Evaluation of PGE Potentiality of Layered Gabbros in the Samail Ophiolite, Oman: Results of Geochemical Exploration and Petrological Examination

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Introduction

Major PGE deposits are found in the mafic-ultramafic layered intrusions in the continental environment, and most of them are located in the stable cratons. Discoveries of PGE and gold mineralizations have been reported from the Skaergaard intrusion and several other Tertiary mafic-ultramafic layered intrusions of North Atlantic Igneous Province in Greenland and northwest Scotland (Bird et al., 1991; Bird et al., 1995; Butcher et al., 1999). Magmatism formed those intrusions in the North Atlantic Igneous Province was resulted from mantle plume activity at the opening of the north Atlantic Ocean (Saunders et al., 1997). Therefore, the discoveries of the PGE mineralizations in the gabbros related to the opening of the north Atlantic Ocean encourage to search the PGE mineralization in the oceanic environment. Large gabbro bodies are present in the oceanic crust, though exposures of the gabbro bodies are limited. The layer 3 of oceanic crust is composed of gabbro with typical thickness of 4km. The oceanic crust is exposed in ophiolite bodies representing upper part of oceanic lithosphere. The ophiolite consists of thin sediments, pillow basalts, sheeted dyke complexes, gabbros, and ultramafic mantle unit. Lower part of the gabbros is typically layered with ultramafic cumulate, thus, the oceanic gabbros have lithology similar to the typical layered mafic-ultramafic intrusions which host the major PGE deposits. However, limited evaluations of oceanic gabbros for PGE resources have been conducted. The Samail ophiolite in Oman is one of the best exposed ophiolite complexes in the world, therefore it is best place to evaluate the potentiality of PGE mineralization in the oceanic gabbros. Furthermore, at one locality in the Samail ophiolite, magmatic sulphide ores were found in the gabbro (Lachize, et al., 1991; Lorand and Juteau, 2000). Although, Prichard et al. (1996) considered that the Samail ophiolite is a member of low PGE type ophiolite. Present study evaluates PGE and gold potentiality in the gabbros of the Samail ophiolite, and examines the exploration methodology in the ophiolite area.

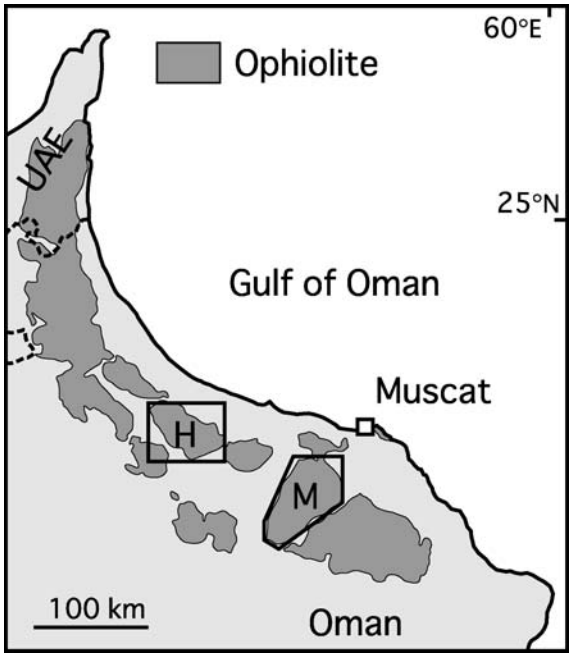

Figure 1. *The Samail ophiolite and studied areas. H: Haylyn block. M: Maqsad block.*

General Geology

The Samail ophiolite comprises of rocks derived from the Cretaceous oceanic crust and mantle which were obducted on to the Arabian continent during the late Cretaceous, and occurs in northern Oman (Fig. 1). The ophiolite is divided into 13 blocks. Magmatic sulphide ores were found from the Wadi Haymiliyah in the Haylayn block (Lachize, et al., 1991; Lorand and Juteau, 2000). The Haymiliyah outcrop is only known location of gabbro-hosted magmatic sulphide ores in the Samail ophiolite. The Haylayn and Maqsad blocks (Fig. 1) are selected for present study. In the Haylayn block, the ophiolite unit has northwest general trend. Gabbros occur in the central part of the block, and lower mantle unit is present southwest of the gabbros. In the Maqsad block, gabbros are present subhorizontally on the mantle ultramafic rocks, and occur mainly in the north and

southeastern parts of the block. Layered gabbros are found in the lower portion of the gabbro unit, and laminate and massive gabbros are present in the upper portion of the unit.

Geochemical Survey

As the exploration in East Greenland resulted in discovery of PGE and gold mineralization of the Skaergaard intrusion had used the stream sediment geochemical survey at the initial stage (Brooks, 1989), the geochemical survey was conducted in present study. Streams or rivers in the Oman Mountain are generally dry, and are described as wadi. However, occasional rainfalls are sufficient to form thick stream sediments in the dry river. We have collected stream sediments of under 60-mesh grain size by dry sieving at the sampling locations. Samples were collected mainly in the area where gabbros are exposed. Major and trace element data were obtained by XRF. Standard fire assay using PbO as collector with ICP-MS finish was used to obtain concentrations of Pt, Pd, and Au. Selected samples were analyzed with NiS fire assay with ICP-MS finish. Most of samples were also analyzed by ICP-AES with sample dissolution by acid reaching method, and the results were compared with whole rock XRF data. Our survey also checked host lithology and structure of gabbros and possible occurrences of sulfide minerals in the gabbros.

Results

SiO_2 contents of the stream sediments from the study areas range from 42 % to 49 %, indicating that those have similar chemical composition to the ophiolite unit. N-MORB normalized plot (Fig. 2) of average chemical compositions of the stream sediments for two blocks shows that the stream sediments are depleted in incompatible elements and enriched in MgO, Cr, and Ni. Although the stream sediments are collected in the area with exposure of gabbros, the difference of the chemistry from N-MORB may be resulted by selective depletion or enrichment of some elements during erosion, transportation, and deposition to form the stream sediments. High Cr concentrations must be resulted by incorporation of chromite grains in the sediments. Furthermore, as the area contains sub-recent alluvial terraces typically consist of calcrete, high concentrations of CaO and Sr must be derived from those. The average MgO, Ni, and Cr values of the stream sediments from the Haylayn block are higher than those of the Maqsad block, suggesting the stream sediments of the Haylayn block contain more materials from ultramafic part of the ophiolite.

Concentrations of Pd, Pt, and Au in the stream sediments are generally low. As detection limit of Pt is high (10ppb), most of the stream sediments have Pt concentration less than the detection limit. Pd content ranges from less than 2ppb to 16ppb. Although the range of the Pd concentration is small, Pd values show systematic geochemical relationships with other elements. Pd vs. Cr_2O_3 diagram (Fig. 3) indicates two trends. The first trend indicates small Pd enrichment with increase of Cr_2O_3, suggesting enrichment of Pd associated with chromites. The other trend is Pd enrichment without or with only small increase of Cr_2O_3 value. This trend might suggest the presence of PGE mineralization related with primary magmatic sulfide.

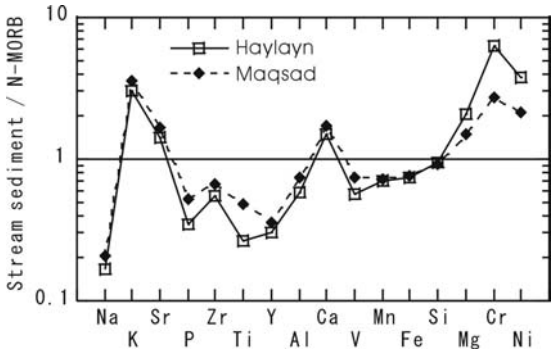

Figure 2. *N-MORB normalized diagram for average compositions of stream sediments from the Haylayn and Maqsad blocks in the Samail ophiolite. N-MORB values are calculated from data of Sun et al. (1979). Elements are positioned according to their relative incompatibility for partial melting of mantle rocks.*

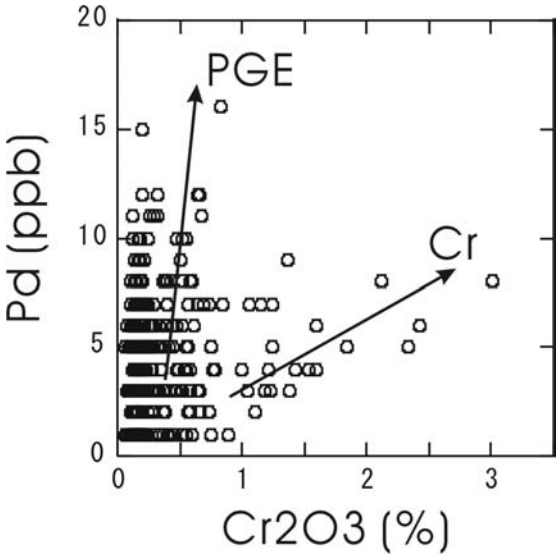

Figure 3. *Pd vs. Cr_2O_3 variation diagram for stream sediments from the Haylayn block in the Samail ophiolite. The small Pd enrichment trend associated with chromites is indicted by the arrow (Cr). Another trend (PGE) may be associated with sulphide minerals.*

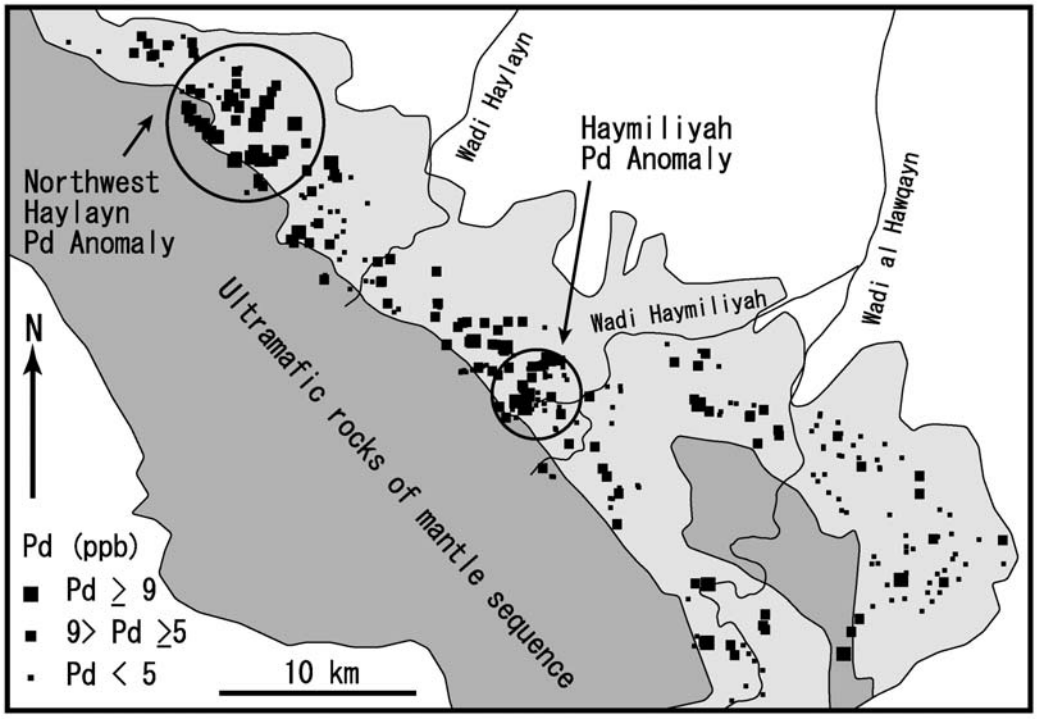

Figure 4. *Stream sediment geochemical anomaly map of Pd for the Haylayn block. Light gray area is crustal sequence of the ophiolite unit.*

Various geochemical maps have been constructed. Most of the maps reflect main lithology, and are conformable to geologic maps. For example, MgO, Cr, and Ni values increase in the area closed to the mantle sequence. Stream sediments with high Pd values are found in the two areas from the Haylayn block (Fig. 4). Small anomaly in the central part of the block is situated around Wadi Haymiliyah. Occurrence of sulphide ores (Lachize, et al., 1991; Lorand and Juteau, 2000) is located in the center of the anomaly, indicating the stream sediment geochemical survey is an effective method to show presence of such sulfide ores. Another area is located in the northwestern part of the block. The area is considered to be potential area for the PGE mineralization, and further detailed stream sediment sampling and geological survey have been conducted.

During the stream sediment sampling, observation of the gabbros has been made to find any sulphide bearing zone. Copper stains are fond at many outcrops, indicating presence of chalcopyrites in the gabbro. Primary sulphide bearing zones have been found at two new locations. However, PGE concentrations of samples from the sulphide rich zones are low, and are similar level to those from the Wadi Haymiliyah (Lorand and Juteau, 2000). Characteristically yellow alteration zones that were resulted by weathering of primary sulphide minerals, have been found at various location in the gabbro. In the centre of the northwest Pd anomaly of Haylayn block, extensive yellow alteration zones are found. Full PGE analysis of an altered sample indicates slightly high Pd concentration.

Summary

Present study intends to evaluate PGE and gold potentiality in the gabbros of the Samail ophiolite, and to examine the exploration methodology in the ophiolite area. The stream sediment geochemical survey was conducted in the two blocks of the Samail ophiolite. The geochemical characteristics of stream sediments are resulted by two components, ophiolitic rocks and alluvial sediments. Pd in the stream sediments shows two enrichment trends, one with small enrichment with chromites and other may be related with sulphide ores. Two Pd geochemical anomaly areas were found in the Haylayn block. Although absolute level of Pd anomaly is not too high, it is significantly higher than the back ground level. The one of Pd anomaly area indicates the location of sulphide ores, suggesting the stream sediment

geochemical survey is an effective method to find such sulfide ores. Yellow alteration zones that were resulted by weathering of primary sulfide minerals, have been found at various locations in the gabbro. In addition to the alteration zones, primary sulphide mineral bearing zones in the gabbro have been found at two new locations. The findings of additional primary sulphide zones in the gabbro suggest that unusual condition to form primary sulphide zones in the oceanic gabbro may not be necessary.

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