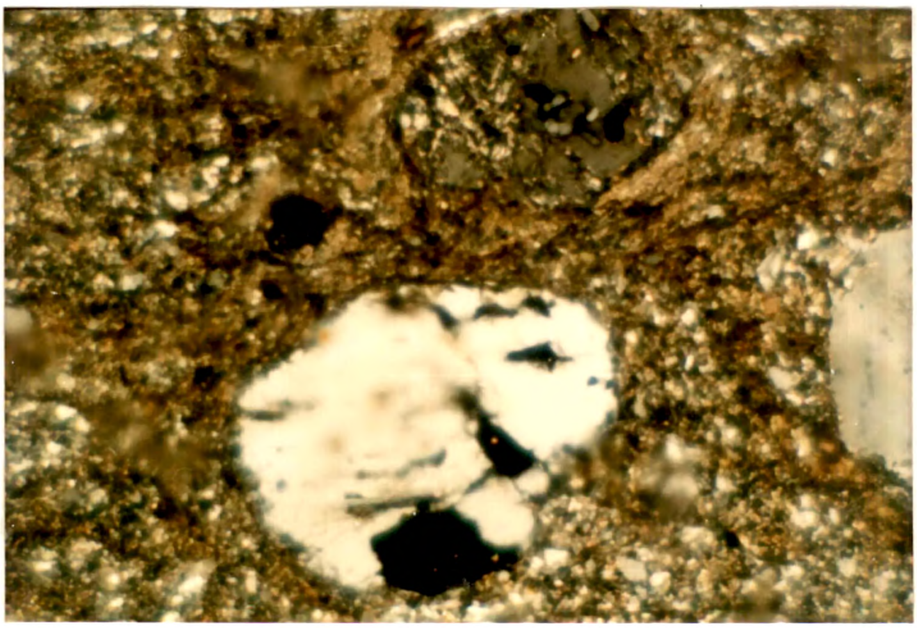

Plate -III.7B Typical mylonitic texture with coarse plates of feldspar full of dusty inclusions standing out like knots or augens around which the quartz flows in long, narrow ribbons of forms lenticular micro to crypto-crystalline aggregates (XPL, 40X).