Chapter VIII

STRUCTURES OF THE WALL ROCKS.

Herein are described the structures that are found in the country rocks forming the walls of the porphyritic granite, impressed, presumably, by the forces incidental on its emplacement.

In spite of the structural conformity of the wall rocks and the granite (except for a few discordances, see the preceding chapter), there are good field evidences signifying a forceful injection of the granite which has its further supports from magmatotectonic and petrotectonic studies.

Along a greater length of the wall, in the granite gneiss in particular, there has been extensive cataclastation that have produced mylonitic gneisses. These intensely crushed mylonites are rather a common feature, extending along a zone to some distance away from the wall. Three sets of joints are seen to have been characteristically developed in wall rocks close to the granite, one trending at right angles to the wall, a second parallel to it and the third diagonal. A statistical study by a painstaking counting and measuring of well over 5,000 joints in the field not only shows the relative importance of the sets and their inter relations, but reveals also a definite connection of these joints with the boundary plane of the granite. The constant relation of the strikes of the joints with the trends of this boundary plane, their close spacing and excellent development near to it, and a gradual diminishing in intensity away from it, prove them to be genetically related with the emplacement of the granite.
The joints are typically well developed in the granite gneiss. In the incompetent mica-sillimanite schists these are often of irregular trends, not so well formed both as regards concentration and spacing, and neither so clear cut, as in the quartz-feldspar rich gneisses, harder varieties or even as in the quartzites. On the whole the joints are most perfect in the granite gneiss and least in the mica-sillimanite schists and sillimanite gneisses.

Of the three sets of joints developed in the wall rocks, the first set, that is the one that strikes roughly at right angles to the trend of the boundary of the granite, has a comparatively greater abundance on the whole and specially close to the granite. It is seen from statistical counting of joints in the wall rocks that there is a decrease in frequency of the joints away from the boundary of the porphyritic granite and the relative abundance of the first and the second set also shows a gradual change. Beyond some 1½ miles from the wall of the granite the second set gains a greater importance. It will be clear from the graph (Fig 43) showing the concentration of the joint planes of the two sets per unit areas in different distances from the granite.

The joints of the first set are seen at places to be continuations of the tension joints, set I, of the porphyritic granite, as seen for example in the exposure in Layara (Chapter VII, page 85). The joint planes dip steeply bothways and are often vertical. These are typical tension joints, mostly unfilled, with clear cut planes, exceedingly close spaced, sometimes only a fraction of an inch apart. In the wall, in contact of, or close to, the granite the spacing is very close and the planes are almost perfect, even in such incompetent rocks as the argillites. With the increase in distance, however, the planes, especially in the argillites,
The third set consists of intersecting diagonal planes with the axis of intersection deviating slightly from the
Fig. 44

Equal area projection of some 2,500 planes of the joints of the first set (tension) in the wall rocks.
Figs. 45 & 46: Frequency distribution of joints in the granite gneiss (wall rock) at two different spots (Sen 1949). The trend of the boundary wall of the porphyritic granite shown by a double arrow.

Fig. 47: Generalised frequency distribution of distensional joints in the wall rocks (close to the wall).

Fig. 48: Frequency distribution of joints in the country rocks (sillimanite almandine gneiss) unaffected by the porphyritic granite. North foot of the eastern extremity of the Ramchandrapur Hill (QM 455103; 73 1/14), SE of Paroli.
vertical plane, instead of being horizontal as in set II. Again unlike the second set, the planes of this set show both the angular relations with respect to the direction of compression, which is obviously contained in a plane at right angles to the trend of the wall, either the obtuse angle or the acute facing this direction. One or both the planes of this set are developed either in association with the planes of the other sets or rarely exclusively of them. In the latter case it more often proxies the second set and is associated with the first, and in such instances it is as well-developed (as regards frequency) as the joints of the second set.

The block diagram, Fig 49, gives a picture of the spatial relation of the planes of different sets of joints and the trend of the granite wall.

At a spot about a mile towards 310° from Juludih (M 188007; 73 F 11) and 3MS from Amalora the granite gneiss, sometimes extensively epidotised in this locality, shows three groups of joints, two of which are very well developed. The first set consisting of vertical planes with a modal strike of 358°, are comparatively sparse. Two other planes comprising the third set, are disposed almost at right angles to each other. One has a strike of 311° dipping 78°SW on the average, the second, strike 40° with an average dip of 45°SW (Fig 50). The obtuse angle of intersection determined from stereographic plot of the planes (Fig 50a) face the inferred direction of compression. Of this set, the first group shows perfectly developed planes, which are comparatively better formed and clearcut, while both the groups are close-spaced. Only a few yards NW of this spot (312° from the village), the first set strikes at 356° on the average, dipping from 82°E to 90°. The third set comparatively better developed and of which only one group is noticed, strikes 305° with the dip varying from 87°E to 90°.
On a nulla section (M 188003, 75 I 10) about NNW or Pagatbari (R 189995, 73 I 11) and about 3 of Anara R.S. three sets of joints are developed in the granite mica. One of the sets strikes 70° dipping 87°SS1 (Set I), and the second strikes 345° with an average dip of 50°WSW (Set II), and the third has both the groups of which one with a nodal strike of 16° (dipping 85°NW) is less developed; the second group, more or less imperfect, in comparison with the first, has a strike of 120°, dipping 50°31' (Fig 51). The trend of the wall of the porphyritic granite, which is at a distance of slightly greater than ½ mile, has been indicated. As seen from the figure the planes of the first and the second sets are disposed, respectively, more or less at right angles to and parallel to the trend of the wall. The obtuse angle (99°30') of the intersecting Set III faces the wall.

ST of the village Amatora (M 149009, 73 I 11) on a river cutting, of the two sets of joints developed, Set II with strike 105° dipping 70°N and 55° is more close spaced. The other joints belong to the intersecting Set III with both the groups noticed, one with a strike of 45° (dipping 74°NW) and the other with a strike of 23° (dipping 70°WSW). The acute angle of the planes faces the wall (Sen 1949).

To sum up in retrospect (i) the joints of Set I show a decrease in proportion both absolute and relative (with respect to the other Sets) away from the wall of the granite, (ii) either Set II or Set III may proxy for each other. They generally occur alone, associated with the first set; rarely all occur together; sometimes Set III occurs exclusive of all the others, (iii) the obtuse angle of intersection of the joints of Set III faces the wall, in all the cases measured, their line of intersection being horizontal and (iv) in Set III the strike, unless otherwise mentioned, is the 'modal' strike of the planes.
Joints in the granite gneiss close to the porphyritic granite near Bagathari (see text).
either the obtuse or the acute angle faces the wall, the line of intersection lying more or less vertical.

The second set is typical compression set formed evidently due to expansion of the chamber of the porphyritic granite, which in this process pushed into the wall rocks causing compression. They represent the diagonal planes intermediate between AB and BC planes of the strain ellipsoid picturing the deformation. In such a squeezing the direction of maximum relief (A) would, obviously, lie in a vertical plane (roughly at right angles to the wall) while B would lie in a horizontal plane, at right angles to the direction of compression i.e. roughly parallel to the wall. The line of intersection of these above planes parallel to the strike of the planes is obviously, the B direction. In terms of such a strain ellipsoid the first set would represent the AC tension planes, suggesting quite an effective elongation parallel to B. Indeed the perfect development of this set close to the wall proves this tension to have been effectively important. The movement of emplacement, towards the last phase, caused an expansion of the chamber on all sides with an incidental tension along the wall; while such expansion into the country rocks, in pushing it apart, caused compression, radially in all directions from the chamber (Sen 1949). Of these two forces, which are essentially simultaneous, tension is more conspicuous close to the wall, dying away in intensity away from it, whereas, however, compression may be still effective, so that the compression joints overstep the tension planes at a certain distance (1½ miles, Fig 43).

The close development of the tension planes at right angles to the walls caused, towards the last phase, a greater effective elongation parallel to it, so that the effect is similar to that of a rotation of the strain ellipsoid with the A' of the new position coinciding with B of the former (Sen 1943a, 1949). The third set of joints were formed at this
stage with their line of intersection (B') more or less vertical, compression continuing to act with maximum elongation parallel to the wall. Thus the third set, like the second, comprise of conjugate shear joints, with a rotation in the spatial position of the direction of elongation, of the plane of maximum deformation and hence of the conjugate planes themselves.

It is difficult to choose between the contending hypotheses of deformation, for an explanation of the angular relation and the formation of the intersecting planes. The strain hypothesis of deformation as presented by Schmidt (1932) offers a plausible explanation for the development of a single set of S planes; the planes of maximum shearing strain along which rupture is assumed to take place, make an angle \( \theta \) (i.e. the angle with \( C \)) greater than 45°. In laboratory experiments, however, the angle is always acute.

In the stress hypothesis of Tresca, Mohr and others (Nadai 1931) the plane of maximum shearing stress is assumed to be the plane of rupture. With an equal tensile stress, the tangential components would have the maximum value at \( \theta = 45^\circ \) (when it is equal to \( 2 \sin \theta \cos \theta = P \)). In such a case the normal stress \( (N) \) vanishes. If \( N \) has a positive value, even at \( \theta = 45^\circ \), the angle of maximum shearing stress is modified by the active normal stress and \( \theta \) becomes less than 45°. In von Mises' modification an active role is ascribed to the intermediate stress whose influence seems to be greater than that of the normal stress (Fairbairn 1942). The stress hypothesis thus explains the acute angle of experiment but it does not offer any explanation to such structures as elongation or unequal development of S surfaces.

Griggs objects to the application of strain hypothesis on the ground that rocks yield by rupturing forthwith, as
brittle substances; under high confining pressure they yield by plastic flow, and that geologic structures are evidently impressed beyond permanent set (Griggs 1935, 1938). It has been claimed by Koenigsherr that plastic flow may be regarded as a specialised case of elastic deformation (Koenigsherr see Fairbairn 1942). Thus, in such cases, rupture could be thought to have occurred along planes whose position is determined by elastic deformation, justifying the application of the strain hypotheses.

Without going into a detailed discrimination between the contending hypotheses, it may be pointed out, in summary, that the two types of angular relations may find two different explanations, when deformation takes place by fracturing without pre-rupture flow. As such a deformation does not provide for grain rotation, the acute angle may be explained to be due to the original position of the glide planes (Fairbairn 1942), or due to interference by tension fractures, i.e., an elongation parallel to B (Griggs 1938, Fairbairn 1942).

In the present case the spatial position of the plane of the second set, with the obtuse angle of intersection facing the direction of inferred compression, requires explanation, especially as close to the wall the rocks show evidences of having yielded by rupture.

The only plausible explanation from the points adduced above is that the planes of the second set were formed at the first stage before rupture occurred, slightly antedating those of the first set which latter continued to form after the completion of the second set when the third set instead of the second began to appear. It has been suggested in the preceding chapter (Chapter VII) that the wall rocks were plastically dragged during the last phase of emplacement of the granite. The joints of the second set formed during the last part of this plastic deformation, when helped by the heat.
of the newly ascended granite and by its hyperfusible deformation in the wall took place by flow – resulting in shear planes with the obtuse angle of intersection facing compression. A simultaneous (slightly post-dating) tension, caused the formation of the tension joints. This phase of heat-tempered 'flow' deformation came to an abrupt closure, the wall rocks now responding by cataclasis, producing at times typical mylonites. The force of tension parallel to the wall now gained the upper hand, and the third set of the shear planes were formed. The set having formed at the ruptural stage has in most cases its acute angle facing the compression, those that have their obtuse bissectrix parallel to compression evidently slightly antedate the rest. The change in the spatial position of this set (in relation to the second) is due to a rotation through 90° of the direction of effective maximum elongation, which at this stage became parallel to the wall, as exemplified by and due specially to the formation of the joints of the first set.

The following may be said in summary, on the tectonic evolution of the wall rocks, presented in terms of Sander's axes of movement picture.

1. The emplacement of the granite set up a stress on the wall rocks, with maximum compression in a direction at right angles to the wall, that is to say roughly radial from the chamber, with consequent elongation parallel to \( \mathbf{b} \). At this stage shear joints were formed intermediate in spatial position between \( \mathbf{a}_0 \) and \( \mathbf{a}_2 \) with obtuse angle of intersection facing \( \mathbf{g} \), possibly in the plane of maximum shearing strain as the rocks did respond by flow. Some \( \mathbf{g} \) tension fractures began to form.
2. Next with further expansion of the chamber the wall rocks began to yield by rupture and the tension also gained the upper hand. Most of the third set of intersecting diagonal joints was formed at this stage, perhaps parallel to the position of maximum shearing stress "determined by the statistical average of the potential glide planes of constituent minerals" (Fairbairn 1942). A significant effect of this stage is the production of mylonites by cataclasis, the texture having been healed up, often, by paratectonic recrystallisation.