Volume : 3 | Issue : 3 | March 2014 • ISSN No 2277 - 8160

Research Paper

Earth Science

Characterisation of Manganese Ores of Shimoga Schist Belt, Dharwar Craton, Southern India

Chinnaiah

Department of Studies in earth science, University of mysore,
Manasagangotri, Mysore-6

ABSTRACT

Shimoga pre bodies are broadly classified based on their mode of occurrence and genesis. The Dharwar group in the Shimoga schist belt is represented by narrow belts of steeply dipping metasedimentary formation and volcanic rocks, including stratiform manganese iron formation, phyllite/argillite, quartzite, greywacke, metabasalt, basic and ultrabasic intrusive.

The late Archaean manganiferous formation in Shimoga area is spatially associated with carbonates (stromatolitic limestone and dolomite) and oxide facies banded iron formation. In the study area, the supracrustal rocks have been subjected to green schist to lower amphibolite facies metamorphism. manganiferous formation and the spatially associated BIF and phyllite in the study areas have been subjected to varying degrees of supergene alteration.

Presence of manganese minerals like pyrolusite, cryptomelane, hollandite, nsutite, ramsdellite, lithiophorite and goethite. Pyrolusite and cryptomelane are different generations. Lithiophorite is encountered as dissolution cavity-fillings in colloform variety of the infiltration type manganese ores. The cavities probably developed after the formation of botryoidal manganese ores by the processes of dissolution and have been subsequently filled by lithiophorite.

Fabrics of different ore minerals observed indicate metasedimentary, infiltration types of manganese ore, more than one generation of pyrolusite and cryptomelane are recognized. Mineral association of manganese and textural characteristics attest a low-temperature formation of metasedimentary ore bodies later subjected to oxidation solution process during weathering in the zone of lateritisation.

KEYWORDS :

Introduction

Manganese deposits of Shimoga area have been considered Fermor (1909) examined the manganese ores in the shallow mining pits of the Shimoga area and reported the occurrence of lateritoid, concretionary and cavernous manganese ores. He indicated the possibility of encountering massive ores at deeper levels in the mines. Roy (1981) classified the manganese ores of the region into: (a) syngenetic ores hosted in phyllite and quartzite and (2) remobilized ores occurring in the weathered zone. He did not emphasize the role of lateritization in the formation of extensive new manganese ore types at the expense of pre-existing metasedimentary manganese ores. Krishna Rao et al., (1982) reported the following four types of manganese ores in the Shimoga area: (a) reworked metasedimentary ore, (b) sedimentary oolitic ore, (c) cavity filling - replacement type ore and (d) float ore. The occurrence of sedimentary oolitic manganese ore, as suggested by Krishna Rao et al., (1982) is questionable, as there are no clear evidences in support of this view. Janardhana (1991) classified the manganese ores of the Shimoga area broadly into: (a) late Archaean metasedimentary ore and (b) lateritoid ore, but did not elaborate on several manganese ore types developed during lateritization event. Lithostratigraphy, mode of occurrence, mineralogy, paragenesis and genesis of manganese ore deposits, of a part of this belt have been worked out by Krishna Rao et al., (1982) Janardhana (1991) has stated that part of the ore bodies showed sedimentary characters and these metasedimentary ores were further modified in the weathered zone.

Mineralogical, textural and geochemical features of different manganese ore types confined to various locales in the weathered profile and the eroded surface have been recognized are presented here.

Ore varieties

Manganese and ferromanganese ores of the study areas were classified based on their mode of occurrence and genesis into i) metasedimentary manganese ore and ii) lateritoid manganese ore. The above two types have been further subdivided as follows.

I. Metasedimentary manganese ores

Unaltered metasedimentary manganese ore
Altered metasedimentary manganese ore

II. Lateritoid manganese and ferromanganese ore.

(A) Infiltration type ore
  (i) Non-colloform ore
  (ii)Colloform ore.

(B) Ferromanganese crust ore:
  (i) Textureless/finely laminated ore
  (ii) Oolitic/pisolitic ore.

Textural and mineralogical aspects of manganese ore types

Mineralogical investigation of representative samples have been carried out by using Leitz Labrolux 12- pol. incident light microscope provided with a photographic attachment. The properties examined for identification of minerals were colour, reflectivity and bireflectance, reflection pleochroism, anisotropic colours, internal reflections, polishing hardness, crystal form and cleavage.

X-ray investigation was carried out on both whole rock (ore) samples and scooped out mineral phases of ore minerals (with the help of a hand drill) identified by petrographic studies. X-ray studies on manganese were done on a JEOL X-ray diffractometer. A JEOL-8P X-ray diffractometer, equipped with an Iron target was operated at 40 KV and 29 MA. A manganese filter was used to eliminate $K\alpha 2$ radiations. $K\alpha 1$ radiations (1.934 A°) were used for determining the diffraction patterns of the sample. Microscopic identification of ore minerals was made referring to the compilation by Ramdohr (1969). Physico-optical data, of Indian manganese minerals presented by Roy (1966) have been useful in context.

Presence of manganese minerals like Presence of manganese minerals like pyrolusite, cryptomelane, hollandite, nsutite, ramsdellite, lithiophorite and goethite. Pyrolusite and cryptomelane are different generations. Lithiophorite is encountered as dissolution cavity-fillings in colloform variety of the infiltration type manganese ores. The cavities probably developed after the formation of botryoidal manganese ores by the processes of dissolution and have been subsequently filled by lithiophorite, (to be confirmed by EPMA analysis) in some varieties is also noted.

Amongst the iron minerals, goethite is prevalent being in many varieties, colloform bands in addition, goethite also occurs as globules and dendrite-like patches.

The unaltered metasedimentary manganese ores exhibiting bedded and banded structures consist of alternating layers of manganese- rich and clastic material (Plate. A). The manganese- rich layers exhibit sharp contact with the host material and at places the layers are warped. Manganese-rich bands consist of densely packed medium-grained pyrolusite with minor amounts of clastic material. Manganese-poor material consists mainly of quartzite or phyllite.

Bedded-type manganese ores are composed of pyrolusite admixed with minor amounts of clastic (essentially argillaceous) material (Plate. B) and exhibits equigranular texture. Pyrolusite is medium- to coarse- grained and occurs as well-developed crystals. Some bedded- and banded- type manganese ores contain clusters of coarse to very coarse-grained pyrolusite, and thus possesses an inequigranular texture (Plate. C). The coarse grained nature of the pyrolusite may be attributed to metamorphic recrystallization of the original medium grained sedimentary pyrolusite.

Metasedimentary manganese ores have been subjected to varying degrees of lateritic alteration, which is manifested by the partial replacement of the metasedimentary pyrolusite by supergene minerals.

Infiltration-type ores exhibit evidences of low temperature cavity filling and replacement textures. The textural features noted in the non-colloform and colloform varieties of infiltration-type manganese ores are described below.

Non-colloform varieties of infiltration-type manganese ores exhibit an intricate network texture (Plate. D). And laminated texture (Plate. E). This variety generally consists of supergene manganese- and iron-minerals represented by cryptocrystalline cryptomelane and minor goethite respectively. In the quartzite-hosted manganese ores, the supergene minerals occur amidst quartz implying that they were precipitated by the replacement of quartz (Plate. F). In case of phyllite-hosted manganese ores, the Mn- and Fe- minerals are encountered as sub-parallel streaks, bands and irregular patches, indicating that both processes of replacement and cavity filling were responsible for their formation.

In the colloform type, concentric bands composed of cryptomelane, pyrolusite, nsutite and goethite, occur as discrete colloform bands (Plate. G). In addition, goethite also occurs as globules and dendrite-like patches. Pyrolusite is represented by coarse-grained crystal aggregates that are commonly oriented perpendicular to banding and rarely occur as randomly oriented crystals (Plate. H). Colloform bands exhibit contraction (syneresis) cracks (Plate. I).which may or may not be filled with supergene manganese minerals.

Banded texture composed of micro layers of single minerals or polyminerals is commonly noticed in colloform ores. The single mineral may be either cryptocrystalline manganese oxide (pyrolusite, nsutite, cryptomelane) or iron hydroxide (goethite). Sometimes, radiating crystals of pyrolusite, nsutite and goethite are also encountered.

Globular masses of goethite in the form of thin films over early-formed cryptocrystalline masses of cryptomelane are noted in some of the samples. This can be readily identified based on optical properties like colour and reflectance.

Detailed characters of individual minerals in different ore types are described below:

Pyrolusite: In the unaltered metasedimentary manganese ore, pyrolusite (I) of sedimentary origin is the sole mineral encountered in the unaltered metasedimentary manganese ore. This was confirmed by X-ray studies on unaltered metasedimentary ore. In the intensely unaltered metasedimentary ores, Pyrolusite (I) is medium- to fine-grained and well crystalline (Plate. A). Pyrolusite (II) is encountered in bedded type metasedimentary ore as clusters of coarse-grained, attributable to diagenesis or metamorphic recrystallization of the pre-existing pyrolusite (I) (Plate. C).

Altered metasedimentary manganese ore resulted from lateritic alteration of the metasedimentary ore. This resulted in the replacement of metasedimentary pyrolusite by supergene minerals of Mn and Fe and development of tensional fractures/joints and dissolution cavities followed by their filling up by secondary manganese minerals. X-ray studies on the bulk altered metasedimentary manganese ores confirmed the presence of pyrolusite, cryptomelane, hollandite, ramsdellite, and goethite.

In the altered metasedimentary ore, four varieties of pyrolusite are encountered, viz., pyrolusite (I, II, III & IV). In the moderately altered metasedimentary ore, pyrolusite (I& II) are encountered either as small broken-up fragments or islands of tiny specks/ particles, having concave surfaces amidst supergene minerals. In the altered metasedimentary ores, pyrolusite (I) is replaced by diverse supergene minerals like cryptomelane, hollandite, and goethite. Pyrolusite (III) occurs as large fan-shaped crystals along with their supergene manganese- and iron-minerals. Pyrolusite (IV) is encountered as veinlets/stringers confined to tensional fractures/joints and as vug-fillings in the altered metasedimentary ores.

Pyrolusite is a common constituent of both colloform and non-colloform types of infiltration-type ores. In the colloform type, pyrolusite II and III are encountered. Pyrolusite II occurs as bands alternating with nsutite (Plate G&I), cryptomelane or goethite as coarse-grained, randomly oriented aggregates or needle-like or fan-shaped crystals (Plate. J). Pyrolusite III occurs as fillings in vugs/dissolution cavities of colloform ores (Plate. K). X-ray studies confirmed the presence of pyrolusite with nsutite, cryptomelane and goethite. In the non-colloform ores, pyrolusite occurs either as a monomineralic phase or the box-work type consists of large prismatic crystal aggregates of pyrolusite II and cryptocrystalline cryptomelane. X-ray studies have confirmed the presence of pyrolusite cryptomelane and goethite.

Cryptomelane: Cryptomelane in the study area is of supergene origin. In the altered metasedimentary manganese ores, cryptomelane occurs mainly as (i) irregular cryptocrystalline masses, (ii) fibrous patches and (iii) fracture/joint fillings. Bulk of the cryptomelane in the altered metasedimentary ore was deposited through low-temperature replacement of the metasedimentary pyrolusite (Plate. L&M) and only a small proportion is encountered as fracture/joint fillings.

In the least altered metasedimentary manganese ore exhibiting banded texture, cryptomelane exhibits relict grains of pyrolusite, implying replacement origin of cryptomelane (Plate N). X-ray diffraction of least altered metasedimentary ore confirmed the presence of cryptomelane and pyrolusite. Depending on the intensity of lateritization, the metasedimentary manganese ores show varying degrees of replacement of pyrolusite (I) by cryptomelane and the proportion of cryptomelane compared to pyrolusite also increases with increase in the degree of alteration.

Cryptomelane is the major phase in both the colloform and non-colloform varieties. In the colloform type, cryptomelane occurs as thin bands alternating with pyrolusite, goethite and nsutite (Plate G). In the non-colloform type, cryptocrystalline cryptomelane is associated with pyrolusite and goethite (Plates E&F).

Hollandite: In the altered metasedimentary ore, hollandite occurs in association with cryptomelane. Under the microscope, hollandite occurs as idiomorphic aggregates replacing pyrolusite (Plate O). X-ray studies on the bulk altered metasedimentary manganese ore confirmed the presence of pyrolusite, cryptomelane and hollandite in these ores.

Ramsdellite: In the altered metasedimentary ore, ramsdellite is of supergene origin and is associated with goethite. It occurs as platelets surrounding the metasedimentary pyrolusite and replaces pyrolusite (Plate P). X-ray studies on the altered sedimentary ore confirmed the presence of pyrolusite, ramsdellite and goethite.

Goethite: In the altered metasedimentary ore, goethite is of supergene origin and it is generally associated with other supergene minerals like cryptomelane, hollandite and ramsdellite. It occurs as cryptocrystalline irregular patches and commonly replaces metasedimentary pyrolusite. X-ray diffraction of the altered metasedimentary ore confirmed the presence of goethite and its associated supergene minerals. In the colloform type ore it constitutes a major phase and is commonly associated with supergene minerals like cryptomelane, pyrolusite, hollandite, ramsdellite and nsutite (Plate G). Goethite constitutes concentric bands and at places well developed radiating crystals of goethite is encountered. X-ray analysis of colloform ores confirmed the presence of goethite and associated minerals. In the non-colloform type, goethite occurs as irregular patches of cryptocrystalline material and is associated with pyrolusite, cryptomelane and hollandite of supergene origin (plate E). In some places, goethite replaces cryptomelane and hollandite. Presence of goethite and associated minerals were confirmed by X-ray studies.

Nsutite: In the colloform variety of infiltration-type ore, nsutite occurs as well developed crystals (Plate R) and as bands alternating with pyrolusite, cryptomelane and goethite (Plate G).

Lithiophorite: Lithiophorite is encountered as dissolution cavity-fillings in colloform variety of the infiltration type manganese ores. The cavities probably developed after the formation of botryoidal manganese ores by the processes of dissolution and have been subsequently filled by lithiophorite. X –ray powder data confirmed the presence of lithiophorite in colloform ores.

Genesis:

In the study area (i) residual alteration of the Late Archean metasedimentary manganiferous formation leading to the development of a thick Mn-rich duricrust, and (ii) deposition of infiltrationtype manganese ores in the permeable zones of the weathered quartzites and phyllites adjacent to the manganiferous formation, are considered here as broadly coeval. late Archaean metasedimentary manganese-rich bodies have been variably altered and the alteration effects are noticed in almost all the ore bodies exposed in the mine workings. Lateritic alteration of the metasedimentary manganese ores involved introduction of considerable quantities of cryptomelane, minor amounts of goethite and insignificant quantities of hollandite and ramsdellite by the process of low-temperature metasomatic replacement of the metasedimentary pyrolusite. Thus, in the altered metasedimentary ore, replacement texture is common apart from structures and textures generally found in the metasedimentary manganese ore. Based on the mineralogy, it can be said that the supergene minerals of these altered metasedimentary ores precipitated from Mn- Fe- alkali- rich solutions, migrating within the weathered profile above the level of palaeo water table.

The late-Archaean metasedimentary manganese ores of the Shimoga area have been subjected to supergene (lateritic) alteration. Structurally and texturally this alteration is discernible by the development of infiltration-type (colloform and non-colloform) and ferromanganese crust ores. Among the supergene ores, the infiltration-type ores are mainly composed of cryptomelane and considerable amounts of pyrolusite and goethite and lesser amounts of nsutite and lithiophorite. Ferromanganese crust ores are made up essentially of cryptomelane and goethite and lesser amounts of pyrolusite and lithiophorite.

The mode of formation of supergene ores, it is necessary to evaluate the nature of ore forming solutions, the source of Mn and Fe of the ore forming solutions, their migration and the mechanism of precipitation.

Chemical composition and nature of the ore forming solution can be evaluated from the textural features of the ores, mineralogical composition and their site of deposition. In the study areas, infiltration-type manganese ores are encountered at shallow depths localized along the secondary structures of the associated rock formations. Ferromanganese crust ores, which formed on the contemporary land surface of the weathered supracrustal rocks now occur as boulders and pebbles in the sandy clay formation of the Shimoga area. The mineral composition and the cryptocrystalline nature of the minerals of these two types of supergene ores suggest that the majority of the lateritoid ores were derived from colloidal solutions rich in Mn, Fe and alkalies.

Regarding the source of Mn and Fe for the formation of supergene ores, it can be visualized that the Mn- and Fe- content of the circulating meteoric waters were derived essentially from the weathering of the metasedimentary manganiferous and iron formations of the study area. The other associated late Archaean supracrustal rocks of the study areas cannot be considered as a potential source of these metals, because only formations containing 100 times the Clarke value of Mn and Fe can account for the metals required for the formation of supergene Mn- and Fe- ores (Lelong et al., 1976).

In a weathering environment, Mn is leached from the source rock after alkaline and alkaline earths, and just prior to or directly with iron (Crerar et al., 1980). In the study areas, during the lateritization process, dissolution of late Archaean Mn- and Fe- ores by the reaction with acidic surficial and near-surface waters may not have occurred on a major scale, as the late Archaean metasedimentary Mn- and Fe- formations are composed respectively of pyrolusite and magnetite. Dissolution of such higher oxides in acidic waters can occur only to a limited extent.

The manganiferous horizon is spatially associated with stromotalitic carbonates, banded iron formation, phyllites and ripple marked quartzites. The chemical analysis data of the metasedimentary manganese ores indicate their derivation from a volcanogene-hydrothermal source. The manganiferous formations are considered to have been deposited in a near-shore environment (Janardhana, 1991).

The manganese released into the near-surface and surficial waters was present probably as simple and complex ions, organo-metallic complexes and colloids. Divalent Mn and Mn-rich colloids precipitate faster. Mn- and Fe- rich meteoric waters permeating through the weathered supracrustal rocks gave rise to infiltration-type ores. Ferromanganese crust ores precipitated probably from Mn- and Fe- rich surficial waters. During wet spells, when the weathering supracrustal rocks were under water-logged conditions, the metal-rich, near-surface waters in the weathering profile, reach the surface. These waters can also reach the surficial layers as a result of evapotranspiration process.

The dissolved Mn and Fe of the near-surface and surficial waters can precipitate by several mechanisms. However, the present author is of the opinion that the higher oxygen content of the circulating meteoric waters in the near-surface zones facilitated precipitation of the dissolved manganese of the circulating waters.

With regard to the site of precipitation of supergene ores, it is clear that the infiltration-type manganese ores are confined only to the weathered portions of the supracrustal rocks and are encountered in the proximity of weathered manganiferous formation. The infiltration-type manganese ores, being confined to permeable zones in the quartzites and phyllites, can be traced to a depth of the palaeo water table.

The precise site of precipitation of the ferromanganese crust ores in the Shimoga area could not be deciphered during the present investigation, because the ferromanagese crust ore has not been preserved insitu and only its fragmentary remnants are encountered as boulders and pebbles within the surficial detrital sandy clay cover and soils. Textural features exhibited by the textureless/finely laminated and oolitic/pisolitic varieties of the ferromanganese crust ore do not provide tangible evidences in support of their origin. The oolitic/pisolitic ores possibly developed in surficial water-bodies as lake deposits. However, certain textural features indicate the possibility of their development in the soil horizon. Thus, it may be said that the ferromanganese crust ore could be either a fresh water deposit or of pedogenic origin. The ferromanganese crust ore is dominated by oolitic/pisolitic variety, which exhibits matrix supported texture. The nucleus of some of the ooids contain pre-formed and broken fragments of ooliths/pisoliths, quartz grains, broken fragments of earlier formed manganese mineral grains, etc. However, majority of the ooliths/pisoliths are devoid of nucleus. The ooliths/ pisoliths of the ore do not exhibit concrete evidences of either concretionary or accretionary growth mechanisms. The development of ooliths and pisoliths under free-rolling aqueous environment points to the accretionary origin of these ores. The textural and mineralogical features of ferromanganese crust ore support their development through sedimentary/diagenetic processes. In the light of the above observations, ferromanganese crust ore may be viewed as a laccustrine deposit. However, manganese and ferromanganese ooliths and pisoliths are commonly found in the weathered profiles of the mangaese deposits, as in the manganese deposits of the Groote Eylandt, Australia. Such secondary concretions are generally considered to be pedogenic origin. The development of pedogenic Mn- and Fe- rich oolitic/pisolitic ore may be attributed to repeated cycles of dissolution of the Mn- and Fe- minerals of the supracrustal rocks, upward migration of the metal-rich waters through several mechanisms and reprecipitation of the same in the soil horizon.

During the late- to post- lateritization period, surficial lateritoid ferromanganese crust was subjected to mechanical disintegration and minor dissolution under pedogenic conditions. During this process, some of the dissolution cavities were partially/fully filled with lithiophorite of pedogenic origin.

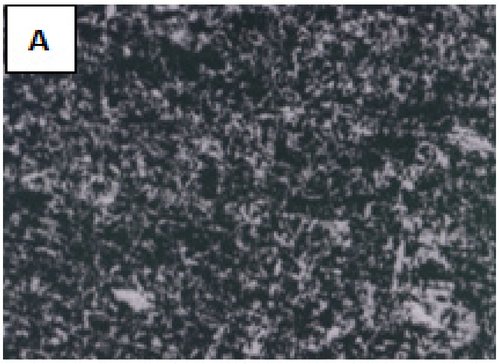
The debris of the mechanically disintegrated ferromanganese crust ore accumulated in the low-lying areas as detrital beds of ore boulders and pebbles during more than one cycle, through the action of gravity and transportation by fluvial/pluvial agencies. The ferromanganese ore boulders and pebbles show both normal- and reverse- graded bedding. These ore boulder/pebble beds of subrecent origin, referred to in the present work as " palaeofloat ore" have been buried under a cover of sandy clay formation of detrital origin, the latter being derived from the weathered phyllites and quartzites.

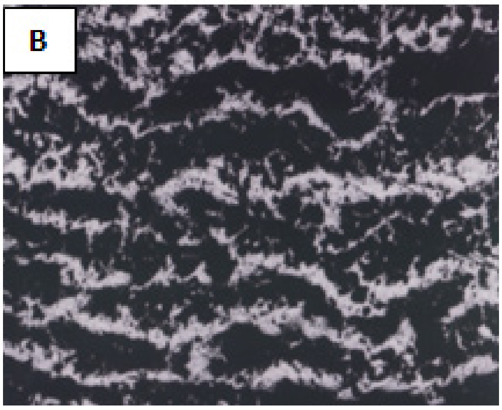
During the continued evolution of the land, several of the ore boulder/pebble beds and the overlying sandy clay beds were subjected to erosion due to surface creep and other denudational processes. In this process, bulk of the sandy clay material was lost and a part of the weathered ore fragments are encountered randomly in the soil horizon. The soil-hosted ore boulders/pebbles, referred to in the present work as "recent float" were thus derived from palaeofloats.

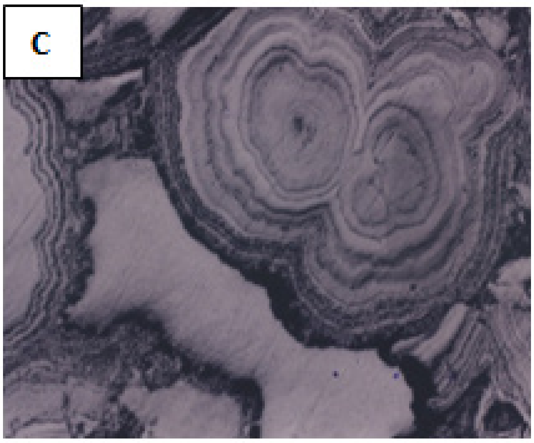
In the Shimoga district, the palaeofloat and float ores of the ferromanganese crust are being mined since the beginning of the 20th Century.

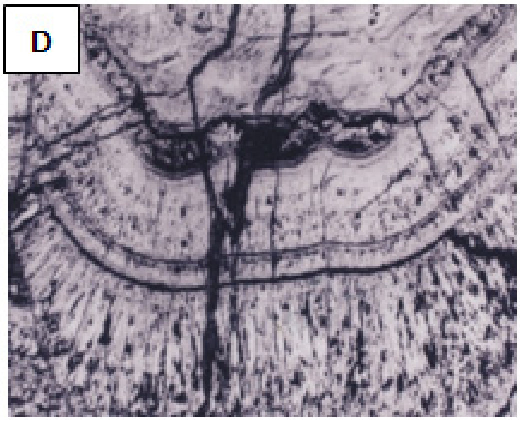
Conclusion

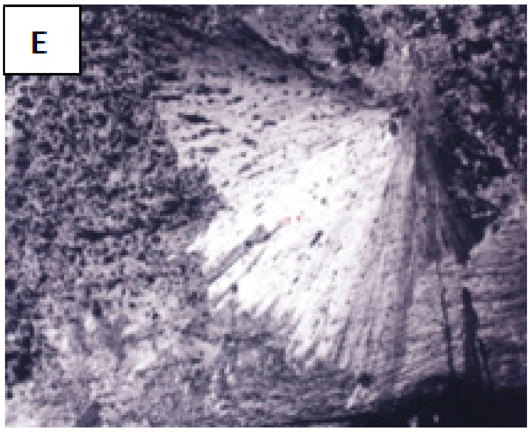
While providing details on the field setting, textural, mineralogical, genetic and depositional features of the manganese and ferromanganese ore types of the Shimoga region, the present study also outlines potential links between the Mn-rich deposits and aspects of Late Archean manganiferous formation evolution In the study area, the Late Archean (~2700 Ma) metasedimentary manganese formation, which has been shown to be of volcanogenesedimentary origin, is underlain by a stromatolitic limestone–dolomite sequence. The latter indicates precipitation in an oxygenated depositional environment, whereas the quartzite–arenite sequence underlying the limestone–dolomite sequence was deposited under anoxic to oxic transitional depositional conditions. The presence of a clastic sedimentary bed, itself deposited in anoxic to oxic transitional conditions and immediately underlying the limestone of the study area, is a unique feature not reported from any other Archean manganiferous terrain. These geological conditions at the time of Late Archean manganiferous formation development in the study area testify to the observation made by Roy (2006) that, in Archean manganiferous terrains, limited deposition of the exogenous manganese mineralization occurred ca. 2750 Ma ago in localized basin-margin, shallow shelf niches where limited oxygenation was triggered by the introduction of photo system II (oxygen oasis of Kasting, 1993). In the extensive Shimoga Schist Belt terrain, the occurrence of mineable concentrations of Mn-rich duricrust clasts in the form of detrital boulder and pebble beds in fluvial palaeochannels, Kumsi–Shankargudda–Harnahalli tract (Krishna Rao et al., 1982), is a rare, if not unique, feature among the manganiferous terrains of the world.

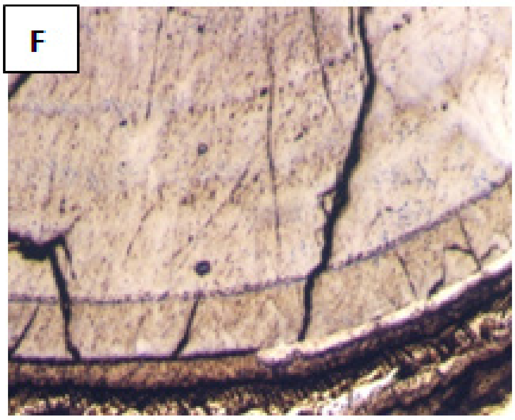

A

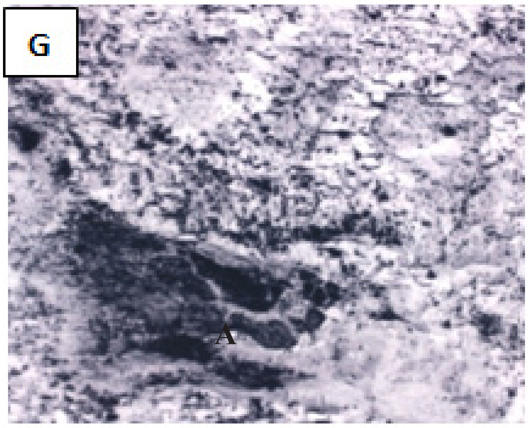

B

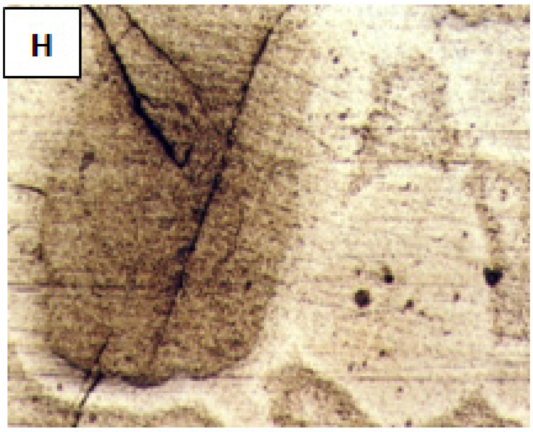

C

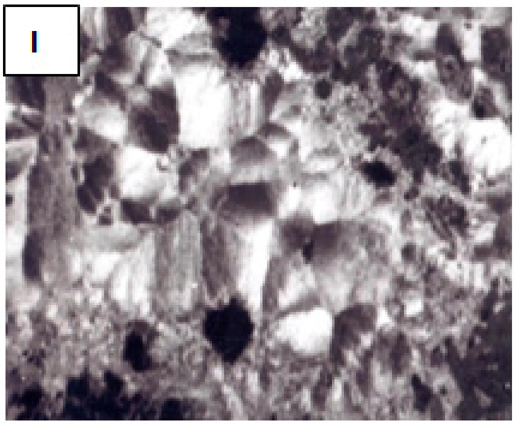

D

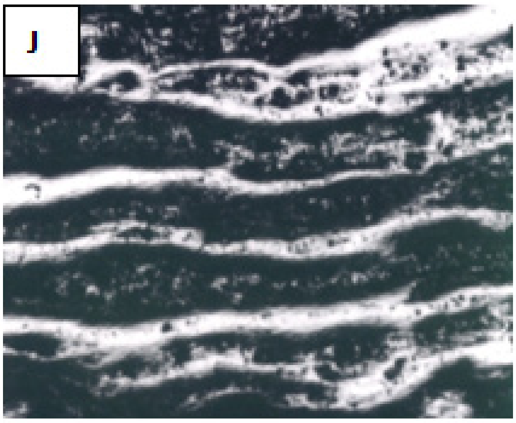

E

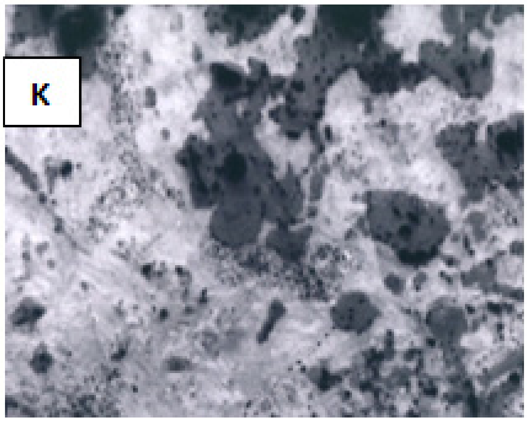

F

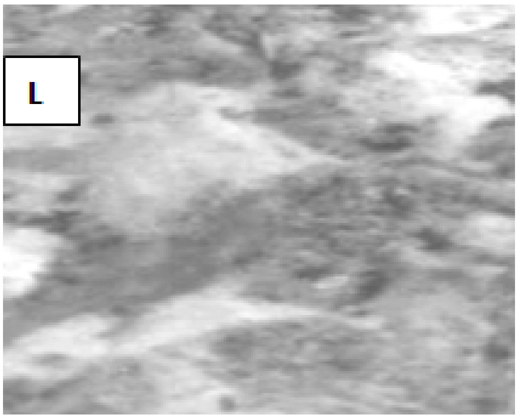

G
A

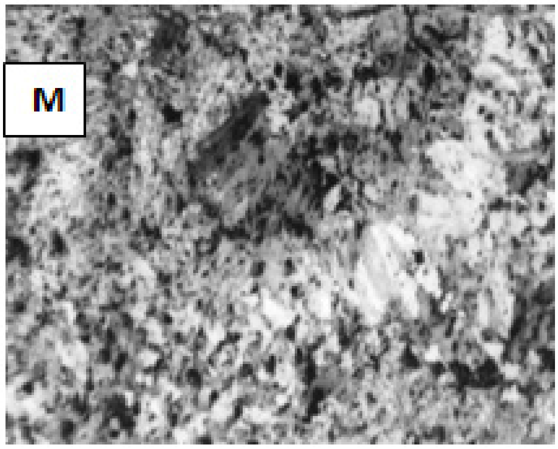

H

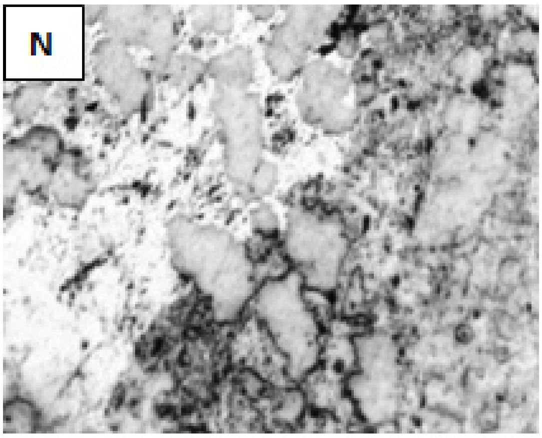

I

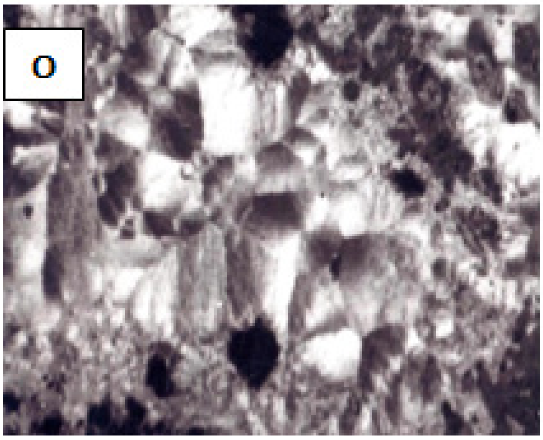

J

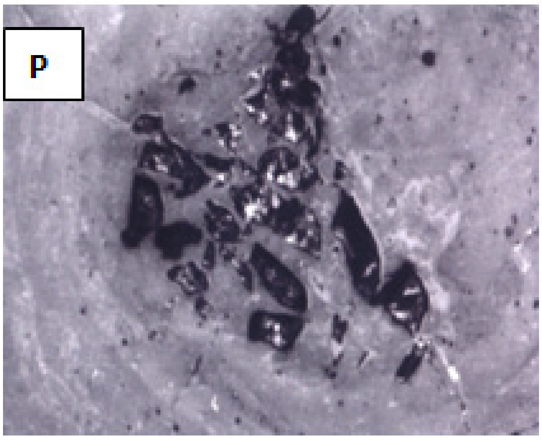

K


L


M


N





Explanation of plate

A. Equigranular texture exhibited by pyrolusite (light grey) and clastic material (dark grey) in unaltered metasedimentary manganese ore 250 X Pol.

B. Inequigranular texture in metasedimentary manganese ore resulting from clusters of coarse-grained pyrolusite amidst medium-grained pyrolusite 250X Pol.

C. Photomicrograph of infiltration type colloform ores showing concentric bands of pyrolusite, nsutite, cryptomelane and goethite 250X Pol.

D. Photomicrograph showing colloform variety of infiltration-type manganese ore in which pyrolusite occurs in bands alternating with other manganese minerals and goethite 250X Pol.

E. Photomicrograph of large prismatic pyrolusite crystals replaced by cryptomelane, goethite, ramsdellite and hollandite in colloform variety of infiltration-type manganese ore 250X Pol.

F. Photomicrograph showing fracture filling of pyrolusite III in colloform variety of infiltration-type manganese ores 250X Pol.

G. Supergene pyrolusite III replaced by cryptocrystalline cryptomelane 250X Pol.

H. Photomicrograph showing cryptocrystalline replacing pyrolusite in altered metasedimentary ore 250X Pol.

I. Photomicrograph showing replacement of pyrolusite by cryptomelane in the altered metasedimentary manganese ore 250X Pol.

J. Photomicrograph of infiltration-type non-colloform manganese ore exhibiting laminated texture defined by alternate bands of cryptomelane (light grey) and goethite (dark grey) 250X Pol.

K. Photomicrograph of infiltration type non-colloform ore showing partial replacement of weathered quartzite by supergene pyrolusite and cryptomelane 250X Pol.

L. Photomicrograph of hollandite occurring as idiomorphic crystalline aggregates replacing pyrolusite in altered metasedimentary ore 250X Pol.

M. Photomicrograph showing replacement of pyrolusite (grey) by ramsdellite (light grey) and goethite (dark grey) in altered metasedimentary manganese ore 250X Pol.

N. Photomicrograph showing goethite-replacing pyrolusite in altered metasedimentary ore 250X Pol.

O. Nsutite in infiltration-type colloform manganese ores 250X Pol.

P. Dissolution cavities in ooliths coated with lithiophorite 250X Pol.

REFERENCES

| Crerar,D.A., Fischer, A.G. and Plaza, C.L. (1980). Metallogenium and biogenic deposition | Calcutta, 219 P. | Fermor, L.L. (1909. The manganese ore deposits of India: Mem. Geol. Survey India. | Janardhan, M. R., (1991) Geological setting, mineralogy, textural, geochemistry and genesis of Shimoga manganese deposits, Karnataka. Unpublished Ph.D. thesis submitted to University of Mysore, Mysore | Kasting, J.F., 1993. Earth's early atmosphere. Science 259, 920–926. | Krishna Rao, B., Srinivasan, R., Ramachandra, B. L. and Sreenivas, B. L. (1982) Mode of occurrence and origin of manganese ores of Shimoga district, Karnataka. Jour. Geol. Soc. Ind., v. 23, PP. 226-235. | Lelong, F., Tardy, Y., Grandin, G., Trescases, J. J. and Boulange, B. (1976) Petrogenesis chemical weathering and processes of formation of some supergene ore deposits. In: Hand book of strata bound and stratiform ore deposits, K.H. Wolf (ed.) v.3, pp. 93-174. Elsevier Sci. Pub. Co. Amsterdam-oxford-Newyork. | Ramdohr,P. (1969) The ore minerals and their intergrowths. Pergamon press, Braunschweig, p.219.of manganese from Precambrian to recent time. In: I. M. Varentsove and Gy. Grassely (Eds). Geology and geochemistry of manganese. V. III. Schweizer bastche Verlagsbuch handling, Stuttgart, pp.285-304. No.37,109 p. | Roy, S., (1981) Manganese deposits, Academic Pres Inc. (London), 451P. | | Roy. S. (1966) Syngenetic manganese formations of India, Jadavapur University publication, | Roy, S., 2006. Sedimentary manganese metallogenesis in response to the evolution of the |