Ni–Cr–PGE-minerals from the Katpal chromite mine, Sukinda chromite field, Orissa

P. V. Sunder Raju[1,3,*], R. K. W. Merkle[1], Peter Gräser[1], Andre Botha[2], S. K. Mohanthy[4] and Marko Classen[1]

[1]Department of Geology and [2]Centre for Microscopy, University of Pretoria, Pretoria 0002, South Africa
[3]National Geophysical Research Institute, Hyderabad 500 007, India
[4]Department of Mines and Geology, Orissa Mining Corporation, Sukinda 755 026, India

Samples collected from a core at the Katpal chromite mine of the Orissa Mining Corporation in Sukinda valley, Orissa, were studied for their mineralogy, including platinum group minerals (PGMs). EPMA study showed the presence of millerite, rammelsbergite, nickeline, laurite, osmiite, ruarsite, chalcopyrite, sphalerite and pentlandite. The PGMs contain Ru, Os and Ir and are concentrated in the chromite and at the grain boundaries of base metal sulphides. It is envisaged that only a detailed study can lead to the evaluation of this platinum group elements mineralization.

Keywords: Katpal chromite mine, mineralogy, platinum group minerals.

THE Sukinda ultramafic field hosts the single largest opencast chromite mining area in Orissa, India[1–4]. Chromite resources of Orissa account for ~98% of the total resources of India[5] and are fourth in terms of identified global resources[6]. Chromite occurrences in India need detailed investigations in terms of petrology of the host intrusions for their evaluation as future targets for platinum exploration[5]. Worldwide, chromitites compared to host silicate rocks are always associated with elevated platinum group element (PGE) content. The Sukinda ultramafic field hosts the Sukinda chromite field and Katpal Ultramafic Body (KUB). It is significant because of the known chromite occurrences, but only a few studies were aimed at characterizing the Ni–Cr–PGE association[7,8]. A thorough understanding of the petrological evolution of the intrusions (magma evolution, ore-forming processes) is missing. The rocks of Sukinda valley are laterized[8] and all primary evidence has been destroyed up to a depth of ~30 m. The area leased by Orissa Mining Corporation (OMC) in Katpal was extensively drilled, but little information is publicly available. We report here on preliminary data obtained from borehole material.

The Sukinda ultramafic field forms a part of the metamorphosed Precambrian of the Indian Peninsula. Dismembered chromitiferous ultramafic bodies occur sporadically with in an area of 420 sq. km around Sukinda[1,3], between latitudes 20°53′N and 21°05′N and longitudes 85°40′E and 85°53′E. The ultramafic rocks are orthopyroxenites, dunites and chromitites. The Katpal body lies ~5 km towards SW in the same strike direction as the Sukinda ultramafic field at latitude 21°01′N and longitude 85°43′E (Figure 1). At Katpal, chromitite bodies are brecciated[9] and are similar to the Nuasahi massif[5] from which PGE mineralization has been reported[10]. The described regional stratigraphic sequence in Sukinda consists of metabasalt (two horizons) and intrusive ultramafic rocks, which occur as a part of a folded sequence of the Iron Ore Group[11]. The contact between the ultramafic rocks and lower metabasalt is brecciated[8]. Chromitite bands and lenses occur within serpentinized dunite, having sharp contacts with unaltered orthopyroxenite. At Katpal, up to ~120 m the stratigraphic sequence with increasing depth is laterite and soil cover, followed by serpentinized dunite with chromitite and metapyroxenite with chromitite. Chromite mining here was discontinued because the ore is lensoid, which makes mining unpredictable and uneconomical.

For this study five drill cores were available. Drill core no. 177 down to a depth of ~120 m was selected because of the absence of major alterations. Also, it appeared representative in terms of its chromite content and brecciation. The borehole stratigraphy is shown in Figure 2. The altered serpentinite contains brecciated chromitite clasts in varying sizes (typically 0.5–3 cm; Figure 3).

The SX-100 Cameca electron microprobe (EPMA) at the University of Pretoria was utilized to carry out analysis of selected mineral grains. Pictures of platinum group minerals (PGMs) were taken in backscattered mode. The possible PGM phases were classified using manual elemental identification using Röntec energy dispersive spectrometer (EDS) for analysis of minerals.

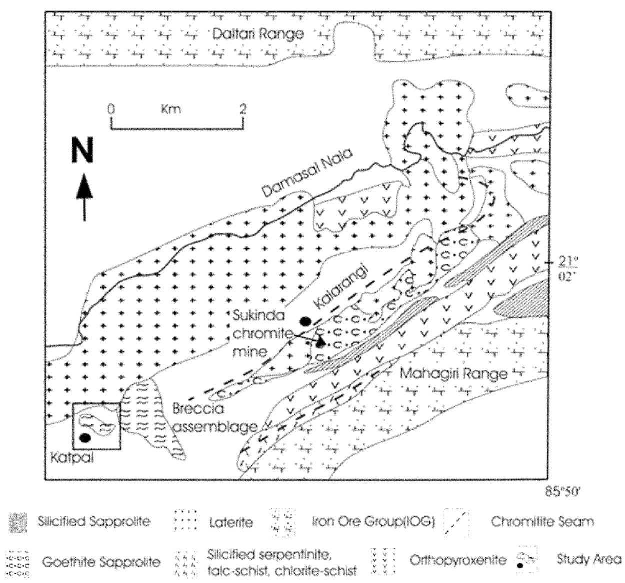

Figure 1. Geological map of the Sukinda massif[3].

*For correspondence. (e-mail: pvsraju@ngri.res.in)

Table 1. Microprobe analysis (in wt%) of laurite (RuS_2) and rammelsbergite ($NiAs_2$) from the Katpal chromite mine, Orissa, India

Section	Ru	Rh	Os	Ir	Pt	S	As	Ni	Total
172/12	49.22	1.36	7.20	1.65	1.08	36.51	–	–	97.02
172/1	58.65	1.22	1.26	0.85	–	39.01	–	–	100.99
172A/1	48.67	0.21	3.21	1.26	–	45.00	–	–	98.35
172/12A	–	–	–	–	–	–	36.45	63.55	100.00
172/1A	–	–	–	–	–	–	36.42	64.22	100.64
172/A1	–	–	–	–	–	–	35.54	62.22	97.86
172B	–	–	–	–	–	–	38.67	60.22	98.89

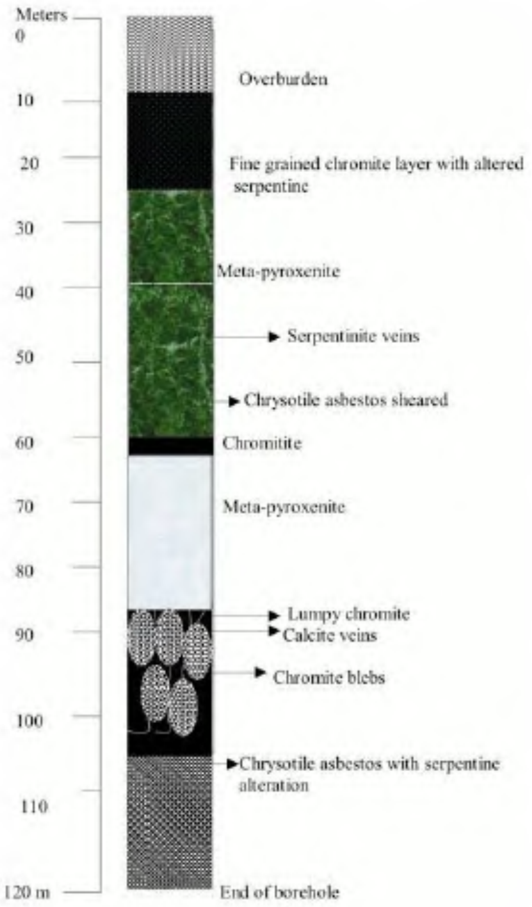

Figure 2. Lithology of the drill core from borehole no. 177, Katpal Ultramafic Body.

The chromite crystals are generally euhedral to subhedral (>90 modal % chromite) in a silicate matrix comprising predominantly of orthopyroxene, olivine and minor serpentine, calcite, talc and sulphides. In some polished sections they show extensive cataclasis. No zonation was observed in the chromite grains in spite of the serpentinization[10,12,13]. Chromite is characterized by high Cr# of 0.70–0.85 and low Mg# 0.30–0.80 (Figure 4), which is different from that of Sukinda[5].

The base-metal sulphide mineralogy of the samples investigated from chromitite were pentlandite (55–70 vol%), chalcopyrite (20–25 vol%) and pyrrhotite (4–5 vol%). The base-metal sulphides appear often to be squeezed out to form thin films between chromite grains. The composite mineral grains are present at the chromite–chromite grain boundaries and within chromite. Subsidiary amounts of millerite (~3 vol%) were also observed in pentlandite grains. Rare grains of sphalerite and galena, usually smaller than 10 μm, occur in association with secondary hydrous silicates. Occasionally chalcopyrite is partially rimmed by sphalerite. Semi-quantitative analysis of a single grain of rammelsbergite is represented in Table 1.

Three distinct PGMs were observed and identified based on EDS and EPMA analysis. Due to limited resolution during analysis of small PGM grains included in the base-metal sulphides and interferences, the presence of nickel, copper, cobalt, and iron in PGMs could not always be established. The three prominent phases are Ru–S (laurite) (Table 1), Ru–As–S (ruarsite) and Os–Ir–Ru–As (omeiite). All the PGMs are either inclusions in chromite or at sulphide–sulphide grain boundaries, or at grain boundaries of base-metal sulphide with silicate.

All magmatic Ni–Cu ± PGE sulphide deposits, whether associated with chromitite or not, are spatially and genetically related to bodies of mafic or ultramafic rocks[14]. Such deposits form when mantle-derived mafic and ultramafic magmas become saturated in sulphide and segregate immiscible sulphide liquid, triggered by magma mixing or interaction with crustal rocks[15]. The sulphides generally constitute a small volume of the host rock(s) and are dominated by a simple major sulphide mineralogy of pyrrhotite, pentlandite and chalcopyrite. In the KUB, chromite is annealed, brecciated and cataclastic. The cataclasis is probably related to post-magmatic tectonic movement and does not bear any significance to the evaluation of PGE potential. However, the complex geological history of the KUB indicates that the present-day observations represent a range of magmatic and metamorphic features. Annealing of chromitite typically leads to reduction in the recovery potential of base-metal sulphides and PGMs from the ore. Future investigations will therefore have to take into account the textural settings of PGMs in chromitite. Although insight into the rocks of the KUB is still limited, the brecciated nature of chromitite constitutes at present a limitation for the evaluation of PGE potential of the body.

Figure 3. Borehole sample with clasts of chromite (left) and granular chromitite (right).

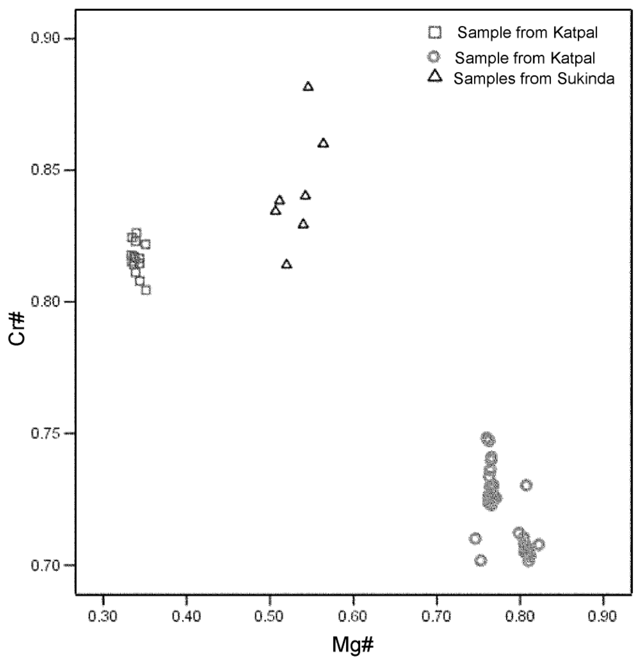

Figure 4. Cr# vs Mg# of chromites from Katpal, compared with those of Sukinda samples.

Texturally it appears that the chromite body is transported, which is supported by the compositional variation of chromite in the neighbouring clasts. At present the clasts represent more than one chromitite-forming event (i.e. they represent fragments of more than one chromitite layer). The dominance of pentlandite over chalcopyrite is in accordance with the formation of sulphide melt from a mafic–ultramafic melt[16]. The scarcity of pyrrhotite relative to pentlandite and chalcopyrite is a common feature of chromitites and reflects the loss of Fe ans S during post-magmatic processes, thus increasing the relative proportion of Ni and Cu manifold[17,18]. The overall low tenor of sulphide implies that only small amounts of sulphide melt are formed. Because of the high partition coefficients of PGMs into immiscible sulphide melt[19], one would expect relatively high proportions of PGMs in the sulphide assemblage. Due to the low solubility of PGE into base-metal sulphides[20,21], these PGEs should exsolve on cooling and form discrete PGMs.

In this study all PGMs observed were rich in Ru, Os and Ir and no minerals of Pt, Pd, or Rh were found. Magmatic PGMs are represented by Ru, Os and Ir mineral inclusions in chromites. We therefore consider it unlikely that the silicate melt from which chromitite formed was depleted in PGEs by the formation of a previous immiscible sulphide melt. May be the R-factor during the chromite formation and liquation of sulphide melt was low. However, we consider it more likely that the small amounts of sulphide melt formation are responsible for the lack of Pt and Pd minerals. In the Bushveld Complex, South Africa it was demonstrated that chromitite layers characterized by low amounts of sulphide melt showed a distinct dominance of Ru, Os and Ir, and an increase in Pt and Pd due to increased sulphide melt formation[22]. Only a comprehensive study, taking the petrological differences in the chromitite clasts into account, will resolve this issue. We consider it unlikely that observations are equally applicable to all chromitite clasts.

The present study has provided an insight into the presence of PGEs from a core sample at the KUB, though the limited data are not sufficient to draw authentic conclusions concerning the distribution of PGEs. The study however, has shown the following:

- Annealing, cataclasis and brecciation of chromite in the core samples studied. The brecciated nature of chromitite and its compositional variation constitute at present a complication for the evaluation of PGE potential of the body.
- The base-metal sulphide assemblage in chromitite consists of pentlandite, chalcopyrite and pyrrhotite. Grains of rammelsbergite, millerite, sphalerite, and galena were also found. It is suggested that the low Fe-tenor of the base-metal sulphide assemblage is due to loss of Fe and S during post-magmatic events.
- Due to the low solubility of PGE in base-metal sulphides, these PGEs should exsolve on cooling and form discrete PGMs.
- The PGM assemblages consist of laurite, ruarasite and omeiite with absence of Pt and Pd minerals. The absence of Pt and Pd could be due to low availability of sulphide melt, a low *R*-factor, or the limited size of the dataset.

1. Banerjee, P. K., Geology and geochemistry of the Sukinda ultramafic field, Cuttack district, Orissa. *Mem. Geol. Surv. India*, 1972, **103**, 17.
2. Chakraborty, K. L. and Chakraborty, T. L., Geological features and origin of the chromite deposits of Sukinda valley, Orissa, India. *Miner. Deposita*, 1984, **19**, 256–265.
3. Page, N. J., Banerjee, P. K. and Haffty, J., Characterization of the Sukinda and Nausahi ultramafic complex, Orissa, India by platinum-group element geochemistry. *Precambrian Res.*, 1985, **30**, 27–41.
4. Varma, O. P., Some aspects of ultramafic and ultrabasic rocks and related chromite metallogenesis with examples from eastern region of India. In Proceedings of the Seventy-third Session of the Indian Science Congress Association, Delhi, 1986, pp. 1–72.
5. Mondal, S. K., Ripley, E. M., Li, C. and Frei, R., The genesis of Archaean chromitites from the Nuasahi and Sukinda massifs in the Singhbhum Craton, India. *Precambrian Res.*, 2006, **148**, 45–66.
6. Vermaak, C. F., A brief overview of South Africa's mineral industry: World context and changing local circumstances. *Miner. Deposita*, 1997, **32**, 312–322.
7. Sarkar, N. K., Panigrahi, D., Ghosh, S. N. and Mallik, A. K., A note on the incidence of gold-PGM in the breccia zone of Katpal chromium quarry, Sukinda ultramafic complex, Dhenkal Dt., Orissa *Indian Miner.*, 2003, **57**, 85–92.
8. Sen, A. K., Sharma, P. K., Mohanthy, D. and Ghosh, T. K., Composition of Cr spinel – An ore gentic indicator of Katpal chromite deposit, Sukinda ultramafic field, Orissa. *Curr. Sci.*, 2005, **88**, 1547–1550.
9. Basu, A., Maitra, M. and Roy, P. K., Petrology of mafic–ultramafic complex of Sukinda valley, Orissa, *Indian Miner.*, 1997, **50**, 271–290.
10. Auge, T. and Lerouge, C., Mineral-chemistry and stable-isotope constraints on the magmatism, hydrothermal alteration, and related PGE – (base-metal sulphide) mineralisation of the Mesoarchaean Baula-Nuasahi Complex. *Miner. Deposita*, 2004, **39**, 583–607.
11. Sarkar, N. K., Mallik, A. K., Panigrahi, D. and Ghosh, S. N., A note on the occurrence of breccia zone in the Katpal chromite lode, Dhenkanal district, Orissa. *Indian Miner.*, 2001, **55**, 247–250.
12. Burkhard, D. J. M., Accessory chromium spinels: Their coexistence and alteration in serpentinites. *Geochim. Cosmochim. Acta*, 1993, **57**, 1297–1306.
13. Mohanthy, J. K., Sahoo, R. K. and Paul, A. K., Chromite alteration at Baula–Nausahi igneous complex, Orissa. *J. Geol. Soc. India*, 1996, **48**, 265–276.
14. Naldrett, A. J. and Cabri, L. J., Ultramafic and related mafic rocks: Their classification and genesis with special reference to the concentration of nickel sulphides and platinum-group elements. *Econ. Geol.*, 1976, **71**, 1131–1158.
15. Arndt, N. T., Lesher, C. M. and Czamanske, G. K., Mantle-derived magmas and magmatic Ni–Cu–(PGE) deposits. *Econ. Geol.*, 2005, 100th Anniversary Volume, 5–23.
16. Naldrett, A. J. and Lehmann, J., Spinel non-stoichiometry as the explanation for Ni-, Cu-, and PGE-enriched sulphides in chromitites. In *Geo Platinum '87*, Elesevier, London, pp. 93–110.
17. Merkle, R. K. W., Platinum-group minerals in the middle group of chromitite layers at Marikana, western Bushveld Complex – Indications for collection mechanisms and postmagmatic modification. *Can. J. Earth Sci.*, 1992, **29**, 209–221.
18. Crocket, J. H., Platinum-group element geochemistry of mafic and ultramafic rocks. In *The Geology, Geochemistry, Mineralogy and Mineral Beneficiation of Platinum Group Elements* (ed. Cabri, L. J.), Canadian Institute of Mining, Metallurgy and Petroleum, 2002, vol. 54, pp. 117–210.
19. Von Gruenewaldt, G. and Merkle, R. K. W., Platinum group element proportions in chromitites of the Bushveld complex: Implications for fractionation and magma mixing models. *J. Afri. Earth Sci.*, 1995, **21**, 615–632.
20. Rajamani, V. and Naldrett, A. J., Partitioning of Fe, Co, Ni, and Cu between sulphide liquid and basaltic melts and the composition of Ni–Cu sulphides. *Econ. Geol.*, 1978, **73**, 82–93.
21. Makovicky, M., Makovicky, E. and Rose-Hansen, J., Experimental studies on the solubility and distribution of platinum group elements in base-metal sulphides in platinum deposits. In *Metallogeny of Basic and Ultrabasic Rocks* (eds Gallagher, M. J. *et al.*), The Institute of Mining and Metallurgy, London, 1986, pp. 415–425.
22. Fleet, M. E., Crocket, J. H. and Stone, W. E., Partitioning of platinum-group elements (Os, Ir, Ru, Pt, Pd) and gold between sulfide liquid and basalt melt. *Geochim. Cosmochim. Acta*, 1996, **60**, 2397–2412.

ACKNOWLEDGEMENTS. The Department of Science and Technology, New Delhi, is acknowledged for providing financial support to carry out this work. The Managing Director of OMC is acknowledged for permission to carry out this scientific study. The Director, NGRI is acknowledged for support and guidance. The work was carried out while P.V.S.R. was a BOYSCAST fellow at the Department of Geology, University of Pretoria, South Africa.

Received 1 December 2006; revised accepted 27 June 2007

A new nightfrog, *Nyctibatrachus minimus* sp. nov. (Anura: Nyctibatrachidae): The smallest frog from India

S. D. Biju[1,2,*], Ines Van Bocxlaer[2], Varad B. Giri[3], Kim Roelants[2], J. Nagaraju[4] and Franky Bossuyt[2]

[1]Centre for Environmental Management of Degraded Ecosystems, School of Environmental Studies, University of Delhi 110 007, India
[2]Biology Department, Unit of Ecology and Systematics, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium
[3]Herpetology Section, Bombay Natural History Society (BNHS), S.B. Singh Road, Mumbai 400 023, India
[4]Laboratory of Molecular Genetics, Centre for DNA Fingerprinting and Diagnostics, ECIL Road, Nacharam, Hyderabad 500 076, India

A new nightfrog, *Nyctibatrachus minimus* sp. nov. (Anura: Nyctibatrachidae) is described from Kurichiyarmala in the Western Ghats, India. Its most distinctive feature is the small adult snout-vent length, averaging only 12.3 mm in adult males ($N = 15$), making it the smallest known frog from India. Analyses of a fragment of the mitochondrial NADH dehydrogenase 1 gene indicate a minimum divergence of 22% with known small-sized congeners. Miniaturization in *Nyctibatrachus* sp. seems to be associated with absence of

*For correspondence. (e-mail: sdbiju@cemde.du.ac.in)