CHAPTER III

DISTRIBUTION AND FIELD CHARACTERS

As has been mentioned in the foregoing chapters, the Champaner Series forms an important Pre-Cambrian formation of Gujarat. It occupies vast areas in the districts of Panchmahals and Baroda, and constitutes a thick group of metamorphosed arenaceous, argillaceous and calcareous sedimentary rocks with many intermediate types. The main rock types are conglomerates, sandstones, graywackes, siltstones, shales and limestones, each showing a number of varieties. A few manganiferous beds are also encountered. Limestones (including dolomites) and manganese bearing rocks are confined to the eastern and western parts of the area, whereas the middle tract consists of various members of a graywacke suite. Metamorphosed equivalents of shales and sandstones are exposed almost throughout the area, and conglomerates form conspicuous lithological units in the eastern and middle sectors.

Structurally, rocks of the Champaner Series show a strong and repeated folding in roughly E-W direction. In a broad way, the whole sequence forms a huge anti-clinorium. Superimposed on the E-W folds, are encountered folds belonging to yet another deformation. This late folding is roughly NS and has given rise to rather open flexures. Effects of the second folding are more conspicuous in the eastern part of the area.

The various sedimentary rocks are, now, represented by their low-grade metamorphic equivalents like schistose conglomerates, quartzitic sandstones, slates, phyllites and recrystallized limestones and dolomites. Near the contact of these rocks with the intrusive granite contact metamorphic derivatives of some of these rocks such as hornfelses, schists and gneisses are encountered. The intrusion has, also, given rise to calc-silicate skarns in originally impure limestone rocks.

Sandstones of Cretaceous age overlie these Pre-Cambrians. Deposition of these sandstones was followed by the great Deccan Trap activity.

SUCCESSION

The stratigraphy of the Champaner Series and the regional geological setting in which this series occurs, is summarized in the table below. The succession is based on author's own investigations.

The names given to the various rock groups are based on the localities where the exposures are typically seen, and in certain cases the old names have been retained. The nomenclature, however, is for the convenience of description only.

Cretaceo-Eocene	Pavagarh Basalts, tuffs and rhyolites (Deccan Traps)
Cretaceous	Bhamaria Sandstone (Bagh beds)
--------------------Unconformity--------------------------	
Post-Champaner (Pre-Delhi)	Intrusive Granites

Champaner Series (Aravallis)	Upper	Rajgad Slates
	----------Para conformity----------	
	Middle	Bamankua Limestones
		Shivarajpur Quartzites & Phyllites
		Bhat Slates
		Jaban Conglomeratic Graywackes
		Jaban Slates
		Narukot Quartzites
	----------Disconformity----------	
	Lower	Gandhra Pelitic Group
		Chhota Udepur Dolomites
		Basal Conglomeratic Quartzites
----------Unconformity----------		
Pre-Champaners		Basement Gneisses etc.

In the following pages, the author has given a detailed field account of the various rock formations of the area. Lithology, structure and megascopic characters of different rock types have been systematically described. Brief references to microscopic characters have been made at places only to facilitate the description, and detailed petrography is discussed in the subsequent chapter.

Although the lowermost members of the Champaner Series and the basement rocks are not encountered in the study area, these have, however, been briefly described to provide a suitable background.

BASEMENT GNEISSES

The rocks over which the Champaners were deposited, are rather difficult to identify at most places, as their nature has been considerably modified on account of the intimate mixing up of the Post-Champaner intrusive granites with the basement gneisses. It appears that the granites, that intruded the Champaners were products of the palingenetic mobilisation of the basement itself. Thus, the mixing up of the Post-Champaner granitic rocks with the basement gneisses has rendered it very difficult to separate the one from the other and in their present form the Pre-Champaner (basement) gneisses cannot be easily demarcated from those which were intruded during and after the orogenic upheaval.

However, undoubted basement gneisses showing distinct depositional unconformity with the Champaner beds, has been recorded at a number of places. The lowermost bed of the Champaner Series, a basal conglomeratic quartzite, is seen to rest unconformably over older gneisses near the villages Deohat (22° 23'; 74° 6'), Ambala (22° 23': 74° 6'), Kachhol (22° 20': 74° 2'), Pavi-Jetpur (22° 20':73° 51'), Dhandhoda (22° 19' : 73° 58'), and Zadawant (22° 23' :74° 10').

In their present form, the basement gneisses, as already stated, consist of two granitic components - an earlier gneiss into which a later granite has mixed in various ways. The existing complex, thus includes a random assemblage of the following three types:-

1. Patches of original basement rocks.
2. Partly mobilized basement of agmatitic appearance.
3. Basement invaded by and mixed with the later granitic components, resulting into a number of 'hybrid' types. Following two types are easily distinguished (i) a porphyritic (or to be more precise porphyroblastic gneiss wherein porphyroblasts of feldspars have metasomatically grown in the older matrix, (ii) a composite banded gneiss comprising of alternating layers of grey streaky gneiss and pink granite.

The entire complex is dissected by veins of quartz and quartz feldspar.

The author found it difficult to identify and distinguish the undoubted basement gneisses from those intruding them, but in a broad way, with considerable certainty, it could be stated that while the earlier gneisses are generally fine to medium grained grey streaky rocks, the latter granites are pink and tend to be coarser. Another helpful criterion in knowing the true nature of these older gneisses; is afforded by the pebbles and boulders of granite-gneiss of the conglomerates occurring in the middle of the Champaner succession. These pebbles are almost invariably of the grey gneiss.

LOWER CHAMPANERS

Rocks of the Lower Champaners are mostly dolomites, dolomitic limestones, quartzites, and metapelites, and stratigraphically, show the following succession:-

Gandhra Pelitic Group

Chhota Udepur Dolomites

Basal Conglomeratic Quartzites.

1. BASAL CONGLOMERATIC QUARTZITES

Conglomeratic quartzites constitute the basal formation of the Series, and occur as small lenticular patches, resting over the basement granite-gneisses. Good exposures of these rocks are recorded 1.5 km to the SE of Deohat just outside the eastern extremity of the study area. The rock is greyish white to yellowish in colour and is a typical basal conglomerate with pebbles of pink, yellow-brown and black jasper, chert and quartz, embedded in a medium to fine grained sandy matrix which is at times arkosic (Plate I A). Most of the pebbles are sub-angular to rounded. From visual estimation it is seen that the pebbles are of odd shapes. Similar is the case with sand grains of the matrix which are firmly cemented by siliceous matter. The rock shows a weak graded bedding (Plate I B). This pebbly rock gradually merges upwards into a highly recrystallized quartzite. The rock extends for about 1.6 km in a roughly NE-SW direction with maximum width of about less than 1/2 km. These conglomeratic quartzites strike due NE-SW dipping moderately (about 60°) due NW.

Another lens of this conglomerate is recorded near village Suskal (22° 19' : 73° 48') in the south of Champaner exposures. The rock is exposed along the road which connects Shivarajpur and Chhota Udepur. Unlike the earlier described exposure, here a faint current bedding is also preserved. The bedding shows a strike of about ENE-WSW with a dip of 40° to 45° due N. Small folds 5 to 20 cm in size are frequently recorded. The axes of these folds plunge due W to WNW at varying angles (15° to 40°).

Several other exposures of these basal conglomeratic quartzite lenses have been encountered to the E and SE of the area near Kachhol (22° 20' : 74° 2') and Ronwar (22° 19' : 74° 3'). But at most of these localities, the beds are seen extensively intruded by veins and lenses of granites from below. From the nature of the pebbles and enclosing matrix, and also looking to the fact that these underlie the dolomites, there is very little doubt that these beds are also basal. The way in which the underlying granitic rocks are seen intruding these beds, clearly suggests reactivation and mobilization of the basement, such that it now shows an intrusive contact.

Some small folds, a few cm in size are recorded in these beds near the road bridge between Chhota Udepur and Deohat. The orientation of these minor folds coincides generally with the Champaner folding i.e. the fold axes show a plunge of about 40°-50° due WNW.

2. CHHOTA UDEPUR DOLOMITES

The next younger formation comprises beds of dolomite with frequent quartzitic layers. These dolomites are found as scattered exposures throughout the terrain between Narukot and Chhota Udepur, and quite often surrounded by the Post-Champaner granite. At several places, these dolomitic beds are seen to rest directly over the basement gneisses, the basal pebbly quartzite having been absent there. The dolomites, often, show a banded structure, the banding characterised by compositional and textural difference.

3. GANDHRA PELITIC GROUP

The formation that overlies the dolomites, consists of a group of metapelites, quartzites and dolomitic limestones. The bulk of the formation comprises pelitic rocks showing various grades of metamorphism. The succession shown by this group is as under:

Upper Slates and Phyllites with a distinct dolomitic limestone band (Gandhra Dolomites)

Poyelli Quartzites

Lower Schists, Gneisses and Hornfelses.

Good exposures of this group are found in the NNE between Gandhra (22° 27' : 73° 42') and Vishengarh (22° 28' : 73° 51'). This tract of about 17 km length and of width varying from 1 km to 4 km forms a hilly terrain marking the Intvada-Poyelli plateau. In fact, these rocks are the oldest members of Champaners succession that lie within the limits of the study area.

The whole group forms a big west plunging anticline (Gandhra Anticline). The distinct quartzite band (referred to as Poyelli quartzites) ideally separates the lower pelitic rocks from the upper. (The Narukot quartzites which rest unconformably over the Upper Slates and Phyllites, are seen to directly overlie the Lower Schists etc. in the E). It is interesting to note that the folded Poyelli quartzites band in the western part and the Narukot quartzites in the eastern part, have acted as effective barriers to the metamorphic and metasomatic changes brought about by the granite intrusion and the rocks lying below these quartzites show very interesting metamorphism. A superimposition of contact metamorphism on an earlier regionally metamorphosed assemblage, is distinctly observed. The invading granites have given rise to contact migmatites as well as varieties of hornfelses.

Lower Schists etc.

These metapelites, occurring in the immediate vicinity of the granite show varied effects of contact metamorphism, and a number of varieties such as chlorite-sericite schists and phyllites (with andalusite), mica schists (without andalusite), cordierite-andalusite hornfelses and gneisses. In a broad way, the western half of these metapelites which lie within the core of the folded Poyelli Quartzite show less effect of granite. Perhaps this is on account of the protection offered by the quartzite. The southern limb of this fold is seen abutting against the granite, and it is only where the quartzite band is stretched and broken, the granitization of the pelitic rocks has been brought about. On the other hand, the eastern half of this formation, shows extensive metamorphism and metasomatism. In this part increasing effect of granite is recorded across the strike of metamorphic foliation when traced from N to S towards the granites. Thus, the phyllites and chlorite-sericite schists occur at the outer margin of the contact aureole, while hornfelses and gneisses are found in the vicinity of the contact with the granite. The transition from one rock to another is gradual, though the transition from one rock type to another is quite rapid and observable over a distance of few metres.

Considering the lithology and metamorphism, the rock types have been classified, for the purposes of this study, as under:

(i) Gneisses (fringing the granite).

(ii) Hornfelses and chlorite-sericite schists (bordering the gneisses) exposed to the E of Intvada.

(iii) Mica schists, chlorite schists etc. lying inside the anticlinal core around Poyelli, W of Intvada.

(i) Gneisses: The gneisses, obviously a migmatitic product of contact metasomatism, occur in the immediate vicinity of the granites, and are exposed as two bands extending parallel to the granite contact. The more prominent band occupies the region, S of Pani Mines. It extends eastward from Intvada (22° 28' : 73° 46') through Kevra to as far as Raypur (22° 26' : 73° 51'), gradually thinning out to the E. While at Intvada, this gneissic band is about 1500 metres wide, at Raypur its width hardly exceeds 300 metres. To the NW of Raypur, this thinned band extends further NE ward for about 2000 metres, flanking the granite boss. Westward extension of these gneisses is hindered by quartzite bands, the latter having acted as a barrier to the granite emanations. The junction between these gneisses and the schists to the N is quite diffused. Similarly, the gneisses merge unperceptibly into granite to the S. The strike of the foliation of these gneisses is generally WNW-ESE except in the NW of Raypur, where strike tends to be NE-SW. Thus, it is seen that the foliation trend is almost parallel with the contact of granite mass. Almost everywhere near the contact, the foliation dips away from the granite, and is obvious that the foliation trends have been modified by the intrusion.

The other a much smaller gneissic band is exposed on the hill side SE of Poyelli (22° 27' : 73° 43'). This band, only about 1500 metres long and 500 metres wide, following the granite contact, is rather discontinuous, broken by a few quartzite lenses which have prevented granitization at some places. This band trends almost NE-SW direction. To the N, the gneisses are found to change over to mica and chlorite schists.

These gneisses are foliated, coarse to medium-grained, showing considerable textural and mineralogical variations. The chief constituents imparting these variations are feldspars and micas. The gneisses can be classified into the following 4 varieties:

(i) Porphyroblastic gneiss

(ii) Augen gneiss

(iii) Permeation gneiss

(iv) Feldspathic schists.

The porphyrablastic variety occupies the southern most portion of the gneissic bands nearer to the massive granite. It is ideally exposed in the high ground around Intvada. Again to the W, this variety is encountered SE of Poyelli where it forms steep scarps. The rock is greyish or pinkish, coarsely foliated with abundant porphyroblasts of feldspars (Plate II A), ranging in size from 10 to 30 mm. Occasionally, larger porphyroblasts of idioblastic outline are also present. The groundmass consist of feldspars, quartz and micas (both biotite and muscovite). Porphyroblasts are seen to have grown along and across the foliation.

The porphysoblastic variety to the N on going away from the granite, changes over to an augen gneiss. This variety of gneiss is characterised by augen-shaped porphyroblasts grown along the foliation. These augens vary in size upto 25 mm to even 30 mm, and are invariably wrapped round by biotite selveges (Plate II B). The feldspars have grown as 'eye' shaped grains by pushing apart the micaceous foliae. In addition to its occurrence as augens, feldspar also forms small grains in the groundmass. Relative proportions of biotite and muscovite are quite variable, and when muscovite predominates, as in the N of Intvada, the rock assumes a rather white shining appearance. On the contrary, when biotite is abundant, the rock has dark grey to black colour. The foliation, as usual is due to parallelism of the mica flakes. This augen bearing variety show unequal development, and its occurrence is rather discontinuous. Good exposures of the augen gneiss are recorded to the N of Intvada. At a few places, these gneisses have been flanked by quartzites to the N and NW, which have acted as barriers to emanations and thus almost unfeldspathised schists occur on the other side of the quartzites. These gneisses contain less felspathised patches of country rocks which conform with the gneissic foliation.

The augen gneiss shows tendency to grade into an augen free variety which could best be described as a permeation gneiss. This variety of gneiss contains felspars as small elongate grains or segregation of grains into small streaks. The grains and their streaks usually do not exceed a few mm in length. The rock contains muscovite in abundance with subordinate amount of biotite. These micaceous minerals wrap round feldspars and quartz grains. The strike of foliation is parallel to the schistosity of neighbouring schists.

Near the overlying schists to the N, the gneissic bands grade into a schistose rock, farther away from the granite, and the transitional variety between gneiss and schist can best be described as feldspathic schist. This rock is more or less schistose, highly micaceous and contains small feldspar grains. The feldspathic schists fringe the gneisses as a narrow and irregular band. Good exposures of these rocks are found near Kevra (22° 27':73° 48') and also in the plains N of Raypur granite boss.

The gneisses have preserved at many places traces of minor folds and puckers which had affected the host rock, and quite often lineations related to this folding are recorded in these rocks. NW to NNW plunging lineations are mostly of puckers and mineral orientation types and these plunge with variable angles ranging between 25° to 60°.

The variation from schists to porphyroblastic gneiss through all the intermediate stages occurs across the strike of foliation. The porphyroblastic gneiss, developed in the innermost zone of contact aureole, gradually merges into a massive granite to the S on account of the increased development of randomly oriented feldspars in the gneiss. As the granite contact is approached, the rocks undergo advanced stages of granitization, the proportion of mica decreases and their parallel orientation is also gradually lost. With a gradual obliteration of gneissic foliation, porphyroblastic gneiss grades into a massive granite.

(ii) Hornfelses: These include all those rocks which show the typical contact metamorphic minerals like andalusite and cordierite and also show the development of hornfelsic textures in the otherwise regionally metamorphosed, low grade schists and phyllites. These rocks are exposed bordering the gneisses to the N and E of Intvada. These rocks appear as a E-W narrow band approximately 0.5 km wide near Intvada continues eastward and attains a width of about 1 km near Kevra. Further E the band pinches out S of Vishengarh.

The rocks that occur nearer to the gneisses form an inner zone of hornfelsic aureole. On the other hand, the schistose and phyllitic varieties away from the gneissic contact constitute the outer-most contact zone and have preserved in them the regional schistosity. The only change shown by the latter rocks is the development of andalusite porphyroblasts. The contact between these two varieties is gradual.

It is evident that the granite intrusion affected the rocks in the following two ways:

(1) Contact metamorphism giving rise to cordierite andalusite bearing hornfelsic rocks.

(2) Progressive migmatisation of the metamorphosed rocks, giving rise to gneisses.

The contact metamorphic rocks of hornfelsic nature containing cordierite, andalusite are ideally exposed around Kevra village. They extend upto Undhania gorge in the north. When traced from N to S across the width, it is seen that andalusite first appears as scattered porphyroblasts in schistose rocks, and then it gradually increases in size and abundance. It occurs as well developed prismatic crystals of more than 20 mm length (Plate III A). Unlike andalusite, cordierite is difficult to recognize in the field, but subsequent petrographic studies have shown that near the contact with gneisses to the S, these rocks contain more of cordierite than andalusite.

The phyllites that form the northern fringe of the hornfelsic rocks, are characterized by the sporadic development of andalusite porphyroblasts. These rocks being away from the granite have developed hornfelsic texture only in part and have considerably retained the impressions of regional metamorphism. Good exposures of these rocks are noted to the N of Intvada and Kevra in the form of thin band of a few hundred metres width. These rocks grade southward into andalusite cordierite hornfelses or gneisses and northward they are overlain by Narukot Quartzites.

Andalusite occurs as well formed crystals (upto 10 cm long and 2.5 cm in cross sections) showing square outline. The andalusites are invariably surrounded by two concentric rims of muscovite and chlorite, the inner rim of muscovite followed by an outer one of chlorite (Plate III B). This alteration of andalusite is obviously related to the hydrothermal action of the granite.

These rocks show relict foliation which strikes WNW-ESE and dips steeply due N. On account of the superimposition of an open NS flexure (N of Kevra) the strike shows almost NE-SW trend near the eastern extremity of the area. Very thin quartzite bands which are occasionally present in these rocks, show minor folds, which are generally tight, strike WNW-ESE, and their fold axes plunge steeply due NW.

(iii) Mica schists and chlorite schists: To the W of the above mentioned rocks, occurs a big exposure of mica schists and chlorite schists around Poyelli. It is so evident that these schists, which are the western extensions of the contact metamorphosed hornfelses, are relatively free from the effects of the granite, on account of the barrier provided by the lenses of quartzites to the S and E.

These are more or less schistose rocks with well developed mica and chlorite, and are seen to comprise two varieties, viz. micaceous (generally sericite or muscovite with subordinate biotite) and chloritic. Whereas micaceous types are light coloured, the chloritic types are grayish-green to green in colour. Although, these two types cannot be clearly demarcated in the field, in general the chloritic type is more developed in the immediate vicinity of the overlying Poyelli quartzites. Thin bands of green quartzites are also noticed in these rocks.

The foliation in these rocks is seen to extend WNW-ESE with moderate to steep dips due NNE, and is obviously an axial-plane cleavage related to the fold in which they occur. The folding of green quartzitic layers into steeply plunging tight folds is conspicuous. A number of small open flexures, trending almost N-S and related to the late folding are also encountered. It is on account of this late folding that the bedding planes and metamorphic foliation (in all the rocks of the eastern exposures) show conspicuous swings at several places between Poyelli and Vishengarh.

Poyelli Quartzites

Overlying the schists, hornfelses, etc. just described, a quartzite band forms an anticlinally folded big lensoid outcrop, the nose of which closes towards W (Gandhra anticline).

The quartzites are compact, cream-white to grayish-white in colour. Wherever these have come in contact with the granite viz. SSW of Intvada on the hill Δ 1240', they have changed over to a rather glassy looking rock. These quartzites are composed mainly of quartz with very subordinate muscovite, and occasionally, contain thin streaks of micaceous hematite. At a few places, bands rich in magnetite are also recorded e.g. between Vadali (22° 28' : 73° 44') and Poyelli.

From NW of Intvada, these quartzites continue for about 4.5 km eastward upto hill Δ 1158'. The thickness of quartzites along this band varies from 200 to 250 metres. This quartzite band shows a number of S shaped folds related to the Gandhra anticline. One such pair of anticline and syncline is recorded 1.5 km W of Intvada. Here the fold axis are seen plunging due WNW.

A few identical minor folds are recorded further west. On account of a late folding, this band of quartzites also shows the development of open N-S flexures. The strike of bedding therefore, fluctuates between ESE-WNW and E-W. This band obviously forms the northern limb of the major anticline. On this limb the dips of the beds of quartzites are quite high (75° to 83°) generally due N or NNW. Two NNW-SSE faults are seen cutting this quartzite band, N and NE of Poyelli.

The hill Δ 1158' (NW of Poyelli) and the exposures to its SW and S, mark the nose of the major anticline. Here the strike of the bed takes a swing due SW and then due N-S. The amount of dips decrease considerably and strata are seen dipping due NW, W and finally SW with rather moderate angles. After crossing the hinge, the strata take a turn to SE direction for a few hundred metres and then assume a strike of almost ESE-WNW. The dips on this southern limb are fairly steep and due South. Small and minor folds related to the anticline are frequently recorded along the hinge and on the southern limb. These folds plunge due WNW with moderate angles (from 25° to 50°).

An interesting phenomenon is seen to occur with these quartzites where they come in contact with the granites. The southern limb, when traced away from the hinge to the E, on coming in contact with the granite, is seen to have been stretched and broken into a couple of lensoid bodies. Also the granite appears to have pushed the quartzites northwards bringing about a swing in the strike from E-W to ENE-WSW with northerly dips, thus causing a local inversion of strata.

Both these lensoids of quartzites bordering the granite, are seen forming very distinct scarps, as high as 375 m. Some minor folds are present in these exposures but their orientations are quite erratic.

A few isolated occurrences of quartzites inside the granite mass to the E and SE perhaps represent the roof pendants of the Poyelli Quartzite, submerged in the invading granite. One such mass forms an isolated hill S of Naravaina (22° 26' : 73° 48') and rises to about 313 m above M.S.L. The quartzite, here, is highly recrystallized and it has become a glassy looking homogeneous rock.

Excellent sedimentary structures are preserved in these quartzites. The structures seen are the various types of current bedding and ripple marks. Uninverted current beddings are recorded practically all over the quartzite band (except where locally affected by the granites contact e.g. SE of Poyelli). Similarly, ripple marks are also ideally seen at a number of places. Excellent examples of all the three types of ripples viz. oscillation, current and linguoid are noted (Plate IV A & B). Oscillation ripple marks ideally occur on both the limbs in the hills N and S of Poyelli. Current ripples are also seen at several places. Linguoid type of ripple marks are noted in the quartzite hills SW and W of Intvada.

Upper Slates and Phyllites

The slates and phyllites that overlie the Poyelli Quartzites show ideal exposures around the village Gandhra. These rocks include a big lens of tremolitic limestone which has been described separately as the Gandhra Dolomite. It is obvious that on account of the underlying Poyelli Quartzites, these slates, etc. have escaped the effects of granite and show only a low grade regional metamorphism.

These phyllites and slates can be traced from NW of Intvada westward almost continuously through Poyelli to Gandhra and then upto Vau (22° 25' : 73° 43') in the SE of Gandhra. At its eastern extremity (near Intvada) these are seen going below the Narukot Quartzites. Upto Poyelli, they run westward, and then take a gradual swing to SW, then to S and finally to ESE, following the trend of the Gandhra anticline. Near Vau, the southern limb abuts against the granite, and has given rise to a narrow zone of recrystallized biotitic hornfelsic rock.

The bedding between Intvada and Poyelli is generally dipping due N. The amount of dips are quite steep NW of Intvada but westward the dips gradually decrease, and near Gandhra, the dips are very moderate (25° to 35°) due W. The southern band from Gandhra to Vau, shows dips due S or SW with steep angles or it is almost vertical.

The metamorphic cleavage (WNW-ESE) which is fairly steady shows either vertical dips or steep dips either way. Very interesting cleavage bedding relationships are shown by these rocks.

On the northern and southern limbs, the slaty cleavage makes a very small angle with the bedding, while in the region around Gandhra on the nose of the anticlinal structure - the cleavage-bedding are almost at right angles.

These metapelites chiefly consist of dark slates, chloritic phyllites and sericite schists. Associated with slates, occur bands of compact and massive argillites. The slates are generally dark grey to steel grey in colour, and contain occasional cubes (3 to 4 mm) of limonite pseudomorphed after pyrite. These slates are ideally exposed around Gandhra Village. Further E towards Intvada, the slates tend to be more of the nature of sericite schists. Chloritic phyllites are seen to have developed SE of Gandhra. From here upto Vau, these occur in intimate association with the slates. Near their contact with the granite, these slaty phyllites have developed 100-200 m wide zone of dark brown biotitic rock.

These rocks form a striking inlier W of Gandhra in the deep valley cuttings around Kuivav (22° 26' : 73° 40'). Very deep channel has exposed these rocks in the heart of the Narukot quartzites, the outcrops of which occur only on the hill tops. This band of slaty phyllites runs almost parallel to the main Gandhra exposures. Fine parallel laminations are preserved to show the sedimentary beddings. These laminations show colour variation in different shades of grey.

All throughout the various exposures, these slates, phyllites, etc. show well developed lineations, parallel to the axes of the regional folds. In most cases, the lineation is the cleavage bedding interesection type, and is seen to impart a very distinct striation to the foliation surfaces. Alternatively, wherever, the sedimentary bedding is well preserved, the lineation is quite often characterised by a fine micro-folding or corrugation of the laminations. In addition, distinct minor folds also are recorded, with their axes showing a rather constant orientation. Most of these fold-axis lineations plunge with moderate angles due WNW to NW. It is significant that minor folds, in the exposures near Intvada, are fairly tight as compared to those occurring in the west. However, the orientation of the axis and axial-plane remains the same, and obviously the regional folds (with associated minor folds) have been tightened in the eastern part.

Gandhra Dolomites

This dolomite occurs as a conspicuous 0-1000 m thick lensoid band inside the above described metapelites. It can be traced more or less continuously from NE of Vadali following the trend of the major anticline. While the northern limb of this fold shows an E-W strike and dips above 60-70 due N, the southern limb extends from Gandhra due SE with very steep dips to the SW. Unlike the Poyelli Quartzites and the enclosing slates, this dolomite formation has become completely massive and structureless in the hinge area of the anticline. Bedding has been mostly obliterated and other structural elements are also few. This dolomite is cut by a strike-slip fault NW of Gandhra, which runs due N 58° W and shows dextral movement (Gandhra Fault).

The eastern extremity of the southern limb of this dolomite has come in direct contact with the granite (N of Vau), and it is so obvious that the granites have truncated this band. Near Gol Dungra (Jothwad), the rocks are dolomitic limestones and the reaction between this dolomitic limestone with the granite has given rise to interesting skarn assemblages at Jothwad hill (22° 24': 73° 44') about 3 km S of Vau. The dolomitic limestone, here, has been highly modified by the surrounding granites. Considering the highly folded nature of the dolomitic limestone here, it appears that somewhere SE of Vau, the Gandhra Dolomite formed another (synclinal) fold hinge, but the same is now difficult to observe on account of the granites. It is seen that the entire limestone patch here was considerably rotated as the fold axes of the numerous anticlines and synclines at Jothwad are seen plunging due N.

The Gandhra Dolomite shows greenish grey to dirty white colour. Its weathered surface assumes darker shades in grey, yellow and brown. Sedimentary bedding is only occasionally preserved, and in hand specimen, in addition to carbonate minerals, quartz, actinolite, tremolite and talc are easily recognized (Plate V A). Depending upon the presence or absence of these minerals and in their relative abundance, the appearance of the dolomite varies from place to place. Crystals of dolomite are recognized on weathered surface by their brown colour. NNW of Gandhra, at Ranjitpura (22° 27' : 73° 41'), talc occurs in such abundance that for a few years a small quarry was opened to exploit that mineral. The rock at this place contains mainly talc and dolomites (Plate V B).

Within this dolomite, several small layers (few cm to a meter thick) of jasper rock are present in the area N of Poyelli. Similarly, these dolomites contain occasional layers rich in iron ore (hematitic)and various manganese ores. Such occurrences are ideally recorded near Ranjitpura and Poyelli.

Affected by the intrusion of granites and pegmatites, the dolomitic limestone at Jothwad hill, is seen transformed into remarkable assemblages of various calc-silicate minerals like wollastonite, diopside, garnet, epidote, phlogopite, scapolite, tremolite, sphene, etc. The interaction between manganese bearing argillaceous rock, occurring with limestone and the intrusive granite has given rise to various manganese minerals like winchite, blanfordite, piemontite and mangano-phyllite.

The wollastonite bearing rocks are restricted to contact zone between limestone and intrusive granites. These rocks are white in colour, coarsely crystalline and contain numerous blades of wollastonite. The blades are arranged in the form of bunches, patches and veins. Away from the contact, this wollastonite rock grades into an assemblage of diopside, garnet, epidote and phlogopite. The inner zone contains tremolitic limestones.

MIDDLE CHAMPANERS

Succeeding the Gandhra group of rocks, is an interesting sequence of pebbly quartzites, slates, graywackes and protoquartzites. The lithology, depositional structures and shapes of the rock bodies amply reveal the deposition of the whole group under an environment characterized by basin instability. Most of the formations of this middle group, are lenticular and tend to progressively overlap the formations below. The succession shown by these rocks, is as under:

Bamankua Limestones

Shivarajpur Quartzites and Phyllites
(with manganese ores)

Bhat Slates

Jaban Conglomeratic Graywackes

Jaban Slates

Narukot Quartzites

NARUKOT QUARTZITES

The Narukot Quartzites are the most conspicuous and widespread formation. All throughout its extension, the thickness of this formation is seen to remain fairly constant, though its outcrop shows variation in areal extent on account of the fold pattern.

The quartzites outcrop over extensive areas, and form a somewhat hookshaped wide exposure west of Gandhra. Here, these form a huge west plunging anticline (Gandhra

Anticline). The northern limb of this fold extends eastward fringing the Lower Champaners, for 19 km, showing a fairly straight strike. The southern limb shows some very interesting structures. Near Vau, it is seen truncated by the granites, a few of its remnants are seen "floating" in the granites. These quartzites are again encountered N of Narukot (22° 23' : 73° 42') where they form a interesting oval dome. Further south, these quartzites are seen outcropping continuously from S of Narukot to Richhbar (22° 23' : 73° 36') in the W, forming conspicuous hills to the S of the highway.

These quartzites rest over the Lower Champaners with a distinct disconformity, and the junction is characterised by the presence of thin (100-150 m thick) conglomeratic horizon recorded at several places all along the base of this quartzite formation.

The conglomerates occur as lenticular bodies ranging from few metres to 2 km in extent. Their thickness are much restricted and range upto 30 metres. The pebbles are mostly of white and grey quartzites, vein quartz and phyllites. The quartz pebbles are rounded to sub-rounded while those of slates and phyllites are angular.

The matrix is usually arenaceous but argillaceous (phyllitic or chloritic) matrix is also common, and depending on its nature, the rock shows grayish-white, brownish or greenish colours. These conglomerates tend to merge into quartzites upwards.

In all 5 such lenses of conglomerates have been mapped (Fig.1.). Ideal exposures are seen at Kevra, Intvada, Vadali, Poyelli, Gandhra and Narukot. Sedimentary bedding is generally not so clearly recognised and when present, it is characterised by a variation in grain size only. Current bedding is occasionally recorded. Good examples of current bedding shown by the sandy matrix of these pebbly beds are seen at Gandhra. In this area, well defined cleavage cuts across the strike of these conglomerates. Cleavage has developed only in those parts of the conglomerates where matrix is dominantly argillaceous.

On the whole, the effect of deformation and metamorphism is confined to the matrix only. However, the pebbles in the conglomeratic lens at Vadali in the NE, have developed strong cleavage parallel to the stratification and they show considerable flattening along the cleavage (Plate VI A).

The author traced such conglomeratic beds even outside the study area to the south and he found that the nature of the matrix affords ideal clues to the source rocks which gave rise to these conglomerates in different parts. While the matrix of these pebbly rocks occurring within the study area, is mostly arenaceous to argillaceous, that in the similar rocks exposed further S at Pipia (22° 19' : 73° 43') about 15 km S of Narukot,is found to consist of quartz, feldspar and muscovite, obviously indicating a granitic provenance - the nearby basement gneisses.

The main mass of quartzites that form a vast formation, in fact, represent an important event in the geosynclinal depositional history of the Champaner Series. As already stated, these rest over the underlying rocks with a disconformity - characterised at several places by intervening lenses of conglomerates just described. Wherever, the conglomerates occur, they gradually pass upward into the quartzites. At other places, the quartzites come in direct contact with successively older formations.

For the most part, these are metamorphosed orthoquartzites (i.e. sandstones composed largely of pure quartz sands). The original rock must have been a fine to coarse grained sandstone tending to be pebbly at several places (Plate VI B). The pebbles, when present, are sub-rounded to rounded and the sandy matrix shown a wider range from sub-angular to rounded. The pebbles are generally those of quartz only. Usually creamy white or dirty grey in colour, these quartzites show almost constant presence of small specks of iron ores-hematite and magnetite. Occasionally, the concentration of these ores, has given rise to highly magnetitic and hematitite quartzites. Such bands occur almost all throughout the formation.

These quartzites are seen to become flaggy in their upper part. On account of gradual increase of the argillaceous matter, these rocks have been rendered softer and show darker shades of colour. This upper part obviously indicates a transition to the overlying slates.

This quartzitic formation, extending practically from one end of the area to the other, has a vast areal extent, compared to which its thickness is quite small. Its continuous and widespread occurrence clearly indicates a 'blanket type' of beach deposit (Krumbein and Sloss, 1963, p.550). Its thickness, extent, lithology, texture and various depositional structures, furnish valuable data so vital for a proper understanding of the environments under which the Champaner Series was deposited.

The Narukot quartzites show excellent folds on regional scale. They form a somewhat triangular exposure W of Gandhra, constituting the nose of the W plunging Gandhra anticline, and are seen to have folded into several smaller anticlines and synclines all plunging due W or WNW. Sedimentary bedding, accordingly in this ore show considerable variation.

An interesting modification of another anticline in these quartzites is seen at Narukot where an oval shaped dome structure has developed. This closed structure, obviously has formed on account of the pushing effected by the granites.

The band of these quartzites that extends from Gandhra eastward, show numerous gentle N-S flexures, evidently representing an effect of the late folding.

This folded outcrop is cut at three places by a series of three almost parallel (N 58° W - S 58° E) strike slip faults, two of which (Gandhra and Kuivav faults) showing dextral movement and the third (Vau fault) showing sinistral movement. These dislocations are quite conspicuous. Two of the three faults extend for about 3 to 4 km while the southernmost is seen to run for 8 km or more. Between Gandhra and Vishengarh, five small faults cut these quartzites. When traced from W to E, the first four faults about 1 km in extent, are seen to strike almost N-S or NNW-SSE. The one at the extreme E (N of Kevra) strikes NE-SW.

These quartzites show good development of sedimentary structures which are enumerated below:-

(i) <u>Cross stratification</u>: All throughout, these quartzites show abundant examples of various types of cross-stratification, the most common being, the terrential or tabular type (Plate VII A). Ideal occurrences are noted at several places between Gandhra

PLATE I

A. Basal conglomerate with pebbles of jasper and quartz.

B. Basal conglomerate showing weak graded bedding.

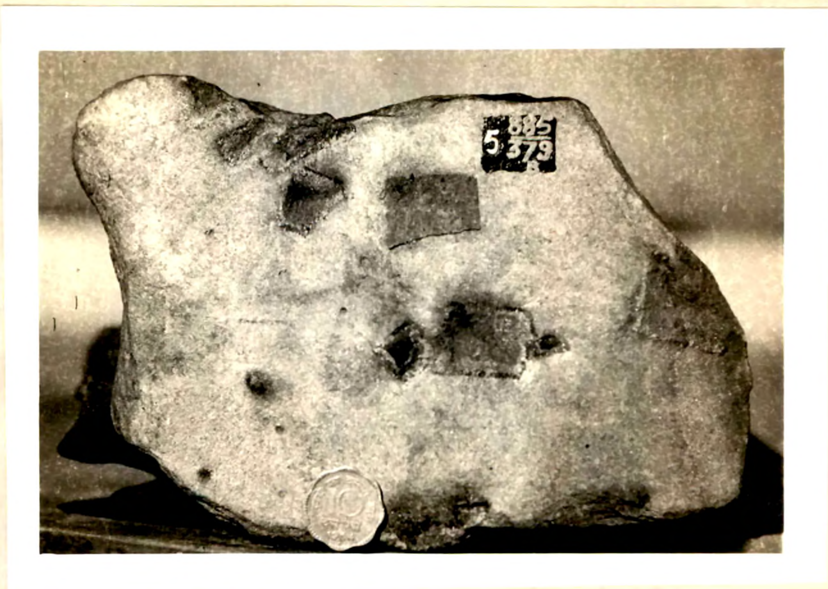
PLATE II

A. Gneiss from Intvada showing feldspar porphyroblasts.

B. Augen-gneiss from Intvada showing augens of feldspars.

PLATE III

A. Prismatic andalusite in hornfels.



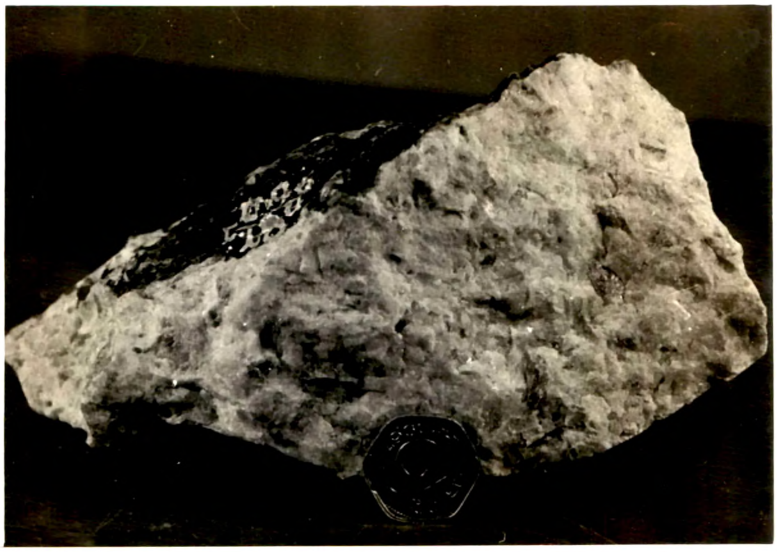
B. Andalusite showing concentric rims of muscovite and chlorite.

PLATE IV

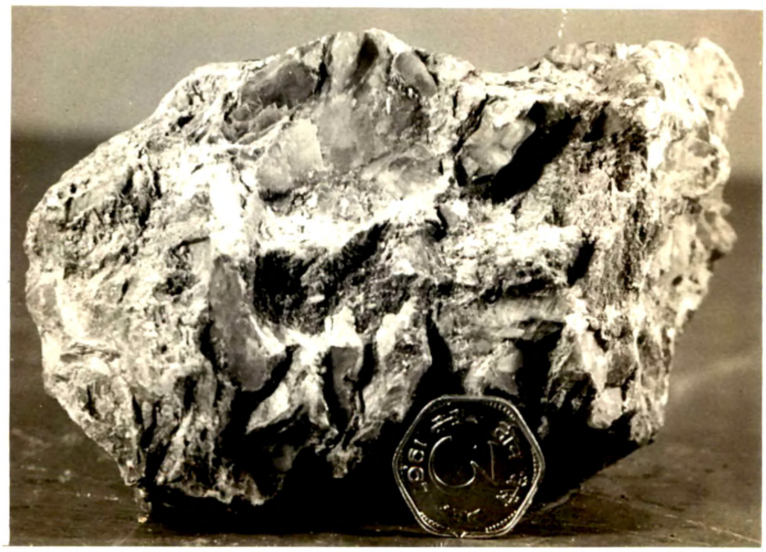
A. Oscillation ripple marks in Poyelli Quartzites.

B. Linguoid ripple marks in Poyelli Quartzites.

PLATE V



A. Tremolite-bearing Gandhra Dolomite.



B. Talc-bearing Gandhra Dolomite.

PLATE VI

A. Flattening of pebbles along cleavages
in Narukot Quartzites.

B. Pebbly sandstone (Narukot Quartzites).

PLATE VII

A. Cross-bedding in Narukot Quartzites.

B. Current ripple marks in Narukot Quartzites.

PLATE VIII

A. Oscillation ripple marks in Narukot Quartzites.

B. Current ripple marks in Narukot Quartzites.

and Intvada. Occasionally, lenticular type of cross-stratification also met with.

(ii) <u>Ripple marks</u>: Widespread occurrences of ripple marks both oscillation as well as current, are recorded from all parts of the quartzite formation (Plates VII B and VIII A,B).

(iii) <u>Overlap</u>: The various younger formations higher up in the succession show a progressive overlap, and successively rest directly on these quartzites. When traced from S to N, it is seen that from Richhbar to Bamankua (22° 27' : 73° 37') through Narukot, these quartzites are overlain by the Jaban slates. Beyond, Bamankua upto Dharia (22° 28' : 73° 40') the graywackes rest directly over these quartzites. Beyond Dharia for about 2.5 km, the next younger formation, Shivarajpur Quartzites and Phyllites come in contact with these quartzites. Finally, further E right upto Pani Mines (22° 29':73° 49') the youngest formation, Rajgad slates rest over these rocks. Beyond this, a lenticular patch of graywacke again intervenes between Rajgad slates and Narukot quartzites.

(iv) Cut and Fill Structures: These structures have developed at many places in the upper part of the formation. These are small channel like structures, scoured by currents and filled subsequently by relatively coarser sands.

JABAN SLATES

The formation that overlies the Narukot quartzites, is dominantly argillaceous. It occupies large areas to the N and S of Jaban (22° 24':73° 39') and forms a 'M' shaped folded, lenticular outcrop. Its two flanks are relatively thinner (400 m thick) while the portion around Jaban is the thickest with a total outcrop width of 3.5 km.

Another smaller lenticular body of the same formation is recorded S of Undhania (in the NE) where it occurs above Narukot quartzites and below the graywackes.

The constituent rocks are slates or slaty phyllites. The lower portions of this formation, are dominantly made up of alternating layers and laminae of silty and shaly material. The silty laminations show light colours while those of shales are greenish-grey or dark grey. Quite often a regular gradation from silt to shale marks individual beds, which themselves are quite thin.

An important sedimentary character shown by these laminated rocks is the breaking up of light coloured layers into plano-convex segments (Plate IX A) such structures known as 'flaser bedding' are produced in the zone of intermitant turbulence (Pettijohn, 1957, p.367). At several places, these graded laminations show distinct sole marks. Broad 'U' shaped channels and grooves excavated in the underlying bed are seen filled with the silty material of the succeeding layer (Plate IX B).

This laminated variety grades upward into a rock containing darker material. The frequency of light and grey bands decreases and the rock is seen to be dark grey or almost black. The laminations are not so well marked as the individual laminae do not show much variation in content and colour. At a number of places, the colour of the rock is found to be steel-grey on account of the presence of graphite. Such rocks have developed very good slaty cleavage.

The topmost portion of this slaty formation just below the overlying graywackes comprises a fairly massive, non-fissile, black rock which can best be described as an argillite. Laminations are very indistinct, and can be seen, occasionally, only on the weathered surfaces. These argillites are hard and compact, and break into angular fragments. Biotite flakes impart a somewhat shining lustre to the rock. Small disseminated yellow grains of pyrite are also present. The junction between these argillites and the overlying conglomeratic gray-wackes, shows numerous structures of penecontemporaneous deformation. Frequently, convolute overturned folds are recorded. Examples of brecciation during deposition also abound. One such typical example is recorded S of Narukot where the underlying rocks are seen grading upward into rocks of graywacke nature. Flat angular fragments of underlying argillites and slates, are seen incorporated in the graywacke above. Blanford (1869, p.42) was very much intrigued by this occurrence and he was not sure whether this phenomenon suggested a brecciation due to secondary deformation or was a sedimentary feature.

It is so obvious that rounded pebbles of quartz and granite brought from some distance got mixed up with angular fragments of underlying argillites and slates, locally picked up, giving rise to an intraformational conglomeratic layer. Evidences of such sedimentary brecciation are noticed intermitantly all along the contact of the Jaban slates with the overlying conglomeratic graywackes.

The Jaban slates have come in contact with the intrusive granites at two places viz. E of Narukot and E of Vadek (22° 24':73° 42'). At both the places, the contact effect has considerably modified these rocks. The contact metamorphism has given rise to 500-600 m wide zones parallel to the granite contact, which show considerable recrystallisation and development of chlorite and biotite. At Vadek, the sedimentary structures are completely obliterated and the rock has assumed a coarse, reddish brown appearance. E of Narukot, the original lithological variations are still preserved although the rock is completely recrystallised. Here, more siliceous (sandy or silty) bands are seen alternating with those containing biotite and chlorite.

Structurally, the entire slaty formation, forms two synclines - one along Vadek - Borkas and another along Malbar Katkua. These synclines are closing due E with an intervening Narukot-Shivarajpur anticline, and they all plunge due W. On account of the force of intrusion of the granite mass, the hinges of the synclines have been considerably disturbed. Sedimentary stratification as already mentioned, is more pronounced in the lower part of the formation, and is clearly recognised practically all over the exposure. The variation in the strike and dip is controlled by the fold patterns.

The metamorphic foliation of the nature of slaty or phyllitic cleavage, cuts the sedimentary beddings at various angles depending on whether readings are taken on the limb or hinges. This cleavage is fairly steady showing a strike varying between WNW-ESE and NW-SE, the dips being vertical or steep generally due SW.

Abundant microfolding of the laminae related to the regional structure, is recorded in all parts of this exposure of the Jaban slate formation. The resulting corrugations have given rise to a very pronounced lineation plunging due WNW to NW. The angle of plunge varies between 25° to 35°. Another related lineation characterised by the intersection of cleavage and bedding, is also widespread and shows an identical orientation.

A prominent fault (Jaban-Shivarajpur Fault) cuts these slates in the south. It strikes due NW-SE and can be traced for 3 km parallel to the road from Narukot to Jaban. In fact, the fault extends further upto Shivarajpur and cuts all the overlying rocks also.

JABAN CONGLOMERATIC GRAYWACKES

The Jaban Slates are overlain by rocks belonging to a graywacke suite. As pebbly horizons are quite common in these graywackes, they have been designated as conglomeratic graywackes. These rocks are exposed in two main patches:

(i) E of Shivarajpur between Jaban and Dharia.

(ii) E of Pani mines near Undhania.

As will be seen in the subsequent account of rocks from the two different group of exposures, each represents separate local basins of deposition characterised by distinct lithology and sedimentary structures. In fact, study of these rocks has helped the author considerably in working out the environment and conditions of deposition of the Champaner Series.

Outcrops around Jaban

Out of the two exposures, that near Shivarajpur (22° 25':73° 37') is the most prominent one. It forms a zigzag folded lenticular band of 24 km length, and occupies considerable ground in the western part of the area. In the W, graywackes are seen forming a 4.5 km wide, E-W exposure extending upto Malbar (22° 23':73° 40') from where its outcrop appear northward following a sinuous pattern, and ultimately near Dharia, these are seen to thin out and go below Rajgarh Slates. Maximum development of these rocks with good exposures are recorded around Malbar, Jaban, Bhat (22° 25':73° 38') and Borkas (22° 25': 73° 40'). About 2 km NW of Borkas, the underlying Jaban Slates pinch out and, beyond this part northwards, the graywackes are seen resting directly over the Narukot quartzites. Eastward, beyond Dharia, after a gap of 2 km, these graywackes are again encountered as a thin (300 m) lens 2.8 km long resting over the Narukot quartzites and lying below the Shivarajpur quartzites and phyllites.

These were the rocks well exposed along the highway between Jaban and Bhat, that Blanford came across during his traverse (1869, p.41,42) and was struck by their peculiar nature.

The formation comprises a highly pebbly rock, the lithology of whose matrix shows a gradual change upwards from dark graywacke through sub-graywacke to gritty protoquartzitic type. The rock consists of a number of pebbly and bouldary lenses occurring in a poorly sorted and variegated matrix (Plat X A). The rock fragments that constitute the pebbles and boulders range in size from a few millimetre to several centimetres. These rock fragments are of vein-quartz, quartzite,granite-gneiss, shales, slates, phyllites and crystalline dolomitic limestones. The shale fragments of original nature are now represented by slaty or phyllitic types on account of metamorphism. All these slaty and phyllitic and limestone fragments show flattening and stretching along the foliation, while those of quartz, quartzite and granite-gneiss are more or less rounded either ellipsoidal or irregular in shape (Plate X B). Most of the slate and phyllite pebbles have developed cleavage that almost coincides with the metamorphic foliation induced in the matrix. Some interesting pebbles and boulders of slates and phyllites collected in the field were found to enclose within them yet smaller granite and quartz pebbles. Occurrences of such 'pebble within pebble' are typical of environments that give rise to graywackes.

The matrix on the whole is coarse and generally consists of small sub-angular to angular fragements of the same rock types that constitute pebbles and boulders. It consists, also, of angular feldspars, quartz, micas, chlorite and other accessory minerals bounded together by argillaceous material. Near the base of the formation, the matrix is rather fine grained and highly argillaceous. In fact, a sort of transitional contact exists with the underlying Jaban slates, and the graywackes that overlie them, are obviously derived from the slates with increased proportion of sand-size grains of feldspars, quartz, micas, and other minerals together with the rock fragments.

Wherever these graywackes are resting over the Narukot quartzites, the contact is rather sharp and the change of lithology abrupt.

It is observed that the dark clayey material from the matrix decreases upwards and the rock passes to a sub-graywacke stage; and finally near the top, gritty arkosic rock of the nature of protoquartzite with abundant white mica predominates. The rock, here, is light in colour and represents the uppermost lithology of the graywacke suite. The pebbles and boulders of granite-gneiss, quartzites, dolomitic limestones and slates are still present but in considerably decreased number. An important feature of this uppermost protoquartzitic portion is the presence of sub-angular pebbles and boulders of dark gritty rock obviously the fragments of the lower members of the same suite to which this protoquartzitic rock belongs.

However, the gradation between the two end-members, viz. graywackes and protoquartzites, occupying the base and the top respectively of the entire formation, does not represent a single gradual transition, but the whole formation significantly consists of several cycles of graded deposits each cycle starting with a dark, coarse gritty rock containing pebbly horizon and culminating into a finegrained rock almost like an argillite or slate. The pebble content too gradually decreases from bottom to the top of each unit. They sometimes indicate penecontemporaneous erosion. The successive units when traced from bottom upward, show gradual decrease in dark argillaceous content and increase in the quartz, feldspar and muscovite so much so that, the dark graywacke changes over to protoquartzite near the top.

Like lithology, the sedimentary structures, too, show variations from bottom of the suite to its top. Sedimentary brecciation and intraformational conglomerates abound in the bottom horizon. Intraformational conglomerates show typical 'pebble-within-pebble' structure. The graded bedding on all scale is quite conspicuous in the lower half of the formation. Even the conglomeratic lenses show a distinct grading. Bigger boulders abount at the base of an individual lens and their size and number gradually decrease upward and ultimately they disappear and the rock merges with the gritty matrix; of course, small pebbles occur sporadically throughout. Just like the pebbly horizons, the matrix, too, shows gradation from coarse sand to silt or clay size particles; and the entire formation is seen to consist of several such graded units. Cross-bedding and ripple marks are not recorded till the lithology is transformed into arkosic or protoquartzitic type in the upper horizons. Here also these structures are not very abundant and have been recorded at a few localities in Bhat and West of Katkua (22° 23':73° 39') only. The ripples are of oscillation types and indicate the beds to be right side up. Current bedding is faint. Graded-bedding is absent.

Stratification in these graywackes is always coarse and indistinct. On account of the peculiar texture and lithology, it is rather difficult to measure the dips and strikes of bedding precisely. Moreover, the deformation and metamorphism, have considerably obliterated this sedimentary structure. A strong cleavage has developed at many places, and is more pronounced than the bedding.

This formation between Bhamaria and Malbar extend roughly WNW-ESE and dip about 50° to 80° due ENE. N of Malbar, right upto Dharia, the rocks show fluctuations in strike and dip, because in this region they form a number of west plunging anticlines and synclines. The metamorphic cleavage has abundantly developed in these folded parts, and are seen cutting the bedding at various angles. Its strike remains fairly steady WNW-ESE, and is always steeply dipping N or S or is vertical.

The entire exposure has been affected by two dislocations: (i) N of Bamankua (Vau fault), (ii) along Jaban-Bhat section - (Jaban fault). In addition, the rock is traversed by several sets of joints out of which those striking NS are of special interest. The pebbles show small dislocations along these fractures (Plate XI A). These show sinistral displacement of a few mm. There are a few another joints striking NE-SW, perhaps showing a conjugate relationship with the above and these also show dextral strike slip of a few mm. Sometimes the slipping is as much as 30 cm.

Outcrops near Undhania

A lensoid formation of graywackes with usual pebble content, and of much smaller extent occurs in the extreme NE. Its outcrop runs for about 4-5 km roughly in an E-W direction, its maximum thickness being about 1.5 km in its middle part. Its upper contact with the Rajgad Slates is not exposed on account of soil cover, but downwards, it is seen resting over Jaban Slates which it overlaps and directly overlies Narukot quartzite at the two ends. Sedimentary bedding is very clear and is seen to be almost vertical or dipping steeply due N (Plate XI B).

The constituent rock types here consist of graywackes, gritty mudstones and shales, embedded with pebbles of quartzite, gneiss, limestone and phyllite. The lower most portion of this formation has contains frequent lenses of somewhat calcareous matrix which in its present metamorphosed form can best be called as calc-schist consisting of calcite, actinolite, tremolite, chlorite, quartz, and feldspar.

The pebbles of varied rocks are seen concentrated in lenses and bands which show a distinct gradation in size and number upwards. The matrix is also equally variable, but shows a haphazard distribution, and unlike the Bhat-Jaban exposures, no lithological gradation exists. The characteristic presence of disseminated grains of pyrite is noted all over.

The formation shows a good variety of the sedimentary structures. They are better developed where the coarser layers alternate with fine grained types. In general, the parallel stratification is well marked and is characterized by layers of varying particle size. The stratification features include graded-bedding, parallel laminations in graded-beds, graded cross-laminations and slump structures like minor folds, faults, etc., convolutions, intraformational conglomerates and breccias. Sole-markings in the form of small flute-casts are only sometimes present.

The entire formation comprises a thick sequence of a large number of graded beds, each bed consisting of an upper silty or clayey layer and the lower consisting of coarser graywacke (Plate XII A). The gradation from graywacke to siltstone takes place within a vertical distance of a few millimetres. The contact between the successive lower bedding planes of graywackes and the upper bedding planes of the siltstones, lying immediately below the former, are quite sharp.

This structure is best observed on weathered outcrops. The differential removal of softer and unstable material such as calcite, feldspars, and chlorite along with the argillaceous and calcareous cement from the graywacke part of a graded unit leaves behind the resistive quartz-grains and few feldspars to stand out in relief. The graded arrangement is readily seen in hand-specimen because more silty or clayey counterparts are less affected by this weathering. Freshly exposed surfaces of this rock is somewhat shining and uniformally dark black in colour, and it is only on a close scrutiny that the variation in grain size is detected. This indicates a thorough mixing up of interestitial finer clayey particles with those forming coarser fractions throughout the lower part of each couplet of graded bed. The lower layer gradually passes into upper one on account of improved sorting and increasing finer detritus. The visual estimation from weathered surfaces shows that unstable material (including argillaceous and calcareous cement) makes up more than 25% of the bulk composition of impure sandstone, and aids to designate the rock to be graywacke. In each couplet of a graded-bed, the lower, coarser layer consists of identifiable fragments while the above one is fine. The deposition of various graded beds is somewhat rhythmic, and resembles varve pattern. Thickness of coarser bands is generally 1 to 3 cm , while the finer top varies from 1 to 2 cm. In several samples, lower and upper portions have equal thickness. The coarser portions show increased thickness in the upper part of the formation, and ultimately the whole rock as such becomes coarse upwards.

Fine parallel laminations (micro-banding) occur in each graded bed. These maintain complete parallelism with the bedding planes. They range in number from 5 to 10 in upper silty layer of the couplets. Such fine laminations are generally scarce in the lower graywacke part, but not totally absent. Usually, each laminae is about a mm or less in thickness, and shows progressive decrease in grain size upwards. The presence of a such graded laminations in the finer layer and their relative absence in the coarser counterpart indicates rapid deposition (Steward, 1962,p.402). Such laminations have been described also by Dewey (1962, p.247) and Kingma (1960).

Cross-lamination, though not very frequent, is occasionally present, in coarser graywacke portion of the beds. This structure is best seen on differentially weathered surfaces. The cross-stratification do not continue for distances longer than a metre or two.

Instances have been recorded where a normal graded-bed replaces cross-laminations within a distance of a few metres only. The more interesting feature of this cross-bedding is that each of its foreset is itself graded, and is coarser at the base and gradually becomes finer upward till another forest comes to rest over it, repeating once again the same grain-size distribution.

Convolute bedding is frequent especially in the middle part of exposure. The convolutions in most cases end up in widespread fracturing, the place of convolutions taken up by a narrow zone consisting of much broken fragments. The shapes of the convolutions are quite variable and comprise overturned folds, recumbent folds or complex and even closed forms. Convolutions appear to have originated due to either the flowing currents over still plastic bed-material before the deposition of the overlying layer or resulted on account of a creep along a bottom slope.

Slump structures affecting more than one strata are also common. They include folded, faulted and fragmented beds. Uppermost parts of this structure show brecciation and overthrusting (Plate XII B) followed in lower portions by isoclinal type of folding which opens up gradually, and dies out in still lower portions. The other conspicuous slump features are the normal faults of very small displacement. These "micro-faults" cut through both the graywacke and siltstones. The fact that these micro-faults are confined to a single band and that the grains (in graywacke) are not broken along the faults, indicate penecontemporaneous deformation before complete cementation of grains. Stretching due to sliding could have been responsible for the formation of such faults. Yet another type of brecciation associated with slumping is seen in the occurrence of caught up halls and pellets of underlying rock.

BHAT SLATES

The slaty formation that overlies the graywacke suite is of very limited extent and occurs as a M shaped folded lens, having its maximum development of 1 km near the village Bhat. As in other formations, the width of these slates is maximum in fold cores and laterally it pinches out. The constituent rock is a uniform slate of dark-gray to greyish-black colour. It shows a characteristic shining lustre on cleavage surfaces. Occasionally, slates tend to be phyllitic, and these show lighter a colour- light gray to dirty white.

Near its contact with the underlying protoquartzitic rocks, the sedimentary beddings are very clear. They are represented by alternate laminations of different colours, the gray colour generally predominating. These phyllites contain manganese nodules in their upper part. These nodules rather elongated measure upto 15 cm and even more along their longest axes. They show almost parallel orientation with the bedding planes (Plate XIII A).

The lensoid outcrop of these slates around Bhat, is intensely folded, giving rise to one anticline and two synclines. The cleavage that has developed coincides with the axial plane of these folds.

Though the rock is highly cleaved, at many places the original stratification is quite distinctly preserved (Plate XIII B). The intersection between cleavage and the bedding has produced a prominent lineation which is seen to plunge due WNW, coinciding with regional fold axes.

SHIVARAJPUR QUARTZITES AND PHYLLITES

The next overlying formation comprises a group of interbedded quartzites and phyllites containing ores of manganese. These rocks are seen to form three distinct lenses, the major one occurring in the western part of the area. About 11.5 km in length, this lensoid outcrop shows a zig zag pattern of roughly 'S' shape. It extends from Bapotia (22° 24':73° 36') in the SW, to as far as village Taldori (22° 28':73° 38') in the N where it pinches out. The maximum thickness of this formation is about 800-900 m in the folded, hinges of anticlines and synclines at Shivarajpur. The Bhat Slates underlie this formation only in the southern half of the band, and beyond which these rest directly over the graywackes.

E of the village Dharia, another lens of these interbedded quartzites and phyllites is encountered. Much smaller in extent and thickness, here, these rocks are seen resting directly over Narukot Quartzites on their two flanks, while in the middle, a thin layer of graywackes intervenes between these and the Narukot Quartzites. Folding is rare in this outcrop except to one flexure recorded near Dharia. Yet another lensoid band of this formation is exposed further E, near Pani (22° 27':73° 48') and here, it rests over the Narukot Quartzites and Jaban Graywackes, in the W and E respectively.

The rocks in the Shivarajpur band are mostly pink and grey phyllites alternating with interbedded quartzites. The pink variety of phyllites predominates. The anticlines and synclines into which these are folded plunge due WNW (Plate XIV A). These folds are open to moderately tight and rather asymmetrical.

The phyllites have developed two types of cleavages. In those portions where the quartzites are thicker and predominent enclosing the pelitic layers, the cleavage that has developed is parallel to the bedding. Obviously, this is a case of flexural-slip. On the other hand, portions with thicker phyllites, show typical axial plane cleavage running WNW-ESE and cutting the bedding almost at right angles in the hinge areas (Plate XIV B). Considerable stretching in this axial plane direction is shown at several places by stretched and boundinaged quartzite layers.

The various manganese ores that occur associated with these rocks at Shivarajpur, have been identified by Rasul (1964, 1965) as polianite, pyrolusite, cryptomelane, wad, braunite and manganite. Both primary and secondary ore bodies exist.

The primary (metamorphic) ores are braunite and some pyrolusite, while the secondary ores are pyrolusite cryptomelane, manganite and polianite. The presence of botryoidal, mamillated, nodular, colloform, tubular, dendritic, kidney-shaped and pisolitic forms indicate secondary origin, perhaps a process of replacement and

PLATE IX

A. Flaser bedding in Jaban Slates.

B. Groove-cast in Jaban Slates.

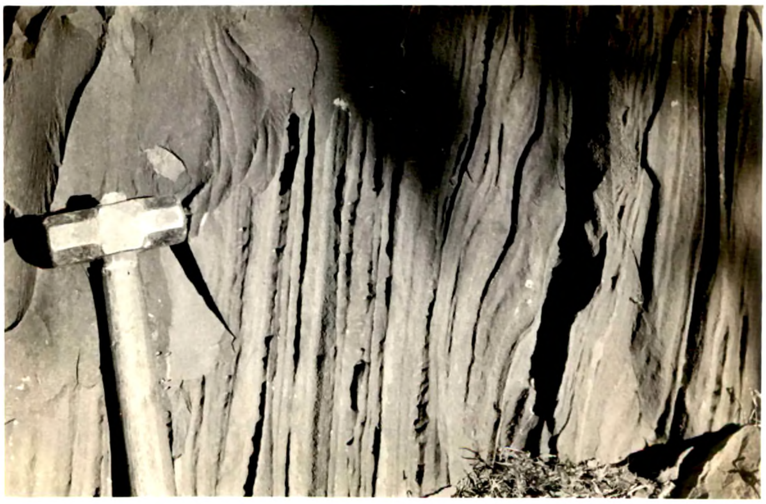
PLATE X

A. Pebbly and bouldary lenses in gray-wackes.

B. Pebbles of different rock types showing varying degree of flattening.

PLATE XI

A. Pebbles showing slipping along fractures in graywackes.



B. Vertical bedding in graywackes at Undhania.

PLATE XII

A. Graded bedding in Undhania Graywackes
showing coarse and fine couplets.

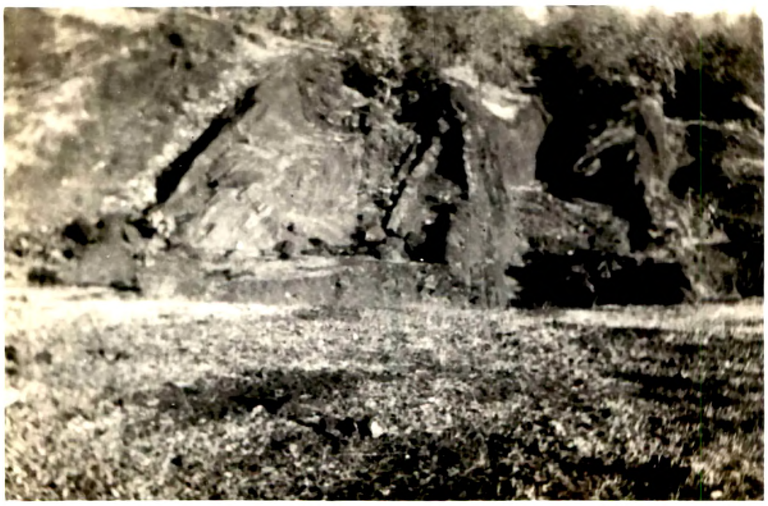
B. Slump structures in the graywackes at
Undhania.

PLATE XIII

A. Deflection of bedding due to manganese nodules, in Bhat Slates.

B. Stratification in Bhat Slates.

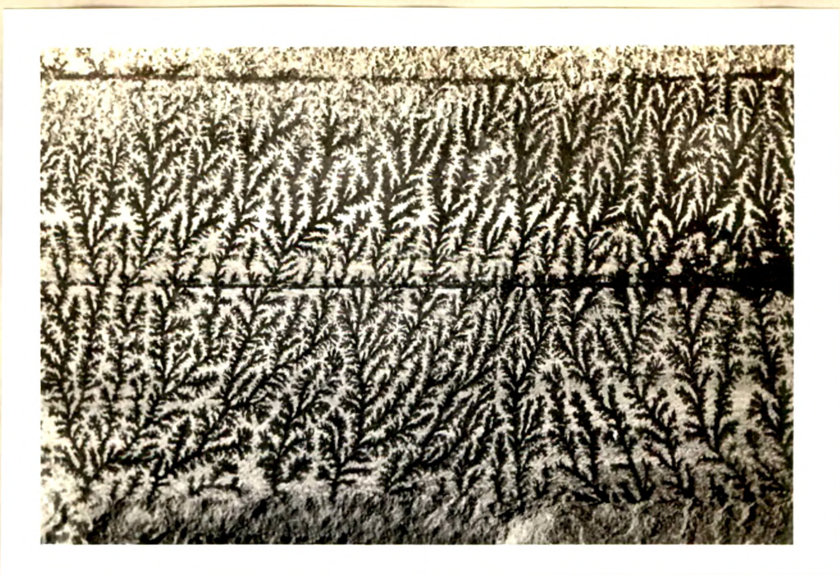
PLATE XIV



A. Folds in Shivarajpur Quartzites and Phyllites.

B. Photograph showing oblique relation between bedding and cleavage in Shivarajpur Quartzites and Phyllites.

PLATE XV



Dendritic structure in phyllites of Shivarajpur Quartzites and Phyllites.

PLATE XVI

Manganese-filled criss-cross joints in Shivarajpur Quartzites and Phyllites.

concentration by meteoric waters (Rasul, 1964). Secondary manganese ores also occupy the numerous criss-cross joints that have been developed in these rocks (Plate XV & Plate XVI).

This outcrop is cut almost in the middle by Jaban fault.

The lensoid quartzite - phyllite formation E of Dharia, does not contain manganese ores. The constituent rocks, otherwise, are identical to those occurring at Shivarajpur.

The easternmost outcrop of these rocks near Pani, is almost identical in lithology to that of Shivarajpur, except that here, the quartzite-phyllite succession contains a few scattered thin lenses of crystalline limestone. The dips of the beds are steep and due N. The manganese ores, here, are also the same with similar modes of occurrence as at Shivarajpur. Structurally, this band is interesting, as it has clearly preserved effects of two folds, though on a small scale. In the vicinity of the NNW-SSE fault (Pani Mines fault) that cuts this formation, early folds show sub-horizontal axes or they plunge gently either due E or W. The late folds strike NNW-SSE and show axes which are almost vertical.

BAMANKUA LIMESTONES

These limestones occur as isolated lensoid bands above the manganiferous horizon. Two lenses resting directly over the Shivarajpur Quartzite-Phyllites, are recorded to the SE and NE of Shivarajpur. Other two exposures are met with in the N and NE, at Dharia and Pani Mines respectively. Here, these occur at a slightly higher horizon and form lenses within the Rajgad Slates. While the first three lenses never exceed 2 km in length and 400 m in width, the fourth one at Pani is more prominent about 5 km long and 500 m wide.

Lithologically, these limestones are quite siliceous and consist of calcite and quartz grains. Pyrite crystals are seen scattered throughout the mass. Different bands are made up of varying proportions of quartz and calcite.

The outcrops of this limestone near Shivarajpur show considerable obliteration of bedding on account of their involvement in the first folding. Stray bedding are recorded and so are the fold-axes that plunge due WNW. The exposure at Pani has, however, preserved good stratification. S-shaped folds on F_1 are abundantly recorded and at many places (Plate XVII A), these folds show distinct faulting and slipping along the axial planes (Plate XVII B).

UPPER CHAMPANERS

RAJGAD SLATES

These are the youngest members of the Champaner Series in the area and comprise a vast thickness of slates and phyllites with occasional layers of quartzites. Near its base, the formation is rather calcareous and contains a few lenses of limestones also. Rama Rao (1931,p.61) described these as Rajgad shales (considering the ideal exposures of the formation at Rajgad in former Bariya State, about 11 km N of the study area). The author has retained the locality name, but has preferred to call these rocks as slates, looking to their metamorphic slates. These Slates make a very striking formation, which is widespread, occupies large tracts in the W and N, extending from one end of the area to the other, and rest with a distinct paraconformity over the older formations. It is interesting to note that this group of slates, comes in direct contact with Bamankua Limestones, Shivarajpur Quartzites and Phyllites, Jaban Conglomeratic Graywackes and Narukot Quartzites at one place or the other. The above mentioned formations that make up the Middle Champaners indicate an environment distinct from that which is heralded by the Rajgad formation. These slates appear to have been deposited in a vast shallow basin whose unevenness had been smoothened out by the deposition of lensoid beds of the Middle Champaners.

Though these rocks have developed a prominent slaty cleavage, their original sedimentary nature is well preserved. The original rocks must be finely laminated shales with frequent bands of massive mudstone. The sedimentary stratification for the most part is clearly preserved and is characterized by grain size and colour variation (which is obviously indicative of variation in lithology. The regional folding has impressed a very distinct axial plane cleavage in these rocks, and they are now more or less slaty or phyllitic.

Folds are seen developed on all scales and the cleavage is always seen cutting the bedding at various angles, depending on whether the readings are taken on the hinges or the limbs. Microfolding is widespread in these rocks in the western part, beyond Shivarajpur. Here, a distinct fold-axis lineation (due to microfolding) has developed on a widespread scale and is seen plunging due WNW with moderate angles. On the other hand, in the area in the N, between Dharia and Vishengarh, the lineation is characterized by a cleavage-bedding intersection , the direction and plunge being almost the same.

In addition to the sedimentary stratification, which is almost universally present in the form of laminations and beddings, the only other structure preserved and occasionally recorded is cross-bedding. Some silty and sandy layers show this structure at a number of places (Plate XVIII A). This slaty formation also shows some very interesting sedimentary fold patterns due to slumping. A close scrutiny of some folded specimens amply proves development of flexures due to penecontemporaneous deformation and in all such cases the slaty cleavage shows no relationship with these folds (Plate XVIII B).

INTRUSIVE GRANITES

The granites that have invaded the Champaner Series occupy extensive tracts to the N and SE of this Series, and in the present area, these rocks are ideally exposed in the SE and E. The contact metamorphic and metasomatic effects of these granites have already been described.

The granites are for the most part coarse and massive showing porphyritic texture (Plate XIX A). The minerals as usual are quartz, feldspar and biotite. Feldspars form the phenocrysts. Both gray as well as pink varieties are present and this colour variation depends on the colour of the feldspars.

All along the contact with the Champaners, the rock is rather fine grained, of both pink and gray varieties.

The entire granite mass is cut by numerous quartz veins and pegmatites,containing muscovite, feldspars, and tourmaline (Plate XIX B). In the contact zone, the quartz-veins and pegmatites are seen intruding the meta-sediments also.

The granites cut across the various Champaner formations, and show a sharp and irregular contact, except in the east where it gradually merges into migmatites. The intrusion has modified the various structural features of the host rocks in the following ways:-

(1) Swinging of the foliation trends parallel to the contact.

(2) Overturning of the dips of the foliation such that they dip away from the granites.

(3) Superimposition of a N-S flexure on an earlier E-W folds, resulting into several dome-shaped structure.

(4) Tightening of the early E-W folds and steepening of their axial plunge.

(5) The rocks caught up within the intrusive mass show rotation from their original position, e.g. the rocks in Gol Dungra (Jothwad Hill).

(6) Development of radial faults (NNW-SSE, N-S and NE-SW) on account of the doming up due to intrusion.

BHAMARIA SANDSTONES

Bhamaria sandstones form a small exposure in the western extremity of the area, where they are seen resting over the Jaban Graywackes and Rajgad Slates with a distinct angular unconformity. These sandstones, equivalent to the Bagh beds of Cretaceous age, overlie the folded, faulted and eroded Champaners, and represent the next marine formation which was deposited after a big hiatus. These rest sub-horizontally over the deeply dissected Champaners, and are coarse sandstones with frequent quartz pebbles. The basal portion of this formation is conglomeratic consisting of vein-quartz and quartzite pebbles set in a sandy matrix.