CHAPTER VII

SUMMARY AND CONCLUSIONS

The thesis is based on the results of the field and laboratory investigations carried out by the author to investigate the geological and structural setting, mode of occurrence, structures and textures, mineralogy, paragenesis, controls of localisation and genesis of the manganese ore deposits of the Sanguem district, Goa.

The territory of Goa has been one of the important producers of iron and manganese ores in India. The region can be divided into two parts on the basis of the occurrence of these two deposits, the iron ore deposits being concentrated in the northern part and the manganese ore deposits in the southern part. Though considerable quantity of manganese ore has been and is being exported from the region, the deposits have not been investigated in details so far and very little information about them is available in the literature. Detailed investigation of the deposit was, therefore, undertaken by the author.

The area, in which the manganese ore deposits are concentrated, covers nearly the eastern half of the southern Goa. Nearly 350 sq. km area was geologically mapped on 1:50,000 scale. Use of aerial photographs on the scale of 1:60,000 was also made in demarcating the lithological units and studying the structural elements like fractures, shear zones etc.

The area forms a part of the Bharwar Supergroup (Archaean) of Peninsular India. It represents the northward extension of
the Castle Rock Band of the North Kanara district of Karnataka. The lithological units exposed in the area include metabasics, mica-schists and chlorite-sericite-schists, meta-conglomerate and metagreywacke (lower), phyllites (lateritised) with bands of sericite-quartzite, and metagreywacke (upper), with metabasics at the base and metagreywacke at the top. This sequence has been intruded by the dykes of metadolerite. This was followed by the emplacement of granite gneisses. The younger basic intrusives include the gabbro and the dolerites. Most of the region is occupied by phyllites which have been intensely lateritised. In the other rocks like gneisses, mica-schists and metagreywackes, the intensity of lateritisation is not as much as in the phyllites.

The granite gneisses do not show much of weathering and exhibit crude foliation in N 40° direction. At places it shows slight pyrite chalcopyrite mineralisation. Along the contact with the mica-schists the gneisses seem to have developed a zone of migmatites. The quartzo-felspathic material is also found to be emplaced along the planes of schistosity of the mica-schists. The mica-schists gradually grade along the dip direction into meta-conglomerates with big ellipsoidal pebbles. These conglomerates grade into metagreywackes which are hard, and compact and form high ridges. The phyllites which come next in the succession are highly lateritised. Above them are the meta-greywacke (upper) which are again very hard and compact. The metabasics are found only in the southern part and are
represented by serpentinites and serpentine-tremolite-talc-schists. The gabbro is exposed in the form of an ellipsoidal body intrusive into the granite gneisses. The metadolerites and dolerites occur in the form of dykes.

Interpretation of the structure of the area is difficult because of the thick cover of laterite over most of the area. Structural elements are exhibited only by the mica-schists and chlorite-sericite-schists. They show four types of foliations represented by bedding planes, planes of schistosity, axial plane cleavage and joints. The bedding planes and planes of schistosity and parallel with one another. All the foliations show different attitudes in different parts of the area. They also show three types of lineations represented by L₁ and L₂ corresponding to axes of two sets of puckers and L₃ represented by the intersection of schistosity with axial plane cleavage. Lineations also show variation in their attitudes in different parts of the area.

Fracture trace analysis was carried out with the help of aerial photographs to interpret the orientation of the forces responsible for their generation. An air-photo fracture trace map of the area has been prepared. Fracture trace rosette diagrams, graphs and histograms for the fracture traces have been prepared and presented. Rosette diagrams for the ground observed fractures are also included. Comparing the air-photo fracture trace data with the ground-observed fracture data and taking into consideration the attitudes of the foliations and lineations the
structure of the area is interpreted. It is suggested that the rock formations in the area have been folded into plunging anticlines and synclines with their axial planes in E-W direction and cross-folded with axes in N-S direction, with the development of different sets of shear and longitudinal and transverse tensional fractures.

On the basis of the occurrence of the different lithological units and the magmatic phases associated with them an evolutionary model has been suggested for the region. Because of the presence of the metabasic rocks at the base, showing affinities towards basaltic and peridotitic komatites, it is suggested that the region finds a parallel in the Barberton Greenstone Belt of South Africa.

The petrology of the different rock types has been studied in all the details. Megascopic and microscopic descriptions of the representative rock types are given. Twentyfive chemical analyses of the different rock types are presented with their C.I.P.W. norms. Fortyseven modal analyses of the different rock types are also presented. From the chemical analyses of the metamorphic rocks ACF and A*KF diagrams were prepared and from the mineralogical assemblage the grade of metamorphism and metamorphic facies determined. It is concluded that the metamorphic rocks of the area have resulted from the low temperature, medium pressure regional metamorphism of the sedimentary and ultrabasic rocks. The chemical analyses of the basic rocks including metabasalts, metadolerites, gabbro and dolerite show
that some of the rocks have distinctive chemical composition with calcium content higher than the aluminium content. They thus show a resemblance to the newly defined class of igneous rocks called komatiites. These analyses have been plotted on the various binary and ternary diagrams to show their affinity towards the peridotitic and basaltic komatiites. The gabbro body is also found to show affinities towards Komatiite. On the basis of the textural, structural and mineralogical characters, crystallisation history of the gabbro body has been interpreted.

Several mining pits were examined to study the mode of occurrence of the deposits. Descriptions of some of the important mining pits, along with schematic diagrams, to illustrate the characteristic features of the host rock and the deposits, are given. Most of the deposits are located in the phyllites which have been lateritised to considerable depth. In all these mines three distinct zones are seen. The upper zone, near the surface, is of laterite which gradually grades downwards into the zone of lithomarge. The bottom of the lithomarge is marked by a zone of wad and this grades downwards into a zone of powdery ore. In some cases powdery ore is found to grade into lumpy ore or mangani-ferous phyllite. The thicknesses of these zones vary in different mines. The ore deposits occur in all the three zones. In the zone of laterite they are in the form of boulders and lenses. In the zone of lithomarge they generally occur in the fracture and shear zones forming lenses and pockets in the brecciated rock. In some cases very crude remnant folding can be seen in
the lithomarge. At the crestal portions of the anticlines of these folds breccia-pipe-like ore bodies have been formed. The zone of wad and powdery ore extends parallel to the strike of the altered phyllites. Their width across the strike is much smaller. They thus form lensoid bodies tapering at the two ends.

All the deposits are found to occur in the phyllites indicating that they are primarily localised by lithology. However, they do not occur everywhere in the lateritised phyllites but are localised in certain places. Wherever they occur, they are followed in depth either by a mineralised fracture zone or by a zone of powdery ore. Thus their localisation is controlled by the mineralised fracture zones or the zone of powdery ore below. In the deposits formed in the shear or fracture zone or along the crests of the anticlines the primary control has been the structural features. In the case of powdery ore, zones the bodies of protore below them appear to have controlled their localisation.

The ores in these different zones exhibit different structural and textural features. In the zone of powdery ore the ore is fine grained, powdery, occasionally containing concretions. In the brecciated and lateritic zones structures like concretionary, mamillary, botryoidal, stalactitic and brecciated are seen. In polished sections these ores show textures like colloform, cockade, comb, spheroidal, pellet, encrustations, and banded veins.

The ore microscopic studies have revealed the presence of
brunite, jacobsite, psilomelane, pyrolusite, manganite and neutite (?) as the ore minerals and quartz and goethite as the gangue. Of these pyrolusite and psilomelane are the most common minerals whereas manganite occurs as well formed crystals replacing both psilomelane and pyrolusite. The optical properties and such tests of these minerals are described.

Gravimetric thermal analysis and differential thermal analysis of the different samples were carried out and thirty O.T.A. curves and twenty D.T.A. curves are presented. On comparing these curves with those published by different workers and also taking into consideration the available data regarding the thermal behaviour of the different manganese minerals, the minerals have been identified. The results indicate that the samples represent mostly the mixtures of psilomelane, cryptomelan, pyrolusite and manganite. Some of the samples of the manganese ores were also subjected to X-ray analysis. Results of six such analysis are presented. The minerals that are identified on the basis of X-ray data include psilomelane, cryptomelan, pyrolusite, manganite and their mixtures. In one sample neutite is suspected. The ores were also subjected to chemical analysis. Forty-two analyses are presented. It is found that the ores have low phosphorous content. Considering the silica, iron and manganese percentages the ores can be classified as B grade ores. The ores were also analysed for the content of Nickel, Cobalt and other trace elements like Lead, Zinc, Silver and Chromium. It is found that though Nickel and Cobalt are
present in good quantity the other elements are present only as traces. However, the concentrations of Nickel and Cobalt are not as high as to consider them economical for extraction.

On examining the mutual relationship of the different minerals paragenetic sequence of deposition of these minerals has been established. Braunite and jacobsite constitute the protore and represent the primary mineralisation. In the secondary deposits, it is found that psilomelane and pyrolusite were deposited more or less simultaneously, pyrolusite being little younger than psilomelane. Deposition of manganite was later than these as it is found to replace both psilomelane and pyrolusite. The last mineral to be deposited was again pyrolusite as it is found to vein the earlier minerals. Quartz and geothite were being deposited from the beginning till the end as they form nuclei and alternate bands in the colloform structure. Veins of quartz and cryptocrystalline silica are also found to traverse all the earlier minerals. It is suggested that the deposition of the minerals took place in different pulses separated by intermineralisation fracturing.

Taking into consideration the mode of occurrence, the textures and structures, the deposits formed in the zone of weathering are classified as secondary deposits formed by weathering and residual concentration, those formed in the brecciated zones are classified as epigenetic cavity filling deposits and wad and powdery ore as epigenetic replacement deposits while the ore below the powdery ore zone is considered as syngenetic.
or protore.

Following characteristic features of these deposits appear to be significant in dealing with the problem of genesis of these deposits. The deposits occur in three different zones viz. (i) zone of laterite, where they are not scattered randomly throughout the area but are localised in certain regions where there is generally a mineralised shear or fracture-zone or a zone of powdery ore below (ii) in the zone of lithomarge, where they occur in the brecciated zones and (iii) in the zone of powdery ore which grades downwards into protore. In the light of these observations the different theories suggested by earlier workers for the formation of similar types of deposits have been critically discussed. It is found that any one of the theories cannot, by itself, explain all the characteristic features of these deposits. It is suggested that the protore, represented by richly manganiferous phyllite in the form of lenticular bodies, enclosed in the phyllite, served as a source of manganese for these deposits. The upper portion of the protore was subjected to oxidation and supergene enrichment during the alternating wet and dry seasons because of the fluctuating water table giving rise to powdery ore. The wad was produced by the replacement of lithomarge by manganese. The manganese bearing solutions were forced up through the fracture zones under semi-artesian conditions. These solutions on rising up to the shallower regions were changed into colloidal sols and when they encountered percolating meteoric waters deposited the manganese in the colloidal state. Such
mineralised shear or fracture zones or the protore, present near the surface at shallow depth, gave rise to the lateritoid type of deposits by weathering and residual concentration.