Discovery of “exotic” minerals in mantle chromitites from Bou Azzer ophiolite (Morocco)

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INTRODUCTION.

The Bou Azzer Neoproterozoic ophiolite complex contains numerous chromitite bodies within serpentinized peridotite. The ophiolite has been interpreted as a fragment of oceanic lithosphere formed in a mid-ocean ridge and later modified in an intra-oceanic supra-subduction zone (Ahmed et al., 2009). The origin of the Bou Azzer chromitites has been related to a high degree of partial melting of peridotite, along with melt/peridotite interaction in the shallow suboceanic upper mantle (Ahmed et al., 2009).

However, the recent discovery of unusual (“exotic”) minerals typical of ultra-high pressure and reduced conditions (diamond, moissanite, coesite, native elements and alloys), together with continental crust minerals (e.g. zircon, quartz, K-feldspar, Al-silicate, corundum…) in some chromitites and their host rocks around the world (e.g. Yang et al., 2007; 2015; Robinson et al., 2015) challenges the traditional models for chromitite formation.

In this work we report, for the first time, the discovery of exotic minerals in the Bou Azzer chromitites.

GEOLOGICAL SETTING.

The Bou Azzer ophiolitic complex is located in the central part of the Neoproterozoic Anti-Atlas orogenic belt (southern Morocco; Leblanc, 1976), located on the northern edge of the West African Craton. The dismembered ophiolite is a remnant of a Pan-African suture zone (650 – 580 Ma) (El Hadi et al., 2011). An age of 697±8 Ma was obtained by El Hadi et al. (2011) in metagabbros. However, the continental rifting associated with the formation of the ophiolite has been dated at 788±9 Ma (Clauer, 1976). The complex is unconformably overlain by late Ediacarian to Cambrian volcanic and sedimentary rocks and Paleozoic sedimentary rocks (El Hadi et al., 2011).

The ophiolite lithologies include (from bottom to top): upper mantle peridotites (2 km of serpentinized harzburgites and dunites), mafic and ultramafic cumulates, massive and layered gabbros, dykes, basalts, and minor volcanoclastic rocks, limestones and red cherts (Leblanc, 1976), with a total integrated thickness of 5 km. However, all parts of the sequence are not present in a single cross-section due to strong faulting.

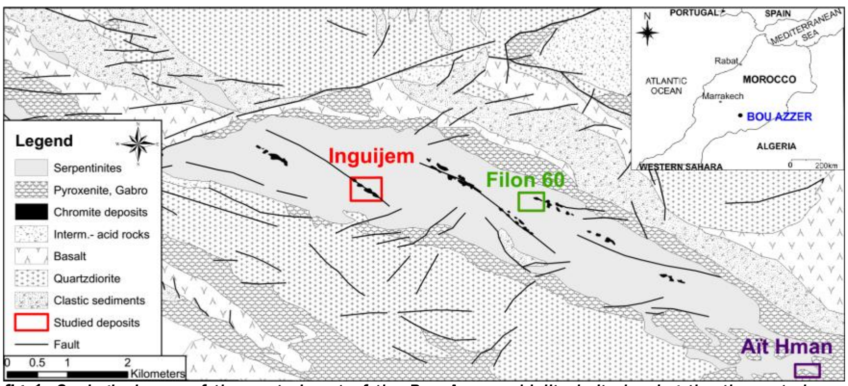

fig 1. Geological map of the central part of the Bou Azzer ophiolite belt showing the three study areas, modified from El Ghorfi et al. (2008). The inset shows the location of the Bou Azzer ophiolite in Morocco.

Podiform chromitite mineralization is found in the mantle peridotite level, forming numerous small-scale bodies (metric) associated with dunite dykes and surrounded by a serpentinized dunitic envelope. These orebodies are concordant to sub-concordant with the peridotite foliation (El Ghorfi et al., 2007; Ahmed et al., 2009).

SAMPLES AND ANALYTICAL METHODS.

Samples from five chromitite pods were selected for this study: three from the Inguijem area, one from Filon 60 and another E of Ait Hman (Fig 1).

Thin sections of chromitites were studied with optical microscope (OM), scanning electron microscope (SEM and FE-SEM) and electron microprobe (EPMA) at CCTiUB, Spain. A representative chromitite sample (4.2 kg) from Inguijem was processed with Frantz and hydroseparation techniques (HS) at the HS laboratory Barcelona in order to recover “exotic” minerals that were studied by OM, SEM and Raman.

MINERALOGY AND TEXTURES.

The chromitite pods show mainly massive texture (>80-95% chromite), which gradually become disseminated (<45%) towards the outer part of the pods. Chromite grains show strong cracking, pull-apart structures and local brecciification. The silicate matrix of the chromitite is completely altered to clinochlore and serpentine-group minerals, minor carbonate (in veins) and Ni-sulphides (<20 μm).

Chromite grains (up to 3 mm in length) are strongly altered, showing rims of ferritchromite, which also forms along cracks. Magnetite and hematite are also common. In spite of strong alteration, unaltered chromite cores are preserved,

palabras clave: Cromititas, Ofiolita, Bou Azzer, Marruecos, Minerales Exóticos, Alta-Presión	***key words:*** Chromitites, Ophiolite, Bou Azzer, Morocco, Exotic Minerals, High-Pressure

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hosting multiple inclusions of "exotic" minerals such as oriented clinopyroxene needles (Fig 2A, similar to those described by Yamamoto et al., 2009 and Griffin et al., 2016), quartz, zircon with apatite inclusions (Fig 2B), corundum (Fig 2C), Fe-oxides, platinum group minerals (PGM; laurite, irarsite, native Os, IrOs and IrRu alloys), native elements (Bi, Cu and W) and alloys (PbNi, CrFe, CuPb). Secondary serpentine (included in zircon), barite and andradite were also recovered.

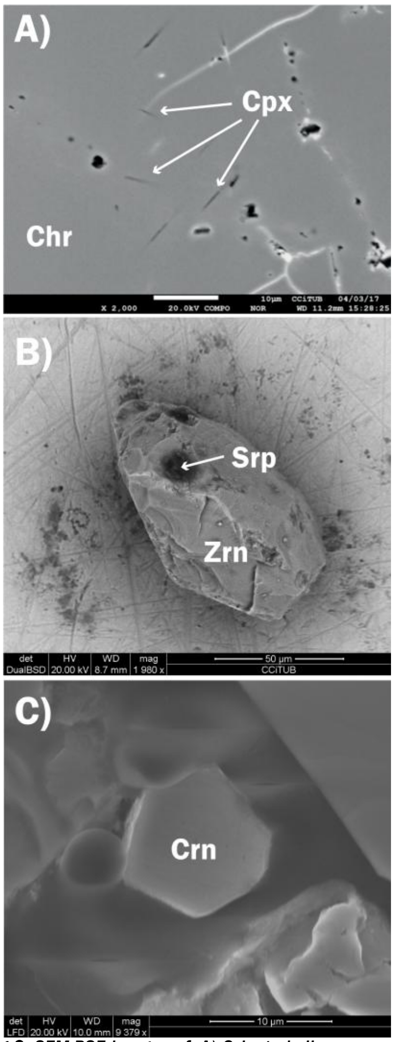

fig 2. SEM-BSE images of: A) Oriented clinopyroxene needles in chromite. Alteration is observed along cracks. B) Zircon crystal with serpentine inclusion. C) Euhedral grain of corundum.

CHEMICAL COMPOSITION.

Chromitites in Bou Azzer are Cr-rich (Cr#=0.60-0.83). The variation of major components in the non-altered chromite cores are (in wt %): 46.6-61.6 Cr_2O_3, 8.4-21.1 Al_2O_3, 12.1-17.6 MgO, 12.5-20.0 FeO and 0.1-1.7 MnO. TiO_2 contents are very low (<0.14 wt %). These compositions are typical of podiform chromitite (Fig. 3).

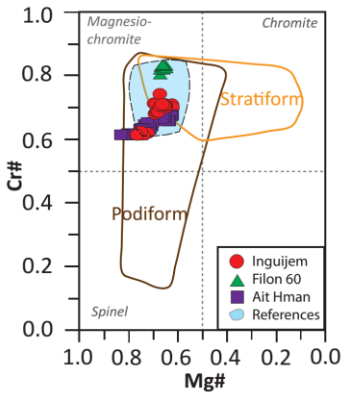

fig 3. Cr# [Cr/(Cr+Al)] versus Mg# [Mg/(Mg+Al)]. The fields "podiform" and "stratiform" are after Irvine (1967) and Leblanc & Nicolas (1992), respectively. The references field is from Ahmed et al. (2009) and El Ghorfi et al. (2008).

DISCUSSION AND CONCLUSIONS.

The studied chromitites are Cr-rich (Cr#>0.6) and TiO_2-poor, which, following conventional models for formation of chromitite (e.g. González-Jiménez et al., 2014 and references therein) indicate a suprasubduction zone setting. In addition, the chemical composition is similar to other Precambrian ophiolites (e.g. in the Arabian and Nubian shields), pointing to a high degree of partial melting during the Proterozoic (Ahmed et al., 2009).

However, our preliminary results challenge this simple view. Clinopyroxene needles have been interpreted as exsolution lamellae formed after a $CaFe_2O_4$-structured (Ca-ferrite) polymorph of chromite characteristic of ultrahigh-pressure conditions (>3 GPa, >100 km, Yamamoto et al., 2009). On the other hand, the presence of continental crust-derived minerals (such as zircon, and perhaps also corundum and apatite...) has been linked to the transference of material from subducted slabs to the upper mantle and later encapsulation within chromite (Robinson et al., 2014). The discovery of such exotic minerals in mantle chromitites from the Bou Azzer ophiolite hence suggests a complex history of crystallization of chromitite at high pressures (Yang et al., 2014, 2015) or recycling of low-pressure chromitites at great depth via mantle convection (Arai 2013; Griffin et al., 2016).

ACKNOWLEDGEMENTS.

This research is a contribution to the MINECO CGL2015-65824 project and a PhD grant to NPS from the Ministerio de Educación (Spain). The help extended by MANAGEM is gratefully acknowledged.

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