SECTION II

STRUCTURAL FEATURES OF THE PORPHYRITIC GRANITE AND THE COUNTRY ROCKS.
Chapter VII

STRUCTURAL FEATURES OF THE GRANITE.

The porphyritic granite shows well-developed planar banding of layers of porphyritic feldspars alternating with layers of a fine grained assemblage. The planar nature of the banding is evident in sections exposed along joint cracks, and river and gully cuttings that show the structures in all the Cartesian planes to advantage. Besides the humps and tors, which give good pictures of the structural elements in three dimensions, some excellent sections are available both near the contact with the wall rocks and inside the granite, which were utilized for structure study.

A detailed statistical study of the structural elements in the granite and the wall rocks was carried out in selected patches, especially near the boundary, and the granite was closely traversed for an appreciation of the general structural makeup.

A consideration of fundamental importance is the recognition in the field of most of the structural elements in the granite as primary. Evidences were cited earlier that gave definite indication that the banding in the granite, together with the joints, had been impressed prior to the complete consolidation of the rock (Sen 1944, 1945, 1948a).

The banding of the porphyritic granite shows a constant relationship with the trend of the boundary wall, and in close contiguity, it runs assiduously parallel to it. Even near considerable changes in the strike of the contact, towards the eastern margin of the granite for example, the banding never cuts across into the country rocks, and there
is no continuity of the structural trends of the granite and the wall rocks. Along a greater length of the exposure of the granite, however, its structures are conformable with those of the gneissose country rocks.

There are instances of local, small scale discordances between the granite and the wall rocks, and near sharp changes in strike of the contact the foliation of the country rocks abut against it. Thus near a hilly exposure, about a mile ENE of Adra (Sen 1948a), or near the contact with the granite gneiss NNW to NW of Raidih (approximately 23° 33' 30"N; 86° 45' 40"W) near sharp bends of the contact, the banding in the granite runs parallel to the contact which cuts across the structural trends of the granite gneiss (Fig 28).

Frequent changes in strike are more common in the granite than in the country rocks, and neither is seen to bear any relation to the other. Indeed in restricted patches along the boundary, the banding in the granite is seen to be related not to the structural alignments of the country rocks but only to the trend of the contact, though, as it has been amply emphasized, the structures of the two are essentially conformable.

There are innumerable instances of xenoliths of country rocks, especially of the norite - amphibolite group, which have been incorporated by the granite. Comparatively smaller ones among them have been drawn out into discoid shapes, flattest surface parallel to the banding, and a few torn off into fragments (Fig 29, Figs 15). The layers of banding of the porphyritic granite always wrap round the xenoliths, even when the trend of the layers change (e.g. near Kalaboni R180915, 73 I/11 etc. Fig 28). Sometimes when the feldspar layers do not show perfect wrapping, they are nevertheless twisted and bodily rotated, away from, and due to the obstruction.
Fig. 27: A small scale discordance between the porphyritic granite and the granite gneiss about a mile ENE of Adra.

Fig. 28: Folded flow layers with included basic lenses near Kalabani in the Sindurpur-Tilabani porphyritic granite.

Fig. 29 (a) Flow layers wrapping round a small basic inclusion near Mulickpara (see Fig. 17).

(b) Flow layers wrapping round an oval basic xenolith near Raghunathpur. The torn off basic inclusion has been twisted round so that its schistose trends now lie athwart the direction of the flow banding.
To the north east of a small hump (M 333062, 73 10) a band of basic rock* is caught up parallel to the banding layers while to the west of the band the feldspar phenocrysts have been obstructed and twisted round, but nowhere does the foliation cut across into the inclusion (Fig 29).

It is of importance to note that the gneissosity or the schistosity strikes of the xenoliths or inclusions have little relation with the strike of the banding in the granite especially in case of small xenoliths which have been twisted, drawn out or partially fragmented. There are instances where small round patches of xenoliths show their schistose strikes to be aligned athwart the strike of banding of the granite (Fig 29).

Sometimes the basic rocks, a few of them of comparatively large dimensions, originally conformable with the country rocks, have been incorporated in the granite parallel to the flow layers. In some instances these inclusions show perfect sets of joints identical with the joints in the granite.

On a nullah section west of the village Chautala (80° 33' 20" N; 23° 31' 30" E, 73 10) the porphyritic granite shows three sets of joints (See structure map, Grid M133052) of which two, one trending 350°-360° and the second 80°, are seen to be quite well developed in a thin band of included amphibolite. The first set is seen to continue bodily from the granite into the inclusion.

Pegmatites and pegmatoid rocks of varying dimensions are found within the granite, running parallel to the banding or cutting across it, following joint planes and

* The exposure occurs not far off from the dyke rock of considerable dimension, passing through Madhuatati, Bero etc, and incorporated by the porphyritic granite (Plate V). There are innumerable such inclusions of varying shapes and sizes in the granite in this area.
often cutting across them. Some of these pegmatitic veins, composed essentially of excessively coarse grained feldspar and quartz or of feldspar alone, with occasional tourmaline or mica, are seen in the field to merge gradually into the feldspar bands of the granite. This structural relation with the pegmatites gives a definite proof of a pre-pegmatite age for the banding and the joints. This is especially pertinent in cases where the pegmatites are seen to merge into the body of the granite, as this proves conclusively that the structures were impressed before the granite became completely solid, the pegmatites having emanated out of the granite itself.

The pegmatites generally do not show any banding, their minerals being arranged in an extremely haphazard fashion (Fig. 35). When, however, in rare cases, they do show some banding, it is always parallel to the wall of the pegmatites whatever be the relation of their trends with the banding of the porphyritic granite.

North of a pegmatite composed solely of big phenocrysts of feldspar, at a place near Railway post 181 14 & 13 on the Asansol - Adra line (M 338068, 72 7 10), the flow layers have been interrupted by it like a slipped sheaf of cards (Fig 30) sometimes the feldspars merge into the body of the pegmatite. The trend changes in this zone, from about 97° to 41° towards the north, while to the south of the pegmatite the banding is more or less parallel to it with a trend of 41°. The feldspar phenocrysts in the pegmatite are arranged haphazard.

While close to the wall, either of the chamber or of big inclusions, the foliation, assiduously parallel to it, is quite perfect, it is important to note that there are instances, though extremely rare, of patches, usually small in
dimensions, away from the walls, where the foliation has not been developed at all and the feldspar phenocrysts are arranged in a perfect jeopardy.

In some instances of partially or completely granitised amphibolites, bordering big roof pendants, or in exposures away from the granite, the feldspar phenocrysts are arranged in a disorderly fashion without any approach to parallelism. These instances, being results of granitisation more or less in situ add support to the view that a similar process could not have been responsible for the banding in the main granite mass.

The presence of local discordances and of folds within the flow layers, that bear no relation to the regional structural trends, all described above, cannot be explained by granitisation in situ. Moreover silent granitisation cannot supply a sufficient incentive to a forceful expansion of the chamber that is proved by the structures of the wall rocks described in the following chapter (Chapter VIII pp 89 - 98). The above features also rule out any possibility of the structures in the granite to have been produced by the diastrophism responsible for the deformation of the country rocks. The structures are evidently of a later age. The relation of these structural elements to the pegmatites and veins emanating from the granite also prove that they were formed before the complete solidification of the rock.

As pointed out on an earlier occasion (Sen 1948a), the recognition of the structures in the granite as primary, that is as having originated prior to the consolidation of the rock, leaves but two alternative explanations for its origin .... "First, the magmatic liquid .... might have penetrated the country rock in an intimate lit-par-lit fashion in situ. In this case the banding is wholly a function of the original structural trends, modified, if at all, by the
injection of the liquid in situ. Secondly, the one that is favoured, the magmatic liquid might have impregnated intimately the roots of the country rocks and converted them effectively mobile by the process. This mushy matter might then have been emplaced higher up in its present position with considerable force. The granitising liquid might however have been non-magmatic too (Chapter XB). This favour, for which reasons have been adduced earlier as well as in the following pages, suggests an origin of the banding due to flow movement of the mush, so that it will be referred to, hereafter, as "Flow Layers" (Balk 1937).

Warping of the layers of banding round xenoliths, and twisting and rotation of feldspar phenocrysts when the banding is slightly interrupted by them (see page preceding) are cited again as evidences of its flow origin. Near Amlatora (M 179008; 73 J) the feldspar bands are seen to swerve round and completely encircle a round clot (Fig 31). This feature, together with the parallelism of the foliation to the xenoliths is difficult to explain except by viscous flow.

Though the granite shows a conspicuously well-formed banding almost all throughout the mass, the foliation is best developed near the walls and near obstructions like xenoliths and the roof. And not quite infrequently, the phenocrysts at these places show some amount of crushing (e.g. near Malikpara Senera, Talsanka etc). It is quite conceivable that in a moving mush of solid and liquid, the solids (intratelluric crystals, early segregations and xenoliths) would be obstructed most in their motion near the walls or near larger masses of xenoliths and segregations which would twist round the solids into a position of least hydrodynamic resistance, parallel to the wall. The obstruction will, obviously, be
Fig. 30: Feldspar bands (flow layers) in the porphyritic granite obstructed by a pegmatite in which the feldspars of the flow layers are seen to merge. The strike of the flow layers change from 95° to 45° within a short range north of the pegmatite. The pegmatite trends 40° and the flow layers south of it have a similar trend (40°). Locality: south of mile post 182/10 close to and SW of Bero R.S. on the Asansol-Purulia (via Adra) line, 73 1/10.

Fig. 31: Feldspar bands swerving round an elliptical basic olo (amphibolite). A few of the alternating bands are of phenocryst of hornblende and biotite (thin lines in fig). Locality: about 3 of Mile-post 183/2 on the Adra-Purulia line NWW of Amlatoria (see text).
greatest near such walls. And near walls, where the solid phase would normally be greater in proportion, in comparison with the rest of the mass, protoclastation would occur with movement of the mass, towards the last stage of complete solidification.

The above evidences prove conclusively that the banding in the granite is not a result of metasomatic replacement of the country rocks that have retained the original structural trends; furthermore all these evidences taken together point to an origin of the structures by flow movement of a crystal-liquid system. When the movement of emplacement is carried beyond the stage of complete consolidation, that is beyond the stage of viscous flow, the elongation is effected by a loss of cohesion and joints and fractures result.

Primary structures thus belong to two stages, and the structures of the porphyritic granite will be described under these two heads.

I. Structures of the late fluid stage (Flow layers and Flow lines).

II. Structures of the late solid stage (Joints and Fractures).

Structures of the late fluid stage (Flow layers and Flow lines)

Broadly speaking the strike and dip of the flow layers show a regional conformity with the gneissosity and schistosity strikes of the surrounding rocks. The flow layers are rigidly parallel to the bounding wall of the granite, changing with the change in strike of the wall. Minute or large scale folding has been noticed within the flow layers (see description pp 82 - 84).
Within the flow layers the feldspar phenocrysts sometimes show a linear arrangement with their longest axes parallel. The lineation is either parallel to the strike of the layers or dip at various angles within it. Occasionally, in small patches throughout the exposure of the granite, the phenocrysts are seen to be arranged in an extremely hap hazard fashion within the flow layers, which may, however, have been perfectly well developed (Fig 1 of Plate III). In some cases locally along restricted zones, flow layers are not well formed, while a perfectly well developed lineation is noticed (e.g., in Bero, Raidih etc).

The regional trend of the flow layers can be seen from the structure map (Plate VII) which has been compiled from a large number of local large scale maps. As mentioned before, the porphyritic granite occurs as an elongate lenticular band that narrows abruptly towards the east and ends east of Bero. For the greater portion of this mass, the flow layers, in proximity to the walls, being parallel to them, have a generalised strike lying within the range of 80° to 100°, varying approximately 10° both ways and changing with a change in trend of the boundary wall. The dip varies; though near the southern wall it has an average value of 42°N and near the southern wall 36°N. Along the greater length east of Talsankra (86° 42'3', 23° 33' 30"N approx) the flow layers along the northern boundary dip steeply south or are more or less vertical, while southwards the dip gradually changes towards north (see structure map). Towards the centre of the mass, the flow layers, often quite well developed, are more or less parallel to the trends of the southern and the northern walls. There are local variations however, and the layers show considerable change in strike, in particular near some obstructions like xenoliths, inclusions or roof pendants, folding round to avoid these. Folding has also
developed in response to synchronous movement of the 'magma', in two directions, towards the last phase of the emplacement (see later).

Some amount of acute changes in strike is noticed, between Banbahira (Grid QM 365090, 73 I/10) and Iagardanga (Grid QM 365100, 73 I/10), for example, where the strike of the flow layers change from north to east. Such changes, in a small scale, are not rare and are found at quite close intervals east of Talsankra (Grid QM 315083, 73 I/10) and in several spots westwards, besides the two zones round Bero and Raghunathpur, as will be seen from structure map (Plate VII).

Inspite of these changes the flow layers are, on the whole, parallel to the two boundaries north and south, running approximately in an east-west trend.

The essential parallelism of the flow layers from the northern to the southern bounding walls both dipping north suggests the general form of the maas to be nearly that of a moderately steep dipping sheet or a lens. Further discussion of the shape has been deferred to a later section, it has been mentioned here only to bring out the divergence from this general picture that is noticed along two zones, one around the small tors near Raghunathpur and the second along the tapering eastern portion of the granite.

Lineation.

The presence of lineation in the granite, made evident by a parallel arrangement of the longest axes of the feldspar phenocrysts, has already been referred to. The lineation, though not as conspicuous as the layers, is nonetheless of considerable importance and occurs frequently enough. When developed, it is always within the planes of the flow layers.
Towards the central portion of the granite, the trend of the lineation varies within a few degrees from the strike of the layers (257° to 299° with the strike of the layers varying from 70° to 110°; also 65° to 100° with similar change in the strike of the layers) pitching at low angles in both the directions, but more often it is horizontal trending parallel to the strike of the layers (Structure map, Plate VII). In the west, close to Harai Nadi the lineation pitches at moderate angles westward (trend 250° to 298° with changes in strike of the layers, pitch 20° to 28° see structure map Plate VII). Locally along a region round Bero a steep lineation has been developed which trends along the dip of the layers. This lineation has, obviously, a different significance than the one developed along the greater length of the granite in the central region. A similar lineation is found, though rarely, in the tors west of Raghunathpur.

In correlating lineation with Sander's axes of movement picture, Cloos suggests that the lineation is in general parallel to \( a \) especially along marginal zones or in narrow cylindrical chambers, while in the central region it may be parallel to \( b \), thus developed at right angles to the direction of movement of the magma. Fabric of igneous rocks show that in most cases the lineation developed is parallel to \( b \), and it is the axis of rotation of quartz and mica girdle diagrams (Sander and Felkel 1929, Knopf and Ingerson 1938, Sen 1949, 1949a, etc).

The horizontal or low to moderate dipping lineation, in the present case has been found by fabric analysis to be parallel to \( b \) (Chapter IX, and Sen 1949, 1949a), while the lineation in Bero and Raghunathpur is parallel to \( a \). The former has thus developed at right angles to the direction of
movement and the latter parallel to it, so that the movement pattern in all the parts of the granite is essentially similar.

Form of the intrusive.

As mentioned earlier, there is a general northerly dip of the flow layers along the greater length of the north and the south wall. From near Talsankra (M 322084; 73° 10') and east of it the dip becomes steeper to vertical and then changes to south varying in amount from over 83° to 65°. The flow layers then turn round running parallel to the boundary, dipping at steep angles qua-qua-versally, where near Bero and south of it, the exposure ends in a two pronged lens. The southern wall has a comparatively steeper dip than the northern though the dip may be at places as low as 30°. The reconstructed form resembles a moderately dipping lens bifurcating at the eastern extremity (Fig 32 & Plate IX). The shape more truly resembles an inclined extremely drawn out dome of an assymetric anticline with the axes plunging at low angles. The eastern portion of the lens has been twisted up, so that the dip in the northern wall changes from outside to inside the intrusive. This portion has thus moved up with respect to the rest of the intrusive, and its form now resembles a drawn out steep walled elliptical funnel open in the west (Plates VII and IX). The lineation parallel to \( a \), so well developed, at times at the expense of the layers, also suggests a considerable differential and forceful movement of the granite along this narrow zone of the chamber.

The lineation where it is parallel to \( b \) indicates to a certain extent the form of the roof. Thus along the length of the exposure, in the central region the trend of the lineation marks roughly the trend of the central axis of the 'lens' dipping gradually at low angles to the east. In the west close to Harai Nadi the lineation pitches west plunging below the thin cover of granite gneiss that extends
in continuation from south over the porphyritic granite. The disposition of the lineation thus also suggests a form pictured above.

Round the tors west of Raghunathpur, well developed flow layers encircle them, for the greater part dipping steeply away from the tors (see description in the next section). The form is that of a narrow steep-walled cylinder or an inclined conical dome (Plate VII & IX). The lineation sparsely developed (parallel to $g$) is indicative of the direction of motion.

II. Structures of the Late Solid Stage.
(Joints and Fractures).

The primary age of the joints in the porphyritic granite has been proved. They have originated due to the continuation of the movement of emplacement just after the rock was consolidated.

The primary joints have been classified by Cloos into the following types (Cloos, H, 1922; Balk, R, 1937).

1. Cross ($Q$) Joints: Tension joints developed at right angles to the direction of movement ($bc$).
2. Longitudinal ($S$) Joints, with strike parallel to the trend of the flow lines; closed set parallel to $ab$.
3. Primary Flat lying ($L$) Joints, well-formed in sheet like intrusions, subhorizontal roofs facilitating their formation.
4. Diagonal Joints. Steep joints striking diagonally with respect to the trend of the flow lines; Tension Joints.

Cloos describes the tension joints formed at right angles to tension, as $Q$ joints (Cross-joints: Balk 1937) which are defined with reference to the flow lines, indicating direction of motion, as at right angles to this lineation. As
77.

Lineation may develop at right angles to the direction of flow, care must be taken before describing a joint set as Q joints.

Three sets of joints are found well-developed in the porphyritic granite, with a fourth not of great importance. One, consisting in reality of two different sets, is roughly parallel to the strike of the flow layers. The planes either cut the flow layers at approximate right angles or are disposed diagonally with respect to these planes. The second set strikes approximately at right angles to the strike of the flow layers, more truly at right angles to the lineation (when low dipping). The third, consisting of two intersecting groups, strike diagonally with respect to the strike of the layers or the trend of the lineation and the fourth, of restricted occurrence, is parallel to the layers. All the sets however do not necessarily occur together.

The first set has a modal strike roughly parallel to the strike of the flow layers, varying to a maximum of 10° bothways. They are however more rigidly parallel to the lineation where a lineation is evident (this excludes the lineation found in Bero, Raghunathpur etc). It includes two distinct sets, one disposed roughly at right angles to the layers, while the second is an intersecting group with one of the planes dipping at steep angles (56° to 90°) towards the same direction as the dip of the layers, and the second at low angles away from it. The last one, comparatively rare in occurrence, is more often horizontal. Generally the acute bisectrix of these conjugate planes lies in the plane of the layers and trend roughly parallel to its dip (see below). This second group is somewhat of a greater comparative abundance, among which again both the intersecting planes may not be simultaneously developed and they are also not equally well developed.
In regions where the flow layers are vertical or dip at steep angles (greater than 80°), some fairly well-developed horizontal joints are found (Plate VII) which obviously belong to the second group of the first set. This group is somewhat better developed in comparison with the intersecting group only towards the eastern extremity of granite exposure.

The planes of the first set (including both the group) are not so perfect or clear cut as those of the second set described hereafter, and they are also less abundant, though locally they may exceed all the other sets in frequency. The two groups of this set, again, are not so close spaced as the joints of the second and the third sets. The planes are most often filled in by quartz and pegmatite veins, which may sometimes follow them for a length and then cut across and even merge into the body of the granite.

The block diagram (Fig 33) shows the relation of the two groups of this set with other structural elements. The planes of the first group of this set are disposed roughly at right angles to the layers. The spatial relation with the lineation shows that these planes containing the lineation are more truly at right angles to the direction of movement of the granite, and hence parallel to $bc$. The joints are thus typical $BC^2$ tension joints formed at right angles to the movement of the granite. The two intersecting planes of the second group are intermediate in position between $AB$ and $BC$ containing $B$. These are diagonal tension fractures with the acute angle of the conjugate planes facing the direction of movement (i.e., the direction of tension).

1. The lineation being parallel to $b$ (Chapter IX), the granite moved up along a direction at right angles to the lineation. The direction is more or less parallel to the dip of the flow layers or is only slightly deviated from it lying on the layers.

2. Axes of a strain ellipsoid picturing the movement.
The second set far exceeds the other sets in concentration, and sometimes in restricted zones, specifically close to the boundary, it develops exclusive of all of them. It consists, most often, of fine open cracks, occasionally filled in by vein minerals, continuing at times within the wall rocks as clear cut tension gaps (see description of areas next section). The planes are well-formed and clearcut with variable spacings, though this set is rather close-spaced as a rule, not quite rarely some fractions of an inch apart. Their perfect development make them, often, a conspicuous feature in the granite. The planes, most commonly vertical or steeply dipping bothways, cut the trend of the lineation at right angles, and are thus approximately at right angles to the flow layers. Fig 34 gives an equal area projection of these joints. As seen from the figure, the distribution of these joints is concentrated about a zone 10° to 12° bothways from 90°-270° i.e. the strike of the joints lies within 347° to 10° with a slight variation. The variation is associated with a similar variation in trend of the lineation and the strike of the flow layers, so that the joints maintain an essentially right-angle relation with these. The set is found to be very well developed in most of the patches mapped in detail, a few of which have been described hereafter.

A striking example of joints of this set is well exposed in a small rise 684', W to WSW of Khajura (W 330069, 73 1/16) where the modal strike of the joint is found to be 6°; the planes are nearly vertical with dips lying between 86° to 90° and are rarely even up to 70° (dipping both ways). The spacing is fairly close and the planes are almost perfect (Plate IV, Fig 2).
Instances are not rare where the planes of this set seem to have been "displaced" along the joint planes of the second set e.g. near Gurguria (M 120054 73 10 and at a spot about 1½ miles NNW of Chapari (M 153038 73 10, Fig 35).

The two intersecting planes of the third set do not always occur together. One or both of them may be associated with the joints of the other sets. As a rule, however, they generally occur alone, and occur only rarely in comparison with the second set. These are close spaced clear-cut planes, often not of any considerable lengthwise extent. All types of angular relations are met with, such that the strike of the flow layers faces either the acute or the obtuse angle of the conjugate planes. The planes sometimes intersect at 90°, and quite often the trend of the flow layers does not coincide with any of the bisectrices of the angles of these intersecting planes. One of the planes thus may make an angle of 20° or thereabout with the strike of the layers and the other more than 60°. The two planes in such cases may possibly belong to two generations one slightly antedating the other. Unlike the joints of the two previous sets the planes of this set are almost always unfilled cracks.

When the first two sets or the three occur in association, while all the planes of the first set are invariably filled in by vein minerals a few of the second set may remain unfilled. The planes of the third set, as already mentioned, are more commonly unfilled. The second and the third sets are thus younger in age than both the groups of the first set and of these latter joints the third set is again comparatively younger.
Fig. 34: Distribution of the joints of set I in the porphyritic granite. Equal area projection.

Fig. 35 (A) Joint planes of set I in the porphyritic granite displaced along planes of the joints of set II.

(B) Magnified view of the enclosed area in A

The feature is seen in the intervening granite between two thin bands of amphibolite included parallel to the flow layers.

Locality: ENE of Barahir (M 150022; 73 I/11) and NW of Chapari (M 163019; 73 I/11).
Fig. 36
BAMBAHIRA (See Text)

Fig. 37
SUNURA
(3W of the village)

Fig. 38
SUNERA
(3W of the village)

Fig. 38
KHAJURA - Rise

FREQUENCY DISTRIBUTION OF JOINTS IN THE PORPHYRITIC GRANITE
Strike of 'Flow Layers' indicated by a double arrow.
**Fig. 39.** Joints in the porphyritic granite near Banbahira.

**Fig. 40.** Joints in the porphyritic granite 3/4 th mile SE of Bero R.S. Strike of the flow layers has been indicated by a double arrow.
The fourth set is extremely rare. These planes, essentially parallel to the flow layers, might have formed along the weak interplanar surfaces due to contraction during cooling.

**Description.**

Some twenty spots, both along the boundary and inside the granite country, have been mapped and studied in intensive detail. Only a few of these are described in the following paragraphs to bring out the structural relations and the details of the structural features.

1. Mapuidih: (Structure map - plate X).

A small exposure within the porphyritic granite country close to Mapuidih (M 130040; 73 1 10) and 165° from the easternmost corner of the village, shows very distinct flow layers, though at places the feldspars are arranged in haphazard without any distinguishable orientation. Most often, where especially the granite has been broken off along joints running roughly at right angles to the feldspar trends, the planar parallelism appears very distinct with a strike varying from 89° to 92° dipping 41° to 46° northwards. Thin quartz and pegmatite veins cut the trends of the flow layers at angles of 20° to 30°. Pegmatites are also seen with trends roughly parallel to those of the layers, filling in the joint planes of the same trend. Thin bands of basic rocks are seen included parallel to the layers, some of the bands showing joints that are continuations of joint planes in the granite body.

A close spaced set of joints is found, on the average some 1½" apart, roughly parallel to the trend of the flow layers, dipping 75° to 70° north, and at moderate angles south. These planes are sometimes of rather inconsiderable length, most often filled in by quartz and pegmatite veins. A second set of joints has also been
well developed. It has a modal trend of 6°. The joints are roughly a few feet to 4" apart, and the planes, dipping steeply bothways, are seen to cut across the basic inclusions and the pegmatite veins. These planes are occasionally filled in by quartz and pegmatite veins.

2. Bamanbad: (Structure map - Fig 41).

At a spot southwest of Bamanbad (M 133069, 73 1/10), close to the northern boundary of the granite, the rock is seen to be more basic in comparison with the normal type, due to the close association with basic rocks. The planar parallelism, though not as conspicuous as found elsewhere in well developed zones, is quite discernible. The strike varies from 82° to 100°, dipping at moderately steep angles (45°) northwards.

Of the joints seen, one with a trend varying from 310° to 325° (Set III) is best developed. The second group of this diagonal set with a trend of 65° is very sparsely developed only a few occurring in the patch mapped. Some of the joints have trends parallel or subparallel to the strike of the flow layers, varying from 85° to 100°, dipping at moderate angles (50°) away from the dip of the layers (Set I). The planes of this set are sometimes filled in by pegmatites and quartz veins. At the northwestern corner a thin basic band is seen to follow this joint. Another group of joints have strike lying within 355° to 20° (Set II) and its planes are seen, on station A and north of it, to be displaced along the planes of the foregoing set (Set I). A few joints trend 65° (Set III A).

Some pegmatite veins are seen to run parallel to the flow layers. One such, after following the layers for a short distance, bifurcates and cuts across the layers at various angles in repeated folds. One pegmatite, comparatively thin
AN EXPOSURE WITHIN THE EASTERN OUTCROP
OF THE PORPHYRITIC GRANITE SOUTH-WEST
OF BAMBAD (See text)
To show the details of structural features.
Scale 1"= 400 ft.

Fig. 41.
and somewhat lenticular in form, following the joint plane of Set II is rimmed on both sides by thin basic bands which meet at both ends and in the north follow as a thin band for a short distance. Similarly a second, shorter, lenticular pegmatite vein is encircled by a thin basic rim which continues further north and south.

3. Shyamsundarpur : (Structure map, Plate XI).

North of and close to the post 181 of the Adra-Anara Rail-line (M 201030, 73 g) north of Shyamsundarpur 2/3 mile from the southern wall, flow layers, though distinct, are not well developed. The layers strike at 70°, dipping 45°. A lineation is seen to have been developed in the plane of the flow layers with a trend of 257° pitching at low angles in that direction.

Joints are seen to be well developed. One set trends roughly at right angles to the strike of the layers, more truly at right angles to the trend of the lineation, with strikes varying from 355° to 5°. Some of the joints planes show a slight variation in trend. The planes dip at 68° to 72° bothways. Some of the joints strike at 75° to 78° roughly parallel to the trend of the lineation, a few trend at 90° - 96°. One such joint, in the southwest corner of the patch folds round to a trend of 46°. Pegmatite bands with trends of 30°, filling in joints of the same trend, are seen to abut against this plane on both sides. Two more groups of joints, one with an average trend of 30° and the second, a close spaced well developed group, with a trend of 125°, are also seen. The last set dips at 41° towards NNE and is on the average 3° apart. Some of the planes of this set also show a little change in strike.
A large number of pegmatite bands are found, some of which follow the planes of the different sets, and a few cut across at random directions. One such, having a sinuous trend, runs along a general direction of $55^\circ$, breaking up into two bands, continuing as such for the greater distance and then meeting again. Two sets of joints, one with a trend of $355^\circ$ (Set I) and the other $125^\circ$ (Set III), are seen to cut across the pegmatite. The pegmatite contains big crystals of tourmaline which are often as much as 6" long.

4. **Anara**: (Structure map, Plate XII).

In the small exposure (M.141014; 73 $\frac{1}{11}$), within the granite country, about $250^\circ$ from the west corner of Anara village, only about 500 yards north of the southern boundary, the flow layers have a strike lying within $96^\circ$ to $104^\circ$. A close spaced set of joints, composed of fine parallel unfilled cracks, small in strikewise extent, has a trend of $7^\circ$. The planes are steep dipping bothways, mostly vertical. A few of these planes (trends between $5^\circ$ to $7^\circ$) extend for a considerable length (Set II). Another set, 1 ft to 2 ft apart, has strikes of the planes varying from $94^\circ$ to $100^\circ$; the trend is thus parallel to the strike of the flow layers (Set I). A third set of finer cracks strikes at $345^\circ$ to $350^\circ$, dipping at moderately steep angles WSW. These planes are well developed in the southern and western margins of the surveyed patch. The relative concentration of the three joint sets is roughly as follows:

$$4(\text{Set II}) : 3(\text{Set I}) : 1(\text{Set III}).$$

5. **Layara**: (Sketch map, Fig 42, Sen 1949)

South of the Raghunathpur - Purulia Road and close to it, south of 31 miles post, west of the village, a small patch of the porphyritic granite is exposed, close to the southern boundary (R 121994; 73 $\frac{1}{11}$), showing alternating bands of the granite gneiss. The porphyritic granite at the northernmost
Fig. 42

Sketch map of the structural features of the granite with lit-par-lit bands of the granite gneiss in a small exposure near Layar (see text).
corner (See Fig 42) is comparatively basic having hornblende crystals beside feldspar phenocrysts. All the bands of the granite show a very well developed rigid parallelism of the phenocrysts, though, as it is nowhere exposed in the third dimension, the planar arrangement of the phenocrysts is not evident, except in the southernmost corner, where the layers dip at steep angles (55°) North. The strike folds round to about 60° in the east. The middle band of the granite gneiss, in a thin zone along its southern contact with the porphyritic granite shows some feldspar phenocrysts, while in contact with the granite in the north, there has been a concentration of garnets which are often as much as 4" in diameter. An exceedingly close spaced set of joints has been developed in this band, the modal trend being 5°. Some of the planes of this set are seen to have continued bodily from the similar joint planes in the porphyritic granite. The joints dip at steep angles 60° - 70° bothways. A joint plan with a trend of 30°, in the southernmost granite band, bifurcates into two planes one with a trend of 28° and the second 10° - 25° which continue bodily in the granite gneiss to its north. Joints of same trend are also seen in the northern band of the granite gneiss.

6. Raghunathpur : (Structure map: Plate XIII), Talsankra, Bero etc.

The tors, S to SSW of Raghunathpur consist of a series of peaks arranged in a crescent encircling the village Nanduara. About quarter mile to the west is a second small ridge. The area to be described is defined by the grids (M) 270 to 290 and 040 to 062 (73 10, see structure map plate VII and also plate XIII). It is divided into four equal quadrants for convenience of description.

North of the western rise, on the N.W. edge of the fourth quadrant, the flow layers strike 80° dipping 70°N. Gradually to the south the value of the dip changes to 85°
close to the rise, where the strike is 94°. In the same quadrant about 95° from the highest peak and approximately 250 yards off from the foot of the rise, the flow layers strike 34° dipping 64° towards NW. South East of this point the strike changes to 160° with the dip varying from 90° to 87° east. The strike sweeps round to 66°, just S of the highest peak, to the N of the second quadrant. To its east and on the eastern foot of the second rise the layers are always vertical or dip at 89°N, the strike varying from 108° to 92°. On the central part of this rise the dip becomes low. The form is on the whole that of an inclined steep dipping cylindrical dome, the low dipping layers forming the apical region.

Along the northern boundary of the porphyritic granite well exposed, for example, in the river cutting North North East of Raghunathpur, the flow layers dip 52° towards N, while just to its North the granite gneiss has a similar structural trend but dips at steep angles south. The dip changes successively to vertical and then to 45°N, further north. Here is a good example of major discordance. The dip of the northern wall gradually steepens further east along Talsankra, Mulikpara and Banbahira. Along the wall north to north east of Berar, there is again a discordant relation, with the planes of the wall cutting across the structural planes of the granite gneiss (the strike remaining constant in each).

A résumé of the observed structural features.

Though the granite shows a broad concordance with its wall rocks for the greater length of the exposure, especially along the southern boundary, it exhibits, towards the eastern margin, from north-north-east of Raghunathpur, a definite discordant relation of the northern wall with the structural
trends of the country rocks. Besides this, mention has already been made of the presence of local small scale discordances that are noticed at many places along the length of the wall.

The banding shows a definite evidence of being a fluxion structure, originating before the complete consolidation of the rock. The pattern of the flow layers does not conform to that of a dome or an arch. It has been likened to the form of an overturned asymmetric anticline pitching at low angles on both sides, or to that of a lens, a lens with its top truncated and flattened down, so that along the greater length in the central portion it forms a moderately inclined sheet. The eastern end of this lens has moved up differentially with respect to the main body, and moved up in the fluxional stage with considerable force resulting in the development of a well formed lineation parallel to the direction movement, an unequivocal example of "flow lines". Then, again, along a zone round the tor SSW of Raghunathpur, the flow layers form locally a steepened inclined cylinder that had domed up its roof suggesting also a secondary doming with differential movement of the granite along this locality.

Of the three important sets of joints developed in the granite, sets II and III post-date the first set. The first set, containing a group of BC tension planes and diagonal tension planes, had formed during the last phase of the upward emplacement of the granite. The excellent development of the joints of the second set, close to the boundary, proves a considerable elongation at right angles, thus a distension of the chamber on all sides, caused evidently by an increase in volume of the chamber due to continuation of the movement of emplacement. The tension would be normally be more effective towards the walls. The distension was great enough to cause well developed tension
joints in the wall rocks (described in Chapter VIII) for a considerable distance away from the boundary. The third set was formed during the last phase of this distension of the chamber concomitant with similar joints forming in the wall rocks.

The joints prove a continuation of the movement of emplacement beyond the stage of consolidation when the rocks yielded by rupture. Some of the structural features could be interpreted as records of movement in the intervening "plastic" stage when the viscosity reaches its maximum, the movement either accentuating the features due to viscous flow or slightly modifying them. The occurrence, locally along the contact with the wall rocks, of almost a schistose banding in the granite, that has dragged up the wall to give rise to thin laminated gneiss, is explained as a feature of this stage, the deformation in the wall rocks having been induced by plastic flow of the solid rock. The wall rocks, in extreme cases, responded by rupture. The granite, near its walls has sometimes (though rarely) an appearance of a drawn out dough and it does not show any granulation under the microscope. The rock in contact is finely laminated sheared granite gneiss.

The absence of any evidence of cataclasis in the granite gneiss could be ascribed to para- or post- tectonic recrystallization. The only plausible explanation is that the continuation of movement just beyond the stage of viscous flow in the granite caused plastic elongation in the same direction aggravating the earlier structures. The wall rocks, first dragged plastically together with it, have, later on, yielded by rupture.