

# Characterization of PGM in Neoproterozoic ophiolitic chromitites from Bou Azzer, Morocco

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## INTRODUCTION.

Ophiolitic chromitites are usually characterized by low Platinum Group Elements (PGE) contents, in the range of 100-500 ppb, and moderate to low Pd/Ir ratios, from 0.8 to 0.1 (Leblanc, 1991). However, they are typically enriched in IPGE (Os, Ir, Ru) and depleted in PPGE (Rh, Pt, Pd). As a consequence, these rocks display chondrite-normalized PGE patterns characterized by a slight enrichment in Ru relative to Os and Ir, and a negative slope from Ru to Pd (Leblanc, 1991). PGE usually form so-called Platinum Group Minerals (PGM), nevertheless they also occur as trace elements within alloys and base-metal minerals (sulphides, arsenides). In general, PGM are small (<30 µm) and rare minerals, which occur included in chromite grains or in the silicate (serpentinized) matrix (González-Jiménez et al., 2014 and references therein). The study of PGM assemblages provides us with valuable information regarding the nature of parental melt(s) involved in the formation of chromitite (González-Jiménez et al., 2014 and references therein).

PGE contents between 182 and 221 ppb have been reported in the Bou Azzer ophiolitic chromitites (El Ghorfi et al., 2008). However, to date very few studies of PGM have been carried out in these chromitites. PGM found are laurite, Os-Ir-Ru alloys, kashinite and unidentified Ir-Ni and Ir-Sb phases (El Ghorfi et al., 2008, 2015).

Hence, this study aims to provide new insights on the PGE mineralogy of the Bou Azzer ophiolitic chromitites. Hydroseparation (HS, [barcelona.com\) techniques have been applied to better investigate the mineralogical assemblage and distribution of PGE in these chromitites.](http://www.hslab-</a></p></div><div data-bbox=)

## GEOLOGICAL SETTING.

The Bou Azzer Neoproterozoic ophiolite complex is located in the central part of the Anti-Atlas orogenic belt, Morocco (Fig. 1). The ophiolite complex was obducted onto the northern margin of the West African craton during the Pan-African orogeny (El Hadi et al., 2011).

According to Leblanc (1981), the ophiolite sequence consists of a lower unit of serpentinized mantle tectonites, a mafic-ultramafic transition zone (mainly werhlite and pyroxenite), and a crustal unit composed of layered gabbros, quartz diorites, mafic lavas and volcano-sedimentary rocks. This sequence is unconformably overlain by late Ediacarian to Cambrian volcano-sedimentary and Paleozoic sedimentary rocks (El Hadi et al., 2011).

Numerous small-scale chromitite orebodies are found within the mantle serpentinized peridotites unit, usually surrounded by a serpentinized dunitic envelope (El Ghorfi et al., 2008). The Inguejem ore deposit, with a size up to 30 m, is the biggest chromite body found in the area and it was mined intermittently between 1900 and 1998.

## SAMPLE AND ANALYTICAL TECHNIQUES.

PGM grains were recovered from a massive chromitite sample from the Inguejem deposit, located in the eastern part of the Bou Azzer ophiolite.

PGE contents analyses were obtained at the Genalysis Ltd. laboratory (Maddington, Western Australia) by ICP-MS after nickel sulfide fire assay collection. 4.2 kg of chromitite were disaggregated, milled and hand-sieved before being processed by HS and/or Frantz techniques at the HS laboratory at the University of Barcelona. Subsequently, heavy minerals were mounted in eight polished monolayers. Textural studies were carried out using a scanning electron microscope (SEM), whereas mineral compositions were measured with an electron microprobe (EMPA) at the CCiTUB, Spain.

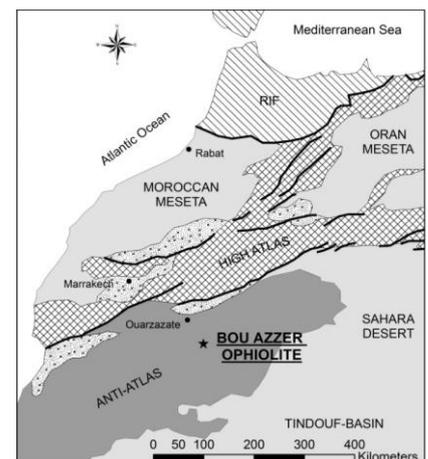


fig 1. Geological sketch map of the main geological units of the Atlas orogenic system. Modified from Ellero et al. (2012).

## GEOCHEMISTRY AND MINERALOGY OF PGE.

Total PGE concentrations in the analysed chromitites from the Inguejem ore body range from 205 to 264 ppb. Chondrite-normalised distribution patterns present a positive slope from

**palabras clave:** Minerales del Grupo del Platino (MGP), Elementos del Grupo del Platino (EPG), Bou Azzer, Cromitita, Ofiolita

**key words:** Platinum Group Minerals (PGM), Platinum Group Elements (PGE), Bou Azzer, Chromitite, Ophiolite

Os to Ru (IPGE) and a negative slope from Rh to Pd, corresponding to the typical patterns for ophiolitic chromitites (Leblanc, 1991). PGM found in this study are phases of Ru, Os and Ir, forming either monomineralic or polyminerallc grains with sizes from 5 to 50  $\mu\text{m}$ . The most abundant PGM is laurite ( $\text{RuS}_2$ ), which is the main Ru mineral. However, minor Ru contents are also present in Os-Ir alloys and irarsite ( $\text{IrAsS}$ ).

Two types of laurite have been identified: the first one is represented by idiomorphic, unaltered grains (Fig 2a), whereas the second shows allotriomorphic crystals partially replaced by nanoparticles of IPGE alloys. Fresh crystals of laurites contain up to 70 wt% Ru, 6.7 wt% Os and 3 wt% Ir. Os-Ir alloys usually present idiomorphic morphologies, as can be seen in one Os alloy grain found hosted in chromite (Fig 2b). These alloys contain up to 73 wt% Os, 41 wt% Ir and 10 wt% Ru, corresponding to the Os field in the Ru-Os-Ir ternary diagram. Irarsite occurs both as a replacement of some of the Os-Ir alloys, forming a porous rim surrounding the alloy (Fig 2c), and in multiphase grains, coexisting with Ni sulphides and/or serpentine.

#### DISCUSSION AND CONCLUSION.

The PGM assemblages in the analysed chromitite sample are dominated by Os-poor laurite and Os-Ir(Ru) alloys. These PGM grains are euhedral and occur as inclusions in chromite crystals. They are interpreted as primary PGM formed at the high-T magmatic stage before or during chromite crystallization (e.g. Zaccarini et al., 2005). At 1200-1300°C and  $\log f_{\text{S}_2}$  from -2 to -1.3 laurite with very low contents of Os and Ir can be formed in equilibrium with Os-Ir alloys (Brenan and Andrews, 2001; Andrews and Brenan, 2002). The experimental data show that Os solubility in laurite increases with decreasing temperature or increasing  $f_{\text{S}_2}$ . The predominance of Os-poor laurite as inclusions in the chromite and the absence of erlichmanite in the studied Bou Azzer chromitite are indicative of a relatively low sulfur fugacity during crystallization. In contrast, irarsite has a porous texture and occurs in the periphery of Os-Ir alloys (Fig 2c). Hence, irarsite is considered a secondary mineral, replacing the primary magmatic assemblages. According to Zaccarini et al. (2005), formation of secondary irarsite is associated with chromitite

alteration to chlorite and ferritchromite, as well as to an increase in As that most likely occurs during late hydrothermal activity involving PGE remobilization and fixing in newly formed arsenides and sulphides. Allotriomorphic laurite grains, partially replaced by IPGE alloys nanoparticles, suggest the interaction of the primary magmatic sulphides with post-magmatic hydrothermal fluids (Gonzalez-Jiménez et al., 2010). Therefore, altered laurite grains would have been re-equilibrated with or formed from these secondary fluids.

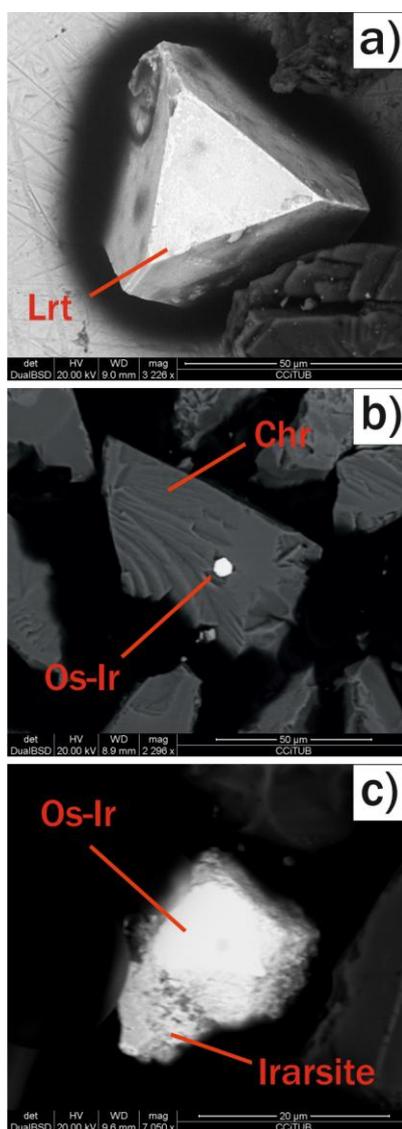


fig 2. SEM-BSE images of a) Idiomorphic laurite crystal b) Os-Ir alloy hosted in chromite c) Os-Ir alloy partially replaced by irarsite.

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