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Occurrence of PGE Mineralisation in Bangur, Kendujhar District, Odisha

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Abstract: PGE mineralisation of significant grade and extent is reported from Bangur chromite mining area, Kendujhar district, Odisha, located to the south of the well known Baula-Nuasahi ultramafic complex. The hitherto unknown PGE mineralisation is established in a ferritchromit rich breccia zone occurring within Bangur litho-mélange. The mineralized breccia zone is traced for about 550m with a mean width of 12m in NW-SE direction. Chemical analysis of drill core samples by ICP-MS indicates an average ΣPGE content of 3.2 ppm dominated by Pt and Rh. Occurrence of discrete grains of PGM in sizes up to 45 microns is confirmed by SEM-EDX and EPMA study. Delineation of this PGE bearing zone stresses the need for preservation of gangue/matrix of the breccia zone, along with ferritchromit clasts, in the ongoing selective mining of chromite in Bangur.

Keywords: Bangur mafic-ultramafic suite, Breccia zone, PGE mineralization, Singhbhum craton, Odisha.

INTRODUCTION

Ultramafic rocks with chromite associations have assumed significance in view of the discovery of the PGE mineralisation in the Baula Nausahi ultramafic complex (BNUC) (Fig. 1A). This oldest PGE prospect of the world, dated at 3.12 Ga (Auge et al., 2003), is located within a breccia zone (2 km x 40 m) at the interface of ultramafic-mafic suite of rocks. The brecciation is believed to have been caused by either late intrusion of a coarse grained Bangur gabbro and its apophyses (Auge et al., 2002) or shearing formed late-kinematically with respect to the main gabbroic intrusion (Mondal and Zhou, 2010). It is classified into Pt-dominant magmatic type and Pd-dominant hydrothermal type (Auge and Lerouge, 2004) and resembles Lac des Isles PGE deposit, Ontario (Hinchey et al., 2005).

The BNUC hosts three chromite layers (Durga, Laxmi and Shankar) ranging in width from 2 to 6m, located in the lower dunite-peridotite units. The lodes have been extensively mined for the last five decades. The southern continuity of these chromite lodes is disrupted by the coarse grained Bangur gabbro exposed in the open pit of Odisha Mining Corporation Ltd. (OMC), where chromite is selectively mined from the 300m wide breccia complex, initially by open cast followed by underground mining at three levels. Exploration for PGE was carried out by Geological Survey of India (GSI) in collaboration with BRGM, France, which led to the discovery of 7.7 million tonnes of PGE resources in BNUC. Although exploratory boreholes were drilled in the adjoining Bangur area of OMC, no significant PGE mineralised zone was identified. This had led to the continued chromite mining in the area, resulting in the loss of potential blocks of PGE. The present paper reports for the first time the PGE mineralised zone in Bangur mine area, forming the southern extension of BNUC.

GEOLOGICAL SET UP

BNUC occurs in the southern flank of the Singhbhum Archaean nucleus in Eastern India (Mukhopadhyaya, 2001). It comprises of an ultramafic unit ranging in composition from dunite, chromitite, peridotite, harzburgite, ortho-pyroxenite to websterite and a mafic unit of gabbro-anorthosite suite of rocks. The ultramafics are intrusive into the Archaean volcaniclastic supracrustal sequence (Hadgarh Group). The interface between the ultramafic and mafic unit is marked by a prominent magmatic breccia zone (Nanda et al., 1996) that hosts the PGE mineralization Bangur mafic ultramafic suite (BMUS) forms the extension of well the documented BNUC. It is exposed in the opencast mine of Odisha Mining Corporation Ltd. (OMC) at Bangur, Kendujhar district, Odisha (Fig.1B).

BMUS consists dominantly of ultramafics in the western

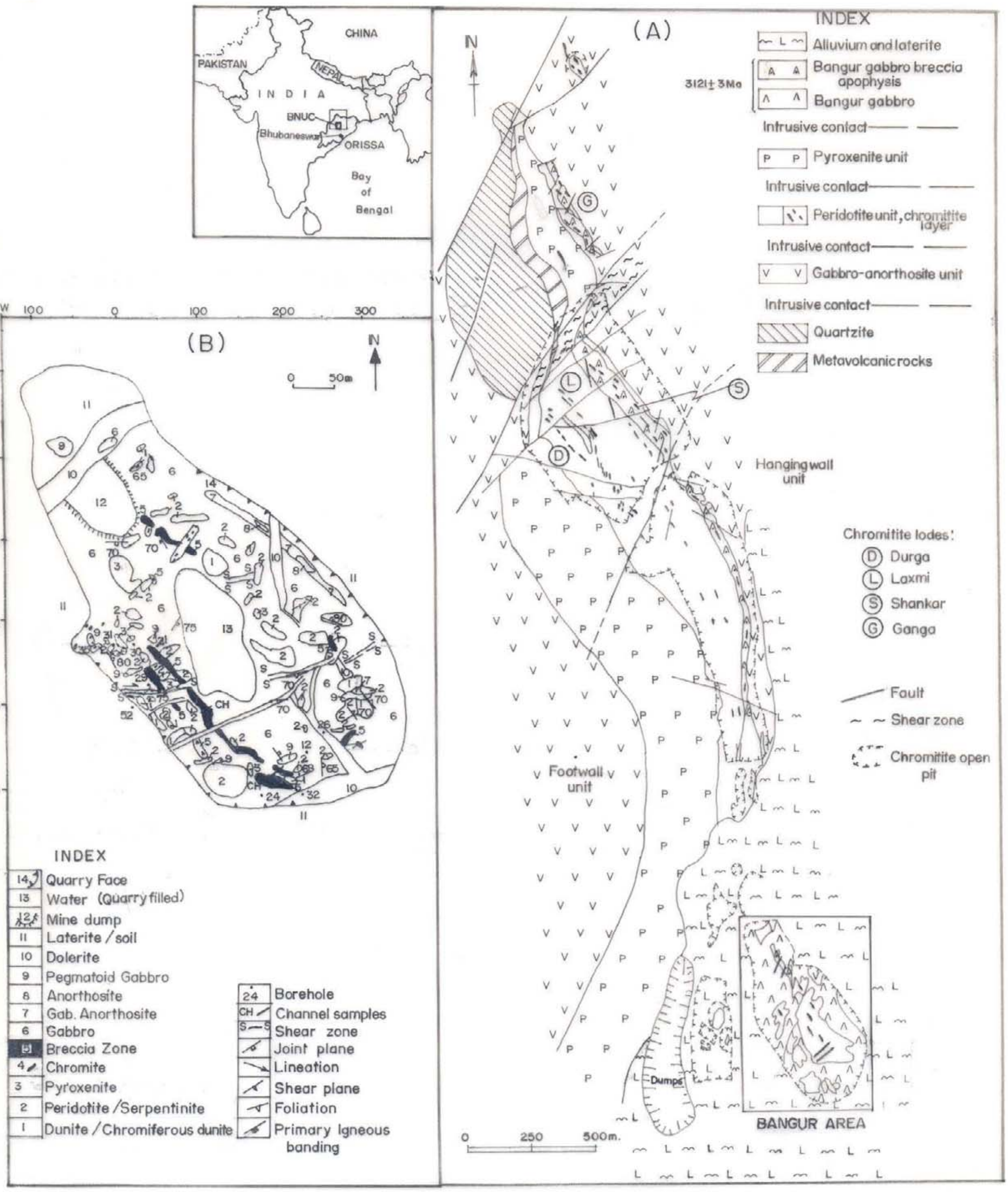


Fig.1. (A) Geological map of Baula-Nuasahi-Bangur mafic-ultramafic suite (modified after Salepeteur et al., 1999). **(B)** Detailed geological map of Bangur area,Kendujhar district, Odisha. (Prepared by K. C. Sahoo, P. Sahoo and M. Mohanty).

part and mafic rocks in the eastern part. The ultramafic suite of rocks is being mined for its chromite repository by OMC since half a century. Parts of this BMUS are concealed under a thick laterite measuring up to 10 m in the periphery of the OMC quarry and beyond. The ultramafics are represented by dunite, chromiferous serpentinite, chromitite, peridotite, orthopyroxenite and websterite and are mostly confined to the western and median part of the quarry. The chromiferous dunite/ peridotite and chromitite with an estimated thickness of 120–150 m constitute the core of the ultramafic suite. The chromiferous ultramafics show primary banding in the form of rhythmic layers of chromite and dunite. They show a general NW-SE trend, parallel to the orientation of the long axis of the elliptical quarry outline. The mafic units are represented by gabbro and its variants viz. melagabbro, noritic gabbro, leucogabbro gabbroic anorthosite) and anorthosite, often associated with thin bands of titaniferous-vanadiferrous magnetite.

A coarse to very coarse grained gabbro-norite, with large euhedral cumulus plagioclase and pyroxene crystals (up to 3 cm across) envelopes the exposed mafic-ultramafic suite of rocks on all sides. This unit, named as Bangur gabbro, intrudes all the lithounits of BMUS and is a prominent geochronological marker (3.1 Ga, Auge et al., 2003). It contains xenoliths of variable sizes of dunite, peridotite (serpentinite) and chromitite. The three chromite lodes (Durga, Laxmi and Shankar) of BNUC, so well exposed in the quarries of FACOR and IMFA to the north, have ceased to continue southwardly to the OMC leasehold in Bangur area, where relict chromite bands, brecciated beyond recognition, occur as clasts / megaclasts within serpentinite / Bangur gabbro. The complex mosaic of assorted clasts of myriad lithology in random orientation can be termed as Bangur litho-mélange (Sahoo et al., 2010). The chromitite clasts / megaclasts, which are at times more than 25 m to 30 m, are mined by OMC by both opencast and underground methods. Dolerite dykes are observed cutting across all the litho-units in NE-SW and NNW-SSE directions. Deformation played a major role in causing the present disposition of rock types, particularly the breccia zone. At least three ENE-WSW trending, transverse shear zones are noticed with development of S-C mylonites showing mostly a dextral sense of movement. Traces of an early NW-SE trending longitudinal shear zone, sub-parallel to the disposition of the mineralized breccia zone, are observed in the western part of the quarry. They get truncated against the transverse shear zones on either side.

MINERALISATION AND CONTROLS OF ORE LOCALISATION

Prospecting for PGE brought to light a prominent NW-SE trending ferritchromit clast ridden breccia zone, in the western footwall side of the Bangur quarry. Its strike extension for a length of ~ 550 m, with a mean width of 12 m and depth persistence up to 100 m below surface is proved on the basis of drilling data and study of underground mine faces. The breccia zone hosts a complex medley of clasts of dunite, peridotite, chromiferous serpentinite and chromitite of variable shape, size and orientation in the matrix of Bangur gabbro (Fig.2). Besides, larger uneven to rounded clasts of chromite, dissemination of chromite in the form of grains, pebble to peanut sized clots in the vicinity of larger clasts is often noticed. The chromite clasts generally show grain coarsening towards the margins and are slightly magnetic because of the presence of ferritchromit. The clast-matrix ratio in the breccia zone varies widely from as low as 5% to 90%, depending on the size of the clasts. Size

Fig.2. Field photograph of mineralised breccia zone containing clasts of ferritchromit in medium grained gabbro matrix. (Bangur quarry)

of the clasts varies from less than a centimeter to more than a meter, where a chromite/ferritchromit band is fragmented due to brittle deformation / pneumatic pressure of gabbroic intrusion. The larger clasts in such cases are surrounded by smaller ones. The size of clasts, at places, is found to diminish with progressive brecciation. Basemetal sulphides are important indicators of PGE concentration in BNUC (Auge et al., 2002), as they are known to scavenge the PG metals from the parent melt. The sulphides notably, pyrite, pyrrhotite, chalcopyrite and pentlandite occur in various forms and associations. They occur as stringers, veinlets and clusters in fractures / shear zones. Primary disseminations of pyrite and pyrrhotite are observed as inclusions in ferromagnesian minerals and/or in the interstitial spaces of grains in peridotite/gabbro within the matrix of breccia zone. The occurrence of sulphides, both megascopic and microscopic, is sporadic and much less pronounced in BMUS than in BNUC, which makes the prospecting for PGE even trickier in the absence of visible base metal sulphides. The breccia zone, however, is a prolific marker rich in ferritchromit clasts. SEM /EPMA study of ferritchromit clasts showed uniform distribution of chromium in bulk of the clasts except a few where titaniferous magnetite occurs as overgrowth on chromite and micro-veinlets in clasts, possibly formed concomitantly during the subsequent intrusion of Bangur gabbro.

Detailed geological mapping (1:500) with the help of electronic total station, brought out the diverse lithologies exposed over an area of 0.50 km^2 in Bangur open cast mine (Fig. 1B). The lithotypes are broadly categorized as ultramafic suite comprising dunite, chromiferous serpentinite, pyroxenite; mafic suite comprising melagabbro, gabbroic anorthosite and anorthosite; breccia zone and base metal sulphide rich gabbro/pyroxenite. Bed rock samples (50 no.) were collected from all the suitable rock types from quarry face, bore holes and underground stopes with the explicit purpose of finding out the preferentiality of PGE distribution across the lithologies. The analysis of PGE in the host rock samples (Table 1) and chondrite normalized distribution pattern (Fig.3) indicate normal fractionation trend and a common parentage for the ultramafic and mafic suites. Compared to Merensky and UG-2 reef, Bushveld complex; the PGE values are substantially low although similar distribution pattern is indicated. The breccia zone with ferritchromit clasts stands out as the most preferred rock type for accumulation of PGE with mean total PGE concentration of the order of 1824 ppb, followed by the base metal sulphide disseminated gabbro/ pyroxenite (650 ppb). While the ultramafic suite shows mean PGE levels of 150 ppb, in the mafic suite it is 187 ppb. Whole rock analysis of a representative ferritchromit breccia sample shows SiO_2 28.33%, Al_2O_3 8.92%, Fe_2O_3(T) 17.99%, MnO 0.50%, MgO 24.22%, CaO 2.42%, Na_2O 0.09%, K_2O 0.04%, TiO_2 0.82%, P_2O_5 0.04% & Cr_2O_3 13.81% and trace elements in (ppm) Co 117, Cu 105, Ga 31, Nb 07, Ni 508, Pb 10, Rb 18, Sr 26, U 08, V 1347, Y 14, Zn 458 and Zr 39 (L.O.I. 2.63(%). Mineragraphically (EPMA) a representative ferritchromit shows composition of Al_2O_3 - 8.5%, Cr_2O_3 - 37.5%, FeO - 54%.

The borehole plan of the ongoing chromite exploitation of OMC at Bangur was carefully studied and fifteen boreholes were selected targeting the breccia zone at depth. These boreholes are logged for recording the lithological variations, occurrence of chromite lodes and breccia zone and their inter-relationships. Core samples collected from the breccia zones rich in ferritchromit or base metal sulphide were analysed for PGE by ICP-MS at chemical laboratory, GSI, Hyderabad. The analytical results are extremely encouraging showing average total PGE (Pt, Pd, Ir, Ru, Rh) content of 3.2 ppm in a population of 200 drill core samples. One peak value of ΣPGE 396 ppm, with 344 ppm Pt, 26 ppm Rh, 15 ppm Pd, 7 ppm Ir and 4 ppm Ru is possibly indicative of the 'nugget effect' in the distribution of noble metals. Out of the population of 200 drill core samples, an overwhelming 153 samples belonged to the ferritchromit rich breccia zone and 47 samples are from base metal disseminated gabbro / pyroxenite. The former shows average ΣPGE content of 4.09 ppm and the latter shows average total PGE of 0.473 ppm, confirming the former as the predominant source of PGE (Table 2). There is a significant enrichment of Pt in the ferritchromit breccia sample (Pt/Pd: 14.6) in comparison to BMS bearing ones (Pt/Pd: 1.95). This is reflected in the chondrite normalized plot (Fig.4)

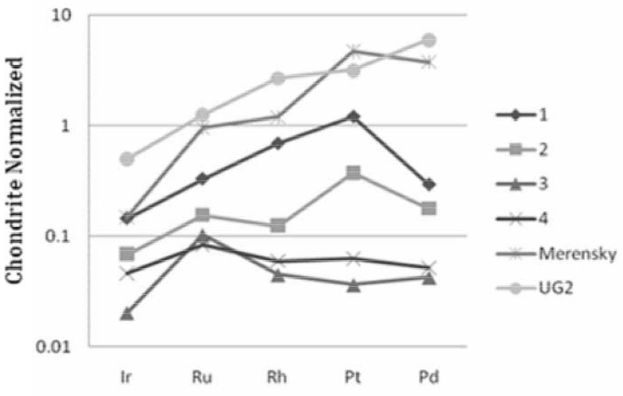


Fig.3. Chondrite-normalized PGE of BMUS compared with Merensky Reef and UG2 (Buchanan, 1988), 1, 2, 3 & 4 as per Table 1.

Table 1. PGE distribution in the host rock sample of Bangur, Kendujhar district, Odisha

Nature of sample	Sample population "N"	Mean Pt (ppb)	Mean Pd (ppb)	Mean Ir (ppb)	Mean Ru (ppb)	Mean Rh (ppb)	Mean ΣPGE (ppb)
1. Breccia zone (BZ) / ferritchromit	22	1222	158	78	228	138	1824
2. BMS rich gabbro/Ultramafic	3	383	97	37	108	25	650
3. Chromiferous serpentinite / pyroxenite	13	37	23	11	71	9	150
4. Gb-An suite/ Bangur gabbro	12	64	28	25	58	12	187
All samples	50	586	87	64	152	74	963

Table 2. PGE distribution in Core samples from Bangur, Kendujhar district, Odisha

Nature of sample	Sample population "N"	Mean Pt (ppb)	Mean Pd (ppb)	Mean Ir (ppb)	Mean Ru (ppb)	Mean Rh (ppb)	Mean ΣPGE (ppb)
1. Ferritchromit rich breccia zone(BZ)	153	3292	225	112	167	294	4090
2. BMS rich gabbro/ pyroxenite/ breccia zone(BZ)	47	250	128	21	39	35	473
All samples	200	2589	203	96	138	242	3268

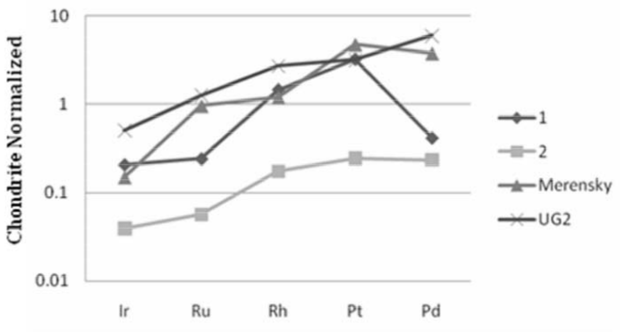


Fig.4. Chondrite-normalized PGE of Bangur Complex compared with Merensky Reef and UG 2 (Buchanan, 1988), 1 and 2 as per Table 2.

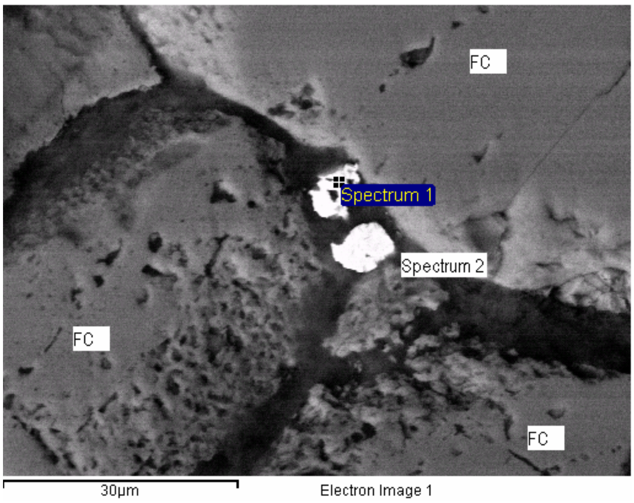
showing a higher enrichment of Pt and sharp depletion of Pd compared to UG-2.

Initially the base metal sulphide rich portions of gabbro/breccia zone were searched for possible PGE mineralization. SEM-EDX study confirmed the presence of platinum group minerals (PGM) like sudburyite (PdSb) and laurite (RuS_2) in association with base metal sulphides. They occur as discrete grains, disseminations or clusters within clinopyroxene/ chalcopyrite with sizes ranging from 1 to 12 micron. In a rare combination, a gold aureole is found within a sudburyite grain (Sahoo et al., 2011). Presence of tiny PGM grains as inclusions within pyroxene clearly suggests their formation prior to the crystallization of pyroxene in melagabbro. Similarly chalcopyrite occupying the interstitial space and along the fractures of chromite grains suggest its formation either during or later stage of crystallization of Bangur gabbro. Enrichment of Pd compared to Pt and presence of Pd-group PGM possibly points to a hydrothermal (type-2) process (Auge et al., 2004) operating either during or later stages of the Bangur gabbro intrusion. It is worth mentioning that major PGE resources identified earlier in BNUC belongs to this type only.

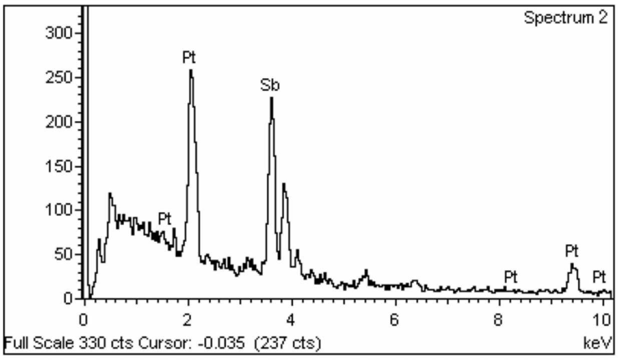
The ongoing prospecting programme has revealed that the breccia zone having higher proportion of ferritchromit clasts with a conspicuous admixture of gabbroic matrix material forms the prime target for PGE mineralization in Bangur. SEM/EPMA study confirmed occurrence of PGM like isoferroplatinum (Pt_3Fe), sperrylite ($PtAs_2$) and hollingworthite (RhAsS), as inclusions in ferritchromit and /or in the interstial space of ferritchromit grains. A cluster of two PGM grains, sperrylite (PtAs2) (spectrum 1) and geversite (PtSb2) (Sp- 2) are noticed in the intercumulus space of ferritchromit in SEM image (Fig.5). The spongy margins of ferritchromit (FC) are Ti rich. A detailed analysis of two sets of samples drawn from clast, matrix and bulk (clast + matrix) material separately revealed that the matrix material holds key to the PGE mineralization (Table 3). The matrix of the two sets although enriched in total PGE show variation of Pt content (7.2 ppm and 0.905 ppm) and Pt/Pd (54 and 1.4) respectively. But the clast and matrix composite sample show consistently high ΣPGE values with higher enrichment of Pt (Pt/Pd: 32 and 8). In contrast, smaller ferritchromit clasts show very low total PGE values in the range of 200 ppb. In the second set of samples, large sized (3 - 20 cm) ferritchromit clasts have accumulated sizable proportions of PGE (4.9 ppm total PGE with Pt/Pd: 6.4). Significant enrichment of Pt and Pt-rich minerals associated with this type can be ascribed to Type-1 or magmatic type of Auge et al. (2003). The genesis of ferritchromit in the Baula ultramafic complex is not yet fully resolved. It is identified with the magmatic differentiation process, the upper sequence becoming more iron-rich giving rise to ferritchromit. However, partial replacement of Cr by Fe during a late hydrothermal process is also advocated for its possible origin (Auge et al., 2004). The present study suggests the formation of a ferritchromit layer during differentiation, in the magmatically layered ultramafic suite at Bangur. This

Table 3. PGE distribution in the breccia zone at Bangur, Kendujhar district, Odisha

S.No	Sample No	Lithology	Pt (ppb)	Pd (ppb)	Ir (ppb)	Ru (ppb)	Rh (ppb)	Total (ppb)
Set-1	BN/BRS/3	BZ matrix material	7255	135	155	625	260	8430
	BN/BRS/4	BZ (ferrit-chromite clast material)	130	10	10	40	10	200
	BN/BRS/5	BZ (clast + matrix)	4965	155	140	730	190	6180
Set-2	BN/BRS/38	BZ (matrix only)	905	655	165	390	185	2300
	BN/BRS/39	BZ (clast + matrix)	3585	445	135	560	470	5195
	BN/BRS/37	BZ (clasts of FC, size 0.5 cm-2.5 cm)	15	156	<3	15	<3	186
	BN/BRS/40	Very big size FC clast (3-20cm)	2950	440	335	670	550	4945



Sperrylite		
Element	Weight%	Atomic%
As L	32.84	53.13
Sb L	13.75	13.69
Pt M	53.41	33.18
Totals	100.00	
Geversite		
Element	Weight%	Atomic%
As L	32.84	53.13
Sb L	13.75	13.69
Pt M	53.41	33.18
Totals	100.00	



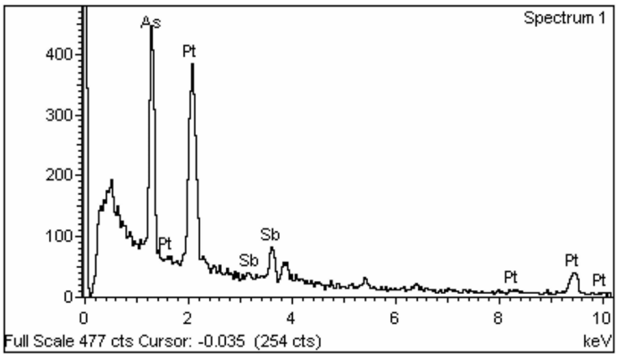


Fig.5. SEM image of PGMs: Sperrylite ($PtAs_2$) (spectrum 1) and Geversite ($PtSb_2$) (Spectrum-2) in the intercumulus space of ferritchromit(FC). The spongy margins of FC are Ti rich.

ferrichromit layer, later on, gave rise to the breccia zone through a sequence of tectonic and magmatic activities.

Generally, the core samples show enrichment of PPGE (Pt, Pd, Rh) over IPGE (Ir,Os,Ru). Pt is dominant followed by Rh, Pd, Ru and Ir in the relative order of abundance. Pt and Pd show positive correlation with Pt/ Pd varying from 13 to 82 for bulk of the samples, unlike the Pd rich mineralisation in the northern part of BNUC. Breccia zone with ferritchromit clasts form well defined zones of mineralization extending over a cumulative strike length of 550 m, ranging in thickness from 1 m to 14 m and PGE content varying from 0.5 ppm to 10.6 ppm. PGE resources of 1.58 million tonnes of ore with average grade of 2.68g/t at 0.5g/t cut-off has been estimated for the Bangur prospect (GSI, ER NEWS, 2011)

CONCLUSION

The dismembered mafic-ultramafic suite of rocks, resting over a canvas of pervasive Bangur gabbro, provide an interesting milieu for the search of PGE in Bangur chromite mining area. The present study establishes that PGE mineralization is mostly confined to the ferritchromit bearing breccia zone exposed prominently in the western footwall side of the chromite quarry maintaining a NW-SE trend. The mineralized zone extends for a strike length of 550m, with an average width of 12 m and proved depth persistence of 100m. The ferritchromit rich breccia zone in gabbro acts as the primary host for concentration of Pt-rich PGE without substantial basemetal sulphide concentration in contrast to the base metal sulphide bearing breccia zone / pyroxenite as the host for PGE mineralization in the northern part of BNUC. Delineation of this PGE bearing zone would help in resource augmentation as well as preservation of gangue/ matrix of the breccia zone, along with ferritchromit clasts, during selective chromite mining for future exploitation of platinum.

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References

Auge, T., Cocheri, A., Genna, A., Armstrong, R., Guerrot, C., Mukherjee, M.M. and Patra, R.N. (2003) Age of Baula PGE mineralisation (Odisha, India) and its implications concerning the Singhbhum Archaean nucleus. Precambrian Res., v.212, pp.85-101.

Auge, T. and Lerouge, C. (2004) Mineral chemistry and stable isotope constraints on the magmaticm, hydrothermal alteration, and related PGE-(base-metal sulphide) mineralisation of Mesoarchaean Baula-Nuasahi Complex, India. Mineralium Deposita, v.39, pp.583-607.

Auge, T., Salpetur, I., Bailly, L, Mukherjee, M.M. and Patra, R.N. (2002) Magmatic and hydrothermal platinum-group minerals and base metal sulphides in the Baula complex, India. Canadian Mineralogist, v.40, pp.277-309.

Buchanan, D.L. (1988) Platinum group element exploration. Developments in Economic Geology, Elsiever, v.26, p.185.

Geological Survey of India, Eastern Region News (2011) A new PGE deposit from Bangur, Kendujhar district, Odisha. Vol. 32, No. 1 & 2, Jan. - Dec. 2011, pp.4-5.

Hinchey, J.G, Hattori, K.H. and Lavigne, M.J. (2005) Geology, petrology and controls on PGE mineralisation of the southern Roby and Twilight zones, Lac des Iles Min, Canada. Econ. Geol., v.100, pp.43-61.

Mondal, S.K. and Zhou, Mei-Fu (2010) Enrichment of PGE through interaction of evolved boninitic magmas with early formed cumulates in a gabbro-breccia zone of Mesoarchaean massif (eastern India). Mineralium Deposita, v.45, no.1, pp.69-91.

Mukhopadhyaya, D. (2001) The Archaean nucleus of Singhbhum: the present state of knowledge. Gondwana Res., v.4, pp.307-318.

Nanda, J.K., Patra, R.N. and Mishra, R.N. (1996) Petrogenetic history of the platiniferousmagmatic breccia zone in Baula igneous complex: A conceptual module for PGM localization: In:Abstracts: Workshop on geology and exploration of platinum-group, Raremetal and Rare earth elements, Geol. Surv. India, pp.17-19.

Sahoo, K.C., Mohanty, M., Rath, S.C., Nayak, S.K., Mohanty, S.K. and Bose, P.K. (2010) Potentiality and exploration strategy of Platinum group minerals in mafic-ultramafic suite at Bangur, Odisha. International seminar on Development of Chromite, Nickel and PGM resources, organized by SGAT, Bhubaneswar. Abs. vol, pp.94-95.

Sahoo, K.C., Mohanty, M., Sahoo, P., Rath, S.C., Ray, S.B., Nayak, S.K. and Bose, P.K. (2011) PGE mineralization in dismembered mafic-ultramafic suite at Bangur, Kendujhar district, Odisha. In Abstracts: Geological Survey of India, Orissa State Unit Golden Jubilee National Seminar on Orissa's Mineral, Environment & Geoscience Assessment (OMEGA) 2011, Bhubaneswar, pp. 30-31.

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Analytical Method

The compositions of PGMs and associated sulphides are determined by scanning electron microscope equipped quantitative energy dispersive spectrometry (SEM–EDS, CARL ZEISS-EVO 40) at GSI, Kolkata. These semi-quantitative data permit identification of the minerals on polished surfaces.

The mineral phases were quantitatively determined employing electron probe micro-analyzer (EPMA–CAMECA SX-100) using Wavelength Dispersive Spectrometry (WDS) at the Central Petrological Laboratory, GSI, Kolkata and GSI, Faridabad. A beam size of 1 micron was used for analysis of minerals under accelerating voltage of 15 kV and current intensity of 12 nA. Natural standards were used for all elements, except Mn and Ti, for which synthetic standards were used.

The chemical analysis of host rock and drill core samples for PGE and gold was carried out by Inductive Coupled Plasma–Mass Spectrometer (ICP–MS) after pre-concentration by nickel sulphide fire assay method.