Chapter III.

CALC-SILICATES AND RELATED ROCKS.

The metamorphic equivalents of impure calcareous and magnesian limestones, though not of extensive occurrence, within the area mapped, are found intermittently associated with the argillites towards the top and then dominating gradually at higher horizons.

Since the author was chiefly concerned with the study of the structure and structural petrology of the granite and its walls, it has not been his endeavour, neither is it possible, to show all the bands of calc-silicates and related rocks in the map. The group is mappable only at the upper horizon of the metamorphites where it predominates - the region showing the exposure, however, falling beyond the area represented in the map (see below).

In the region under consideration, these rocks occur as impersistent, lenticular bands sometimes continuing strikwise for a considerable length, in intermittent streaks. A few are, however, of considerable strikwise extent. North to northeast of the area, near Pahargora (N 364162; 73 $\frac{1}{10}$), beyond the mapped area, a thick band of calco-silicate rock is seen to be interbanded with amphibolite bands or lenses which alternate intimately with it in thin bands, often one passing imperceptibly to the other. This alternation and gradual and irregular passage of one type into the other in all directions is seen even in a small compass in a hand-specimen. The calco-silicate schists and granulites associate with thick bands of amphibolites are the dominant rock types in this part of the area. Megascopically these amphibolites and amphibolitic rocks differ from those derived from gabbroid and noritic rocks, that occur elsewhere in the area (Sen et al 1949).
Within the mapped area, "amphibolites" are noticed which are very similar to those described above, though not so intimately associated with calc-granulites or schists. Sometimes total absence of any field evidence as to their relation with the calc-schists makes it difficult to identify them as para-amphibolites. Mineralogically at times, and megascopically they bear identity with the para-amphibolites of the north. It seems probable also that some thick bands of amphibolitic rocks that occur associated with pyroxene-amphibolites, especially towards the northern edge of the southern exposure of the metamorphites, showing schistosity perfectly conformable with the schistose alignments of the associated country rocks, are presumably metamorphic equivalents of highly impure calcareous rocks. The group is thus likely to represent the uppermost horizon of the metamorphites. South of the Ramchandrapur hill (QM 440120; 73 1/14) a quartz feldspar rich amphibolite occurs along the southernmost hills and along rises extending from south of Dubrajpur (QM 420091; 73 1/14) to Malibana (QM 445088; 73 1/14) etc (see chapter II). It is intermittently associated with very thin and rare streaks of calc-granulites. To its south (beyond the map in Plate V) amphibolites similar to those described earlier make their appearance. These rocks have extensive areal outcrop extending further east in the district of Bankura, where they have been found to be associated with thick but intermittent bands of calc-granulites and schists.

* The area is being mapped and studied by B. Roy Chowdhury for his M.Sc thesis, under the guidance of the author.
Like the argillaceous and other metamorphites, these rocks also occur as streaks or lenses in the granite gneiss. One of the bands studied in some detail for its petrography, occurs within the granite gneiss country, lying south of Lipanya (86°29'E; 23°27'N, 73 I/7). It is seen to continue strike-wise, intermittently, for a short distance. Small lenticular bands of schistose amphibolites are also noticed in the granite gneiss. Several such lenses are found in the Beko Nadi cutting 333 of Beko (M 280005, 73 I/11; see Fig. 9 & Plate I fig 2). The granite gneiss (sp 42111) in contact with the amphibolite, is very rich in biotite which has a shredded appearance.

Petrography:

In colour the calc-silicate granulites vary from pale greenish white or pale green to greenish grey or darker shades of greenish black. They are commonly gneissose, but are, at times, compact fine grained, and granoblastic. Coarse granoblastic texture is also noticed, as in the calcite - diopside rocks, but even in these, green streaks or tremolite (if present) may impart a faint gneissosity. Tremolite, when present, is more often arranged in a decussate manner.

There is a wide mineralogical variation, both qualitative and quantitative, though the high temperature minerals above Bowen's fourth step of reaction (Bowen 1940) are absent in this part of Maibhum. The relative proportions of the constituent minerals vary widely in different parts of the same exposure or even in a smaller compass in a hand specimen.

The mineral assemblages of a number of systematic samples and a few other specimens from different localities are given below:
Specimens from Lapunya:

Nos.

154 - Hedenbergite - calcite - grossularite - quartz
(- zoisite - hornblende - chondrodite).

154A - Hedenbergite - plagioclase - quartz - grossularite
(- sphene - ilmenite - epidote - hornblende).

151 - Diopside - plagioclase - quartz (- scapolite - orthoclase - sphene).

155 - Diopside - plagioclase - scapolite - (sphene).

145 - Diopside - plagioclase - quartz (- allanite - scapolite).

146 - Hedenbergite (Heg) - grossularite - plagioclase
(- allanite - sphene).

158 - Hedenbergite - grossularite - plagioclase
(- zoisite - sphene).

Other occurrences.

161 - Diopside - scapolite - quartz - calcite - (sphene).

180 - Diopside - grossularite - plagioclase - quartz.

277 - Diopside - scapolite - calcite - quartz.

278 - Diopside - plagioclase - scapolite - (sphene).

591 - Quartz - diopside - scapolite - plagioclase - axinite -
(orthoclase - sphene - chloritoid) intimately
penetrated by runites.

183 - Diopside - tremolite (actinolitic) - plagioclase -
clinohumite - quartz (- sphene).

The rocks from Pahargora, lying at a distance of about
6 miles to the north of the present area, show phlogopite as
an important constituent (Sen et al 1949).

Hornblende, which sometimes occurs as an accessory in the
above assemblages, increases gradually to gain prominence when the
rock becomes an amphibolite. The amphibolites show the following
assemblages, the relative proportion of the individual phases
varying widely as in the former types.

(i) Hornblende - plagioclase - quartz; grading through
etc ) (ii) Hornblende - diopside - plagioclase - quartz, into
(iii) Diopside - tremolite - plagioclase - granulites
(both may have a little calcite as accessory).

153 - Hornblende - plagioclase - quartz (- sphene - apatite -
calcite).
Diopside is a constant member in all the groups of assemblages, except in the purer amphibolites. It has a composition varying from hedenbergite to diopside, in most cases nearer hedenbergite, lying within the range of Di$_{14}$H$_{24}$ to Di$_{76}$H$_{24}$. Such a variation is noticed even in different parts of the same exposure as in that of Ipanya. The colour changes with composition from a comparatively dark shade of green to almost colourless, the darker coloured varieties showing a faint pleochroism (better seen in strong light with the converging lens pushed in). They show a gradual variation in the values of their optic axial angles, $N_m$ and the angle between $Z$ and $c$ (see table below). The mineral occurs as equigranular, xenoblastic grains, often in intimate association with similar xenoblastic grains of garnet.

<table>
<thead>
<tr>
<th>No</th>
<th>$N_m$</th>
<th>$Z\wedge c$</th>
<th>$2V_\gamma$</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>154</td>
<td>1.723</td>
<td>46.5°</td>
<td>60° 45'</td>
<td>Di$_{14}$</td>
</tr>
<tr>
<td>158</td>
<td>1.722</td>
<td>44.5°</td>
<td>61° 15'</td>
<td>Di$_{30}$</td>
</tr>
<tr>
<td>146</td>
<td>1.712</td>
<td>44.5°</td>
<td>61° 15'</td>
<td>Di$_{41}$</td>
</tr>
<tr>
<td>155</td>
<td>1.710</td>
<td>44°</td>
<td>60° 30'</td>
<td>Di$_{45}$</td>
</tr>
<tr>
<td>151</td>
<td>1.701</td>
<td>45°</td>
<td>60° 15'</td>
<td>Di$_{61}$</td>
</tr>
<tr>
<td>183</td>
<td>1.711</td>
<td>43.5°</td>
<td>61°</td>
<td>Di$_{47}$</td>
</tr>
<tr>
<td>5911</td>
<td>1.581</td>
<td>39.5°</td>
<td>59° 45'</td>
<td>Di$_{76}$</td>
</tr>
</tbody>
</table>

The garnet is generally light pink in colour, rarely almost colourless, with specific gravity approximately 3.5. In some of the specimens (e.g. 146 and 155 from Ipanya) the garnet is seen to have a brownish pink colour - distinct from the colour of garnet occurring in other parts of the exposure not far from the above specimens. There is a possibility of some of the garnets being comparatively rich in the pyrope

* less than the specific gravity of a saturated solution of Cadmium borotungstate.
molecule*. The proportion of the garnet varies widely and the mineral shows a definite correlatable relation to the granites developing in a zone in direct contact with it. Thus in the calc-silicate band south of Lipanya an enclosed elliptical area could roughly be defined, separating an outer garnetiferous zone from an inner non-garnetiferous.

Plagioclase is generally of Labradorite - bytownite composition (An$_{58}$ to An$_{88}$). In specimens close to the granite-gneiss it is generally not associated with calcite such that in a single exposure some portions might have one exclusive of the other, generally towards the border, while towards the central portion the two might be associated together. Sometimes the plagioclase may show cores of calcite, an example of disequilibrium assemblage. In the rocks of Pahargora plagioclase (An$_{76}$, all refractive indices greater than No of quartz, 2V$_{oc}$ = 58°) is sometimes seen to surround a core of calcite having a frayed margin. In a few instances a more acid plagioclase (approx. An$_{68}$) is surrounded by a rim of albite. The albite shows no definite outline (Sen et al op cit).

Microcline, more common in the granitised specimens, or in those occurring close to granites or pegmatites, forms the mesostasis, evidently introduced from the granite. Some of the xenoblastic grains may possibly represent either recrystallised products of original K-feldspar or products of neocrystallisation from clay minerals originally present in the sediment. The definite relation of this mineral to the granites and the pegmatites, however, lends a greater support to the suggestion that they have been introduced from outside.

The composition of the scapolites varies but slightly**, lying between Mg$_{60}$ to Mg$_{75}$ (N$_0$ between 1.591 ± .003 to 1.595 ± .005)

* A systematic chemical analysis of individual minerals is in progress.

** Determined from the values of refractive indices.
The mineral occurs in equigranular, xenoblastic grains. Other minerals, beside scapolite, that prove the effects of the granite through hyperfusibles, are the typical contact minerals chondrodite (golden yellow to pale yellow, 2V large), clinohumite (colourless, $X \setminus 001 = 11^\circ$, $2V_{\gamma} = 79^\circ$) and axinite (colourless, $Z \setminus 110 = 40^\circ$, $2V_{\alpha} = 74^\circ30'$). These are, however, rare in occurrence.

Of the minerals of the epidote group, often associated with the common minerals in some of the above assemblages, clinozoisite ($Z \setminus 001 = 16^\circ$, $2V_{\gamma} = 74^\circ$, ultra blue interference colour) is more common. Any one of the minerals clinozoisite, allanite (pale yellow, very low birefringence, causing characteristic radiating fractures in the surrounding minerals) or epidote may be found as an accessory. In a few slides clinozoisite occurs in considerable proportion, and some of these are seen forming at the expense of the plagioclase feldspar.

Tremolite is rare and is found only occasionally, as in specimen 183, occurring near the southern band of the porphyritic granite. The mineral is common in the purer calco-silicate bands in the extensive impure calco-magnesian metamorphites of North Manbhum. Tremolite and hornblende do not occur together, and in specimens showing passage between amphibolites and the granulites, the two are more or less complementary. The tremolite in such rocks takes a green tinge showing a faint pleochroism and is actinolitic in composition.

Important accessories are sphene, ilmenite and pyrite. Graphite occurs in some specimens in disseminated flakes. Chloritoid has been found in one specimen (5911).

The amphibolites of Pahargora show a gradual change in the characters of the hornblendes, which have darker shades of pleochroism in the pure amphibolites than in the passage types, close to the granulites. The pleochroism is as follows:
In amphibolites with accessory diopside, just in the purer amphibolites from contact with the granulites.

X = light greenish yellow - changes more to green.
Y = light brownish green - the colour deepens.
Z = green - changes to dark green.

The value of 2V varies from 83° to 86° even in the same specimen (11112), and ZAc is 24°. A little diopside may be present as accessory. The plagioclase is labradorite. Part of the quartz, elongated ribbon shaped in appearance, sometimes partially enclosing the assemblage, has been introduced later, as in the calc-granulites. Also present are all or some of the following minerals: sphene and a few specs of ilmenite and phlogopite. In specimen 153, associated with the calc-granulites of Lipanya, the hornblendes show a slightly different scheme of pleochroism with X = light yellowish green, Y = olive green and Z = dark green. The feldspar is andesine (An33; 2V = 81°30').

One specimen, Sn12, occurring within the band of the porphyritic granite, between Sanar (M 141045, 73 10') and Damanbad (M 133068; 73 10'), about SW of Dheria (Ml 46063; 73 10'), is a typical feather amphibolite, all the hornblendes grains having a large proportion of poikiloblastically included feldspar that gives it a characteristic appearance (Plate XVII, Fig 3).

When close to the granite, or intimately 'penetrated' by pegmatites and runites in the process of granitisation, as in the peaks south of the Ramchandrapur peak, the amphibolites (9110, 11211a etc) show scapolite and axinite (cf 5911 from the same locality, page 19) besides the normal constituents, and at times also microcline as an accessory. Sometimes streaks
of amphibolites with coarse recrystallised hornblendes, or of coarse grained diopside-granulites may remain in an almost wholly granitised rock imparting a characteristic patchy appearance.

There is thus a wide variation in character and composition (especially that of the plagioclase) of these amphibolites. Though, as already mentioned, they show, in general, a distinctive difference, with regard to their texture and structure, from the rocks associated with the norites, a few showing undoubted relation with the calc-silicates are almost exactly similar to the latter. Thus a few of these showing no definite field evidence as to their genetic connection with one group or the other, may be related to the calc-silicates, the suggestion getting a support from the field mapping done towards the east of the present area.

The difference in the mineral assemblage between the amphibolites and the calc-granulites, which could not obviously be ascribed to different grades of metamorphism, are also not ascribable to a difference in the proportion of added foreign material in view of the very intimate association of the two types, occurring in intercalations of bands or lenses of varying thicknesses. Besides both the groups show definite evidences of granitisation, in the entrance of albite K-feldspar and quartz (See description above and Chapter X). Not quite rarely, in Pahargora and Lipanya, for example, paper thin bands of amphibolite may be seen alternating with the calc-granulites, or they may be seen to merge gradually into the granulites. There could only be two possible explanations (Sen et al 1949, Sen and Raychaudhuri 1951 in press). The difference may either reflect an original difference in composition in different parts of the

* See foot note, page 27
A study of systematic samples from the calc-silical band south of Lipanya, shows interesting changes in assemblage and a systematic variation in composition of some of the minerals. Mention has already been made of the possibility of demarcating two zones, by a roughly elliptic enclosure, the outer being garnetiferous while the inner contains no garnet. There is again a gradual change in the composition of the diopsides, changing from pure diopsides \((D_{i2})\) in one end to hedenbergite \((D_{i4})\) in the other \((154)\). The latter with hornblende as accessory gives place, in its strikewise extension, to an amphibolite \((153)\). The exact field relation is, however, obscured.

**Summary of mineralogical changes and the type assemblages.**

The more important feature in the mineralogical changes is thus the appearance of grossularite and of tremolite in close proximity to granites or in granitised bodies. Formation of sphene is also associated with these effects of the granites. Forming at the expense of the ilmenite, the change is at times unaccompanied by other mineralogical changes; as in assemblages containing chiefly diopside-calcite-quartz etc. Effects of exudations have resulted in the formation of minerals of the haxmite group, axinite, scapolite etc. Specimens unaffected by granitisation show an association of calcite and plagioclase, while where they are very close to granites (when grossularite makes its appearance) the two are rarely associated together.

In summary of the above descriptions, the calc-silicate granulites and the associated amphibolites could be

* Suggesting magnesian limestone bands in the calc-magnesian shales, the limestone bands containing alternate lodes or bands of these shales.
grouped into the following generalised type assemblages. To these are to be added the assemblages of the hypersthene-diopside granulite group (Page 33, Chapter IV pp 27-41).

Calc-silicates,

I  Diopside - scapolite (-plagioclase) - calcite - quartz.
II  Diopside - scapolite - quartz.
III  Diopside - calcite - grossularite (with accessories).
IV  Diopside - zoisite - grossularite.

Sometimes III and IV or III and V are intermingled, pointing to a disequilibrium.
V  Diopside - plagioclase - grossularite.
VI  Diopside - tremolite - plagioclase.

Amphibolites,

VII  Hornblende - plagioclase - quartz (associated with VI)
VIII  Hornblende - plagioclase - quartz (-sphene).