

## HOGBOMITE FROM Fe-Ti OXIDE DEPOSIT, BOULA-NAUSAHI IGNEOUS COMPLEX, KEONJHAR DISTRICT, ORISSA, INDIA

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### ABSTRACT

Primary and secondary hogbomites occurs both as well developed crystals and anhedral grains in Fe-Ti oxide ores of Boula-Nausahi igneous complex. Primary hogbomite is pyrogenic in nature having formed from the magma at a low temperature. The secondary hogbomite has formed at the expense of spinel by the substitution of  $Ti^{2+}$  for  $Mg^{2+}$  and  $Fe^{3+}$  for  $Al^{3+}$ . EPMA of hogbomite showed 6-9.59 wt%  $TiO_2$ , 57.51 - 59 wt%  $Al_2O_3$ , 0-1.99 wt%  $Cr_2O_3$ , 21.43-29.93 wt%  $FeO(t)$ , 0.02-0.23 wt%  $MnO$ , 2.46-8.17 wt%  $MgO$  and 1.03-1.84 wt%  $ZnO$ . The stoichiometric formula,  $Fe^{2+}_{(2.7-5.09)}Mg_{(0.81-2.66)}Ti_{(1-1.156)}Fe^{3+}_{(0.432-1.124)}Al_{(14.86-15.345)}O_{32}$  suggests that hogbomite has an open structure as compared to associated magnetite and ilmenite.

Key words: Hogbomite, Fe-Ti oxide ores, Boula-Nausahi complex, India.

### INTRODUCTION

Hogbomite has been reported from different parts of world and in a wide spectrum of igneous and metamorphic associations (NEL, 1949; FRIEDMAN, 1952; WOODFORD and WILSON, 1976; ZAKRZEWSKI, 1977; GATEHOUSE and GREY, 1982; ANGUS and MIDDLETON, 1985 and GREW et al., 1990). However, in India, occurrence of hogbomite was first reported by DEVRAJU et al., (1981). Subsequently, JAYARAY et al., (1995) have recorded widespread distribution of the mineral in the Ti-V magnetite deposits in Shimoga and Uttara Kannada districts of Karnataka. In this paper, an attempt has been made to study the textural characters, mineral chemistry and origin of the hogbomite from Boula-Nausahi igneous complex, Orissa, India.

### GEOLOGICAL SETTING

Boula-Nausahi Igneous complex (21°15'-21°18'N: 86°18'-86°20'E) is intruded into the Precambrian metamorphics of Iron Ore Group and the age of emplacement is around 2200 Ma (SAHA, 1994). This complex consists of the ultramafics, the mafics and the felsic rock units. The ultramafic rocks (now altered to serpentinites) host chromite ore bodies whereas the mafic rocks represented by gabbro, norite, anorthosite host titaniferous magnetite ore bodies.

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## MINERALOGY

The Ti-V-magnetite ore consists of titanomagnetite (magnetite), ilmenite, spinel, hematite, rutile, houghomite, goethite, martite, lepidocrocite etc., in varied proportions. Chalcopyrite, covellite and pyrite are present in very minor amounts. Magnetite occurs in coarse, irregular to subhedral grains making upto 70% of the ore. Besides being intergrown with ilmenite, it also occurs as small granules in ilmenite grains, minute platelets in ilmenite along fractures and at the ilmenite grain boundaries. Ilmenite occurs as broad and fine lamellae and as discrete euhedral to irregular grains. Spinel is present as fine rod-like exsolution in magnetite and as tiny dots along ilmenite boundaries. Hematite occurs as exsolved lamellae in ilmenite.

Magnetite exhibits a characteristic polycrystalline granular texture in which the grain boundaries meet at triple points with an interfacial angle of 120°. Ilmenite occurs in juxtaposition with magnetite developing non-interfering boundary relationship. Besides, several textures such as (1) crystallographic intergrowth viz. ilmenite in (111) and (100) planes of magnetite, spinel in (111) plane of magnetite, hematite in (0001) plane of ilmenite, (2) graphic intergrowth between magnetite and ilmenite, (3) eutectoid like intergrowth between rutile and hematite, (4) external and internal granular intergrowth of ilmenite and (5) replacement texture (viz., replacement of magnetite by martite, goethite and lepidocrocite and ilmenite by rutile) are noted. The oriented intergrowths appear to have resulted due to exsolution above magnetite-ulvospinel solvus and exsolution-oxidation below magnetite-ulvospinel solvus (REYNOLDS, 1985).

TABLE 1

*EPMA of Magnetite and Ilmenite grains in the Ti-V magnetite ores*

	1	2	3	4	5	6	7	8	9	10
FeO	74.43	75.87	73.95	76.16	73.26	45.68	44.31	43.84	45.64	43.61
TiO <sub>2</sub>	12.93	13.92	13.75	17.86	14.81	53.11	54.11	54.38	50.88	53.38
MgO	0.19	0.05	0.06	0.65	0.33	0.16	0.36	1.56	0.15	1.30
Al <sub>2</sub> O <sub>3</sub>	0.76	1.37	0.32	0.19	0.19	0.01	0.15	0.02	0.09	0.03
MnO	0.14	0.20	0.11	0.26	0.32	0.87	1.02	0.91	0.81	0.93
Cr <sub>2</sub> O <sub>3</sub>	1.35	1.27	1.19	0.05	0.22	0.13	0.11	0.05	0.20	0
ZnO	0.09	0.13	0.01	0.08	0	0.12	0.09	0	0.12	0
V <sub>2</sub> O <sub>3</sub>	0.06	0.08	0.08	0.08	0.08	0.29	0.28	0.28	0.28	0.29
Total	89.95	92.87	89.47	95.34	89.21	100.38	100.42	101.04	98.16	99.53
	Cations on the basis of 4 (O)					Cations on the basis of 3 (O)				
Fe	2.923	2.860	2.921	2.76	2.883	0.977	0.921	0.902	0.984	0.913
Ti	0.457	0.472	0.488	0.582	0.524	1.001	1.012	1.006	0.986	1.005
Mg	0.013	0.003	0.003	0.042	0.023	0.006	0.013	0.057	0.006	0.048
Al	0.042	0.073	0.018	0.028	0.01	0	0.004	0.001	0.003	0.001
Mn	0.006	0.008	0.004	0.01	0.013	0.019	0.021	0.019	0.018	0.02
Cr	0.05	0.045	0.044	0.002	0.008	0.003	0.002	0.001	0.004	0
Zn	0.003	0.004	0	0.003	0	0.002	0.002	0	0.002	0
V	0.002	0.003	0.003	0.003	0.003	0.006	0.006	0.006	0.006	0.006
Total	3.496	3.468	3.482	3.428	3.465	2.013	1.981	1.991	2.008	1.992

Sample: 1-5 Magnetite; 6-10 Ilmenite

Chemical composition and structural formula of magnetite and ilmenite are presented in Table 1. In this ore, chlorite is the major silicate mineral. Except for somewhat higher alumina and lower silica (Table 2), chemically it is comparable with sheridanite reported by WILSON (1977) and DEVRAJU et al., (1981).

TABLE 2

*EPMA of the associated chlorites*

	1	2	3	4
FeO	9.02	10.69	9.44	10.82
TiO <sub>2</sub>	0.31	0.16	0.64	1.65
MgO	26.13	26.36	25.23	24.93
Al <sub>2</sub> O <sub>3</sub>	31.66	31.57	32.37	29.90
MnO	0	0.03	0.09	0.08
Cr <sub>2</sub> O <sub>3</sub>	0	0	0.08	0.10
ZnO	0.05	0	0.09	0
V <sub>2</sub> O <sub>3</sub>	0	0	0.01	0.01
SiO <sub>2</sub>	21.05	21.79	21.32	22.64
Total	88.21	90.61	89.24	90.13
Cations on the basis of 10 (O)				
Fe	0.520	0.605	0.539	0.617
Ti	0.016	0.008	0.033	0.086
Mg	2.686	2.657	2.566	2.525
Al	2.572	2.516	2.853	2.394
Mn	0	0.002	0.005	0.004
Cr	0	0	0.004	0.008
Zn	0.003	0	0.005	0
V	0	0	0	0
Si	1.450	1.473	1.455	1.540
Total	7.247	7.260	7.459	7.174

**Hogbomite**

This is a minor mineral in the magnetite ore. It shows deep brown colour, feeble pleochroism, one set longitudinal cleavage and irregular cracks under transmitted light. Under reflected light, it is characterized by grey colour with or without pinkish tinge, feeble birefractance, very low reflectivity (around 8%), distinct anisotropism, reddish brown internal reflection and high microhardness (VHN = 1000 to 1250 newton). Presence of hogbomite is also confirmed by d values of 2.438, 1.427 and 2.098 Å in XRD pattern.

**Textural characters**

Textural hogbomite occurs as (a) idiomorphic (rhombohedral, bipyramidal, hexagonal), hypidiomorphic (prismatic, pinacoidal, tabular, platy and cylindrical) and irregular shaped disseminations, (b) irregular grains intergrown with spinel, (c) partial overgrowth in spinel in a matrix of magnetite and in the interface between ilmenite and magnetite, (d) mosaic aggregates showing scalloped boundaries against magnetite and (e) subhedral grains partially rimmed by dark chlorite. Rows of hogbomite disseminations are

crystallo-graphically oriented along both cubic and octahedral cleavages in magnetite. It is observed that highly martitised ores contain more hogbomite which can be explained by removal of alumina from spinel concurrently with oxidation of Fe during martitisation (ZAKRZEWSKI, 1977). Moreover, well developed crystals of hogbomite have been found to occur in ores containing higher modal percentage of hogbomite.

### Mineral chemistry

Electronprobe analyses of a few hogbomite grains are carried out by JEOL JXA-8600 M Superprobe using SPI standards with an accelerating voltage of 15 KV, specimen current of 2 mA and online oxide ZAF correction programme. The elemental composition and the cation contents obtained are given in Table 3. Selected analyses of hogbomites from different parts of world are also presented for comparison.

TABLE 3  
*EPMA of hogbomite of Boula-Nausahi complex compared with hogbomites from other parts of world*

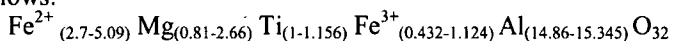
	1	2	3	4	5	6	7	8	9
FeO	29.93	28.63	29.20	21.42	22.39	20.27	24.78	21.02	12.36
TiO <sub>2</sub>	6.21	6.92	6.01	9.59	8	6.19	7.41	6.01	6.42
MgO	2.51	2.46	2.6	7.59	8.17	9.96	5	9.66	16.6
Al <sub>2</sub> O <sub>3</sub>	57.51	58.14	58.5	59	57.72	59.86	58.53	59.94	63.75
MnO	0.23	0.17	0.23	0.03	0.02	0.13	0.26	0.14	0.13
Cr <sub>2</sub> O <sub>3</sub>	1.88	1.99	1.77	0	0.08	0.29	0	0	0.31
ZnO	1.27	1.04	1.03	1.47	1.84	0.87	2.74	1.06	0.46
V <sub>2</sub> O <sub>3</sub>	0.03	0.04	0.04	0.05	0.04	0.13	0	0.21	0
Total	99.57	99.39	99.38	99.51	98.26	97.64	98.72	98.04	100.03
Cations of the basis of 32 (O)									
Fe <sup>2+</sup>	5.078	4.884	5.09	2.706	2.97	2.929	4.343	3.136	1.04
Fe <sup>3+</sup>	0.518	0.432	0.342	1.124	1.12	0.724		0.66	1
Ti	1.045	1.156	1.004	1.542	1.314	0.994	1.168	0.976	0.96
Mg	0.835	0.813	0.863	2.533	2.662	3.2	1.562	3.108	4.92
Al	15.152	15.219	15.345	14.868	14.86	15.205	14.457	15.304	14.96
Mn	0.043	0.032	0.041	0.005	0.004	0.02	0.05	0.004	0.04
Cr	0.33	0.347	0.31	0	0.013	0.049	0	0	0.04
Zn	0.208	0.171	0.168	0.233	0.295	0.14	0.424	0.168	0.08
V	0.003	0.003	0.003	0.008	0.006	0.021	0	0.036	0
Total	23.212	23.056	23.167	23.019	23.244	23.282	22.414	23.352	23.04

Samples: 1-5 Boula-Nausahi complex, 6: JAYARAJ et al., (1995), 7: GREW et al., (1990), 8: DEVRAJU et al. (1981), 9: ZAKRZEWSKI (1977)

From the Table 3, it is observed that hogbomite grains show considerable compositional variation in respect of FeO, TiO<sub>2</sub>, MgO, MnO and Cr<sub>2</sub>O<sub>3</sub>. Average chemical data when compared with the analyses from other parts of the world show that the hogbomites of the present area are rich in FeO, TiO<sub>2</sub>, Cr<sub>2</sub>O<sub>3</sub> and ZnO and impoverished in MgO. TiO<sub>2</sub>, MgO and ZnO show inverse relation with FeO where as MnO and Cr<sub>2</sub>O<sub>3</sub>

exhibit a positive relation with FeO. As compared to the hognomites of Tanzania, the hognomites of present area are rich in FeO, Cr<sub>2</sub>O<sub>3</sub> and poor in MgO and Al<sub>2</sub>O<sub>3</sub>. Compared to the hognomite from Karnataka, India these are richer in Fe, Cr, Ti and Zn but poorer in Mg and V (JAYARAJ, et al., 1995). Negative relationships between Fe and Ti (r = -0.94), Fe and Mg (r = -0.98) and Fe and Al (r = -0.40) indicate that Ti, Mg and Al replace Fe<sup>2+</sup> and Fe<sup>3+</sup> in the hognomite structure. Higher {Fe(t)/Fe(t)+Mg} ratio of 0.78 to 0.94 is attributable to very low concentration of Mg in the mineral derived from the magma having very-low MgO content (MANCKTELOW, 1981, ANGUS and MIDDLETON, 1985, RAMMLMAIR et al., 1988, GREW et al., 1990; JAYARAJ et al, 1995). From the chemical analyses, it is seen that the structure of hognomite is more open than the co-existing magnetite and ilmenite and can admit a variety of substitution.

A generalized stoichiometric formula calculated according to ZAKRZEWSKI (1977) is as follows:



## DISCUSSION AND CONCLUSION

Based on textural features and the pattern of association with magnetite, chlorite and spinel, hognomite formation in Fe-Ti ores of Boula-Nausahi complex can be put into two categories i e., (1) primary or pyrogenic eg., those formed directly from the magma either as external granule exsolution or as oxidation-exsolution at a slightly low temperature and (2) secondary eg., those formed after spinel as alteration product.

Isolated hognomite grains of varied morphology may have formed by external granule exsolution skin to formation of coarse grained euhedral ilmenite in most titanomagnetite ore bodies (BUDDINGTON and LINDSLEY, 1964, GREW et al., 1990). These alongwith very fine grained hognomite grains found enclosed within the titanomagnetite ore under electron microscope and exsolved blebs of hognomite found oriented along (111) cleavage in magnetite can be termed as primary having formed directly from the magma at falling temperature.

Association with spinel and chlorite points to the secondary nature of hognomite. Spinel-hercynite can alter to hognomite (GREW et al., 1990). Scanning Electron Microscopic study of hognomite grain in association with spinel-hercynite and mutual textural and interface boundary relationship indicate the secondary nature of a few hognomite grains. The hognomite associated with spinel is formed at the expense of spinel by the substitution of Ti<sup>2+</sup> for (Mg<sup>2+</sup>, Fe<sup>2+</sup>) and Fe<sup>3+</sup> for Al<sup>3+</sup> under silica undersaturation and high oxygen fugacity condition. The scooping/scalloping of boundaries of hognomite suggest late stage replacement of spinel/hognomite by magnetite.

Fe-Ti oxide ore bodies in this area are formed around 700-900 °C temperature and oxygen fugacity of 10<sup>-9</sup> to 10<sup>-17</sup> (TUGARINOV et al., 1973, MOHANTY, 1994.) Previous works suggest that primary hognomite can be formed at a low temperature of 400-500 °C (SOUTHWICK, 1968; MICLKE AND SCHREYER, 1972; RUMBLE, 1976; BRAUN and RAITH, 1985). Though direct estimation of temperature and oxygen fugacity of hognomite formation could not be determined in the present case, based on textural relation it may be surmised that hognomite at Boula-Nausahi igneous complex has formed at low temperature, and high oxygen fugacity and in the presence of water.

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