Chapter V

STRUCTURE OF THE ORE DEPOSITS

GENERAL STATEMENT

The close association of the iron ore deposits with the banded ferruginous quartzite in Bicholim and Sanquelim warrants study of their structure as one unit instead of dealing them here separately. Hence, the structure of banded ferruginous quartzite, which is the protore in this case, has been described interchangeably with the ore deposits.

Due to their greater resistance to weathering and erosion, these ferruginous quartzites generally form conspicuous ridges which extend over a considerable distance in the area. Among them, Sirigao-Bicholim ridge is by far the longest and extends for about seven kilometers. The other two, viz., the Redeval and Sanquelim ridges are comparatively shorter and extend for about 1.75 and 2.5 km respectively. Remarkably, the strike of all these ridges is from NW to SE, excepting a few local departures from this direction.

Extensive lateritization has hardly left any fresh outcrop of the iron deposit or banded ferruginous quartzites in the area under review. On the contrary, the laterites have greatly obscured most of their structural features on the outcrops. To a large measure the data, which were collected from the various open cast mine sections, were found to be most useful for this study. It is, therefore, obvious that under such field conditions all other data collected from outside the mines were comparatively less important. The author, however, made use of all available data from the mine sections, bore holes and also from the scanty natural exposures of the formations. Perhaps a more comprehensive account of the structural features of ore deposits could have been presented if the area had no such limitation of their exposures.

The structures of the Sirigao-Bicholim and the Sanquelim deposits have been described separately. A portion of the Sirigao-Bicholim deposit, falling within the property of Chowgule and Co., at Sirigao, was mapped in detail by means of a plane table because it was found to be a key area for structural study of the deposit.

STRUCTURAL FEATURES

For descriptive purpose, the deposits were broadly divided into two sectors viz., 1) northwestern sector consisting of Sirigao-Bicholim and Redeval deposits and 2) southeastern sector consisting of Sanquelim deposit.

Northwestern Sector

Again, in the northwestern sector, there are two separate deposits of iron ores occurring in the country rock, phyllites (Fig.5). The two deposits have a general NW-SE strike. The longer one is the Sirigao-Bicholim deposit which extends from Sirigao to Bicholim and the smaller one, known as Redeval deposit, occurs about 400 m northeast of the former.

Sirigao-Bicholim Deposit.- A first hand knowledge of the structure of Sirigao-Bicholim deposit can be gathered from the topography of the ridge of ferruginous quartzites which extends from Bicholim-Piligao road on the southeast to Sirigao on the northwest. Between its southeastern end and Sirigao hill in the northwest, the ridge runs almost straight for a distance of about 4.5 km and gains height northwestward. At Sirigao hill the ridge suddenly takes an acute turn southwards and continues in that direction for about a km or nearly so. Near the boundary between Chowgule and Bandakar mining concessions, the ridge again turns to its original northwest direction. The ridge gradually converges and ultimately disappears west of Sirigao village, which is about 1.5 km from its last bend. The topography of this ridge has largely been controlled by the major structural features of the ore deposit as would be described hereafter.

The structure of the iron ore deposits at Sirigao mines affords a very interesting problem for field study and mapping. For this purpose the Sirigao mine section was mapped carefully by a plane table on a scale 1 : 2,400. Additional informations, obtained from the bore holes particularly, in those places where mines have not been opened, were of much help to complete the structural map of the mine section which ultimately proved to be a key area.

The Sirigao mines have been developed from the northern and southern slopes of the quartzite ridge between survey stations B and M (Fig.6). Rest of the concessions remain to be worked out.

Locally, the northern and southern workings are known as Coplegaichem and Goigonem concessions respectively.

The northern ore body in Coplegaichem concessions has been exposed well through continuous and systematic mining between survey stations B and I. On the eastern part of the concessions, ores are generally hard and laminated whereas friable and soft ores predominate on its western part. Therefore, bettwr structural details of this ore body were available from these concessions than elsewhere in the mines. Again, in the northern deposits, between the survey stations C and F i.e., on 30M, 35M, 40M and 45M levels, the workings were more developed than on 50M, 60M and 65M levels. The general strike of the ore body recorded in this well-developed mine section is about N 40°W to N 50°W. The amount of dip, however, varies greatly ranging from 35° to 50° northeast. The attitudes of the joints, which were recorded from the faces of 30M, 35M and 45M levels, are mostly oblique and either vertical or steeply dipping at 80° to 85° SE. Minor folds are more conspicuous in the foot wall clays and ochreous country rock than in the main body of the deposit. The axial trend of these minor folds is more or less the same as that of the general strike direction of the deposit. On account of their small dimension it was not possible to show them on the map. The maximum thickness of the deposit recorded here is about 36 m , but it may not be the true thickness because of the presence of a number of minor folds in the ores. At 20M level, a vertical fault of some significance crosses the ore body obliquely in the direction N 35° E. Lateritic materials occurring as fault gouge give the appearance of a dyke along the fault plane. The fault has not much affected the alignment of the ore body.

The ores quarried at the lower 15M level on the western part of the mine are soft and friable. They grade into ferruginous laterite towards the hanging wall side and into powdery ore towards the foot wall. Their strike in this part is about N 35°W and dip, 30° to 50° northeast. Minor folds and faults are conspicuously exposed in the undisturbed face of 15M level where powdery ore predominates.

Further westwards, beyond the survey station B, the ore body disappears below a laterite capping. However, its underground continuity in this unexposed portion, particularly, west of the survey station A, has been proved by the data obtained from the bore hole Nos. 246, 247, 252 and 264 (Fig.7).

Unlike in the Coplegaichem concessions, where a thick and continuous ore band was encountered, in the Goigonem concessions, there are several minor ore bands with intervening clay and ochreous bands which could be seen between survey stations K and N and particularly, in 50M and 58M level workings, now lying almost in an abandoned state. In the bench faces, these alternate thin bands of ore and country rock are somewhat well-defined. The bands generally strike NW to SE but their amount of dip are variable as could be seen at the ore bands I, II, III, etc.. For example, the strike and dip of band I is N 47°W and 53°NE and those of band II is N 40°W and 48°NE. Likewise, the width of the bands are also variable and they are as follows :

Band			width
I	...	...	12 meters
II	...	...	20 ,,
III	...	...	10 ,,
IV	...	...	8 ,,
V	...	...	11 ,,

A close examination of these ore bands indicates that they are the traces of subsidiary anticlines and synclines truncated by mining operation and that their axes trend NW-SE. Widespread mining at Goigonem workings has left a few synclinal troughs from which the ores are being mined leaving the intervening anticlinal portions composed of foot wall rocks. Since there is no mining activity in the area lying between survey stations N and T, no surface indication regarding the continuity of these ore bands westwards was available. However, several bore holes (nos.54A, 158, 159, 206, 222, 224, 227, 236 and 239) in this area proved the existence of a number of ore bands at various depths. A careful study of these bore hole data indicates that the number and position of the concealed ore bands fairly agree with those encountered on the surface. Therefore, on the basis of the above data the continuity of some of the ore bands ,encountered at 50M and 58M levels further westwards below the surface could fairly be ascertained. It is, however, obvious that their thickness may not remain uniform over a considerable distance. Further, it may be deduced from the bore holes (nos. 242, 245, 253 and 263) that these small ore bands gradually converge north-westwards with diminishing width of the intervening phyllites until they coalesce into a single wide band somewhere below the survey station T. The strike of the country rock recorded here is about N 40°W. The amount and direction of the dip are about 55°NE. Further westwards, beyond the survey station T, a small portion of the ore body is exposed on the side of a road leading to the Chowgule's mine office. The strike of this exposed part of the ore body is about N 42°W while the dip is either vertical or about 80°NE.

Thus, it is evident that there are distinctly two separate parts of the ore band with an intervening tract of phyllites. The band occurring at Coplegaichem and the other at Goigonem concessions, are the productive workings of Sirigao mines. Since the dip and strike of these two ore bands are more or less the same and they converge northwestwards, the structure indicated is an isoclinal anticline plunging northwestwards.

The intervening portion of the two ore bands at Sirigao mines consists of weathered phyllites mixed with clay and ochre, the presence of which below the surface was also confirmed from some bore hole data of this part (nos. 160, 161). However, the bore hole no.160 recorded three thin ore bands with intervening phyllites at depths of 9.2 m, 12.2 m and 14.2 m. These ore bands in all probability correspond to some of the individual thin iron ores exposed at the Goigonem concessions.

Therefore, analysing the structural data as stated above, it is evident that the iron ore bands of Coplegaichem and Goigonem concessions correspond respectively to the northern and southern limbs of the Sirigao plunging anticline, which was folded isoclinally and overturned southwestwards. Its plunge is 20° northwestwards. At the western extremity of the deposit i.e., west of the survey station A, where the two ore bands converge and ultimately disappear, the anticline closes on itself indicating its nose. Accordingly, the two ore bands may be regarded as belonging to one and the same ore body folded into an isoclinal anticline plunging N 40°W. The axis of the anticline would then pass somewhere through the middle of the phyllites included between the two ore bands. The crestal region of the anticline has largely been eroded and as a result of which the anticlinal limbs appear as two different bands seperated by the foot wall phyllites. Among these two ore bands, the southern one at Goigonem mines is more instensely folded than the northern one. The intensity of folding was judged by the presence of a number of minor folds which appear on the surface as several subparallel ore bands.

A cross-section along the line AB illustrates structure of the Sirigao deposit.

At the eastern extrimity of the Coplegaichem concession, between the survey station G and 80M level, the strike of the northern ore body of Sirigao mines gradually changes from N 65°W to about E-W within a distance of about 230 m. The amount of dip at 60M level is about 40°N. Further north, at Bandakar's mining concession, existence of the ore body has been proved from a number of small quarries (Fig.5). The strike recorded in the quarry sections is about N 30°W with northwesterly dips amounting from 40° to 52°. Owing to unsystematic mining or no mining operation in a major portion of this concession, further structural details were not readily available from the deposit. However, it is conclusive that the two deposits, one in Bandakar's property and the other at Coplegaichem concessions of Sirigao mines, though seperated by a valley, converge towards each other at the concessions boundary of Chowgule and Bandakar. The structure of this part of sharply bent ore body having opposing dips, is that of a syncline plunging NNW. Its axial trend is NNW-SSE, which makes an angle of about 15° north of the axial trend of the Sirigao anticline.

Beyond the Bandakar's mining concession, further northwards and northeastwards there are several small pits and quarries of Dempo and Co., from which ore body was found to be continuous and to change its strike gradually to N 40°W, east of Sirigao hill (161.34 m). In this part, changes in strike and dip are : N 20°W, N 10°W, N 48°E and N 70°W corresponding to the dips 38°SW, 34°SW, 30°NW and 70°NE. Such conspicuous changes in strike and dip in this section of the deposit are attributed to an anticline corresponding to the syncline on its south, described earlier. The axis of this anticline is parallel to that of the adjacent syncline.

From the foregoing structural description it may be seen that the ore body is bent in the form of an 'S' between the survey station A in Sirigao mines and east of Sirigao hill. This 'S'-shaped outcrop pattern of the deposit is due to the presence of a drag fold affecting the isoclinal anticline which was encountered at Sirigao mines.

The portion of the deposit between east of Sirigao hill and south of the Bicholim township are mostly well-exposed as a result of almost continuous mining operation all along this belt. The general directions of strike and dip of this part of the deposit remain unchanged excepting some local variations. The amount of dip, however, varies greatly. For example at 4-Top workings, strike of the ore body is about N 40°W whereas the amount of dip varies from 45° to 60° NE. The joints noted in the mine faces are mostly oblique and their attitude is either vertical or dipping about 80°SE. At a lower level in the same workings where mostly powdery ores are exposed, there are some minor folds and faults.

Similarly, about a kilometer southeast of Lamgao, at 2-Top workings and further eastwards, the ore body gradually thins out and ultimately disappears near the Bicholim-Piligao road. The strike of the ore body in this part is about N 43°W. Amount of dip varies between 40° and 50°NE.

Redeval deposit.- The Redeval deposit forms a seperate outcrop about 400 m northeast of the Sirigao-Bicholim deposit and runs almost parallel to the latter for about 1.75 km along a quartzite ridge. The intervening tract consists of phyllites which are covered by laterites sloping northwards. Both northwestwards and southeastwards, the ridge gradually loses its height and width till it merges in the country rock at lower levels.

The Redeval deposit is being worked out on almost all along the northern slope of the ridge. The northwestern and south-eastern parts of the workings are locally known as 4-Bottom and 3-Bottom workings respectively. The workings are confined to hard and laminated ore zone close to the surface. Structurally, the deposit seems to be rather simple since there is practically no change in strike and dip along the entire length of the deposit. At 4-Bottom workings, the ore body shows about N 45^{o}W strike and northeasterly dips ranging from 50^{o} to 55^{o}. The deposit extends continuously along its strike direction from 4-Bottom to 3-Bottom workings. The strike and dip of the ore body at 3-Bottom workings are about N 40^{o}W and 48^{o} to 65^{o} NE respectively.

The above structural features suggest that the lenticular Redeval deposit has a general NW-SE strike and northeasterly dip. Its structural relation with the adjacent Sirigao-Bicholim deposit has so far been controversial as could be judged from the following account :

Krishnan (1955, p.103) mentioned this lenticular deposit of iron ore as the northeastern limb of an isoclinal syncline. Obviously, then the other limb of the syncline would correspond to that part of the Sirigao-Bicholim deposit which occurs on its southwest i.e., between Sirigao hill and south of Bicholim township.

According to Gokul (1963), this smaller outcrop of iron ore is the repetition of the Sirigao-Bicholim deposit due to a strike fault which extends northwestwards from Lamgao.

It may be pointed out here that Gokul (1963) has not shown any field evidence in support of his statement. In the absence of any positive field evidence, it would rather be difficult to entertain the above suggestion. Further, the question as to why the strike fault is restricted to this part only instead of extending further westward and displacing at least a part of the 'S'-shaped deposit on its northeastern side creates some doubt in this case.

In the light of above argument added with the nature of the deposit which converges northwestwards and slightly diverges southeastwards, and absence of any distinct fault valley in the intervening country rock, the present worker considers the Redeval outcrop to be a case of repetition due to truncation by erosion of the Sirigao-Bicholim anticline in this part.

A cross-section along the line CD shows structural relation between the Sirigao-Bicholim and Redeval deposit with associated country rock in between(FIG.5).

An overall picture of the Sirigao-Bicholim and Redeval deposit, the structure of which have so far been described in parts is summarised as follows :

It is fairly well-established that the part of the Sirigao-Bicholim deposit forms an isoclinally folded anticline with its axis trending NW-SE. The same anticline was also found to be continuing southeastwards with the same general trend of its axis. The southwestern limb of the anticline, between Sirigao hill and Bicholim-Piligao road, is wider and also larger than its northeastern limb represented by the Redeval deposit. The 'S'-shaped bend of the anticline between the Sirigao hill and Sirigao mines represents a drag fold due to which the main anticline was refolded and dragged further southwest of Sirigao.

Southeastern Sector

There is only one major deposit of iron ore in the southeastern sector of the area. It is locally known as Sanquelim deposit.

Sanquelim Deposit.- The Sanquelim deposit crops out on a quartzite ridge which extends over a distance of about 2.5 km from west of Valvota river to the village, Gauntana and follows the general NW-SE strike of the country rocks (Fig.5). From Sanquelim hill (97.03 m) the ridge gradually diminishes in width and relief northwestwards and finally merges into the laterite, west of the Valvota river. The deposit is being worked out both from the northern and southern slopes of this ridge.

In the middle of the southern workings, the ores are represented by all the three known varieties which are well - exposed due to extensive mining activity. The strike of the ore body is about N 40°W. Amount and direction of the dips are not uniform in a sense that besides the dominant northeasterly dip amounting to about 60° - 70°, there are a few steep south-westerly or almost vertical dips. These variation of dips are, however, local and due to a series of minor folds in the ore body.

Further westwards, where the deposit becomes narrow, there are still a number of quarries in which the strike of the ore body is about N 45°W, whereas the amount of dip varies from 70° to 75° SW.

As compared to the working on the southern slope, the major portion of the northern slope of the Sanquelim deposit has not yet been worked out except at a few places viz., northeast of Sanquelim hill and east of Valvota river. The strike of the ore body northeast of Sanquelim hill is about N 43°W with the amount of dip varying from 56° to 65° NE. The same northern deposit was again exposed, east of Valvota river, in several abandoned quarries. The strike and dip for this part of ore body are about N 46°W and 54°NE respectively.

The deposit bifurcates into two narrow strips on its south-eastern side between Sanquelim hill and Gauntana. A narrow band of lateritized phyllites occurs between the two strips.

Although the amount and direction of dips in this part are locally variable yet the general northeasterly dip is maintained and the strike continues to be NW-SE.

Considering seperately the structural elements of the northern and southern ore bands of the Sanquelim mines, it is evident that both the ore bands converge northwestwards and finally they join up and constitute one deposit. Thus, between the river Valvota and Gauntana, the deposit forms an elongated 'V'-shaped outcrop which obviously represents an eroded anticline, the axial trend of which is almost NW-SE and plunge about 30°NW. The dip readings of the limbs of the anticline suggest that this anticline is also isoclinal and somewhat overturned.

The nose of this anticline is located about 1.5 km northwest of Sanquelim hill while its two limbs correspond to the two different outcrops between Gauntana and Maulingiem. Obviously, due to erosion of the crest of the anticline on its southeastern side a narrow patch of foot wall phyllites was exposed and divided the deposit into two parts.

A cross-section along the line EF illustrates structure of the Sanquelim deposit (FIG.5).

STRUCTURAL CONTROL ON RESIDUAL IRON ORES

It has been widely accepted that two distinct relations may exist between the ore deposits and folds. A syngenetic or primary ore is older than folding while the epigenetic or secondary ores are introduced after the folding (see Newhouse 1942, p.39). In other words, mineral deposits of syngenetic origin would obviously be subjected to the same tectonic influence as the enclosing rock and epigenetic deposits will mostly be guided by the rock structure (see Fermor, 1924).

According to the author's view, which will appear later in the text, the iron ore deposits of Bicholim and Sanquelim were originally syngenetic and subsequently, they were subjected to processes of residual concentration and enrichment. It is, therefore, expected that both the primary and secondary structures of the iron formations played their respective roles in controlling the localization of the iron ore deposits. It is also evident that the secondary ores were all derived from the protore ,banded ferruginous quartzite after their deposition, folding and subsequent alteration. Such structural features as bedding lamination, steeply dipping limbs of the isoclinal folds, etc., were basically responsible for localizing secondary ores since they make easy opening and channelway in host rock through which mineralizing solution may readily move (see Sullivan, 1957).

Narayanaswami (1959, p.96-97) pointed out that some of the Indian Precambrian terrains of intense deformation marked by en echelon folds and drag folds along the limbs of the major folds may be acknowledged as the structures favourable for localization of secondary iron and manganese ores. For example, the supergene iron ore deposits of Naomundi, Bonai, Keonjhar of Bihar and Orissa ; Bailadila iron ore deposits of Madhya Pradesh;

metasedimentary iron ores of Mysore and the manganese ore deposits of the Sausar series of Madhya Pradesh as well as those of Panch Mahals, Jhabua, Tirodi, etc., are all localized in synclinal troughs or anticlinal crests of en echelon folds.

Another noteworthy fact in the area under study, is that there is generally a great residual concentration of iron ores in the deeply truncated portions of the anticlines than those portions where the anticlines suffered limited erosion. In such deeply truncated anticlines, larger surface area of their limbs is exposed to meteoric water to percolate easily through the highly dipping bedding planes of the quartzites. A plausible explanation for the mode of concentration of ores in the limbs of truncated anticlines has been given by Adams (1911, p.168) while describing the origin and secondary concentration of the Cuynna iron ores of Lake Superior. Finding a more or less similar relation of the iron ore deposits of Bicholim and Sanquelim to their structures, the author finds logical justification to accept the idea of Adam (1911) which can be expressed better through quoting him as follows :

> The circulating waters entered the iron formation where the truncated lenses were exposed on the limbs of the anticline folds and tended to concentrate in the natural channels thus formed. At one time the actual rock surface was exposed and the level of the ground water stood some distance below the surface, and the meteoric waters entering the exposed surface worked downwards till the level of the ground water was reached. These downward circulating waters, heavily charged with oxygen, were responsible for the chemical reactions in the alteration of the iron formation.

If the above view is acceptable it can also explain for practically no residual concentration of iron ore in the untruncated part of the Sanquelim anticline.

Therefore, from the above consideration it may now be concluded that both the primary and secondary structural features of the iron ore formations have not only greatly controlled the distribution but also the concentration and enrichment of the iron ores of the area.