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Ni-Co-Cr-Bearing Phokpur Magnetite Deposit Associated with Naga Ophiolite Belt, North-East India and its Economic Viability

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Abstract: **Nickel (Ni) - cobalt (Co) - chromium (Cr) - bearing magnetite deposit at Phokpur in Kiphire district of Nagaland is a rare type of occurrence associated with Naga Ophiolite Belt. The magnetite deposit is associated with ultramafic rocks and occurs at north-easternmost part of the ophiolite belt. The Naga Ophiolite Belt extends for about 90 km with width ranging from 4 to 15 km. Detailed field and laboratory studies reveal that the magnetite in the study area occurs as a tabular body at the top of the ophiolite sequence. Magnetite and chromite are observed as the two discrete mineral phases under ore microscopic studies of the magnetite samples. Concentration of nickel and chromium in the magnetite band ranges from 0.14 to 0.91 % and 1.33 to 3.79 % respectively, where as the iron content ranges from 40.51 to 55.95%. Small concentration of cobalt (0.008 to 0.14 %) is also present in the magnetite samples. With development of the *state-of-the-art* technology, the multi-metallic deposit of Phokpur, Nagaland containing nickel, cobalt, chromium and iron is ready for commercialization to extract the valuable metals in the product 'Special Iron Alloy'. This will bring several benefits to the state of Nagaland and the country, as India depends on import for nickel and cobalt requirements.**

Index Terms: **Magnetite, Naga ophiolite belt, Nickel, Ore microscopy, ultramafic rocks.**

I. INTRODUCTION

Ophiolite suites are usually considered as fragments of the oceanic lithosphere emplaced during obduction of the continental margins. The rocks of the ophiolite suites (mostly mafic and ultramafic) have got much interest among the Earth Scientists of the world. They have been proved potential sites for exploration of various metallic deposits like copper sulphides, cobalt-nickel-chromium bearing magnetite, podiform chromite etc. (Coleman, 1977) and constitute favorable locales for occurrences of precious metals like PGE and gold. Consequently, the ophiolite belts are being explored for their mineral wealth.

The Naga Ophiolite Belt (extended up to Manipur) forms a part of the Indo-Burman Ranges comprising the Arakan Yoma, Chin and Naga Hills. The ophiolite belt within India extends for about 200 km from Pang (Nagaland) in the north to Moreh (Manipur) in the south with width ranging from 5 to 16 km. The part of the ophiolite belt within Nagaland extends for about 90 km and is termed as Naga Ophiolite Belt. It is placed between the Nimi Formation in the east and the Disang flysch in the west (Ghose, 1980; Acharyya et al., 1984; Singh et al., 1989). Various government and private agencies have explored for metals in this difficult terrain, and have indicated the possibilities of PGE and gold incidences, but till date no promising mineral pockets are discovered except the magnetite deposit.

Nickel (Ni) - cobalt (Co) - chromium (Cr) - bearing magnetite deposit associated with Naga Ophiolite Belt is a rare type of occurrence. The main deposit, popularly known as the Phokpur magnetite deposit, occurs at eastern-most part of the Nagaland. It is located at the Matungse Kein Hill, about 4 km east of Phokpur village in Kiphire district of Nagaland. Phokpur is about 60 km from Kiphire and is connected by unmetalled road (Fig. 1). A number of small magnetite incidences have also been reported in Meluri area of Phek district of Nagaland (Chattopadhyay and Bhattacharya, 1986; Ghose and Goswami, 1986).

Nickel and cobalt are the strategic metals in our country and therefore, even a small deposit of nickel and cobalt bears an utmost importance in the national economy. In the present paper, field observation, ore microscopy and chemical studies of the nickel-cobalt-chromium-bearing magnetite deposit at Phokpur in

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Kiphire district of Nagaland have been discussed with special reference to the presence of nickel and its economic importance in national scenario.

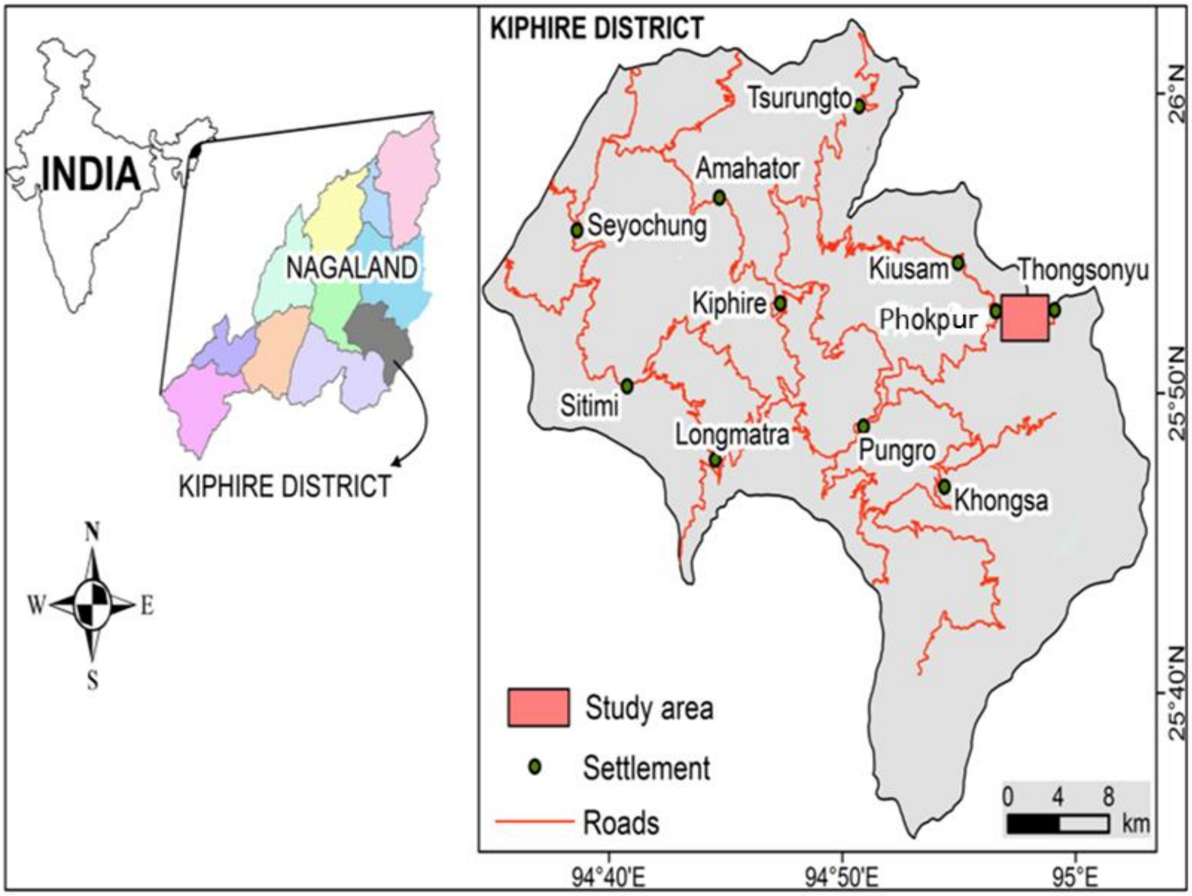

Fig.1: Location map of the study area

II. GEOLOGICAL SETTING

The Naga ophiolite suite of the rocks is sandwiched between the Nimi Formation in the east and the Disang flysch in the west. The strike direction of the ophiolite belt, viz. N-S to NNE-SSW, coincides with that of the country rocks. It comprises of mafic-ultramafics, plagiogranites, metabasic-volcanogenic sediments and late felsic intrusives. Mafic associated rocks include sheeted dyke complex, mafic volcanic complex, mafic cumulates with podiform chromites, limestone, chert, shale and late-felsic intrusives. Ultramafics consist of variable proportions of harzburgite, lherzolite and dunite with a metamorphic tectonic fabric (serpentinite). The cumulative mafic and ultramafics are represented mainly by peridotites, pyroxenites and gabbros (Ghose, 1980).

The oldest Nimi Formation, covering the eastern fringe of Nagaland, extending from Mollen in the south to Saramati Peak in the north for about 30 km in strike length, is thrusted over the ophiolite complex from east and consists of crystalline limestone, quartzite, phyllite, and quartz-sericite schists. The largest limestone deposit of the state occurs in this formation. This litho-association appears to be a detached slab of a pre-Tertiary Burmese continental crust.

Disang flysch sediments consist of a great monotonous thickness of splintery grey shales, interbedded with bands of fine grained sandstones. Disang sediments show increasing metamorphism towards its eastern part becoming slaty and ultimately hard glassy, dark grey slates (Singh et al., 1989). The Phokpur magnetite deposit is located in the northern part of the Naga Ophiolite Belt and exposed as a tabular body (massive sheet like band) at the top of the ophiolite sequence. It is underlain by serpentinised peridotite, harzburgite, pyroxenite with almost a sharp contact and overlain by Mio-Pliocene mollasic sediments, viz. shale, sandstone and conglomerate (Jopi Formation) with an unconformity (Majumdar and Prabhakar, 1975; Majumdar et al., 1976; Kumar and Prabhakar, 1979; Sen and Chattopadhyay, 1979). The geological map of the study area is shown in Fig. 2.

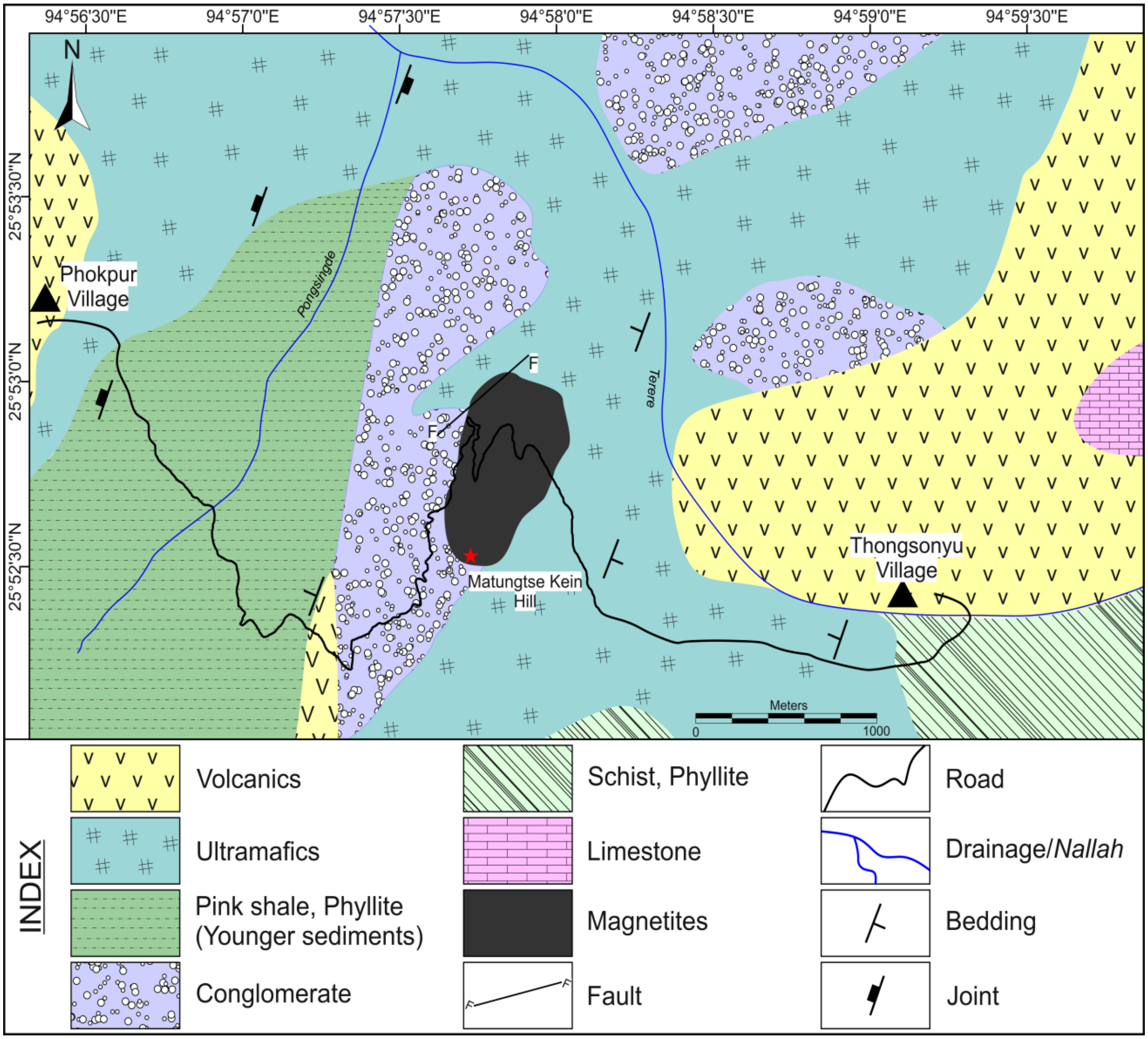

Fig. 2: Geological Map of the Phokpur Magnetite Deposit

III. DIMENSION OF THE ORE BODY

The strike length of Phokpur magnetite deposit is about 1 km along NNE-SSW direction with a 30° to 40° westerly dip (Fig. 3). General thickness of the ore body varies between 5 m to 15 m, and usually thins out towards the south. The average thickness of the ore body is about 8 m with an average outcrop width of about 300 m. From the hilltop, the magnetite band extends down to a maximum inclined distance of about 600 m with ground slope 30° west. The outcrops are better exposed in north. The ore body in general show swelling and pinching both along the strike and dip direction (Majumdar et al., 1976; Agrawal and Rao, 1972 & 1978; Venkataramana and Bhattacharya, 1989).

IV. ORE MICROSCOPY

Ore microscopic studies of Phokpur magnetite reveal that magnetite and chromite are the two discrete ore mineral constituents of the ore body (Fig. 4 and Fig. 5). Fractures are present in both the magnetite and chromite grains which indicate the deformational activities after the formation of chromite and magnetite. At places, magnetite is martitised along fractures. The discrete chromite grains are often rimmed by magnetite. The chromite grains are also replaced by the magnetite along the fractures and cleavage planes. The separate nickel-bearing phase (mineral) is not observed in the polished magnetite ore samples. This indicates that the nickel is concentrated in silicate matrix of the ore formed probably during later hydrothermal alteration activities.

Fig.3: Field photograph showing magnetite blocks with westerly dip

Fig.5: Photomicrograph showing magnetite (light) and chromite (gray) in dark silicate matrix (PPRL)

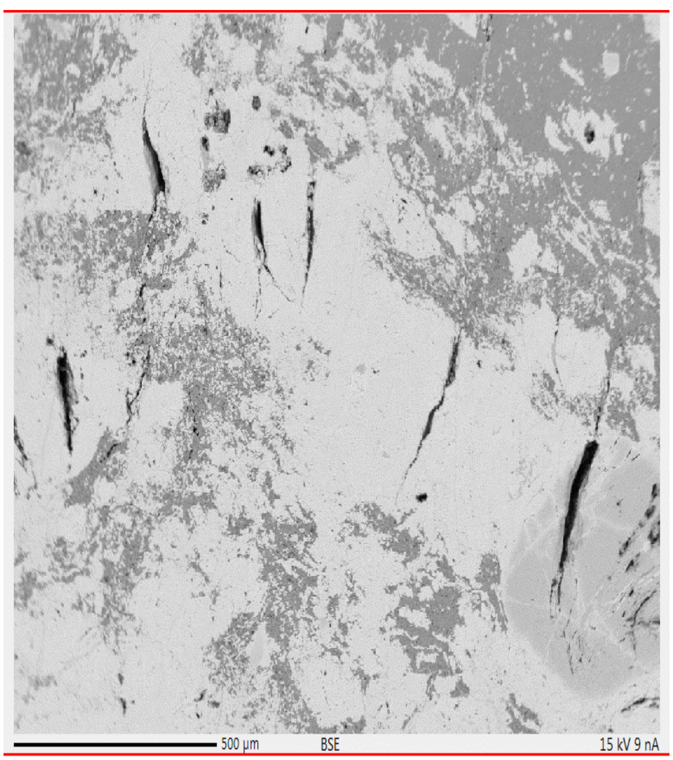

Fig.4: Photomicrograph showing magnetite (light), chromite light gray and silicates (dark). Fractures are also shown in both the magnetite and chromite grains (PPRL)

V. CHEMISTRY OF PHOKPUR MAGNETITE

The chemical analyses of the 10 samples from the Phokpur magnetite ore body was carried out in National Metallurgical Laboratory, Jamshedpur, Jharkhand and the results are shown in Table I. Concentration of nickel and chromium in the magnetite band ranges from 0.14 to 0.91 % and 1.33 to 3.79 % respectively, where as the iron content ranges from 40.51 to 55.95%. Small concentration of cobalt (0.008 to 0.14) has also been reported in the magnetite samples.

Table I: Chemical analyses of magnetite samples from Phokpur (in %)

Redical Sample Nos.	Ni	Cr	Co	Ti	V	Fe
OG 01	0.65	2.37	0.03	0.26	0.01	55.95
OG 02	0.26	2.38	0.008	0.79	0.019	47.58
OG 05	0.14	1.33	0.01	1.77	0.06	40.51
OG 10	0.44	3.79	0.02	0.10	0.008	51.63
OG 13	0.55	3.11	0.01	0.50	0.021	54.66
OG 16	0.91	3.16	0.13	0.10	0.011	54.66
OG 20	0.52	1.87	0.03	0.36	0.013	49.39
OG 25	0.38	1.69	0.04	0.52	0.016	54.70
OG 36	0.31	2.15	0.012	0.79	0.017	45.91
OG 42	0.76	1.93	0.14	0.43	0.011	50.42

According to Directorate of Geology & Mining, Govt. of Nagaland, unpublished report (F.S. 1979-81), the general grade of Ni in the magnetite massif is computed with respect to the prevailing cut-off grade of nickel (0.89%) in the country. On the basis of nickel distribution, three zones are classified:

(a) Grade with < 0.8% Ni

(b) Grade with > 0.8% Ni

(c) Grade with > 1% but <2% Ni

The first type of sample is generally distributed irregularly both along the strike and dip of the magnetite band. The thickness of this zone is up to 4 m. This grade is recorded in the top and bottom of the band. The second type is well developed in the central part of the ore body compared to its flanks with the thickness up to 4.3 m. The third category is present in lensoid fashion and the thickness is more on the flanks in comparison to the central part.

VI. RESERVE OF THE ORE BODY

The probable and estimated reserves of the magnetite at Phokpur have been calculated on the basis of drilling results available and taking the specific gravity of rock/ore to be 3.6. Thus, the total probable reserve is of the order of 5.5 million tones of which estimated reserve would be approximately 5 million tones. It could not be possible to exactly figure out the distribution of the total quantum of nickel and cobalt in the deposit. Assuming average Ni and Co content to be 0.7% and 0.09% respectively the ore body contains 33.6 thousand tons of nickel and 4.32 thousand tons of cobalt (Bhowmik et al., 1973; DGM, Nagaland, 1987 and 2012; IBM, 2014).

VII. NICKEL IN INDIAN SCENARIO

Nickel, when added in small quantity to iron, increases its properties manifold and makes the product hard. The reason behind the demand of primary nickel all over the world is for the production of stainless steel. When it is used in plating, it makes the surface tarnish-resistant and provides polished appearance. The most important use of nickel is in production of stainless steel and other corrosion-resistant alloys. Nickel/chrome plating is still the most widely used decorative electroplated finish on metals. Conventional plating is still much in favour but other technique such as electrolytic coating or sintered slurry coating are used for applications like turbine blades, helicopter rotors, rolled steel strips and extrusion dies. Nickel is an important ingredient in coins. Nickel is also used as a catalyst in hydrogenation. Other commercial uses are in ceramics, special chemical vessels, rechargeable nickel-cadmium storage batteries, electronic circuits, in computer hard discs and preparation of nickel compounds.

World over, stainless steel is the major end-use sector of nickel having over 66% consumption share. Other uses include electroplating (8%), steel alloy including casting (24%) and chemical application like nickel-cadmium battery (3%). Domestic consumption of ferro-nickel during 2010-2011, 2011-12 and 2012-13 was 2,000 tonnes, 2,235 tonnes and 2,235 tonnes respectively, all in alloy-steel industry.

Nickel is not produced from primary sources in India. However, it is being recovered in very small amount as nickel sulphate crystals, a by-product obtained during chromite and copper production. As such, the entire demand in the country is met through import of the metal.

Important occurrence is nickeliferous limonite in the overburden of chromite in Sukinda valley, Jajpur district, Odisha, where it occurs as oxide. A suitable process is being developed for its utilization. Nickel also occurs in sulphide form along with copper mineralization in East Singhbhum district, Jharkhand. In addition, it is found associated with uranium deposits at Jaduguda (Jharkhand) and process is being developed for its recovery. Other reported occurrences of nickel are from Karnataka, Kerala and Rajasthan. Polymetallic sea nodules are another source of nickel.

As per United Nations Framework Classification (UNFC), the total resource of nickel ore in India (as on 01/4/2010) is estimated to be 189 million tonnes. About 92% resource (175 million tonnes), is in Odisha. The remaining 8% resource is distributed in Jharkhand (9 million tonnes) and Nagaland (5 million tonnes). Nominal resource is reported from Karnataka (0.23 million tonne).

VIII. ECONOMIC VIABILITY OF THE DEPOSIT

Nickel and cobalt are the strategic metals in our country, and therefore, even a small deposit of nickel and cobalt bears an utmost importance in the national economy. Therefore, National Metallurgical Laboratory, Jamshedpur and the Directorate of Geology and Mining, Govt. of Nagaland, jointly took the responsibility of investigating the multi-metallic deposit of Phokpur, Nagaland with a view to extract the valuable metals from this ore body in the product 'Special Iron Alloy'. This technology of special iron alloy production has been developed under National project entitled *"Pilot scale smelting and pre-feasibility studies on Nickel-Chromium-Cobalt bearing magnetite ores from Nagaland"*. The project has been completed and ready for commercialization in small/medium scale (7.5 MVA/10 MVA) Submerged Arc Furnace commercial plant. The utilization of this technology in the form of small/medium scale commercial plant is likely to bring several benefits to the state of Nagaland and the Country as India depends on import for nickel and cobalt.

CONCLUSIONS

On the basis of ore microscopic studies of the Phokpur magnetite samples, it can be said that that magnetite and chromite occur as float in silicate matrix. The silicate matrix accounts for most of the nickel and cobalt contents of the ore. Chemical analysis of the whole magnetite samples reveals that the concentration of nickel and chromium in the magnetite band ranges from 0.14 to 0.91 % and 1.33 to 3.79 % respectively, where as the iron content ranges from 40.51 to 55.95%. Small concentration of cobalt (0.008 to 0.14 %) has also been reported in the magnetite samples.

India depends on import for nickel to fulfill its domestic needs until a technology to recover nickel from the overburden of chromite ores in Odisha is established on a commercial scale. In the meantime, the multi-metallic deposit of Phokpur, Nagaland containing nickel, cobalt, chromium and iron is ready for commercialization to extract the valuable metals in the product 'Special Iron Alloy'. This will bring several benefits to the state of Nagaland and the Country as India depends on import for nickel and cobalt.

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