NEWS AND NOTES

Platinum Group Minerals from the Madawara Ultramafic-mafic Complex, Bundelkhand Massif, Central India: A Preliminary Note

– *S.P. Singh[1*], V. Balaram[2], M. Satyanarayanan[2], D.S. Sarma[2], K.S.V. Subramanyam[2], K.V. Anjaiah[2] and A. Kharia[1], [1]Department of Geology, Bundelkhand University, Jhansi – 284001, Uttar Pradesh; [2]National Geophysical Research Institute (CSIR), Uppal Road, Hyderabad - 500 007. Email: spsinghbu@ rediffmail.com*

The occurrence of platinum group minerals (PGM) and gold are reported in association with chromite- and sulfide-bearing ultramafic rocks of the Madawara Igneous complex, Lalitpur district, Uttar Pradesh. The igneous complex is intrusive into the granite-gneisses of the Bundelkhand gneissic complex in the southern part of the Bundelkhand Massif. Minerals, such as sperrylite, cobaltite, pentlandite, chalcopyrite, and an unidentified mineral containing iridium and tungsten have been identified by scanning electron microscope equipped with an energy dispersive spectrometer (SEM-EDS). These minerals occur as disseminated grains in the interstitial spaces of olivine and pyroxenes. The geochemical analyses by NiS fire-assay technique coupled with ICP-MS show relatively anomalous ΣPGE of ≈700 ppb (Pt = 23 - 277 ppb, Ir = 8 - 23 ppb) and also gold (22 - 1425 ppb). Sperrylite ($PtAs_2$) is the most common mineral of Pt from these rocks and is associated with chalcopyrite in the pyroxene matrices.

Platinum group minerals (PGM) in association with silicates, base metal sulfides and chromites are reported from ophiolitic complexes (e.g. Eliopoulos et al. 2008; Prichard and Brough, 2009), komatiite hosted Ni-sulfide deposits (e.g. Lesher et al. 2001; Barnes et al. 2004), layered intrusions (e.g. Cawthorn et al. 2005; Mondal and Mathez, 2007; Maier et al. 2008), and Alaskan type complexes (e.g. Ripley, 2009). The PGM are very small grains (only few microns), and usually associated with either Ni-sulfides or chromite grains or sometimes present as disseminated grains. This report describes few PGM grains from the Madawara Igneous complex, Uttar Pradesh (India) where PGE prospects have been suspected by several workers in the recent past (Farooqui and Singh, 2006; Balaram, 2008; Singh et al. 2010; Satyanarayanan et al. 2010, 2011).

Geology

The southern part of the Bundelkhand craton represents a semicircular outcrop of granite-gneisses of the Bundelkhand massif around Madawara and is overlain by metasediments of the Bijawar and the Vindhyan Group of rocks (Fig.1). Geological investigations around Madawara (Fig.1) have shown the occurrences of E-W trending ultramafic rocks intrusive into high-grade metamorphosed rocks of the Bundelkhand Gneissic complex (Prakash et al. 1974; Sharma, 1982; Basu, 1986; Singh et al. 2010). These lensoidal bodies of ultramafic rocks occur extensively around Madawara in an area of approximately 400 km^2. The different rocks are dunite, lherzolite, harzburgite, olivine-websterite associated with gabbro and diorite rocks (Satyanarayanan et al. 2010, 2011). The lenses of ultramafics are characterized by different dimensions (≈ 500 - 1500 m in length and 50 - 600 m in width), and mostly aligned in E-W direction that are exposed at Madawara, Ikauna, Bhikampur, Pindar, Ramgarh, Hansra and Hanumathgarh areas (Fig.1). The largest ultramafic body is exposed at Madawara village, where most of the lithounits are well preserved.

The ultramafic rocks are characterized by lowland topography where fresh rocks are hard, and compact; dark bluish grey colored, and medium- to coarse-grained. The rocks are usually massive where granular crystals of olivine, pyroxene and chromite are common (Fig.2a). Ultramafic rocks are commonly altered to talc-chlorite

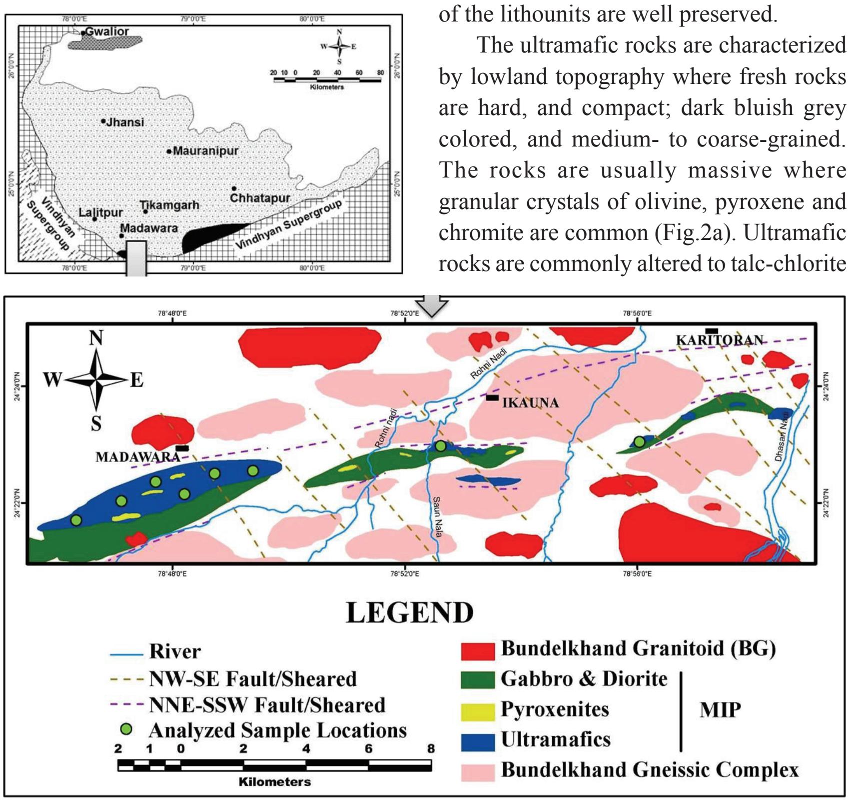

Fig.1. Location map of Madawara (top) and geological map of Madawara Igneous Complex, Bundelkhand Massif, Central India.

schist and serpentine-chlorite schist. The sulfides and chromites are seen in hand specimens at many places where they occur as disseminated grains (Fig.2b). Petrographic study confirms that the ultramafic rocks contain chromite and pyrrhotite which are present at the interstitial spaces of cumulus olivine and pyroxenes. In places chromite is extensively altered to ferritchromit and magnetite (Fig.2c and d; Fig.3f). Fine- to medium-grained sulfides are also found along the cleavages of pyroxenes, and along the fractures of olivine.

Geochemistry

These rocks are characterized by MgO = 24 - 48 wt%, Ni = 1347 - 2395 ppm, Cr = 4651 - 5298 ppm (Singh et al. 2010; Satyanarayanan et al. 2010). The Madawara ultramafic rocks are usually low in S content (96 - 675 ppm). The ultramafic rocks have moderate Au (up to 1425 ppb), and low Cu (< 60 ppm). The highest PGE content of the ultramafic rock is ≈ 700 ppb. These rocks have Pt = 23 - 277 ppb, Pd = 12 - 142 ppb, Ir = 8 - 23 ppb and Ru = 17 - 300 ppb, and low Pd/Ir ratios varying between 0.8 and 7.9. The total (Pt+Pd) values ≈ 315 ppb appear to be confined to websterite and olivine-websterite or at the contact of olivine-websterite and lherzolite.

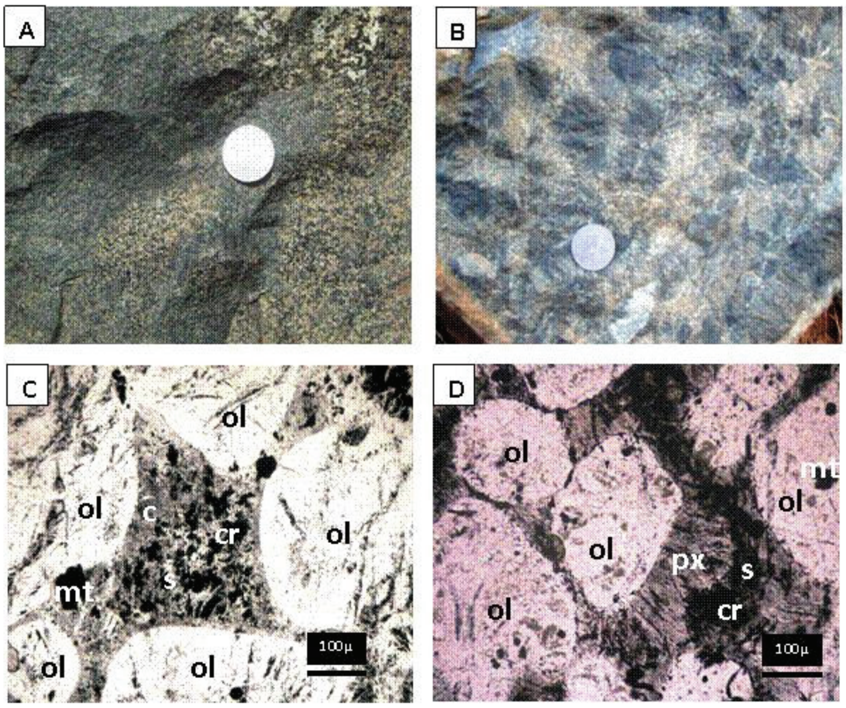

Fig.2. (*a*) Disseminated grains of chromite and sulfides in peridotite. (*b*) Globules (dark, sub-circular) of sulfide-rich peridotite in olivine-websterite. (*c*) Photomicrograph of peridotite showing disseminated crystals of magnetite (mt), chromite (cr) and sulfides (s) within the interstitial spaces of olivine grains (ol) under transmitted and reflected light (*d*) Photomicrograph showing the cumulate texture of the peridotite (ol = olivine, px = clinopyroxene, cr = chromite) under transmitted light

Composition of Minerals

About twenty representative thin-polished sections were prepared from ultramafic rocks for this study.

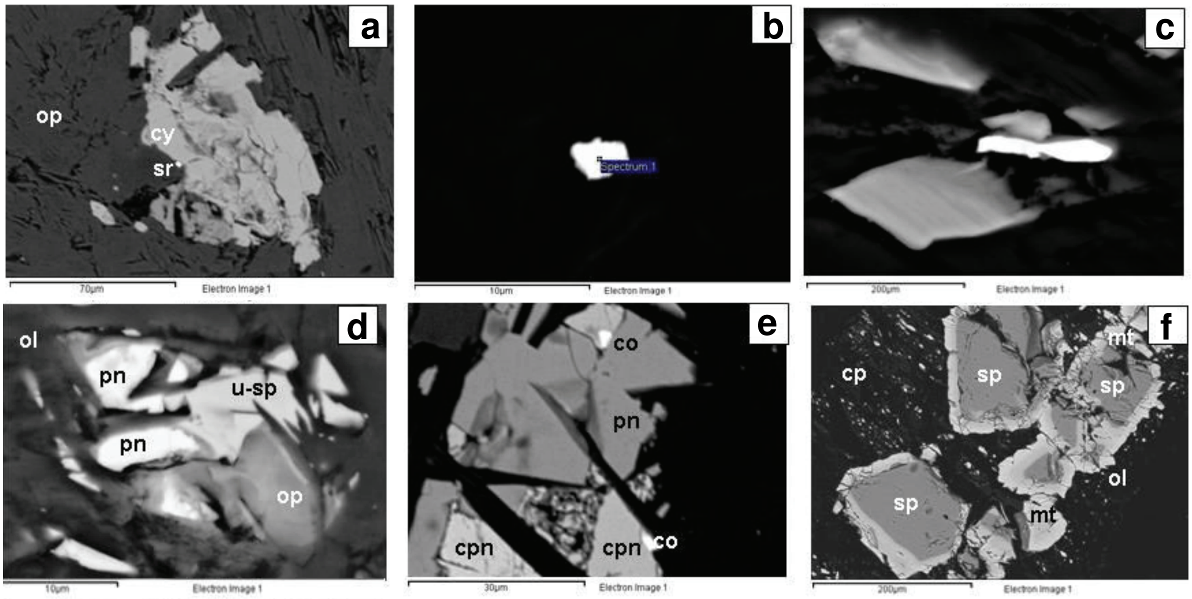

Fig.3. SEM image showing **(a)** sperrylite (sr) associated with the chalcopyrite (cp) in the matrix of clinopyroxene (cpx); **(b)** gold speck occurring as discrete grain; **(c)** Dumble shaped Iridium-Tunsgten alloy, **(d)** pentlandite (pn) in the matrix of olivine (ol), **(e)** pentlandite (pn) within the matrix of olivine (ol); **(f)** chromite rimmed by ferritchromit.

Mineralogical data for typical samples were acquired at National Geophysical Research Institute using Scanning Electron Microscope (Hitachi®) equipped with an Energy Dispersive Spectrometer (SEM-EDS) for semi-quantitative mineral analysis. The thin-polished sections were investigated using both reflected light and scanning electron microscope. Chemical compositions were determined using the Oxford Inca® energy dispersive analytical system (EDS), operating at accelerating voltage of 15 kV, beam current of 2.9 nA and measurement time 60 second. Atomic ratios were calculated with the ZAF-4® program, which performs the necessary corrections for the overlapping peaks of different elements.

Pentlandite is the most common sulfide mineral in the ultramafic rocks of Madawara. It has two distinct associations: (i) occurs as inclusion in chromite (Fig.3d and 3e), and (ii) as disseminated grains in the interstitial spaces of pyroxene and olivine. Formation of ferritchromit rim around the chromite grains is common in the ultramafic rocks (Fig.3f). These are commonly found in altered ultramafic rocks (e.g. Mukherjee et al. 2010 for review). Galena and sphalerite are also associated with pentlandite. Chalcopyrite is usually medium- to coarse-grained and associated with galena in the matrix of pyroxene from the olivine-websterite.

The PGE-bearing minerals are present as small grains (< 10 microns) in the matrix of either pyroxenes or in the interstitial spaces of olivines. Gold grains were also documented (Fig.3b). Beside these, galena, sphalerite, cobaltite, pentlandite were also identified. Sperrylite (EDS elemental values in wt%: Fe = 1.1, Cu = 9, As = 32.6, Pt = 34.2, Bi = 0.8, Fig 3a) was found to be associated with chalcopyrite in the pyroxene matrices. These grains are subhedral to euhedral showing high reflectance. The grain sizes of gold usually vary from 1 to 5 µm and are found to be associated with quartz, sometimes with magnetite in silicate matrix. Some iridium-bearing alloy phases having very high reflectance were found in the matrix of pyroxene.

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