ORE-MICROSCOPIC STUDIES OF THE MANGANESE ORE-MINERALS OF OLD M.P.

II. Satak, Beldongri, Lohdongri and Kachurwahi, Nagpur District

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INTRODUCTION

The paper gives an account of the mineralogic study of the manganese ore-minerals collected from Satak, Beldongri, Lohdongri and Kachurwahi manganese mines, in Nagpur district (Bombay State). All these four deposits lie approximately on the same line of strike and form a part of the belt of manganese ore-deposits stretching in an easterly direction from Dumri Kalan to Khandala, a total distance of 12 miles, and containing the above-mentioned deposits successively as we go from west to east. The area forms a part of the topographical sheet No. 55 O/7 and lies about four miles to the east of Dumrikhurd railway station which is about 20 miles to the north-east of Nagpur and lies on the Nagpur-Ramtek branch of the S.E. Railway.

J. A. Dunn (1936) was the first to carry out a mineralogic study of some selected specimens, mainly of Vredenburgite, from L. L. Fermor’s (1909) collection of the manganese ores of Beldongri. But apart from this, no systematic mineralogic study of the ores from the deposits in this belt, has been made hitherto.

GEOLOGY OF THE AREA

All the ore-deposits are isolated outcrops in alluvium and are probably hills now submerged in the alluvium of the Sur river.

The ore-deposit at Satak outcrops as a low flat bare mound about ¼ mile long and striking E. 10° N. The dip is about 40°-50° to the south. There are two parallel ore-bands, both about 7 feet thick and separated by a layer of mica-schist. The wall rocks consist mainly of mica-schists with subordinate gneisses and quartzites.

The Beldongri deposit is situated about a mile E.N.E. of the Satak deposit. The ore-band is about 60 feet thick with an exposure of about 100 yds. The
strike is E. 5° N. at the west-end veering round to E. 40° N. at the east-end. The dip averages about 50-60° to the south. The underlying rocks were not exposed but the overlying rocks consist of schistose micaceous gneisses. Gondites, schists and quartzites are intercalated with the ore-band. Intrusions of felspathic rocks occur in both the Satak and Beldongri deposits (Fermor, 1909). However, at the time of the author's visit, the mine was an abandoned pit with about 70 feet of water. The specimens were collected from the talus ore scattered around the pit.

The deposit at Lohdungri formed a low flat mound about 380 yds. long from east to west, 200 yds. broad and about 30-35 feet thick, which is now largely excavated. The ore layers, striking due east (with a steep dip to the south), vary in thickness from 2 feet to 2 inches and more and are crumpled about axes parallel to the strike. The total thickness of the ore-bands is probably about 60 feet (Fermor, 1909). The underlying (footwall) rocks consist of mica-schists with some quartzites.

The ore-band at Kachurwahi strikes E. 10° N. on an average with a dip of about 60-70° to the south. The ore-band is separated into a number of bands, each about 5-10 feet thick, by layers of quartzites and schists. The hanging wall consists of felspathic mica-schist and the footwall is a mica-quartz-schist. Intrusions of felspar rock are also seen here (Fermor, 1909).

**MINERALOGY OF THE ORES**

The Satak deposit contains about equal proportions of all the three types of ores found in this area, i.e., the Braunite ore, the Vredenburgite-Braunite ore, and the Sitaparite-Hollandite-Braunite ore. At Beldongri, only the Vredenburgite-Braunite ore is found, while at Lohdungri, only the other two types are found. The Kachurwahi deposit contains both the Vredenburgite-Braunite ore and the Braunite ore.

The mineragraphic study of a number of polished sections, prepared from carefully selected specimens, revealed the presence of the following ore-minerals: Braunite, Sitaparite, Hollandite, Jacobsite, Hausmannite, Manganite, Psilomelane, Pyrolusite and two unidentified minerals. The identifications were based on optical characters under polarised light, reflectivity as measured by the Berek’s Slit-microphotometer (in green light in air) and the action of standard etch reagents.

**Braunite**

The mineral takes a good polish. Colour: Grey with a faint brownish tint. In oil a lilac-brown tint is visible. Reflectivity: Low. The value

Etch Reactions

Positive.—

\[ \text{H}_2\text{O}_2 \] — Slow effervescence. No stain.

\[ \text{H}_2\text{O}_2 \text{ (concentrated)} + \text{H}_2\text{SO}_4 \text{ (concentrated)} \] — Faster effervescence. Darkens and produces etch scratches. After 4 minutes develops parting planes.

\[ \text{SnCl}_2 \text{ (saturated)} + \text{HCl} \text{ (concentrated)} \] — Tarnishes permanently light brown and develops etch scratches. Strong action after 4 minutes.

Negative.—\text{HNO}_3, \text{HCl}, \text{KCN}, \text{FeCl}_3, \text{KOH}, \text{HgCl}_2, \text{Aqua Regia}.

Braunite occurs as crystalloblastic aggregates of coarse to fine-grained rounded or elongated grains often with Vredenburgite (this name, wherever it occurs in the paper, refers to the intimate oriented intergrowth of Jacobsite and Hausmannite) occurring as interstitial grains (Fig. 1). It often shows mutual boundary relationship with the Vredenburgite and the Jacobsite and also veins the latter (Fig. 3). Numerous rounded inclusions of Braunite are sometimes seen in Vredenburgite (Fig. 5). In the Sitaparite-Hollandite-Braunite ore, it occurs as distinct bands, often intergrown with Sitaparite and unidentified mineral A in lamellar fashion. It veins Hollandite, mainly along grain boundaries and cleavage planes.

Sitaparite

It takes a good polish. Colour: Light-grey with a distinct yellow tint. The tint changes to brownish in contact with Hollandite. Reflectivity: Low. The value is about 21–22. Pleochroism: Not observed. Anisotropism: Either very weak or isotropic. Some grains show beautiful polysynthetic twinning in one or more directions, often forming a complicated mesh.

Etch Reactions

Positive.—

\[ \text{SnCl}_2 \text{ (saturated)} + \text{HCl} \text{ (concentrated)} \] — Etches strongly with the development of etch scratches and a light-brownish stain.

\[ \text{H}_2\text{O}_2 \text{ (concentrated)} + \text{H}_2\text{SO}_4 \text{ (concentrated)} \] — Produces weak etch scratches.

\[ \text{HF} \text{ (concentrated)} \] — Develops texture. Produces slight etch scratches and stains faintly light-brown.
Negative.—HNO₃, HCl, HNO₃ (concentrated), HCl (concentrated), KCN, FeCl₃, KOH, HgCl₂, H₂O₂, Aqua Regia.

Sitaparite [though the mineral Sitaparite has been shown to be identical with Bixbyite by Mason (1942), he thinks it desirable to retain the name Sitaparite for the specimens occurring in the metamorphosed manganese ores (Mason, 1944). The name Sitaparite is, therefore, retained in this paper] often shows an idioblastic habit. It occurs as bands containing coarse to medium-grained crystalline aggregates of subhedral crystals, in the Hollandite-Sitaparite-Braunite ore. It is often intergrown with Braunite and the unidentified mineral A in lamellar fashion. It also shows euhedral crystal outlines against the Hollandite and the Braunite.

One peculiar occurrence of Sitaparite has been observed in an ore from Beldongri. It shows a light-grey colour with a distinct pinkish yellow tint in oil and very weak anisotropism with dirty pink, yellowish, greenish and grey colours. It occurs as medium to fine-grained crystalline aggregates of irregular grains included in very coarse-grained crystals of Hausmannite (Fig. 6). Jacobsite (with a few Hausmannite lamellae) also occurs as similar inclusions in Hausmannite. Very small grains of Jacobsite are sometimes included in this Sitaparite. The association of Sitaparite with Vredenburgite is very peculiar (as they belong to different suites) and the author has not seen it reported anywhere. However, the mineral under consideration may not be Sitaparite because it shows a slightly different colour and gives an entirely different reaction with SnCl₂ (saturated) + HCl (concentrated). While the reagent produces distinct etch scratches on Sitaparite, it attacks this mineral very strongly, scratches it heavily and turns it nearly completely black. The reaction of H₂O₂ (concentrated) + H₂SO₄ (concentrated) on this mineral is also distinctly stronger than on ordinary Sitaparite.

It is possible that in this particular association the composition of the Sitaparite might be different and hence shows variation in properties. But it is noticed that even a wide range in the composition of Sitaparite has got very little effect on its properties (Mason, 1942). So it is possible that the mineral is not Sitaparite but might be the original alpha-Vredenburgite, in which the dissociation in the two component phases (i.e., Jacobsite and Hausmannite) did not take place. Van Hook and Keith (1958) state that the tetragonal mineral reported by Mason (1943 b) as alpha-Vredenburgite might be cation deficient and hence occurs as a single phase instead of as an intergrowth and the existence of single phase metastable mineral in the composition range of Vredenburgite is possible but we would expect it to be cubic if the cation : oxygen ratio is stoichiometric. This view can explain the
isotropic or very weakly anisotropic character of the mineral under consideration. X-ray diffraction studies only, which are to be carried out shortly, can perhaps throw light on the real nature of this mineral.

**Hollandite**

Sections showing a well-developed prismatic cleavage take a fairly good polish. Other sections are very difficult to polish. Colour: Grey-white to white. A faint yellowish tint is visible in oil. Reflectivity: Moderately high. The value varies from 28–30. Pleochroism: Distinct in oil. Anisotropism: High. Yellowish, purplish, greenish and bluish-grey colours. Badly polished sections with no cleavage show weak anisotropism and pale violet pink, dark violet grey, greyish brown and bluish grey colours. Cleavage in one direction is well developed in some grains.

**Etch Reactions**

*Positive.*—

SnCl₂ (saturated) + HCl (concentrated)—Etches heavily. Brings out close lamellar striations and cleavage. Effect very strong on sections with no cleavage. These sections get almost completely black. Drop of the reagent turns yellow.

H₂O₂ (concentrated) + H₂SO₄ (concentrated)—Vigorous effervescence. Blackens and brings out cleavage and grain boundaries. Effect very strong on sections with no cleavage.

H₂O₂ (dilute)—Slow effervescence. Slightly attacks sections with no cleavage.

*Negative.*—HNO₃, HCl, HNO₃ (concentrated), HCl (concentrated), Aqua Regia, KCN, FeCl₃, KOH, HgCl₂.

Hollandite occurs as a crystalline aggregate of medium to coarse-grained and stout prismatic subhedral crystals usually occurring as well-defined bands alternating with those of Braunite, Sitaparite and occasionally the unidentified mineral A (Fig. 8). Pyrolusite and Psilomelane often vein and replace Hollandite along the grain boundaries and the cleavage planes. Braunite also veins Hollandite mainly along the grain boundaries and the cleavage planes.

**Unidentified Mineral A**

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Etch Reactions

Positive.—

SnCl₂ (saturated) + HCl (concentrated)—Produces etch scratches and stains permanently light-brown.

H₂O₂ (concentrated) + H₂SO₄ (concentrated)—Produces weak etch scratches and a light-brownish stain.

HF (concentrated)—Produces weak etch scratches.

Negative.—HNO₃, HCl, HNO₃ (concentrated), HCl (concentrated), Aqua Regia, H₂SO₄ (concentrated).

The mineral occurs as a crystalline aggregate of medium to coarse-grained grains. It forms distinct bands alternating with those of Braunite, Sitaparite and Hollandite, and its grains are always coarser than those of the associated Braunite and Sitaparite. It is often intergrown with Braunite and Sitaparite in lamellar fashion. In the bands of this mineral, lamellar or irregular but oriented inclusions of some gangue mineral are found (Fig. 8). The gangue mineral is either forming a lamellar intergrowth with this mineral (because wherever Braunite is also intergrown with the same crystals its lamellae are parallel to those of the gangue mineral) or the unidentified mineral A has been formed by the oriented replacement of this gangue mineral and the lamellar inclusions of the gangue mineral are the leftovers after replacement. Which of these two interpretations is correct is difficult to determine.

A similar mineral was found in the ores of Gowari Warhona and was fully described in a previous paper (Deshpande, 1959).

The unidentified mineral A has got properties (like the mineral from Gowari Warhona) intermediate between those of Braunite and Sitaparite but it differs from the latter in showing weaker pleochroism and giving slightly different etch reactions; but they mainly differ in one important respect. In the ores of Gowari Warhona a very fine intergrowth of Braunite and Sitaparite was observed, which had properties intermediate between those of Braunite and Sitaparite, and it was suggested that the mineral might have originated from the intergrowth (though for other reasons it was thought that the mineral was quite distinct from such an intergrowth), but in these ores from Satak no fine intergrowth of Braunite and Sitaparite, which could have led to the formation of the unidentified mineral A, was noticed. The observed intergrowth between Braunite and Sitaparite was quite coarse and distinct and was comparatively rare. The mineral from Gowari Warhona was thought to be probably Alpha-Vredenburgite but this unidentified
mineral cannot be Alpha-Vredenburgite because it shows a very weak anisotropism and might be regarded as isotropic at times. It may be a variety of Sitaparite or possibly a different mineral having affinities with Sitaparite and Braunite. The real nature of this mineral can only be unravelled by X-ray diffraction analysis.

**Jacobsite**

It takes a fairly good polish. Colour: Grey with a distinct yellowish olive tint. In contact with Hematite, the tint is brownish yellow. In some specimens from Beldongri, a pinkish yellow tint is seen in addition and there is often an irregular transition from this to the yellowish olive tint. Reflectivity: Low, the value being about 19.5-20. Pleochroism: Not observed. Anisotropism: Very weak or isotropic. Red internal reflections are occasionally visible in oil.

**Etch Reactions**

*Positive.*—

\[ \text{SnCl}_2 \text{ (saturated)} + \text{HCl} \text{ (concentrated)} \]—Occasionally darkens slightly and produces very weak etch scratches but mostly negative.

\[ \text{HF} \text{ (concentrated)} \]—Develops texture (Fig. 5). Produces etch scratches, blackens differentially and stains light olive.

*Negative.*—Negative to all other standard etch reagents.

Jacobsite occurs in these ores in two ways. Firstly it occurs as rounded medium to coarse-grained crystalline aggregates (containing Hausmannite lamellae) interstitial to those of coarse-grained Braunite (Fig. 1). Such Vredenburgite also often shows mutual boundary relationship with the Braunite and contain numerous small rounded inclusions of Braunite (Fig. 5). Secondly, it occurs as rounded medium to coarse-grained crystalline aggregates (Hausmannite-free) showing mutual boundary relationship with the Braunite. Secondary Braunite and Hematite also clearly vein Jacobsite in this ore (Fig. 3).

**Hausmannite**

The mineral takes a good polish. Colour: Light-grey to dark-brownish grey. Reflectivity: Low. The value is about 20–21. Pleochroism: Distinct. Anisotropism: Strong. Yellowish grey, bluish grey and brownish grey colours. Numerous scratches are visible in the lightest position. Coarse lamellar twinning in one or more directions is observed. The lamellae are often intersecting and are of unequal width. At places small lamellae are arranged diagonally between two adjacent principal lamellae
and the structure resembles that of a distorted ladder (Fig. 6). Red internal reflections are abundant in oil.

**Etch Reactions**

**Positive.**—

HCl (concentrated)—Etches weakly. Develops texture.

SnCl₂ (saturated) + HCl (concentrated)—Darkens and develops twinning planes.

H₂O₂ (concentrated) + H₂SO₄ (concentrated) — Same as above. Also produces slight etch scratches.

H₂O₂—Effervescence. Surface unaffected.

**Negative.**—HNO₃, HCl, HNO₃ (concentrated), H₂SO₄ (concentrated), Aqua Regia, KCN, FeCl₃, KOH, HgCl₂.

Hausmannite usually occurs as lamellae in the octahedral directions of Jacobsite grains (Figs. 1, 2, 5). It also occurs as irregular segregations of medium to coarse-grained crystals in the Jacobsite. Occasionally, it forms extremely coarse-grained granoblastic aggregates of rounded subhedral crystals. Medium to fine-grained and irregular inclusions of Vredenburgite and Sitaparite (?) are found in them (Fig. 6). Hausmannite is always largely replaced and veined by Psilomelane often along the twinning planes.

**Manganite**

It takes a good polish. Colour: Light-grey to dark-brownish grey with olive tint in one position. Reflectivity: Low. The maximum and minimum reflectivity values are 19.5 and 16 respectively. Pleochroism: Very strong. Anisotropism: Very strong. Yellowish, bluish grey and dark-violet grey colours. Internal reflections are red and are quite abundant in oil. One directional prismatic cleavage is visible in some coarser needles.

**Etch Reactions**

**Positive.**—

HCl (concentrated)—Produces slight etch scratches.

SnCl₂ (saturated) + HCl (concentrated)—Etches heavily. Blackens considerably.

H₂O₂ (concentrated) + H₂SO₄ (concentrated)—Tarnishes strongly. Brings out grain boundaries and probably cleavage in some grains.

**Negative.**—HNO₃, HCl, HNO₃ (concentrated), Aqua Regia, H₂SO₄ (concentrated), KCN, FeCl₃, KOH, HgCl₂.
Manganite forms finely crystalline aggregates of thin prismatic needles which are sometimes radiating. It veins Braunite, Jacobsite, Hausmannite and the gangue minerals often along with Pyrolusite and Psilomelane. It also replaces the gangue minerals. Pyrolusite often replaces it mainly along the cleavage planes and also forms pseudomorphs after it.

Psilomelane


Etch Reactions

Positive.—

HNO₃—Stains light-brown. Some specimens negative.
HCl—Stains permanently brown.
H₂O₂—Strong effervescence. No stain.
SnCl₂ (saturated) + HCl (concentrated)—Etches completely black.
H₂O₂ (concentrated) + H₂SO₄ (concentrated)—Etches completely black.

Negative.—Aqua Regia, KCN, KOH, HgCl₂.

Psilomelane usually occurs as extremely fine-grained and almost crypto-crystalline aggregates but occasionally it forms fine-grained needles (sometimes fibrous) showing strong anisotropism. It replaces some of the gangue minerals metasomatically and in these replacements it shows coarse-grained form with strong anisotropism. It veins and replaces Hausmannite (often along the twinning planes), Braunite (mostly along the grain boundaries), Hollandite (mostly along the grain boundaries and the cleavage planes), Jacobsite and the gangue minerals. It often gives rise to Pyrolusite after dehydration.

In the vugs of an ore from Beldongri, Psilomelane is found showing a brownish grey colour, high anisotropism and stout prismatic habit with probably a one-directional cleavage at places. It is associated with Pyrolusite which shows a similar habit. The author believes that the Psilomelane has replaced the Pyrolusite (mainly along the cleavage planes) and has formed pseudomorphs after it.

Unidentified Mineral B

It takes a good polish. Colour: Yellowish white to grey. Colour slightly uneven at places. Reflectivity: Moderate. Maximum reflectivity
slightly lower than that of Pyrolusite and minimum reflectivity slightly higher than that of Psilomelane. The value varies from 28–30. Pleochroism: Distinct. Anisotropism: Strong. Pinkish white and brownish yellow to dark brownish-grey colours.

**Etch Reactions**

*Positive.*

- \( \text{HCl} \) — Darkens slightly or negative.
- \( \text{SnCl}_2 \) (saturated) + \( \text{HCl} \) (concentrated) — Etches completely black. Reaction slower than for Psilomelane.
- \( \text{H}_2\text{O}_2 \) (concentrated) + \( \text{H}_2\text{SO}_4 \) (concentrated) — Etches completely black. Reaction faster than for Pyrolusite.

*Negative.* — \( \text{HNO}_3 \), \( \text{HNO}_3 \) (concentrated), \( \text{HCl} \) (concentrated), \( \text{H}_2\text{SO}_4 \) (concentrated), Aqua regia, \( \text{KCN} \), \( \text{KOH} \), \( \text{HgCl}_2 \).

The mineral occurs as coarse-grained irregular grains associated with Pyrolusite and Psilomelane in the vugs of an ore from Beldongri already referred to in the description of Psilomelane. It is excessively veined by Psilomelane. The grains at places show colloform outlines (Fig. 7).

The mineral shows properties which are intermediate between those of Pyrolusite and Psilomelane. But its coarse-grained nature and strong anisotropism (with typical anisotropic colours) clearly distinguishes it from both Psilomelane and Pyrolusite. X-ray diffraction analysis of this mineral is expected to throw light on the identity of this mineral.

**Pyrolusite**


**Etch Reactions**

*Positive.*

- \( \text{H}_2\text{O}_2 \) — Strong effervescence. No stain.
- \( \text{SnCl}_2 \) (saturated) + \( \text{HCl} \) (concentrated) — Etches instantaneously black.
- \( \text{H}_2\text{O}_2 \) (concentrated) + \( \text{H}_2\text{SO}_4 \) (concentrated) — Etches completely black. Reaction slower than for Psilomelane.
H₂SO₄ (concentrated)—Tarnishes some specimens permanently brown.

Negative.—HNO₃, HCl, HCl (concentrated), HNO₃ (concentrated), Aqua Regia, KCN, KOH, HgCl₂.

Pyrolusite usually occurs as medium to fine-grained aggregates of stumpy prisms veining the earlier-formed manganese minerals. It also replaces Psilomelane and Manganite, the latter often along the cleavage planes. Crystalline aggregates of medium-grained Pyrolusite (often altered to Psilomelane) occur interstitially to Braunite in the Braunite-Vredenburgite ore and Braunite forms a reaction rim between Pyrolusite and Vredenburgite in these ores (Fig. 2).

**Textural Features**

The manganese ores of this area occur in the following mineralogical assemblages:—

(a) Braunite Ore.

(b) Sitaparite-Hollandite-Braunite Ore.

(c) Jacobsite-Hausmannite-Braunite Ore.

The textural relationships of the minerals in these assemblages will now be considered.

(a) **Braunite Ore.**—In this ore Braunite forms coarse to fine-grained aggregates of rounded anhedral crystals. The ore is often traversed by innumerable veinlets of Psilomelane which are veining and replacing the Braunite mostly along the grain boundaries of the latter. Replacement of Psilomelane has given rise to Pyrolusite at many places. The ore sometimes shows a rough banded texture with coarse-grained Hematite occurring interstitially to Braunite in certain bands. Fine veinlets of Hematite are given off from these bands into the Braunite.

In the vugs and open spaces in this ore, coarse-grained Pyrolusite, unidentified mineral B and Psilomelane have been deposited, at places. It appears that the first two have been deposited earlier, and later Psilomelane veins and replaces them. Psilomelane is probably pseudomorphous after Pyrolusite at places.

(b) **Sitaparite-Hollandite-Braunite Ore.**—The typical ore of this type shows a crystalloblastic banded texture of a metamorphic rock. Bands of Hollandite, Braunite, Sitaparite and occasionally those of the unidentified mineral A, alternate. Hollandite forms medium to coarse-grained subhedral prismatic grains which are roughly parallel to the banding. Braunite, forming medium to fine grained-aggregates of rounded anhedral cystals,
shows concave outlines towards Hollandite. Sitaparite forms medium to fine-grained aggregates of euhedral to subhedral crystals and shows crystal outlines against both Braunite and Hollandite. Braunite and Sitaparite are often intergrown in a lamellar fashion. Wherever the unidentified mineral A is found in these ores, it forms coarse-grained aggregates of anhedral to subhedral grains with abundant lamellar or irregular inclusions of some gangue mineral. Braunite and Sitaparite also form lamellar intergrowths with the unidentified mineral A. Where Braunite is intergrown with grains of the unidentified mineral A containing lamellar inclusions of gangue, the lamellae of Braunite and those of the gangue mineral are parallel. Minute Hollandite inclusions are abundant in both Braunite and Sitaparite but are rarely found in the unidentified mineral A.

Psilomelane veins and replaces Braunite and Hollandite mainly along the grain boundaries and the latter also along the cleavage planes. Braunite also veins Hollandite mainly along the grain boundaries and the cleavage planes.

(c) Jacobsite-Hausmannite-Braunite Ore.—In the typical ore, Braunite forms medium to very coarse-grained granoblastic aggregates of rounded anhedral grains. Medium to coarse-grained Vredenburgite is crystallised in the interstices of the earlier formed Braunite grains. At places the Vredenburgite extends out as long narrow zones between the Braunite grains. In the Vredenburgite, the Hausmannite lamellae occupy the octahedral directions in the crystals of Jacobsite which occur as groundmass. Irregular medium to coarse-grained crystals of Hausmannite are also included in the Jacobsite. Occasionally, Hausmannite forms extremely coarse-grained aggregate of rounded subhedral grains with medium-grained inclusions of Vredenburgite and probably Sitaparite. This Sitaparite (?) in turn sometimes contains minute inclusions of Jacobsite.

Vredenburgite also sometimes shows mutual boundary relationship with Braunite and this Vredenburgite is often quite coarse-grained and contains innumerable minute and rounded inclusions of Braunite. Later Braunite also veins the Jacobsite.

Occasionally we get Hausmannite-free Jacobsite showing mutual boundary relationship with the Braunite. Hematite veins both the Jacobsite and the Braunite and sometimes forms coarse-grained irregular grains showing twinning. Braunite veins Jacobsite in this ore.

Braunite often forms a sort of a reaction rim between Jacobsite and some gangue mineral and also between Jacobsite and Pyrolusite. Aggregates of Pyrolusite crystals are found only in the Braunite areas and they are never
found in contact with Jacobsite. This Pyrolusite is often altered to Psilomelane. Dunn (1936) had recorded the reaction rim of Braunite formed between the Jacobsite and the Pyrolusite in his studies of the Beldongri ores, but the reaction rim of Braunite between the Jacobsite and the gangue mineral (found in the ores from Satak) has hitherto not been reported. It will be discussed more fully while discussing the paragenesis and origin of the ores.

Psilomelane, Pyrolusite, Manganite and occasionally Hematite vein Jacobsite, Braunite, Hausmannite and the gangue. Psilomelane also replaces Hausmannite mainly along the twinning planes and also the gangue along with Manganite.

**Paragenesis**

The textural characteristics of the ores described above provide sufficient evidence towards the interpretation of the order of formation of the various minerals and also to some extent of their origin.

Starting with the Vredenburgite-Braunite ore, it can be inferred that the Braunite was the first mineral to crystallise in the earlier phases of the regional metamorphism when the temperature and the pressure was increasing. The Pyrolusite, crystallised in the interspaces of the Braunite grains, was probably introduced by hot solutions in these earlier phases. The impurities in the ore formed some gangue minerals along with Braunite. As the intensity of the metamorphism increased, Jacobsite containing Mn$_3$O$_4$ in solid solution started crystallising in the interspaces of the Braunite. Wherever Jacobsite crystallised along with Pyrolusite and one of the gangue minerals which was chemically unstable at the contact, Braunite was formed as a reaction rim probably in the declining phases of the metamorphism. As the conditions of the metamorphism gradually declined, Hausmannite was exsolved from the Jacobsite which originally contained excess of Mn$_3$O$_4$ in solid solution, and it occupied the octahedral directions in the Jacobsite. According to Dunn (1936), this ore might have suffered later metamorphism whereby Hausmannite was segregated into larger grains leaving wide areas of Jacobsite clear.

Where Mn$_3$O$_4$ was far in excess of Fe$_3$O$_4$, we encounter large crystals of Hausmannite, obviously formed in the slow cooling process, containing inclusions of previously formed Vredenburgite and Sitaparite (?).

The Sitaparite-Hollandite-Braunite-unidentified mineral A assemblage was probably stable in the medium grade of the regional metamorphism. Sitaparite, showing euhedral crystal outlines against both Hollandite and Braunite obviously started crystallising first, Hollandite, showing euhedral
outlines against Braunite started crystallising a little later, and Braunite, conforming to the outlines of Hollandite crystals, was the last to form. The Sitaparite-Braunite lamellar intergrowth suggests that they were formed contemporaneously and hence we can say that though most of the Braunite was later than Hollandite, it enjoyed a longer period of crystallisation which overlapped that of Sitaparite. The unidentified mineral A, showing lamellar intergrowth with both Braunite and Sitaparite, was probably contemporaneous with the Braunite-Sitaparite intergrowth, but the possibility that it was formed by the oriented replacement of the earlier formed gangue cannot be excluded. Later Braunite veined (and to some extent replaced) all the earlier formed minerals in the declining phases of the metamorphism.

Exactly what conditions led to the formation of the Sitaparite-Hollandite-Braunite ore on one hand and the Jacobsite-Hausmannite-Braunite ore on the other hand cannot be inferred with any certainty. It is definitely not correct to say that the former prevailed in the medium grade (or even in the oxidising conditions) and the latter in the high grade (or in the reducing conditions) of regional metamorphism, as no transition from one to the other is found, and therefore, apparently they are distinct suites of ores. This lack of transition might be due to the shortcomings in the way the ore-specimens were collected and we may perhaps be able to get specimens containing both types of ores which will facilitate a better understanding of their exact relationship. In the absence of such data, we can only say that in the formation of the Sitaparite-Hollandite-Braunite ore, lateral pressure played a very significant part and there was complete obliteration of previously formed minerals with consequent rearrangement in which Sitaparite started crystallising first, Hollandite a little later and Braunite still later, though for a considerable part their periods of formation overlapped. On the other hand, the Jacobsite-Hausmannite-Braunite ore was formed under deep-seated conditions where uniform pressure takes the place of directed pressure. Earlier formed minerals like Braunite recrystallised to form coarse-grained aggregates and Vredenburgite was crystallised in the interspaces of the Braunite grains, the periods of formation of both the minerals overlapping slightly. With uniform pressure prevailing, all the traces of banding, etc., disappeared and the ore assumed a granular texture. Dunn (1936) had reported Vredenburgite-Braunite with a similar texture which he says can also form from igneous melts and that such a possibility cannot be ignored. But the author believes that the assumption of a granulitic stage of metamorphism (highest grade) can very well explain the formation of the texture, and therefore it may be quite unnecessary to introduce the idea of igneous origin for ores which have been repeatedly proved to be undoubtedly of metamorphic origin.
Psilomelane, Pyrolusite, Manganite and Hematite vein all the previously formed minerals and are obviously of later formation. Manganite is replaced by later Pyrolusite.

The unidentified mineral B, deposited in vugs and open spaces of the earlier formed minerals, is probably contemporaneous with the other secondary minerals. Later Psilomelane veins it. Psilomelane often gives rise to Pyrolusite after dehydration.

The paragenesis based on textural features and the conditions of formation is given below:

<table>
<thead>
<tr>
<th>Conditions of formation</th>
<th>Ore-minerals</th>
<th>Time—→</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Secondary</td>
</tr>
</tbody>
</table>
| Medium-grade Metamorphism | Braunitide | ——| —— |...
| (Directed pressure prevailing) | Pyrolusite | — | |...
|                        | Sitaparite | —— | .. |
|                        | Unidentified mineral A | —— | .. |...
|                        | Hollandite | — | |...
| High-grade Metamorphism | Braunitide | ——| —— |...
| (Uniform pressure prevailing) | Jacobsite | — | |...
|                        | Hausmannite | — | |.
| Secondary minerals after the decline of Metamorphism | Manganese | .. | |.
|                        | Unidentified mineral B | .. | |.
|                        | Psilomelane | .. | |.
|                        | Pyrolusite | .. | |.

**SUMMARY**

The paper gives an account of the mineragraphic study of the manganese ore-minerals collected from Satak, Beldongri, Lohdongri and Kachurwahi manganese mines in Nagpur District, Bombay State. The ore-minerals identified in polished sections are Braunitide, Sitaparite, Hollandite, Jacobsite,
Hausmannite, Manganite, Pyrolusite and Psilomelane. In addition, two unidentified minerals have been fully described and the problem of their nomenclature is discussed. Unusual textural features such as the reaction rim of Braunite between Jacobsite and Pyrolusite and Jacobsite and gangue have been described along with a detailed description of the more common textural features. The mineral paragenesis, based on textural features and physico-chemical considerations, has been determined. It is followed by a short discussion on the relationship of the ore-mineral assemblages and the type of metamorphism they have suffered.

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EXPLANATION OF PLATE IV

Fig. 1. Vredenburgite (V) occurring interstitially between the Braunite (B) grains. Etched with SnCl$_3$ (saturated) + HCl (concentrated). Oil immersion, × 90.

Fig. 2. Braunite (B) occurring as a reaction rim between Pyrolusite (black) and Vredenburgite (V). Etched with SnCl$_3$ (saturated) + HCl (concentrated). Oil immersion, × 90.
Fig. 3. Braunite (B) veining Jacobsite (J). Etched with HF (concentrated). Oil immersion, \( \times 210 \).

Fig. 4. Braunite (B) occurring as a reaction rim between Jacobsite (J) and gangue (black). Etched with HF (concentrated). Oil immersion, \( \times 210 \).

Fig. 5. Minute rounded inclusions of Braunite (B, white) in coarse-grained Vredenburgite (V, grey). Braunite (B) also occurs as a reaction rim between Vredenburgite and gangue (black). Oil immersion, \( \times 90 \).

Fig. 6. Inclusion of Sitaparite (big dark grain near the centre) in Hausmannite (H). Hausmanite shows complicated polysynthetic twinning. Crossed nicols. Oil immersion, \( \times 210 \).

Fig. 7. Strongly anisotropic grains of the unidentified mineral B (white) being replaced and veined by Psilomelane (black). Crossed nicols. Oil immersion, \( \times 155 \).

Fig. 8. Oriented and at places irregular inclusions of gangue (black) in the Unidentified mineral A (grey). A few inclusions of Hollandite (white) are also seen. Oil immersion, \( \times 90 \).