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# Platinum-Group Element Geochemistry in Podiform Chromitites and Associated Peridotites of the Precambrian Ophiolite, Eastern Desert, Egypt

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## Abstract

The ultramafic portions of the Proterozoic ophiolite, Eastern Desert, Egypt, contain significant chromitite concentrations that are mainly located in the central and southern parts of the Eastern Desert as small and irregular bodies within a fully serpentinized dunite and harzburgite. Chromitite spinel exhibits a wide range of composition from high Cr to high Al varieties. The Cr# of chromian spinel ranges from 0.65 to 0.85 in dunite, very similar to that in the high-Cr chromitite, whereas it is around 0.5 in harzburgite. Unusually high platinum-group elements (PGE) contents have been found for the first time in chromitite deposits and associated peridotite of the Precambrian ophiolite, Eastern Desert, Egypt. The PGE-rich chromitite have approximately 1343 ppb as a total PGE, being highly enriched in IPGE and slightly enriched in PPGE. The dunite envelope around the PGE-rich chromitite have also unexpectedly high-PGE content, up to 2258 ppb, showing a positive slope of PGE pattern. Both the PGE-rich chromitite and associated dunite are characterized by a common abundance of carbonate mineral(s) interstitial to chromian spinel. The PGE-rich chromitite probably precipitated from a PGE-rich magma generated by high-degree partial melting at a supra-subduction zone setting compared with the PGE-poor one which may formed by a low degree partial melting at a mid-ocean ridge setting. The post magmatic hydrothermal alteration resulted in an enrichment of Pt and Pd in both PGE-rich chromitite and its associated dunite.

## Introduction

The PGE concentrations within ophiolitic chromitites are now well known (Legendre, 1982; Page et al., 1982, 1984), and PGE are considered as one of targets for mining exploration in ophiolites (Leblanc, 1991). The PGE abundance systematic, give us information about the petrological nature and evolution of the mantle source from which they were derived and, to a lesser extent, can be reflected the post magmatic events affected their host rocks.

Very few studies have been found

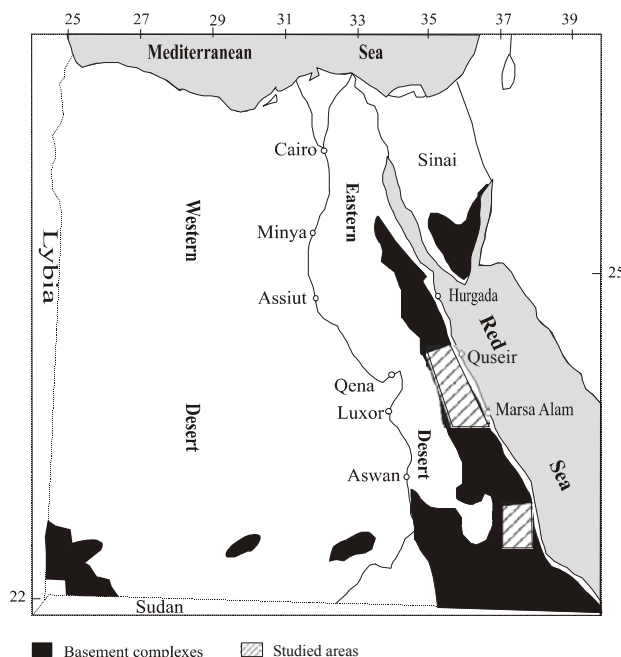
concerned with the PGE concentration and distribution patterns in the Proterozoic chromitite deposits and associated rocks of Egypt. In this article, we present a new data set about the PGE concentrations and distribution patterns in podiform chromitites and associated peridotites in the Proterozoic ophiolite of Egypt. The PGE enrichment origin is also discussed.

## Geology

Dismembered ophiolite complex, as fragments of mafic-ultramafic associations, is abundant in the Late Precambrian Pan African Belt of the Eastern Desert of Egypt to the north-east Sudan along the Red Sea coast (Neary et al., 1976). The better known occurrences of ophiolite in the Eastern Desert lie to the south of latitude 26°N, such as Wadi Ghadir ophiolite (El-Sharkawi and El-Bayoumi, 1979), and on the Qift-Quseir road (Nasseef et al., 1980). The podiform chromitite deposits are mainly concentrated in the central and southern parts of the Eastern Desert of Egypt where the studied areas are located (Fig. 1). The ultramafic bodies consist mainly of serpentinite, associated with many lenses and pockets of chromitite ores with different sizes, and less abundant talc carbonate rocks as well as minor amounts of ultramafic schists. Primary textures and silicate minerals of peridotites have not been observed, except from one locality (Abu Dahr area, south Eastern Desert) where the primary textures of peridotite were observed (e.g., Ahmed et al., 2001). Despite of the severe serpentinization of ultramafic rocks, the primary lithologies were identified by relic textures (Ahmed et al., 2001; Ahmed, 2001). Harzburgite is usually dominates over dunite which is enveloped chromitite pods. In some localities in the central Eastern Desert, chromitite-serpentinite association characterized by the abundance of black to dark green graphitic soapstone rocks (Ahmed, 2001).

## Chromite Chemistry

Chromitite spinel in the Proterozoic ophiolite of Egypt exhibits a wide compositional range from high-Cr to high-Al varieties. The Cr#



**Fig. 1.** Location map showing the distribution of basement complex in Egypt and the studied chromitite localities.

[Cr/(Cr+Al), atomic ratio] of chromian spinel is more uniform and restricted around 0.85 in the southern Eastern Desert, while it is widely varied in the central Eastern Desert chromitites, ranging from 0.5 up to 0.9 (Ahmed et al., 2001).

Chromian spinels in dunite usually have similar Cr contents like those from the associated chromitite. The Cr# ranging from 0.5 in dunite associated with high-Al chromitite to 0.85 in those associated with high-Cr chromitite. Chromian spinel in harzburgite, on the other hand, is compositionally distinct from those of enclosed dunite and chromitite. It has a limited range of Cr#, around 0.5 in almost all studied localities (Ahmed et al., 2001).

### PGE Results

Chromitite and associated rocks (dunite and harzburgite) in the studied localities were analyzed for all PGE (Os, Ir, Ru, Rh, Pt, Pd) and Au, using ICP-MS after the Ni-sulphide fire assay collection at the Genalysis Laboratory, Australia. Detection limits are 2 ppb for Os, Ir, Ru, Pt and Pd, 1 ppb for Rh and 5 ppb for Au.

Consistent with the compositional variation of chromian spinel, PGE contents and distribution patterns are very restricted and uniform

in the southern Eastern Desert chromitites, whilst are widely variable in the central Eastern Desert ones (Fig. 2A and B). The PGE contents of the southern Eastern Desert chromitites vary from 100 to 200 ppb, showing a negatively sloped PGE patterns from Ru to Pt with a positive Au anomaly (Fig. 2A). The Pd/Ir ratio, one of the best parameters for PGE fractionation (Naldrett, 1979), is very restricted, varies from 0.06 to 0.44 (Ahmed, 2001). Central Eastern Desert chromitites, on the other hand, exhibit variable PGE contents and distribution patterns, ranging from PGE-rich to PGE-poor chromitites. The former has up to 1343 ppb total PGE content, and is highly enriched in IPGE (Os + Ir + Ru = 956 ppb) and slightly depleted in PPGE (Pt + Pd = 332 ppb). It shows a gentle negative slope from Ru to Pd, having a Pd/Ir ratio up to 0.14. On the other hand, the PGE contents of PGE-poor chromitites ranging from 58 up to 365 ppb, having a different PGE patterns, including flat pattern, V-shaped IPGE pattern with strongly positive Au anomaly, and normal ophiolitic chromitite PGE pattern with a general negative slope from Ru to Pt (Fig. 2B).

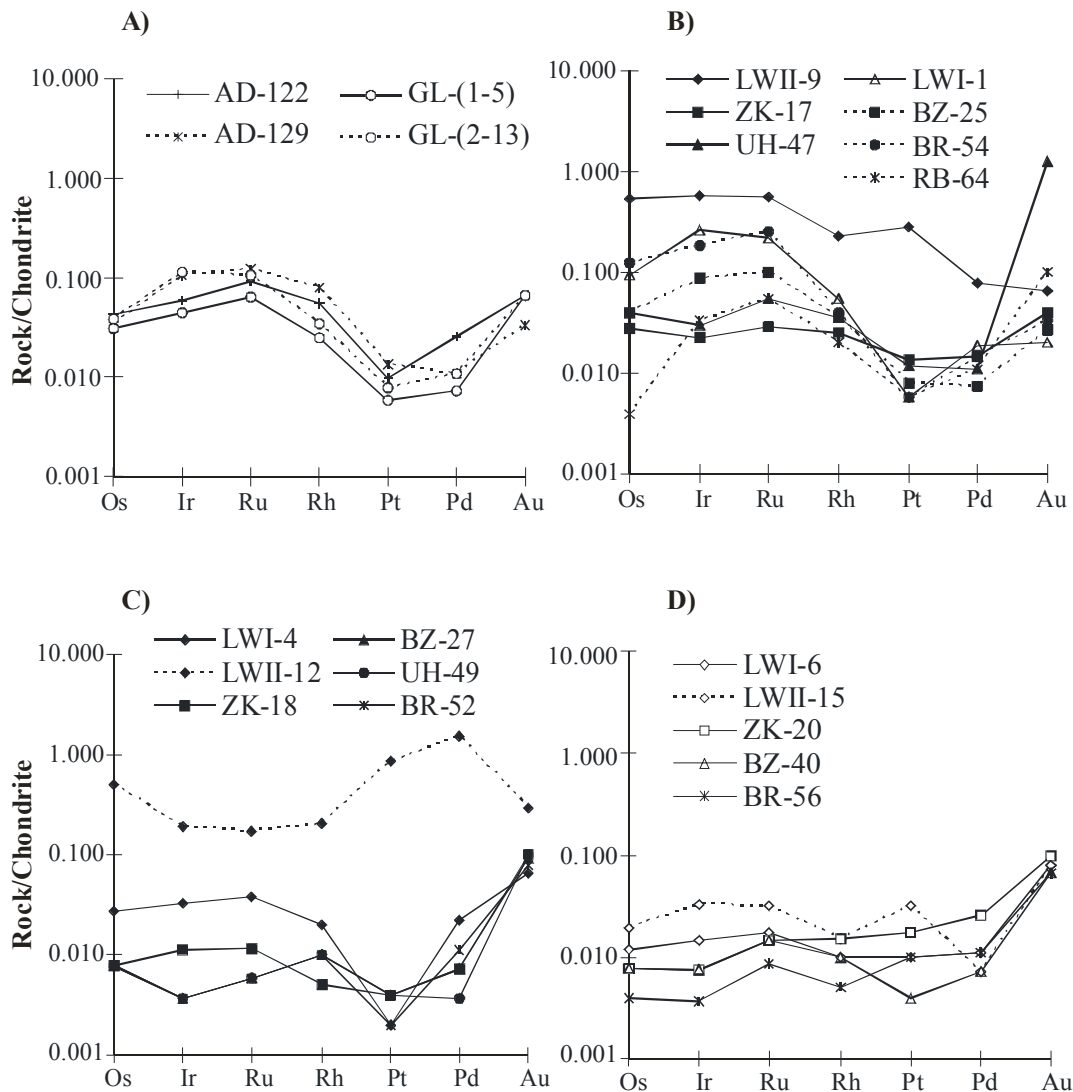
In most cases, dunites and harzburgites generally have low PGE contents relative to the associated chromitite deposits. However, in some localities in the central Eastern Desert, dunite enveloped the PGE-rich chromitite pod have an unexpectedly high-PGE content reached up to 2258 ppb, being highly enriched in Pt and Pd (Pt + Pd = 1740 ppb) and slightly enriched in IPGE (Os + Ir + Ru = 477 ppb), exhibit a positive-sloped PGE pattern (Fig. 2C). Carbonate mineral(s) (mainly dolomite) is characteristically interstitial to chromian spinel grains either in dunite or in associated disseminated chromitite in this locality. Almost all other dunite envelopes show a negatively-sloped PGE patterns at which PGE contents vary from 18 up to 76 ppb (Fig. 2C). Harzburgites in all the studied localities show flat or nearly flat unfractionated PGE patterns (Fig. 2D), exhibit a restricted PGE contents vary from 27 up to 89 ppb.

### Genetic Implications and Conclusions

It has been assumed that the Proterozoic ophiolite of Egypt is a fragment of oceanic lithosphere that had been substantially modified by supra-subduction zone components after the initial formation at the mid-ocean ridge setting (e.g., Ahmed et al., 2001). The high-Cr# spinel chromitite and dunite have been added as a mantle member within the host harzburgite. The PGE contents increase with an increase of Cr content suggesting the co-precipitation of chromian spinel

and PGM in a deep magmatic process (e.g., Arai et al. 1999); there is a strong direct correlation between Cr# and PGE contents in the ophiolitic chromitites (e.g., Ahmed, 2001). The ophiolitic chromitite is usually characterized by enrichment in Os, Ir and Ru relative to Pt and Pd, showing a general negative slope from Ru to Pt (Barnes et al., 1985; Leblanc, 1991). The characteristically magmatic PGE signature of the ophiolitic chromitite can be modified by the post magmatic hydrothermal alteration. The Au and Pt are more easily mobile than the other PGE during the alteration process, and Pd may be mobilized by

hydrothermal fluids (e.g., Barnes et al., 1985; Leblanc, 1991). The PGE-rich chromitite was most probably precipitated from a PGE-rich magma generated by high-degree partial melting possibly at a supra-subduction zone environment, while the PGE-poor chromitite might be formed by a low degree partial melting at a mid-ocean ridge setting (e.g., Prichard et al., 1996). The slightly negative slope of the PGE distribution patterns of dunites, in almost all studied localities, are best explained by their nature of early precipitates where PGE-bearing phases have relatively high IPGE/PPGE ratio.



**Fig. 2.** Chondrite-normalized PGE patterns of the studied chromitite and associated peridotites showing the PGE-distribution patterns of: **A)** southern Eastern Desert chromitites, **B)** central Eastern Desert chromitites, **C)** dunite envelopes, and **D)** harzburgite host. Abbreviations: **AD.** Abu Dahr area, **GL.** El-Galala area, **LW.** Wadi El-Lawi, **ZK.** Wadi El-Zarka, **UH.** Wadi Um Huitate, **BZ.** Wadi Bezah, **BR.** El-Barramyia area, and **RB.** Gebel El-Rabshi.

The gentle negative slope of the PGE-rich chromitite and the unusually high-PGE content of the associated dunite in the central Eastern Desert with a remarkable enrichment in Pt and Pd may be attributed to the progressive remobilization of Pt and Pd by acidic hydrothermal fluids from the interstitial sulphides and then reprecipitated within chromitite and associated unite. Since both Pt and Pd are incompatible elements and have low melting points compared with other PGE, they tend to be precipitated in the interstitial sulphides which are more easily to be remobilized by hydrothermal fluids and then reprecipitated again in chromitite and dunite. The flat or nearly flat PGE distribution patterns of harzburgite may indicate to the unfractionated nature of an undepleted mantle peridotite with respect to the PGE.

In conclusion, PGE in chromitite deposits and their host rocks were originally magmatic. Hydrothermal PGE signature has been originated by the remobilization of PGE, especially Pt and Pd, during the hydrothermal alteration of chromitite and associated rocks. The post magmatic hydrothermal alteration may involve in the remarkable Au anomaly in chromitite, the PPGE enrichment in the PGE-rich chromitite and associated dunite, as well as the common abundant carbonate mineral(s) interstitial to chromian spinel.

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