CHAPTER VI

S T R U C T U R E

The Champaner Series in the present area, forms a 'S' shaped regionally folded structure plunging due west. The structure comprises several large somewhat asymmetrical synclines and anticlines. The outcrop pattern ideally brings out this structure on the map, and in the field too, numerous mesoscopic folds conform to the regional structure. For the most part, the competent layers of quartzites and limestones, follow the fold trends, while the incompetent shales (slates and phyllites) have developed a strong cleavage.

This cleavage in a broad way, coincides with the axial plane direction of the folding, and thus can be considered as an axial plane cleavage. It is further noted that this folding was responsible for the development of numerous sets of joints which criss-cross the different formations.

The main fold pattern of the Champaners is seen to have been considerably affected and modified by the subsequent granite intrusion, especially in the eastern half of the area. The tectonic effects of the granite emplacement include superimposition of numerous N-S flexures on the E-W limbs of the early folds and the modification of the geometry of early structures.

In this chapter, the author has discussed at length the entire structural history of the Champaner Series, which he has built up with the help of various planar and linear structures preserved in the rocks.

CHAMPANER FOLDING

Regional Pattern

The rocks form a huge regional structure, comprising two anticlines and two synclines, which plunge gently due west. The geometry of the entire structure is such that its two flanks in the NE and SW run straight in E-W direction, imparting a 'S' shape to the fold. It is obvious that this 'S' shaped structure characterises the limb of a big syncline to the north and an anticline to the south.

Geometry and mechanism of folding

The various constituent folds are moderately closed and angular. The limbs are rather straight, though the actual hinge areas are somewhat rounded. The mechanism of folding is dominantly of the similar type, except for a small portion occupied by the alternating Shivarajpur Quartzites and Phyllites. But for the above portion, in rest of the area the folding has taken place by differential slipping along the axial plane direction (Plate XXXIV). This slip plane is now characterised by the metamorphic cleavage in the rocks. While the shales and graywackes have developed the slaty or phyllitic cleavage, the sandy layers show an ill defined fracture cleavage. It is not clear whether the deformation was essentially a product of shearing stress alone, or was aided by compressional stresses.

In the Shivarajpur Quartzites and Phyllites (around Shivarajpur-Bamankua) the folding mechanism was dominantly of the flexural slip type. Folding here was brought about by the slipping of the competent sandstones along incompetent shales. As a result, the phyllitic cleavage is seen parallel to the bedding planes and follows the fold trend.

Stereograms showing poles of bedding and lineation of the western half of the area (which is free from the deformational effects of granite intrusion) ideally illustrate the nature and mechanism of the folding. The author has plotted two separate stereograms - one for the rocks around Shivarajpur-Bamankua (showing a flexural slip mechanism of folding) and the other for the rocks around Jaban, Narukot, Gandhra (showing a similar fold mechanism) (Figs. 5 and 6). In both cases, the bedding poles are arranged in a girdle whose axis, defining B (fold axis), plunges about 20° due WNW. The plots of the lineations are scattered around the B. The geometry of the macroscopic folds, as revealed by the stereograms, matches fairly well with that of the mesoscopic folds. The folded area, thus represents a domain of 'Plane Cylindrical Folding of Turner & Weiss' (1963).

Stereogram of the concentrically folded Shivarajpur-Bamankua area, typically shows absence of maxima in the girdle; the pole of the axial plane is marked by a minimum concentration. On the other hand, the diagram for the rest of the area, shows a girdle with a pair of maxima (corresponding to the two limbs), minimum both at the hinge and at the pole of the axial plane. Such a pattern is characteristic of open similar folds (Turner and Weiss, 1963,p.158).

The folding for the most part is broadly symmetrical, the axial planes being sub-vertical. Though actually in various constituent folds, it is seen to dip very steeply either due N or S. This fluctuation in the dip of the axial planes, is found to be due to the phenomenon of a slight fanning of these planes, disposed almost symmetrically to the fold axis (Fig. 7). Similarly, the slaty and phyllitic cleavages, which are parallel to the axial planes (except in the Shivarajpur Quartzites and Phyllites), when plotted on a stereogram, also show a similar fanning, interesecting along the fold axis (Fig.8).

Lineations related to folding

The folding has also given rise to a large number of linear structures parallel to the fold axis (Fig. 9). These linear structural elements include minor fold axes, crenulations, cleavage-bedding interesections and boudinages. Minor fold axes are on various scales ranging from a few metres to a few cm and are mostly confined to thinly bedded quartzites and limestones. Crenulations, which also have an orientation identical to that of the axes of minor folds, show an interesting origin. It is seen that the orientation of these crinkles is similar to the major fold axes. Obviously, continued deformation caused differential slipping along the already formed axial plane cleavages and thus the latter got folded into small crinkles with axes parallel to the major fold axes (Billings, 1962, p.359). Thus the crinkles imply a late phase of the same movements that gave rise to the original cleavage (Hills,1965,p.307). The lineation due to the interesection of cleavage with bedding is widespread and ideally noted in the various pelitic formations. This lineation is however, absent in the Shivarajpur Quartzites and Phyllites which have been folded by a flexural-slip mechanism. Boudinage on the other hand is restricted to the Shivarajpur Quartzites and Phyllites, because differential flexural slipping here has caused stretching of thinner quartzite layers and this has resulted into boudinaging. The axes of the boudins are parallel to the fold axis.

Fracture pattern related to folding

Although no special study of the joints was attempted by the author, he has collected adequate data on the fracture pattern of the area to classify the various joint sets and faults, and correlate them to the major deformational events. The author's investigation has revealed that the jointing and fracturing of the rocks belong to two distinct periods - one, of main folding and the other of uplifting due to granite. In the following lines, he has analysed and discussed the joints that developed during the main folding episode.

Ignoring the local variations and many ill defined joint sets, the area could be said to contain following four major sets of joints:-

(I) NNE-SSW, dipping steeply due E

(II) NE-SW, dipping steeply due SE

(III) NNW-SSE, dipping steeply due E

(IV) WNW-ESE, dipping steeply due N or S.

Stereograms of the poles of these joints very clearly show the close relationship between the folding and fracturing (Fig.10). The relationship has been summarised below:

Joint Set I (NNE-SSW) represents 'ac' joints, almost normal to the fold axis (b).

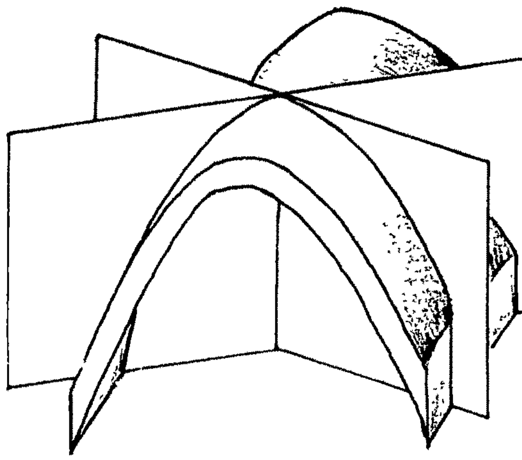
Joint Sets II and III (NE-SW and NNW-SSE) are obviously a pair of conjugate shear fractures, disposed symmetrically to the fold axis, such that their intersection lies in the axial plane and is at right angles to the fold axis. These joints are essentially shear fractures, placed at angles of 30° from 'ac' joints on both sides and show evidence of slipping along them. This slipping is recorded as kinking in pelites and fracturing of pebbles in graywackes.

Kinks along the conjugate shear joints: It is already noted above that the drag or displacement along a pair of conjugate joints to the folding has thrown the slaty cleavage into folds with straight or nearly straight limbs and sharply curved crests and troughs; the resulting structures are kink bands (Ramsay, 1967; Hills, 1965; Dewey, 1965). By definition, the distance between the adjacent axial surfaces does not exceed about 10 cms, otherwise these structures would have been termed zigzag folds or knee folds (Ramsay, 1967,p.436).

Fig. 11

FOLD WITH CONJUGATE JOINT SYSTEM

SHOWING VERTICAL DIAGONAL PATTERN.



It has been concluded that the major sets of kinks in the present area, were produced on account of drag along conjugate shear joints and that they were formed during the later phases of folding (because these kinks are seen to deform the axial plane cleavages). The author's findings are quite similar to those obtained by Ramsay (1962 b, p.525), who concluded that "conjugate folds and related structures (kink bands, knick bands, joint drags) are characteristic of rock deformation under brittle conditions, and appear to be produced by a movement on one or more shear surfaces which usually (but not invariably) make an angle of less than 45° to the principal stress axis. They are frequently found in rocks deformed during later phases of orogenic deformation and are often related both in space and in time with the development of faults, thrusts and joints".

The mechanism of the development of conjugate sets of shear joints and their relation to the folding is ideally shown in the accompanying diagram (Fig.11). The block diagram shows the relationship between the fold-axis and the conjugate shear joints that would develop in a case where compression acts on the limbs and the direction of easiest relief coincides with the fold axis (Billings, 1962, p.118).

Joint Set IV (WNW-ESE) which is comparatively less developed, is an example of jointing parallel to the 'ab' plane (axial plane) of the folding.

Considering the close geometrical relationship between the joints and the folding, it can be stated that the jointing was essentially contemporaneous with the Champaner folding.

DEFORMATIONAL STRUCTURES DUE TO THE GRANITE INTRUSION

The granite intrusion has considerably modified the pre-existing structure of the area and has also impressed new structures. The deformational effects of intrusion, however, are confined to the eastern half of the area, where the granites occupy large tracts in the E and SE. The forceful injection of the batholithic mass has obviously pushed and arched up the folded series.

The various effects of the granite intrusion have been listed as under:

(i) Swinging and deflection of the foliation (bedding, cleavage) trends and regional boudinaging of beds.

(ii) Superimposition of N-S flexures and doming up of pre-existing folds.

(iii) Tightening of earlier minor folds and steepening of their axes.

(iv) Development of numerous faults showing a radial pattern.

Deflection of trends, stretching and boudinaging

Swinging of foliation trends is widespread all along the margin of the intrusion, the deflection being such as to fit the form of the igneous body. It is seen that the schistosity and bedding to the E of Narukot and Vadek, S of Poyelli, and Intvada, and S of Vishengarh, show this phenomenon. Deflections to fit with the granite contact are quite a common feature of the bodies forcefully injected into the country rocks. Pitcher and Sinha (1958) and Akaad (1957) have reported very identical phenomenon from Donegal granites of Ireland. According to Nevin (1960, p.196-197), this moulding of earlier structural trends to the outlines of the intrusion is a good evidence of the fact that considerable space was won for the granite by thrusting aside the walls.

Stretching and boudinaging on a rather regional scale are observed in the quartzite band S of Poyelli. Here, the southern flank of the anticlinally folded Poyelli Quartzite, is seen stretched and broken into two lenses, fringing the granites. The stretching is accompanied by a deflection in the strike of the band also.

Superimposition of N-S flexures and formation of Narukot dome structure

The granite emplacement which pushed the strata away and also lifted them up all along the junction, also gave rise to a new set of rather open flexures which are best recorded in the schists and phyllites of Poyelli and Intvada. The E-W bands of Poyelli Quartzites and Narukot Quartzites also show small folds, so easily recognised in the field and also in the map.

The formation of the Narukot dome also is connected with the action of granite. The arching up of a west plunging anticline on account of interference with another N-S anticline accompanied by a deflection of the strike at the granite contact has given rise to the interesting domal structure. In fact, the Poyelli Quartzite-band around Poyelli shows a tendency to close due E, and has formed an incomplete dome shaped structure.

Tightening of the earlier minor folds and steepening of their axes

The granite has pushed the rocks northward, and the effects of this pushing is ideally seen in the NE part of the area around Intvada-Poyelli. In this area, the quartzite bands in schists and phyllites abundantly show minor folds related to the main folding. The lateral compression caused by the granite, has resulted in the lightening of these folds, such that most of them look almost isoclinal. In addition, the N-S folding has also so affected these folds that their axes plunge very steeply due W or NW. Such effects by the intruding granites have been observed by many workers elsewhere also Akaad (1957), Pitcher and Sinha (1958), Nevin (1960, p.195) has suggested that "such effects on pre-existing folds take place at relatively high levels in the crust and may be inferred to a cause - the upward and outward pressure of intrusion".

Radial faulting

A perusal of the geological map will clearly show that a number of faults cut the entire folded sequence, and that the faults show a coarse radial pattern, converging towards granite. Trends and the sense of movement along such major faults have been given below:

Name of the fault 1	Trend 2	Slip 3	Formations affected 4
Jaban-Shivarajpur fault	N55°W-S55°E	Dextral	1. Jaban Slates 2. Jaban Conglomeratic Graywackes 3. Bhat Slates 4. Shivarajpur Quartzites and Phyllites 5. Rajgad Slates.

1	2	3	4
Vau Fault	N64°W-S64°E	Sinistral	1. Upper Slates and Phyllites (Gandhra Pelitic Group) 2. Narukot Quartzites 3. Jaban Conglomeratic Graywackes 4. Shivarajpur Quartzites and Phyllites 5. Rajgad Slates.
Kaivav Fault	N50°W-S50°E	Dextral	1. Upper Slates and Phyllites (Gandhra Pelitic Group) 2. Narukot Quartzites 3. Jaban Conglomeratic Graywackes 4. Rajgad Slates.
Gandhra Fault	N58°W-S58°E	Dextral	1. Upper Slates and Phyllites 2. Gandhra Dolomites 3. Narukot Quartzites 4. Shivarajpur Quartzites and Phyllites 5. Rajgad Slates.
Hathani Fault	N6°W-S6°E	Sinistral	1. Upper Slates and Phyllites 2. Narukot Quartzites 3. Rajgad Slates.
Bhabar Fault	N17°W-S17°E	Dextral	1. Upper Slates and Phyllites 2. Narukot Quartzites 3. Shivarajpur Quartzites and Phyllites 4. Bamankua Limestones
Intvada Fault	N6°W-S6°E	Sinistral	1. Lower Schist etc. (Gandhra Pelitic Group) 2. Narukot Quartzites 3. Shivarajpur Quartzites & Phyllites 4. Bamankua Limestones

1	2	3	4
Pani Mines Facult	N20°W-S20°E	Sinistral	1. Lower Schist etc. 2. Narukot Quartzites 3. Shivarajpur Quartzites and Phyllites 4. Rajgad Slates.
Undhania Fault	N40°E-S40°W	Dextral	1. Lower Schists etc. 2. Narukot Quartzites 3. Jaban Slates 4. Jaban Conglomeratic Graywackes. 5. Rajgad Slates.

These radiating faults are definitely related to the intrusion and have developed on account of the lifting up of the overlying strata by the rising granitic mass. A fan shaped radiating pattern with faults showing tendency to converge at a point within the granite intrusion strongly suggests a lateral stretching and doming of the mass under continued upward pressure from the magma below (Hills, 1965, p. 367, 377). Similar mechanism has also been advocated by Billings (1962, p.309,311), Nevin (1960, p.401), Read and Watson (1962, p.401).

It is obvious that the faults to the W and NW of granite are of larger extension, and they become progressively smaller to the E. Although all the faults have developed due to an arching up of the country rocks around the intrusive granite, those in the W and NW seem to have occupied positions of joints and cleavage related to the main folding. Wherever the direction of the tension fractures due to granite intrusion were parallel with the weak zones (like axial plane schistosity), the faults were propagated to longer distances from the intrusive body and in other instances, they were much restricted in length. Hills (1965, p.174) has clearly noted that in some cases the cleavage planes afford a predetermined direction of ready shear which is made use of later faulting.