Chapter IV.

NORITES, PYROXENE GRANULITES AND AMPHIBOLITES.

Pyroxene granulites, amphibolites and norites occur as dykes and sills in the sedimentary metamorphics. They are also found in the granite gneiss and the porphyritic granite country.

Lack of definite field evidence leaves a possibility that some of the pyroxene granulites, pyroxene amphibolites and amphibolites are related to the calc-silicates described before (Chapter III). At least in one instance, however, the granulites and amphibolites are seen to grade from a more or less unrecrystallized olivine norite, and in many others the direction of their trends cut across the schistose and gneissose strike of the country. There is hardly any difference in the petrography of such definite dyke rocks and the rocks of most of the other occurrences.

They occur in exfoliated rounded masses, or as interrupted hummocks all along the trend. Sometimes they weather into a sort of woody form.

Chatterjee describes as norites and granulitic gabbros a suite of rocks co-magmatic with the anorthosites of Bankura, which are closely similar to the rocks of

* In the eastern extension of the present area in the district of Bankura, B. Roy Chowdhuri has found hyperstenogranulites which are intimately associated with calc-silicate granulites. They give all evidence of having been derived from impure calcareous sediments. The dissertation under preparation will be submitted as part fulfilment of the M.Sc degree examination (Calcutta University, 1954).
E. Manbhum (Chatterjee S.C., 1936). According to him these rocks are later than the granite gneiss which is continuous with the granite gneiss of the area under consideration. He further correlates this group with similar rocks in Bero which show evidences of being post-porphyrictic granite in age. This suggestion that the norite suit is intermediate in age between the granite and the granite gneiss points to a considerable difference in the period of their emplacement a suggestion which is extremely remote and also contrary to evidences (see Chapters VI and X).

While discussing the petrology of hypersthene dolerites and related rocks in Deoghar, Ray has made the interesting suggestion that these rocks may prove to be equivalent to the Anorthosite suit of Bankura and to similar rocks in Manbhum (Ray S., 1941). Indeed the rather close similarity in their petrography and in the relation of these rocks with associated rock types lends a support to such a suggestion. He finds the members of his gneissic complex, consisting of different types of granite gneisses, to exhibit intrusive relation with the basic rocks, which show also effects of granitisation. This proves the members of the basic suit to be older than the granites which later could be correlated with the Chotanagpur granite gneiss of Durr.

S. Roy describes pyroxene granulites and amphibolites from Baghmundi Plateau, W. Manbhum as older than the porphyritic granite and the Baghmundi granite gneiss (equivalent to the granite gneiss of West Manbhum). He has not found any intrusive basic suit younger than the granites (S. Roy, 1942).
Though in most cases, in the area under review, the exact nature of the contact of these rocks with the porphyritic granite and the granite gneiss is obscured by excessive weathering, there are good evidences in the field, as well as under the microscope, of the effects of incorporation and granitisation whenever these rocks occur inside or close to the granite, or in the granite gneiss country.

Basic dyke rocks of considerable dimensions, like the one near Bero, whose trend lie across the trend of the banding of the granite, reveal on careful examination small xenoliths and inclusions of the same rock in the granite, evidently torn off from the main mass, and granitised through different degrees. The inclusions are sometimes seen to have been shattered (Chapter VI page 51). In Bero both the smaller inclusions as well as the main mass of the dyke rock have been highly granitised.

The effect of granitisation is well shown in the production of lower phase minerals e.g. hornblende from pyroxene, or biotite from both hornblende and pyroxene, (ii) in the modification of the original textures, (iii) introduction of quartz and feldspars and (iv) in the appearance of apatite, a mineral which is present almost parasitically in the basic suite of rocks as well as in the porphyritic granite itself.

Gradual stages of progressive granitisation of the basic rocks into a normal type of the porphyritic granite is noticed in rocks occurring within or close to the granite. There has thus been produced some hybrid types with hypersthene - hornblende - biotite etc, some intermediate rocks of granodiorite - diorite composition, some hypersthene bearing granites with a comparatively larger proportion of dark minerals, and some biotite rich gneisses. Sometimes in
contact with the granite or with thick bands of pegmatites, amphibolites and amphibolised pyroxene granulites have been converted, along a thin zone in contact, into a biotite schist composed only of biotite (predominant) quartz and feldspar.

The granite gneiss has penetrated these rocks in an intimate lit-par-lit fashion producing, in extreme cases, well banded composite gneisses which are often pytymatically folded, or streaky gneisses with small, lenticular, hybridised basic streaks that have no sharp outline (Fig. 12). In most cases in the granite or in the granite gneiss country, these rocks have been crossed and re-crossed by pegmatites and quartz veins in every conceivable manner (Fig. 11), the rocks showing good evidences of granitisation.

The evidences for a pre-granite * age of the suit are convincing. No basic intrusive later in age than the granites has been met with, though a few showing a definite cross cutting relation with the composite gneisses have been found to the northeast of the area in N. Manbhum**.

It is difficult to correlate these rocks with similar formations in Singhbhum. They may be equivalent in age to the Dalma Lavae, or they may represent a basic phase of the Singhbhum Ultrabasics (Dunn 1929, Dunn and Dey 1942 etc).

Unlike some of the other areas referred to above (S. Ray and S. Roy), pyroxene granulites form the chief rock type in East Manbhum, and typical amphibolites (hornblende-plag- quartz rocks of the amphibolite facies) are rare. Only one

* including the granite gneiss.

** see foot note page 9 Chapter II. These dykes might possibly be of the same age as the Coal Field dykes, as suggested by their proximity to the Raniganj Coal Field and also by the petrographic similarity.
Fig. 11: Pegmatite - granite bands in amphibolite showing ptygmatic folding; on the river cutting about 125° from Petajor (R 042982, 73 I/7) within the northern band of the porphyritic granite (see text) also Plate II A).

Fig. 12: Streaky gneiss with lenticular streaks of basic (amphibolitic) rock in granite. The basic streaks have no sharp boundary. At a spot (approx R 089916, 73 I/7) close to the southern boundary of the southern band of the porphyritic granite.
occurrence of olivine norite and a few norites have been noticed which occur associated with the pyroxene and the amphibolised pyroxene-granulites.

**Petrography.**

**Olivine Norite and Norites.**

The specimen of olivine norite comes from the north of Haripalpur (M11020; 73 11), close to the village, associated with pyroxene granulites (see later, page 38).

The rock is coarse grained, dark greyish black in colour. The texture is xenomorphic granular, ophitic or subophitic, with partial or complete inclusion of pyroxene and olivine in feldspar and of olivine in pyroxene. There is no mesostasis, though the over-sized pyroxene crystals included subophitically in feldspars, cause thinning out of the latter in the borders giving a false impression of mesostasis.

Olivine appears rather fresh, only slightly altered along fractures into antigorite, chrysotile and enstatite. The mineral has a sub-rounded appearance, sometimes rimmed by a thin band of light coloured hornblende. The $2V$ is 86°30' (showing slight variation, lying within a limit of 84°45' to 87°30'), which suggests MgO : FeO to be roughly equal to 67 : 33 (Winchell 1933, p. 191). The pyroxene is very light pink brown in colour with characteristic brown schiller inclusions which impart a deeper shade of brown colour to the portion richer in these. The mineral shows a weak pleochroism under strong light from very light pink to a similar shade of green. The $2V$ is 79°30' (also variable in different individual crystals) with Z = c. This points to a composition of a hypersthene with MgO : FeO roughly 66 : 34 (Winchell 1933, p.218), though the mineral lacks the characteristic deeper shades of pleochroism of hypersthenes. The plagioclase feldspar has $2V = 89^\circ$ on the average. It is labradorite - bytownite in composition (An90).
Hornblende, pleochroic in comparatively light shades of green, (X = light greenish yellow, Y = light green, Z = greenish brown) with ZA c = 28°, is invariably secondary, formed at the expense of both pyroxene and olivine, often occurring in cleavage interspaces or as rims round the minerals sometimes with frayed marginal contacts. Biotite, occurring often in large sized plates, is seen to have been derived from all of the ferro-magnesian minerals named above, including hornblende.

Rarely the plagioclase is seen to contain tear drop inclusions of the pyroxene, close to big crystals of the latter, and also of olivine, most of which have been converted to diopside (Z A c = 39° ca) and hypersthenes (with strong green to pink pleochroism). Such instances are rare, but they supply ample evidence for the formation of diopside and hypersthenes at the expense of anstatite-hypersthenes, and to the fact that the plagioclase molecule entered into the reaction so that the transformation is possibly a result of reaction of these two minerals. Some of the diopsides have possibly been similarly derived from olivine. The rock should better be described as an olivine meta-norite.

The mode and the chemical composition of the rock are shown in the two succeeding tables:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Chemical composition.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olivine</td>
<td>SiO₂ 49.69</td>
</tr>
<tr>
<td>Anstatite-hyperstene</td>
<td>TiO₂ N.D</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>Al₂O₃ 19.14</td>
</tr>
<tr>
<td>Hornblende</td>
<td>Fe₂O₃ 2.01</td>
</tr>
<tr>
<td>Biotite</td>
<td>MgO 7.81</td>
</tr>
<tr>
<td>Other minerals</td>
<td>CaO 3.01</td>
</tr>
<tr>
<td></td>
<td>Na₂O 2.32</td>
</tr>
<tr>
<td></td>
<td>K₂O 0.96</td>
</tr>
<tr>
<td></td>
<td>H₂O 0.35</td>
</tr>
</tbody>
</table>

Normal norite is also associated with the above, and is more common elsewhere. The norite in the above dyke rocks (Sp 82a) varies but little. The hypersthenes show a slightly stronger pleochroism.
Fig. 10.

Olivine - metanorite (SnB 210) from Hariharpur (see text).

× 42
II. Pyroxene granulites, Pyroxene-hornblende granulites etc.

The rocks are medium grained, but sometimes also fine grained, granoblastic. Rarely they may be gneissic, the alternating bands showing even grained, polygonal granulitic texture that is commonly noticed in the fine grained types.

The constituent minerals are hypersthene, diopside, plagioclase, hornblende, ore, apatite, biotite, occasionally also quartz and rarely orthoclase. The assemblages found could be grouped as follows:

1. Hypersthene-diopside-plagioclase (biotite-quartz).
2. Hypersthene-diopside-hornblende-plagioclase (biotite-quartz).

The mineralogical and textural changes accompanying granitisation have been considered in Chapter VI, and the hybrids or the intermediate stages leading to granites have been described therein. It has to be pointed out that quartz in the above assemblages is essentially a result of ingress showing a direct relation to the proximity of the granites and increasing regularly in the passage types in the results of granitisation. Orthoclase occurs only in the highly granitised varieties. In the first assemblage quartz is always associated where the pyroxenes show a chemical granulation in the process of being made over to the lower phases, while in the type assemblage of the group quartz is absent. Biotite, similarly, shows a definite genetic relation to granitisation.
Hypersthene, of varying sizes, having generally an indefinite outline, appears fresh and is devoid of schiller inclusions. Inclusions of magnetite and ilmenite are common. The mineral is strongly pleochroic in deep shades of pink and green with $X =$ pink, $Y =$ yellowish pink and $Z =$ green; $2V$ is between $52^\circ40'\text{ to } 53^\circ30'$ and $N_m^*$ is $1.731 \pm .003$. The extinction angle on the plane of section may be up to $16^\circ$. On orientation in the universal stage, the stereogram shows $Z$ to be parallel to $c$ (Fig 14). Diopside, having a similar tinge of green as the hypersthene, has $2V_y = 59^\circ$ and $N_m = 1.673 \pm .003$.

None of the rocks with the above assemblages, show primary hypersthene noticed by Ray and others in similar rocks in areas described by them (op cit), except in the olivine norite** and some norites and metanorites (e.g. in Bankura), where however the hypersthene has a widely different composition. This happens to be a distinctive difference from the description of Ray and others where the primary and the secondary hypersthenes have, presumably, the same composition (Ray 1941).

Both hypersthene and diopside, except in the type pyroxene granulites showing assemblage 1, which are comparatively few, are bordered by a light coloured rim of hornblende, which often occurs in cleavage interspaces of the pyroxenes, or show imperceptible gradation with them. The mineral takes a definite shape and the proportion gradually increases in the succeeding assemblages, and the third type (i.e. assemblage 3 shown above) with predominant hornblende could be described as a pyroxene amphibolite. In the rocks showing the assemblages 2 and 2a the hornblende has the value

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*Sodium monochromator was used in R.I. determinations.

**See page 31, secondary hypersthene is almost absent from this rock.
Fig. 13:
Stereogram of the (110) and (110) cleavages and the axes of symmetry of the indicatrix ellipsoid of hypersthene from a pyroxene granulite. It shows Z to be parallel to 'c'. (see text).
of optic axial angle (over X) varying from 86°20' to 87°, with 
Z Ac = 20°. It is pleochroic in shades of green with X = light 
greenish yellow, Y = green and Z = dark brownish green. Grains 
with a light green colour, having a light blue tinge, parallel to 
Z are found in some of the rocks. This is, however, characteristic 
in hornblende that first appears as rims round the pyroxenes. The 
mineral is always secondary after the pyroxenes, retaining small 
cores of the latter even in assemblage 3, and passing, with total 
conversion, into pure amphibolites.

This amphibolisation of the pyroxene granulites and norites 
is succeeded by a direct effect due to the granitisation, in 
producing biotite at the expense of all the above minerals 
(pyroxenes and hornblende), in all the above assemblages. Sometimes 
there is an ingress of quartz and K-feldspar (which may be 
accompanied by precipitation of the plagioclase) without much 
conversion of the pyroxene into biotite, resulting in the 
formation of intermediate granodioritic and granogabbroic rocks, 
(Chapter VI). In contact with the ingressing quartz, chemical 
granulation may result in the plagioclase, the texture simulating 
that due to cataclasis, producing in some cases, symplektic 
structures. Anipertithites are common in such rocks. Production of 
biotite is, however, a conspicuous feature, prominent especially 
in regions of direct contact. The mineral, first appearing as 
shreds, or in cleavage interspaces, gradually increase in size and 
proportion in contiguity with the granites. And in close contact, 
as already mentioned, a pure biotite schist results, which is often 
seen in the field to grade from rocks having any one of the above 
assemblages. Such conversion is more common in contact with 
pegmatites.

The plagioclase feldspars were determined by orienting 
the optic symmetry planes of the twin lamellae and the composition 
plane of the twins, in the universal stage, and comparing the 
stereogram obtained therefrom with Fedorov-Nikitin stereograms.
Emmons 1929, 1934). The value of the optic axial angle was also determined. The mineral shows a gradual change in composition in the different types of assemblages and also in the intermediate rocks (ultra metamorphites) leading to the composition of the granite. Slight acidification is seen to accompany the formation of diopsides and hypersthenes, and the amphibolisation of the pyroxenes. Plagioclase in the biotite rich varieties is comparatively more acid, and a considerable degree of acidification accompanies the transformation into granites.

The following table gives the composition of plagioclases of the rocks of different groups, the number in parenthesis indicating the assemblage given in a previous page (page 33).

<table>
<thead>
<tr>
<th>5 (1)</th>
<th>2V = 87°30'</th>
<th>An66</th>
</tr>
</thead>
<tbody>
<tr>
<td>98 (1a)</td>
<td>2V = 85°20'</td>
<td>An64</td>
</tr>
<tr>
<td>Granitised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>241 (2)</td>
<td>2V = 78°10'</td>
<td>An59</td>
</tr>
<tr>
<td>with biotite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 (2a)</td>
<td>2V = 76°20'</td>
<td>An57</td>
</tr>
<tr>
<td>Granitised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>241 (2)</td>
<td>2V = 80°10'</td>
<td>An62</td>
</tr>
<tr>
<td>225A (3)</td>
<td>2V = 78°</td>
<td>An49</td>
</tr>
</tbody>
</table>

Apatite, characteristic of the granitised products, especially in the ultra metamorphites, occur in shapeless blebs which are occasionally of considerable size. Fine automorphic needles of the mineral, rarely found, are perhaps primary, occurring as they do, as inclusions in the feldspars of the olivine norite. Sphene, also not rare, is found in shapeless grains closely associated with ilmenite. The ore minerals are ilmenite, magnetite and pyrite.
Amphibolites:

It has been stated earlier that rocks showing a typical equilibrium assemblage of the amphibolite facies (hornblende-plagioclase-quartz rocks) are very few. Amphibolites showing an undisputed relation with "dyke rocks" are fewer. Those intimately connected with the calc-silicates and evidently related to them, have been described in Chapter III. A few others showing no definite relation in the field with any one of the two groups have, on the grounds of some mineralogical and textural similarity, been described with the former.

The pyroxene granulites are seen in the field to grade into the amphibolites, specially close to the granites, having undergone different degrees of granitisation. The amphibolites unaffected thus show typical linear parallelism appearing granoblastic in one plane, and also typical amphibolite assemblage of hornblende, feldspar and quartz.

The hornblendes consisting of stout crystals are arranged in parallel to subparallel streaks alternating with granoblastic polygonal aggregates of quartz and feldspar, some few small needle shaped crystals occurring interspersed throughout. The mineral is pleochroic with X = yellow, Y = dark green Z = bluish green and Z ± c = 23°. The plagioclase is andesinic (all indices greater than No, and Ng and Na > Nα of quartz).

The effects due to contact with the granites, as in the former rocks, is the production of biotite at the expense of hornblende and finally with introduction of quartz and K-feldspar (Slides 98, 117 etc) a complete transformation into a granite.

Sometimes in contact with the porphyritic granite the introduction of K (shown by the K-feldspars), Na (proved
by considerable acidification of the plagioclase and Si has
directly converted an amphibolite to a granitic composition
without much conversion of the hornblende into biotite. The
plagioclase becomes acid (An90 ca). Sometimes a core of bi-
basis andesine plagioclase is rimmed by a more acid
plagioclase, oligoclase. The hornblendes may show a chemical
granulation giving a diablastic growth with feldspar trapped
as tear drop inclusions.

The Nature of Mineralogical Changes.

The progressive mineralogical changes in an exposure
near Baishkuli ( MI31028; 73 21 10') - Hariharpur (MI10019; 73 21 17'),
studied in some detail is described below, as a prelude to
summarizing the general nature of such change in the basic
suit, especially in relation to the effects of granitisation.

The exact relation of this exposure with either the
porphyritic granite or the granite gneiss is obscured by
excessive weathering. It runs parallel to the structural in-
trends of the country rocks, and has a considerable
lengthwise extent. It may be in the nature of a dyke or a
sill. The porphyritic granite 'incorporates' it without
visibly disturbing its disposition, implying, evidently,
little displacement, occurring as a roof pendant.

The central portion of the rock is almost
unreconstituted, varying in composition from a norite to an
olivine norite, with slight impress of granitisation. The
outer portion grade successively into pyroxene granulite and
amphibolised pyroxene granulite showing also evidences of
granitisation. These variations could be described under
three groups (besides the norite and olivine norite, pp 31-32):
1. Pyroxene granulites, 2. Pyroxene granulites amphibolised through different degrees into a pyroxene amphibolite and 3. Ultrametamorphites. It has to be mentioned that all the rocks of the above groups show biotitisation and more or less of the other effects of granitisation.

The pyroxene granulites (206, 212) are similar to those described above. Biotite appears invariably, in proportions large or small. In the more granitised varieties the minerals have a fresh appearance, the biotite occurs in stout crystals, and the plagioclase is comparatively more acid (An₆₉ to An₆₅).

Slides 200, 202-205 and 207 of the amphibolised rocks, occurring in an outer zone, have even in the less granitised varieties, plagioclase comparatively more acid (An₅₉ to An₅₅ approximately) than in the normal pyroxene granulites. Slides 200, 203 etc show biotite forming at the cleavage interspaces of the pyriboles, or occurring in shredded grains, while a few other show a large proportion of biotite (205, 202).

Specimen 207 closer to the surrounding granite shows ribbon shaped quartz, a granulation of the pyroxene and the hornblende often incorporated as tear drop inclusions.

Specimen 201 comes from the outermost zone, nearly in contact with the porphyritic granite. Hornblende forms about 60% of the pyriboles and the pyroxenes, both hypersthenes and diopsides, show alteration to hornblende along the cleavages. There are a few grains of biotite associated with both the hornblende and the pyroxenes. A feature of importance is the presence of a considerable proportion of symplectic intergrowth of quartz and plagioclase (acid andesine An₃₂), a large proportion of quartz and albite. Specimen 201 a, just from the contact, shows a complete reconstitution with considerable proportion of orthoclase.
The presence of chlorite in some of the amphibolites requires mention. Such rocks lie very close to the porphyritic granite (SnB 178, 117 etc). Hornblende in these rocks are seen, under the microscope, to be changing over to chlorite and the feldspars are altered into an almost indeterminate aggregate of fine specs giving high polarisation colour. These latter are sometimes recognisable grains of epidote, calcite and sericite. A little biotite may be present, which also shows conversion to chlorite. The conversion is to be ascribed mainly to hydrothermal action connected with the granitisation.

The assemblage Chlorite - epidote - (hornblende - plag.) - sphene - quartz, thus derived, shows a transition possibly to the actinolite - epidote - hornblende subfacies of the epidote - amphibolite facies (Nikola 1935, 1939, Turner 1948; equivalent to the almandine zone of regional metamorphism). As in the other cases, the assemblage does not reach the equilibrium paragenesis. Chlorite is always subordinate. Such assemblages are also rare in occurrence.

![Fig. 14](image-url)
Summary of the Mineralogical Changes.

In the exposure described above norites and olivine norites are surrounded by pyroxene granulites showing the typical high grade metamorphic assemblage of hypersthene-dioptase-plagioclase. Successively in the outer zones the pyroxene granulites show amphibolisation through different degrees. All these rock types have undergone different degrees of granitisation marked by the appearance and gradual increase in proportion of biotite, an acidification of the plagioclase, ingress of quartz, albite and K-feldspar and production of symplektic structures.

Taking cognisance of the descriptions presented above, the successive stages of mineralogical changes in the suite of basic rocks in Manbhum may be summarised under the following heads:

1. Formation of secondary pyroxenes from hypersthene (and olivine).
2. Formation of hornblends from the pyroxenes and plagioclase, and acidification of the feldspars.
3. Formation of biotite at the expense of the pyriboles, further acidification of the plagioclase (by introduction of Na) and entrance of quartz and K-feldspar.