CHAPTER VI

GENESIS OF THE MANGANESE ORE DEPOSITS

In the preceding chapters, the geological and structural setting, lithological characters of the host rocks and the modes of occurrence, mineralogy and paragenesis of the manganese ore deposits have been described. With this available information, it is now proposed, in this chapter, to discuss the genesis of these deposits.

The problem of the genesis of the manganese ore deposits of Goa is not simple. In fact there has been hardly any attempt in the past to approach and solve this problem systematically. Fermor (1909), who was the pioneer worker in the field of manganese ore deposits of India, though gave a detailed account of the deposits in different parts of India, only cursorily mentioned the deposits of Goa as of lateritoid type, on the basis of a couple of observations and those too relating to deposits associated with iron ore deposits and not the manganese ore deposits proper, perhaps because of the limitations imposed on him as the territory of Goa was under the Portuguese rule. Other workers in the field (Roy, 1968) write briefly about the Goa deposits only on the basis of the scanty information available in the literature (Fermor, 1909; Pascoe 1965). Thus the problem of the genesis of the manganese ore deposits of Goa...
has so far remained almost untackled and unsolved.

In order to understand the exact nature of the problem it is necessary to have a general picture of the different types of manganese ore deposits of India and the theories propounded by various workers in the field, to explain their origin. With this view in mind a short resume of the aspects mentioned above, may not be out of place here.

All the reported manganese ore deposits of India are associated with the metamorphosed rocks of the Dharwar Super-group (Precambrian) of Peninsular India. These deposits are localised in three different orogenic belts viz. (i) the Dharwar Orogenic Belt (2300 ± 100 m.y.) which includes the manganese ore deposits of Karnataka and Goa, (ii) Eastern Ghats Orogenic Belt (1600 ± 80 m.y.) which includes the manganese ore deposits of Andhra Pradesh and Orissa, and (iii) Satpura Orogenic Belt (950 ± 50 m.y.) which includes the manganese ore deposits of Gujarat, Maharashtra, Madhya Pradesh (ages according to Ashwathnarayana, 1964). The deposits in these three different belts show different characteristics and rock associations and have been classified into three types. For example, the deposits in the Satpura Belt are associated with a typical rock called gondite which is a quartz-spessartite rock and which is associated with high grade metapelites and metapsammites. The type of deposits is called 'Gondite Type'. The second type of deposits, found in the Eastern Ghats Belt, is associated with kodurites which are supposed to be hybrid rocks formed by the
addition of acid igneous material to the manganese ore bodies and manganese silicate rocks corresponding to gondites (Fermor, 1909) and this is called the 'Kodurite Type'. The third type of deposits, found in the Dharwar Belt, which includes the manganese ore deposits of North Kanara district of Karnataka, and Goa, is associated with the phyllites and quartz-mica-schists and is commonly designated as 'Lateritoid Type'.

The most important deposits that have been yielding the largest quantity of manganese ore in India are of the Gonditic type. These deposits are found in the rocks of the Chilpighat Group and the Sausar Group. The deposits occur in the form of lenticular bodies or reefs which are parallel to the strike of the enclosing rocks. The ore bodies are quite extensive and some of the major ore bodies may vary in length between 2 km and 20 km and in width between 15 m and 30 m when they are doubled or trebled by folding along with the rocks in which they are enclosed. The rocks are phyllites, mica schists or manganiferous quartzites. Generally the ore body grades into gondite. The ore minerals, commonly found in these deposits, are braunite, jacobsite, haussmannite, hollandite, psilomelane and pyrolostsite. Most of the ore is hard and compact, showing schistose structure but ore showing cavernous, banded, reniform, botryoidal and stalactite structures is also found.

Regarding the origin of these deposits it was suggested by Fermor (1909) that a part of these deposits was originally laid down as manganese oxide sediments along with the enclosing
shales and sandstones. These were subsequently subjected to metamorphism due to which the pure manganese oxide layers were recrystallised into various manganese oxides, the mixture of manganese oxide, clay and sand gave rise to different members of the Gondite series and the shales and sandstones were transformed into phyllites, mica-schists and quartzites. He also suggested that the gonditic rocks were subsequently altered and the manganese silicates in them partially reverted to oxides. In many cases it is found that the ore has been formed by the chemical alteration accompanied by the replacement of manganese silicate rock. According to him, it is often impossible to say whether the homogeneous masses of ore represent the original manganese oxide sediments or whether they represent completely altered gonditic rocks.

Straczek et al (1956) suggested that the gondites and associated manganese ore bodies were formed by the metamorphism of manganese sediments. They also stated that the abundant manganese dioxide minerals extending up to 400 feet below the original surface outcrop and 250 feet below the present water table were formed by supergene oxidation of gondite.

Roy (1959) agreed with Straczek et al (1956) in as much as the fact, that gondites and associated ore deposits were formed by the metamorphism of manganese rich sediments. But he differed from them in, regarding the cavernous, banded and stalactitic ores to have formed purely by oxidation and supergene enrichment. He suggested that the manganese dioxide ore
was formed by invading colloidal gels rather than by just enrichment in situ due to supergene oxidation and weathering. According to him the colloidal gels invaded the highly foliated schists taking advantage of the foliation, porosity and fault planes.

The manganese ore deposits associated with the kodurites can be classified into three types (i) those of bedded nature found in association with khondalites (quartz-sillimanite-garnet-graphite schist), (ii) those of botryoidal and irregular structures found in association with highly weathered and altered khondalites, (iii) those replacing the country rock.

Regarding the origin of these deposits Fermo (1909) suggested that the manganese ores were formed from the kodurites which he considered to be an igneous rock rich in manganese and intrusive into the khondalites. The validity of the kodurites being igneous intrusives was criticised by Cross (1914) who suggested that the kodurites were formed by the assimilation of the manganiferous sediments by granite.

Mahadevan and Krishna Rao (1956) and Krishna Rao (1960, 1964) studied these deposits in detail and suggested that the bedded deposits were syngenetic; they were laid down as sediments along with the enclosing strata and were subsequently metamorphosed. The deposits with botryoidal and irregular structures associated with weathered khondalites were suggested by them to have formed by alteration of the manganese silicates by groundwater and solution and deposition of manganese oxides.
in favourable places either by cavity fillings or by replacement of the country rock. In their opinion circulating waters are the most important agents responsible for the formation of ore in the superficial layers and the compact bedded ores below the zone of weathering are syngenetic, formed due to sedimentation by chemical processes.

The term lateritoid manganese ores was introduced by Fermor (1909) to include manganese ores which are associated with laterites and which also extend below the zone of laterite into the underlying weathered rock. Such deposits include those of Karnataka, Goa, some deposits in Madhya Pradesh and Bihar. Of these the deposits in Karnataka are perhaps the largest and are found in the following four regions - (i) North Kanara, (ii) Bellary, (iii) Shimoga and Chikmagalure, (iv) Chitradurga and Tumkur. Next to these are the deposits in Goa which occur in rocks which are the northward extension of the rocks in North Kanara district. The Goa deposits, therefore, can be considered to be the Northward extension of the deposits in North Kanara.

About the origin of these deposits Fermor (1909) suggested that they were formed by the residual concentration and supergene enrichment due to circulating groundwaters which derived the manganese from the phyllites in which it was disseminated. The formation of the deposit is considered by him as a part of the process of lateritisation. He attributes the extension of the deposits downwards below the zone of laterite to the percolat-
ing solutions subsequent to lateritisation. Subsequently, Karunakaran (1956) and Roy (1966) also considered these deposits to be of lateritoid type. Roy (1958) remarked that, lateritic ores of North Kanara district were formed as a result of concentration of iron and manganese of the underlying Dharwars by capillary action accompanied by segregative changes. With reference to Goa he later on mentioned that manganese rich beds of silicates or sulphides were not found below the supergene concentrations and hence he postulated that the shales and phyllites contained disseminated manganese in low amounts which could possibly account for the source (Roy 1968).

Naganna (1971), however, did not agree with the above views fully and suggested that the ores of Karnataka cannot merely be called either 'lateritoid manganese ores' or 'epigenetic ores'. In his opinion these ores should be called syngenetic in the same way as the ores occurring in the northern part of India, i.e. the gonditic type of ores.

A careful examination of this review, regarding the prevalent views about the origin of the three types of manganese ore deposits in India, will reveal that two broad conclusions can be drawn about their genesis. These are as follows:

(i) A part of the ores was laid down as manganese oxide sediments along with the host rocks and was subsequently metamorphosed.

(ii) Supergene alteration, solution and concentration by deposition of manganese oxides in favourable parts took place
subsequently to give rise to the secondary epigenetic deposits.

The genesis of the manganese ore deposits of the area under investigation, can now be discussed in the light of the above mentioned observations. In doing so the following characteristic features of these deposits appear to be significant:

(i) The deposits occur in phyllites which are intensely lateritised and are highly weathered to great depths, sometimes up to 100 m.

(ii) Some of the deposits occur in the zone of laterite but they are found only in some regions and are not scattered randomly throughout the zone of laterite.

(iii) Below the deposits in the zone of laterite there is usually a fracture zone or a shear zone. These fracture and shear zones contain lenses and pockets of the manganese ore. The deposits in the laterite zone may be considered as the surface expressions of these mineralised zones. Generally the deposits in the laterite zone show approximately the same trend as the fracture or shear zones.

(iv) In most of the ore deposits the upper zone of laterite is followed in depth by a thick zone of lithomarge. The lithomarge generally does not contain any segregations of manganese ore excepting some occasional cavities filled with the ore or the deposits formed in the fracture of shear zones cutting through the lithomarge.

(v) In the lithomarge the structure of the parent phyllite
is occasionally retained. In some cases along the crest of anticlines a breccia zone contains mineralisation and a breccia-pipe-like ore body having the same plunge as the axis of the anticline is formed.

(vi) The lithomarge gradually grades downwards into a zone of wad and the wad grades downwards into a zone of powdery ore.

(vii) The zone of wad and also of the powdery ore has in general, a lateral extent parallel to the strike of the enclosing phyllite. Across the strike the width of the ore body is much smaller. The ore bodies also taper laterally parallel to the strike. They extend downwards along the dip.

(viii) The zone of powdery ore in a few cases grades downwards into lumpy ore. The lumps contain braunite and jacobsite in addition to psilomelane and pyrolusite.

(ix) The ores in the zone of laterite and in the brecciated zones show structures like concretionary, botryoidal, stalactitic, colloform, cockade, comb, etc., whereas in the zone of wad and powdery ore they show replacement texture. The minerals in these ores are psilomelane, manganite and pyrolusite.

Any theory, proposed for the origin of these deposits, must satisfactorily explain all the characteristic features of the deposits listed above. It will be interesting now to see if the theories so far proposed can satisfactorily explain these characteristics.

As stated earlier, Fermor (1909) suggested that the deposits
were formed by residual concentration during the process of lateritisation, the manganese being derived from the phyllites. In suggesting this he assumed that the manganese was disseminated in small amounts throughout the phyllites and it was removed in solution by circulating meteoric water. A similar process has been proposed for the origin of some of the manganese ore deposits of the world as for example the manganese ore deposits of Appalachian region (Dorr II and Sweney, 1968), Don Bosco Quadrangle, Minas Gerais, Brazil (Johnson, 1962), Itabira district, Brazil (Dorr II and Barbosa, 1963), Serra do Curral Minas Gerais Brazil (Simmons, 1968), Gold Coast deposits Africa (Service, 1943), Elba manganese deposits, Egypt (Basta and Saleeb, 1971). In most of the cases the manganese ores occur in the form of nodules and concretions scattered in the upper weathered zone or ferru superficial concentrations randomly distributed in the zone of laterite. However, in the deposits under investigation such is not the case. Had they been formed by the residual concentration they should have been present throughout the lateritised region. On the contrary they are found to be concentrated in certain regions only. Fermor's theory does not provide a satisfactory explanation for this. He has also not given any consideration to the occurrence of deposits in the fault zones or shear zones or along the crests of the folds, nor has he mentioned the powdery ore below the zone of lithomarge.

Roy (1968), like Fermor, suggested that the Goa deposits
were formed by leaching and residual enrichment through the agency of circulating ground water. He further stated that because there were no manganese rich beds of silicates and sulphides below the supergene concentrations, the manganese must have been supplied by phyllites and shales in which it was disseminated in small amounts. Roy’s argument is based on the assumption that, there are no manganese rich beds below the superficial concentrations. Had it been known to Roy that there could be such manganese rich beds below, he might have postulated that the deposits were formed by leaching and residual enrichment by percolating waters and by in situ oxidation and enrichment of the pre-existing manganese deposits, a process which he suggested for superficial deposits in Maharashtra, Madhya Pradesh and Andhra Pradesh. He also does not seem to be aware of the existence of the deposits in the fracture zones or shear zones and also the powdery ore zone, below the lithomarge. In fact his inferences appear to have been based, as Naganna (1971) has stated, on the information available in the literature. The only reference to the Goa manganese ore deposits by Pascoe (1965) is as follows. “The rocks of this belt are generally manganiferous except in the immediate neighbourhood of Deccan Trap where they have been much hardened. Manganese ore has superficially replaced some of the decomposed quartzite and has itself originated no doubt from the Dharwar rocks especially from the iron ore beds and phyllites.”
Gokulam (1972) in his work on the iron ore deposits of Goa, while dealing with the origin of iron ore deposits, has stated that the pink phyllites contain manganiferous chert breccia which have subsequently given rise to small irregular deposits due to residual concentration. He, however, has not described the manganiferous chert breccia and it appears that he considers the manganese ore containing fragments of chert present in the brecciated zone as manganiferous chert breccia. In such a case, the manganiferous chert breccia has to be regarded as a product of the process of mineralisation and not as a source of manganese. Moreover, the manganiferous chert breccias occur below the zone of laterite in the lithomarge and wad zones and therefore appear to be subsequent to the formation of lithomarge and wad, thus indicating that the manganiferous chert breccia did not represent the primary bands precipitated along with the deposition of the enclosing sediments as suggested by Gokulam (1972).

Thus it will be clear that none of the three views discussed above, take into consideration all the characteristic features of the deposits and explain them satisfactorily. An alternative explanation is, therefore, necessary. Taking into consideration all the characteristic features the following processes appear to have operated during the formation of these deposits.

The most important point that has to be satisfactorily explained is regarding the source of manganese. The present
investigation has revealed that the source of manganese existed as protore in the form of lenses enclosed in the phyllites. This is clear from the fact that the powdery ore grades downwards into lumpy ore or a manganiferous phyllite. Such type of occurrences of manganiferous bands, bodies or layers have been accepted to be present in the manganese ore deposits of Gondite type and Kodurite type. Fermor (1909) and Roy (1968) have both suggested that the gonditic type of deposits were formed by the metamorphism of manganese oxide precipitated chemically along with the Dharwar sediments. Mahadevan and Krishna Rao (1956) have also suggested that the manganese was precipitated chemically along with the sediments which gave rise to rhondalites on metamorphism. If such was the condition in these basins in Dharwar times, similar situation could also have existed during the sedimentation in the geosyncline of the Dharwar belt. This has been also suggested by Naganna (1971) in the case of the manganese ore deposits of Sandur area of which the Goa deposits can be considered as the northward extension. About the origin of Mysore (Karnataka) manganese ore deposits Naganna (1971, p. 519) states - "the manganese ores in the state are associated with the Dharwar rocks which are known to have been formed by both mechanically and chemically derived sediments with contemporaneous extruded material in some places. During the deposition of the sediments, the incoming waters sometimes must have been free from mechanically carried material containing salts of manganese besides other salts. These must have got precipitated
as manganese oxide through atmospheric oxidation. Besides this, manganese might have also been deposited admixed with silty material when the incoming waters carried mechanical sediments besides dissolved salts. After the manganese deposited the associated sediments laid down, they were affected by low grade regional metamorphism, where the silty matter has been converted into phyllite, the sand into quartzite, the manganese into braunite and pyrolusite." A similar sequence of events can also be visualised for the Goa deposits. However, it may be suggested that the manganese could have also been derived by the leaching of the metabasics which are found at the base of the sedimentary sequence in the area.

Thus the manganese required for the formation of these deposits could be considered to be present as protore in the form of reticular bands intercalated with the pelitic sediments. When these were subjected to metamorphism and orogenic movements the pelites along with the enclosing manganese bands were folded and metamorphosed into phyllites. Naturally the reticular bands of manganese ore, containing minerals like braunite and jacobsite formed by metamorphism, would have the same attitude as the phyllites and would exist at different levels with respect to the erosional surface. It is possible that some of the manganiferous lenses have been completely eroded as the erosion progressed to the present day erosional surface. If some of the bands were encountered during the progress of erosion near the present day erosional surface, they must have been subjected
to the process of supergene enrichment by \textit{in situ} oxidation and residual concentration. Such deposits formed by weathering and superficial concentration of manganese bearing protore are reported from parts of Minas Gerais, Brazil (Wallace, 1963). Nasul (1963) considers the manganese ores of Shivrajpur in the Panch Mahal district of Gujarat as a product of supergene weathering accomplished by the ground water action of the earlier metamorphic and deep secondary ores up to a limited depth below the surface. Such ore deposits have been designated by Fermor (1909) as outcrop secondary ores. This can explain why the deposits in the zone of laterite are found localised in certain regions and not scattered throughout the laterite zone.

It is also possible that some of the lenses were much below the erosional surface. In such cases the protore will not be subjected to the processes of weathering, leaching and enrichment, unless the water table reaches their level. As stated earlier in most of the mines three distinct zones are encountered viz. the upper zone of laterite, intermediate zone of lithomarge and the lowermost zone of wad grading into powdery ore. The interface between the lithomarge and wad is found to be at a maximum depth of about 100 meters from the present day erosional surface. This indicates that the percolating ground water acted up to the depth bringing about the coersion of the original phyllites into laterite at the top and lithomarge at the bottom. Thus the process of lateritisation operated through a thickness of more than 100 meters. As stated earlier similar
observations have also been made by Straczek et al. (1956) and Mahadevan and Krishna Rao (1956) in the case of gondite and kodurite type of deposits respectively. Generally the laterite grades into the lithomarge with an intermediate transitional zone of pale yellowish or cream colour indicating that the iron content in the laterite goes on decreasing and the aluminium content goes on increasing downwards. The percolating waters must have leached the silica and iron from the phyllites and the iron must have concentrated in the upper layers to form laterite. The process of lateritisation indicates that there were alternating wet and dry seasons during which the groundwater table was fluctuating.

If supposing that the top of one of such lenses of protore, was upto the level of the water table, then the top portion of such a lense would be submerged completely below the water table in rainy season, when it rises up and may emerge out of the water table into the zone of aeration, when the water table goes down during the dry season. Thus during the dry season the upper portion of the primary ore body (protore) would be oxidised in the capillary zone of the zone of aeration and suspended water above the permanent water table. Because of this oxidation the upper portions of such ore bodies will become more and more porous during successive periods of dry season. During the dry season the Eh and pH of water will be lowered because of increase in the concentration of acids due to lack of addition of fresh rain water. Under such conditions manganese will be
taken into solution (Norton 1973). During the wet season, when the water table rises up, the upper oxidised portion will be submerged under water. The Eh and pH of the water will be raised because of the addition of fresh rain water. Under such conditions manganese will become immobilised and therefore will be precipitated (Serge, 1971). The precipitation will take place in the phyllite which is being converted into lithomarge by the same process and, therefore, replacement of lithomarge by manganese will take place giving rise to a zone of wad. Thus during the prolonged period of alternating wet and dry seasons the wad will go on thickening with the removal of upper oxidised portion of the protore and the zone of powdery ore will go on extending downwards. This will thus explain the occurrence of a zone of wad and powdery ore with protore at the bottom below the zone of lithomarge. The shape of the zone of wad and powdery ore will thus be determined by the shape of the primary ore body, i.e. they will have a similar lateral extent in the strike direction and limited extent across it.

The water which is enriched in manganese content during the dry season will become mobile during the rainy season and will rise up through the fracture and shear zones under semiartesian conditions as explained by James et al (1968). The water, as mentioned earlier, will have high Eh and pH and so will not be able to retain the manganese in solution. When this water rises up through the fracture and shear zones, it may encounter the downward percolating fresh water and because of intermingling of these two, Eh and pH will be still increased
and precipitation of manganese will take place in fracture and shear zones and along the crest of the anticlines to give rise to cavity filling deposits. The ores in these fracture filling deposits show banded structures and intermineralisation fracturing and fracture filling by either manganese oxides, goethite or quartz. This indicates that the solutions having manganese, iron and silica came up in pulses and deposited their load. This will also explain the presence of alternate bands of the different minerals exhibited by colloform structures. If such mineralised fracture and shear zones are exposed on the surface, residual concentration will take place along these zones giving rise to deposits in the zone of laterite.

In the deposits in the fracture and shear zones and also in the zone of laterite, the ores show colloform structures, which indicates that the deposition took place in the colloidal state. As these deposits are formed at relatively shallow depths, it can be assumed that the deposition took place at relatively low temperatures. Under such conditions the colloids are most stable and so it can be assumed that manganese was present in the waters in the colloidal state when it was deposited in the fracture and shear zones. It may also be suggested, as has been pointed out by Herzenberg (1936), that the water carrying manganese could have changed from solutions at depth to colloidal sole in near surface environments.

This theory can explain satisfactorily the following points: (i) why the manganese deposits are localised only in
certain regions of the lateritised phyllites, (ii) the presence of the zone of wad and powdery ore below the zone of lithomarge, (iii) lateral extent of the zone of wad and powdery ore parallel to the strike of the enclosing phyllites, (iv) occurrence of ore in the fracture and shear zones and along the crests of the anticlines, and (v) the source of manganese.

In conclusion it may be suggested that the manganese ore deposits of the Sanguem district of Goa have resulted by three different processes in three different environments viz. by residual concentrations of pre-existing protore and mineralized fracture and shear zones in the zone of laterite, by oxidation and supergene enrichment and replacement of the lithomarge forming zones/wad and powdery ore and by cavity filling in the fracture and shear zones.