Acta Mineralogica-Petrographica, Szeged, XXII/1 133—141, 1975

SOME PROBLEMS ON THE MANGANESE ORES OF ANDHRA PRADESH

J. S. R. KRISHNA RAO

INTRODUCTION

The author summarizes his experiences with manganese ores of Andhra Pradesh, over 25 years. Manganese ore of the former Vishakhapatnam district was reported in 1858 during the laying of the railway track by Britishers. Subsequently FERMOR [1909], a Geological Survey of India official described the deposits in his manganese memoir. The Visakhapatnam deposits were of academic interest also, because, FERMOR classified them as secondary, formed from magmatic manganese rich rocks named by him as '*kodurite*' which according to him occurs typically at Koduru, intrusive into the khondalite series. Fermor suggested kodurite as a suit of rocks rich in manganese content showing differentiation crystallization trends, characteristic of magmatic products. But when he classified them according to C. I. P. W., he had to provide new minerals like tephrite in the C. I. P. W. Norm. CROSS and latter FERMOR [1915] suggested that the manganese deposits of Visakhapatnam district were formed by alteration of hybrid rocks which are formed when granites intruded into the manganese bearing sediments in the area.

Since, the Geology Department of Andhra University took interest in the above mentioned problem and worked on manganese ores of Koduru and adjoining areas where similar features were shown by manganese ores. RAO [1948] worked and stated that the parentage of manganese ores is a hybrid rock rich in manganese. The field observations by various people not only at Koduru and Garbham but also in other places like Chipurupalle, Gotivada, Kottakarra, Ramabadhrapuram, Rayagada, Andra brought out conclusions that the association of the khondalite and manganese is a fact and that the manganese ores generally follow the trends of the khondalites. Manganese ores or manganese bearing rocks do not show any intrusive nature or contacts with khondalites in the area. They sometimes show lenticular bands pinching off along strike, and are folded and faulted similar to the khondalite series and hence be considered as syngenetic and syntectonic with the khondalite series. More and more observations have been made as mining expanded, and it is observed that the manganese ores occur as beds and follow a NE—SW trend (general strike direction of the khondalites), generally show folding symmetric/asymmetric, plunging folds etc. Further, the manganese bearing area being vast and stratigraphically being the oldest much confusion is introduced due to latter metamorphism and metasomatism, with the result, a continuous tracing of the manganese bands is hampered. The khondalite series of rocks and manganese ores which are closely and intimately associated show cross folding and at many places are traversed by pegmatitic veins, quartz lenses, secondary ore veins, thus complicating the structural features.

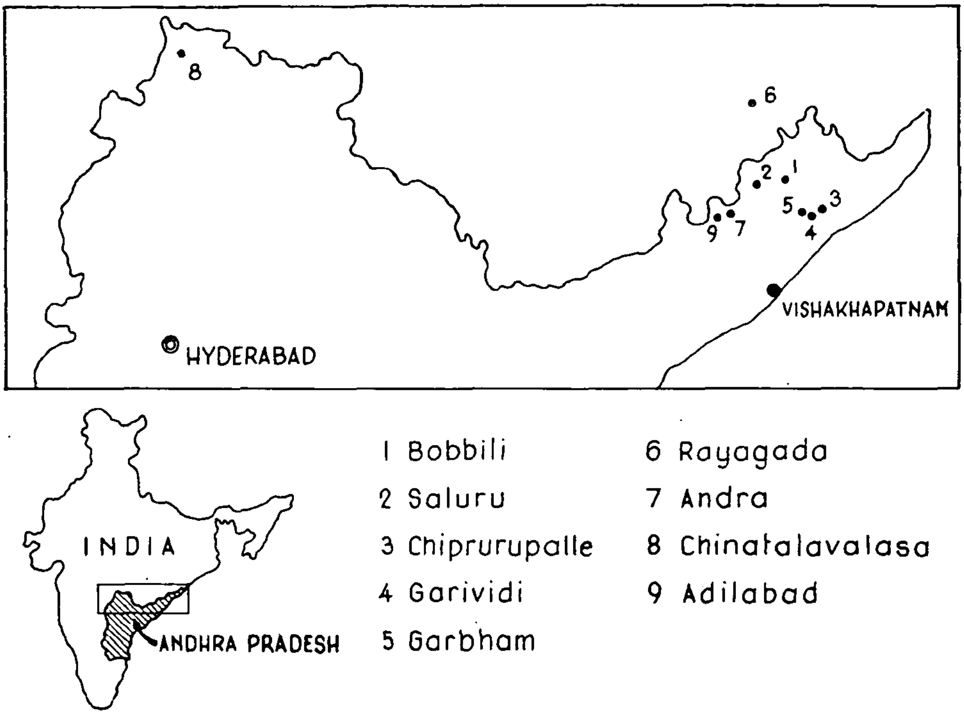

Fig. 1.

Some important structures of primary and secondary ores are given below:

1) At Garbham the manganese ores occur as conformable beds with quartzites with or without garnets. The manganese beds on average are 25 feet in thickness and show thickening due to folding. There is faulting also associated with chert formation, development of slicken slides, lithomarge, fault gouse, chlorite and epidote mineralisation.

2) At Koduru manganese beds occur discontinuously showing folds but appear as local pockets due to much disturbance. Weathering of the manganese bands, particularly by circulating waters concentrate secondary ores in the oxidation zone, extending to a depth of 75 to 100 feet. The manganese ores and associated rocks are metamorphosed and hence the recognition of their original features is difficult. Added to this, a step-like faulting in E—W direction is probable in Koduru area and hence in places like Devada, Duvvam, Sadanandapuram and Chipurupalle the deposits are of different thickness, width and are complicated by chertification and lithomarge formation.

3) In Rayagada and Saluru-Bobbili areas, manganese ores occur along with the khondalites conformably as beds and are concentrated on the surface as secondary ores. The khondalites are lateritized but did not give rise to manganese ores by themselves except some of the garnets of the khondalites show alteration to manganese ores.

4) Calc-granulites overlie manganese ores in Koduru, Garividi, Nellimarla areas. The manganese ores and calc-granulites form conformable bands and are surrounded by huge mass of granite gneiss with or without garnets in them. As in

Koduru the khondalites are enclosed in garnetiferous gneisses. At Taduru, Andra and Chintalavalasa the khondalites are conformable with manganese beds. Thus the khondalite series constitute quartzites with or without garnet; khondalites most of them devoid of graphite; calc-granulites mostly consisting of calc-silicates like diopside-hedenbergite series, anorthite, wollastonite, scapolite, garnet associate the primary manganese ores. The secondary manganese ores occur as powder up to a depth of 100 feet near Duvvam mine overlain by highly altered lithomarge, suggesting disintegration of manganese ores in situ.

Vizianagram Mining Company made some bore holes at Koduru where compact to friable ores are observable in logs, the ores are extending beyond a depth of 150 feet and are overlain by the khondalites. Alteration due to oxidation and formation of secondary ores is prevalent in the zone of meteoric waters up to 100 feet. It is important to note that these bore holes do not have any rock type similar to the so called '*kodurite*'.

At Adilabad manganese ores occur in association with limestones which are least metamorphosed. The ore bands associated with jasper bands which are a few centimeters in thickness. The layered nature of these ores is similar to a banded hematite quartzites in Bihar. Also some layering is found between silica and manganese ores observed in other places of Andhra Pradesh like Gotnandi, Yettacherla [KRISHNA RAO, 1955]. Perhaps this represents the original gel like formation of manganese oxide and silica in Precambrian rocks.

ASSOCIATION AND FIELD RELATIONS

Chipurupalle

The khondalites which form the country rock of the area have a wide distribution, and most of the hills are composed of it. These occur as low lying hills covered by laterite soils on sides. The khondalites show a general strike direction N 45° E and dip is varying about 45°—75° S.

Quartzites in the southern part of Chipurupalle area, occur in close association with khondalites showing the same strike direction and also dip as those of the khondalites.

Calc-granulites are few being confined to one patch at Chipurupalle over a width of about 10 feet striking N—E, another at Gadabavalasa distributed for a length of 60 feet striking N 35° E and dipping at 50° S and another at Viziarampuram south of Chipurupalle over a width of 4 to 5 feet.

Granites occur all around Chipurupalle. These are small mounds and, occur typical at Gollalapeta, Kottapeta, Muchinivalasa and Jada. Towards the north of the area Maradubaka, Jaggayyapeta, Aguru, Terlam and Panukuvalasa, an inequigranular variety of granitic gneisses are observed. The granites in the above places are more prominant than south of Chipurupalle where these are equigranular. Quartz, felspar, muscovite veins and quartz veins occur at a number of places cutting along the khondalites.

Manganese rocks — the so called '*kodurite*' of FERMOR which according to him are exposed in manganese mines are not found in these places. The various manganese pits observed show ores of all grades and the ore occurs mostly in the oxide form, pyrolusite and psilomelane. Pyrolusite is more abundant than psilomelane. Braunite in crystalline form occurs in Bondapalle. The pits are shallow and the important pits are Garraju Chipurupalle, Avagudem and Perumali, and they are worked to a depth of 100 feet. At various places kaolin, chert and silica are seen. These are secondary products associated with the ore and their amount is not always the same as seen in the various pits of manganese.

Garividi and Garbham

The khondalite hill north of the Garbham pit is traversed by quartz-felspar veins at the contact of which large flakes of graphite have developed. Graphite has been prospected in this area as is evidenced by the presence of several small shallow trail pits. In the hill south of the Garbham pit the sillimanite gneisses at the base are succeeded by coarse grained quartzites on top with a bed of manganese ore about one foot in thickness sandwitched at the junction of the two.

The quartzites maintain the same strike as the underlying khondalites dipping 62° SW.

Cherts are very common and have small shining crystals of the garnet in them. Generally the garnets show alteration. The cherts are traversed by several small ramifying veins and stringers of white secondary silica. These appear to be latter than the actual masses of chert which enclose them. At Garbham south side of the main pit, huge irregular masses of chert are found. These cherts are exposed during the mining operations and are found to pass imperceptibly into kaolin.

Andra

Khondalites occur striking N 70° E and dipping 65° in SE direction. In south east corner of the area the strike changes to N 125° E and the dip is 70° SW.

Garnetiferous-biotite gneisses strike N 70° E and dip 65° SE direction at Kondagudavalsa. But in the south east corner of the area, the strikeis N 125° E and dip is 70° in SW direction. Some of these gneisses have concentration of felspars in them.

Khondalites occur and strike N 70° E and dip 65° SE. Further in the southern mid half of the area, the rocks strike N 125° E and dip 70° in SW direction.

Quartzites are sometimes banded containing garnets and graphite occur in the area, and exhibiting varying strike and dip.

Calc-granulites and calciphyres are also found as bands near about the adjoining area.

Manganiferous rocks occur in manganese pits of Garuguvalasa. The manganese band is traced over a distance of 350 feet striking N 70° E and dipping 65° in SE direction. The thickness of the band is 10 feet. The manganese band also consists of manganese pyroxenes and garnets.

Saluru — Bobbili area

The general strike of the rock formations consisting of khondalite series veers from N. N. W.—S. S. E in the west to N. N. E—S. S.E in the east and the dip is generally high (60°—70°) with a corrosponding swing from E.N.E to E. S.E.

Rayagada

The important rock formations are khondalites and charnockites occur in a dreary repetition, with general strike N.E—S.W to N.N.E and S.S.W.

Khondalites show a general N.N.E direction though the strike varies N.E and S.W locally. The dip varies from 50° to 70° E. Manganese ore occurs in close association with the khondalites. The persistance of the same strike for the manganese deposits and their occurrence all along the strike and gradation into garnetiferous gneisses and quartzites suggest that the magnanese bands are formerly sedimentary later metamorphosed like the other para-gneisses in the area.

The close association of garnetiferous gneisses and quartzites is an indication of the sequence in the deposition of sediments. They contain garnest, biotite, graphite, sillimanite and apatite as accessories.

Calc-granulites occur between Karli and Miragai over a distance of nearly 2 miles. The strike is N 25° E and the amount of dip is 50°. The calc-granulites are devoid of any manganese ores.

GEOCHEMISTRY

Manganese ores are variable in their manganese content at various places. But when compared to Madhya Pradesh the ores are lower in grade ranging anything from 22% to 45% rarely 48% to 50%. The phosphorous content is distinctly high in these ores and ranges from 0,1 lowest to 0.3 and sometimes 0,4 to 0,5. The average phosphorous content can be 0,15 to 0.25 in most of these ores. As the phosphorous is high the ores are not in demand and blending with low phosphorous bearing ores necessary to market them. Many Ferroy Alloy Plants were so designed that the phosphorous content of the ores is deliterious and hence methods for removal of phosphorous have to be adopted. The iron content and aluminium content also show variation. The following table shows some elemental distribution at various places.

Constituents	Chipurupalle	Garividi Garbham	Duvvam	Andra	Adilabad	Rayagada
MnO	3.70	2.27	0.09	0.50	0.50	0.99
Al_2O_3	20.64	17.30	12.49	9.65	5.00	19.66
Fe_2O_3	0.86	1.20	3.76	2.68	1.00	2.67
FeO	1.12	8.04	6.70	5.03	—	5.04
P_2O_5	1.01	0.75	—	0.18	—	0.39
SiO_2	68.38	58.04	70.16	74.35	19.22	74.38

The manganese ores consist of primary and secondary minerals particularly those from the oxidation zone. The following minerals are identified by ore microscope and confirmed by *X*-ray methods.

Name of the mineral	Garividi	Koduru mines	Adilabad	Rayagada	Andra	Garbham
Pyrolusite	+	+	+		+	+
Psilomelane	+	+	+		+	+
Vredenburgite	+	+				+
Braunite	+		+			+
Bixbyite	+					
Lithiophorite	+					
Franklinite		+				
Rhodonite	+	+			+	
Mn-garnet	+	+			+	
Coulsonite		+				
Hausmannite	+	+	+			+
Jacobsite	+	+			+	+

+ Present

The mineralogy of manganese ores is distinct in that it has no representation of carbonates or sulphides. It may be also noted that the mineral apatite in some of these ores or associated rock formations did not contain manganese in their constitution.

Texturally the primary ores exhibit gneissic foliation, the granularity being medium. The mineral vredenburgite is well known consisting of hausmannite-jacobsite intergrowth. Braunite is subhedral, associating with jacobsite and shows boron content in it [KRISHNA RAO, 1956]. The jacobsite is shown to be a solid solution series with magnetite [SUPRIYA ROY, 1959]. The coulsonite and franklinite are described by KRISHNA RAO. Pyrolusite is common in lamellar and granular form. Garnet, rhodonite and bustamite are the silicates. The mineral aggregates are recrystallized.

The secondary minerals are psilomelane varieties with barium and other elements like Co, Ni, etc. The secondary ores associate with silica, jasper bands and consist of various amounts of H_2O, limonite, goethite. The ores show botryoidal, stalactitic, sometimes stalagmitic and concretionary appearance, of various sizes. The secondary minerals also occur in joints and cracks.

The distribution of manganese content in various rocks in the area is as follows:

Rock	Koduru	Raya-gada	Saluru Bobbili	Andra	Chipuru-palle	Garbham
Khondalite		0.99		0.99	3.70	2.27
Granite		0.78	0.23	0.03		tr
Calc-granulite	3.36	0.33	0.31		2.37	0.14
Quartzites		1.05				
Garnets				24.46	0.25	12.72

The rocks and minerals with or without manganese deposits in the area do not show trends of variation of manganese content that could be correlate with magmatic process. It is also to be stated that some of the granites like that of Chipurupalle are paragneisses and not magmatic. The contact of various rocks in the area do not show manganese enrichment or segregation of manganese bearing minerals. The distribution of manganese is essentially an original constituent formed by the same geochemical process as the rocks and minerals in the area. Many of rocks in the manganese bearing areas have been shown to belong to khondalite series considered as paragneisses.

The following Table shows the mineral assemblages characteristic of upper amphibolite — granulite facies, found in association with manganese ores:

Chipurupalle

Khondalites	*Calc-granulites*	*Quartzites*	*Kodurites*
Quartz	Diopside	Quartz	Quartz
Garnet	Scapolite	Garnet	Felspar
Sillimanite	Wollastonite	Apatite	Garnet
Felspar	Felspar		Apatite
Apatite	Calcite		Biotite
Magnetite	Sphene		
	Apatite		

Garividi and Garbham

Garnet-sillimanite gneiss (Khondalite)	*Calc-granulites*	*Charnockites*	*Granite-gneisses*
Garnet	Diopside	Hypersthene	Felspar
Sillimanite	Wollastonite	Hornblende	Quartz
Felspar	Scapolite	Biotite	Garnet
Quartz	Apatite	Felspar	Biotite
Apatite	Felspar	Quartz	Apatite
Magnetite	Sphene		Magnetite
Sphene	Quartz		Sphene
Graphite	Calcite		
Biotite			

Andra

Khondalites	*Calc-silicate-rocks*	*Charnockites*	*Interaction rocks*
Quartz	Diopside	Diopside	Quartz
Felspar	Felspar	Hornblende	Orthoclase
Garnet	Quartz	Hypersthene	Plagioclase
Sillimanite	Plagioclase	Plagioclase	Garnet
Biotite	Sphene	Magnetite	Biotite
Magnetite	Wollastonite	Ilmenite	Hornblende
Graphite		Apatite	Hypersthene
Apatite			Zircon
Rutile			Ilmenite
Chlorite			
Zircon			

Saluru—Bobbili

Khondalites	*Calc-silicate-rocks*	*Charnockites*
Quartz	Diopside	Hypersthene
Felspar	Plagioclase	Biotite
Garnet	Feldspar	Garnet
Sillimanite	Quartz	Felspar
Graphite	Sphene	Quartz
Apatite	Wollastonite	Norite
Magnetite	Scapolite	
Rutile	Enstatite	
Biotite	Zoisite	
Cordierite	Sapphirine	
Spinel	Calcite	
Talc	Garnet	

Rayagada

Khondalites	*Calc-granulites*	*Quartzites*
Quartz	Diopside	Quartz
Sillimanite	Calcite	Garnet
Garnet	Wollastonite	Biotite
Felspar	Sphene	
Apatite	Feldspar	
Magnetite	Apatite	
	Quartz	

The manganiferous beds have been deposited as oxides pure to impure in nature and are recrystallized forming braunite, vredenburgite, pyrolusite, pyroxene and granulite assemblages, sometimes with relict primary sedimentary features. Therefore it is surmised that there should have been peculiar geochemical conditions in the formation of manganese oxides during Precambrian in India. It is also possible that some biogenic process may be operating at some stages as in Adilabad where fossil imprints of very primitive nature were observed.

The geochemistry has an important unique problem namely the association of high phosphorous in the ores unlike in many other parts of manganese deposits of India. Apatite could be a source for high phosphorous and it is found as granular, needle like, platy [KRISHNA RAO, 1966] or as crystals through which cavities are made and secondary manganese solutions are circulated. The apatite is present in accessory amounts in granitic gneisses, calc-granulites to certain extent and rarely with manganese bearing bands. Such apatite occurring free in ores can be separated by mechanical methods. But the phosphorous content is not fully due to this type of associated with iron content of manganese ores. It is stated by the mine owners in these area that phosphorous increases with depth. However, it is observed [KRISHNA RAO, 1956] that bore hole samples of manganese ores at depth are relatively poor in phosphorous. It is also observed that phosphorous distribution is not following any regularity either area wise or ore wise or depth wise. Thus the problem of high phosphorous has to be sorted out yet, and the phosphorous is to be located carefully befor this undesirable element is removed for better use and market of the ores.

CONCLUSIONS

The above account on structure, ore petrology and geochemistry of manganese ores of Andhra Pradesh throws open very interesting and challenging problems. The ores needed to be located in interior Eastern Ghats where these may be more amenable for geological prospecting by structural mapping of major as well as minor structures. The primary ore band consisting of oxides, sometimes silicates is confirmable with the khondalite series (with one of the members) which show drag folding locally.

The secondary ores formed in fault zones both major and minor. The mineral assemblages observable in reflected light with the aid of *X*-ray confirmation can again be sorted out into primary and secondary, the latter being called as '*wad*' usually. The mineralogy and textures give an important information on geochemical evolution of the ores since their formation.

The structure and mineralogy of the ores and distribution of elements like P, Ni, Cr, Co should be examined and geochemical process studied so that the ores can be categorized for special use and to carry out experiments to eliminate deleterious elements for a better use of these ores.

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Manuscript received, May 31, 1975

DR. J. S. R. KRISHNA RAO
Department of Geology,
Andhra University,
Waltair — 530003
India