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Geochemical Characteristics of the Raohe Ophiolite, Heilongjiang Province, Northeast China

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Located in the easternmost part of Heilongjiang Province, Northeast China, Raohe County is geologically a part of the Sikhote-Alin accretionary orogen, which is bounded by the Jimusi massif in the west, and by the Xingkai massif in the south. A sequence of basalt, diabase, gabbro and ultramafic rocks occurs in the western Raohe County, and consists of the ophiolitic "stratigraphy" similar to the typical Penrose ophiolite suit. This study report the high-precise analysis of major and trace elements for the mafic and ultramafic rocks of Raohe mafic-ultramafic suit, and propose that it belongs to the plume-type (P) ophiolite.

Four groups of mafic rocks are categorized based on the major element (MgO, SiO_2 contents, Mg#), trace element (Ni, Cr, REE contents), and MORB-normalized trace element pattern. The first group of mafic rocks exhibit very high contents of MgO (13% ~ 16%), Ni (490 ~ 840 ppm), Cr (740 ~ 940 ppm), and high Mg# (66 ~ 70), with LREE-enriched pattern as well as small positive anomaly of Ti in the MORB-normalized trace element pattern (Fig.1). They represent the primitive mafic magma which was equilibrated with mantle pyrolite. The cumulative gabbro and serpentinous ultramafic rock composed of the second group. The cumulative gabbros have relatively slight LREE-enriched pattern and significant Nb-Ta-Ti positive anomalies in the MORB-normalized trace element pattern; meanwhile, the ultramafic rock exhibits low content of trace elements, but have relatively slight LREE-enriched pattern and positive Ti anomaly (Fig.2). The third group presents evolved mafic magma. Compared with the Group 1 rocks, they have lower MgO, Ni, Cr content and Mg#, but still exhibit LREE-enriched pattern and positive Ti anomaly (Fig.3). The fourth group is the basalt with slight LREE-depleted as well as flat MORB-normalized trace element pattern (Fig.4). There are some intermediate rocks with SiO_2 content of ~ 60% and total alkali (Na_2O+K_2O) content of 10%. It have a significant LREE-enriched pattern but very low content of Ti and compatible elements (Ni, Cr, V, Co) (Fig.4).

The major mafic rocks of Raohe ophiolite have Nb-Ta-Ti enrichment (relative to Y or Yb) and LREE enriched pattern. In the Th/Yb vs. Ta/Yb diagram the Raohe rocks cluster around the OIB position. The group 1 and 3 rocks also plot in the OIB field by the traditional ("standard") tectonic discrimination diagrams as well as the discrimination diagrams based on the La, Sm, Yb, Nb, and Th proposed by Agrawal et al. (2008). Accordingly, they belong to the plume type ophiolite (Dilek and Furnes, 2011).

The significant enrichment of Nb-Ta over HREE (e.g., Y, Yb) of Raohe primitive mafic rocks implies that the position of sublithospheric mantle plume melting beneath the Raohe oceanic island should be deep (Pearce, 2014). The plume melts deep or shallow beneath mature (age > 20Ma) or young oceanic lithosphere, respectively (Richards et al, 2013). It means the Raohe plume type ophiolite was born in a mature oceanic lithosphere.

In conclusion, the mafic volcanics, diabase, gabbros, ultramafic rocks and associated intermediate rocks occurred in Raohe County, easternmost of Heilongjiang Province, China, is a typical plume type ophiolite sequence. The geochemistry of the majority of these rocks shows significant Nb-Ta enrichment and positive Ti anomaly over HREE, indicating the strong alkaline characteristics of the rocks and the plume melting generation, respectively. Originally, the Raohe OIB-type ophiolitic sequence was formed by plum melting under a mature (age > 20 Ma) oceanic lithosphere.

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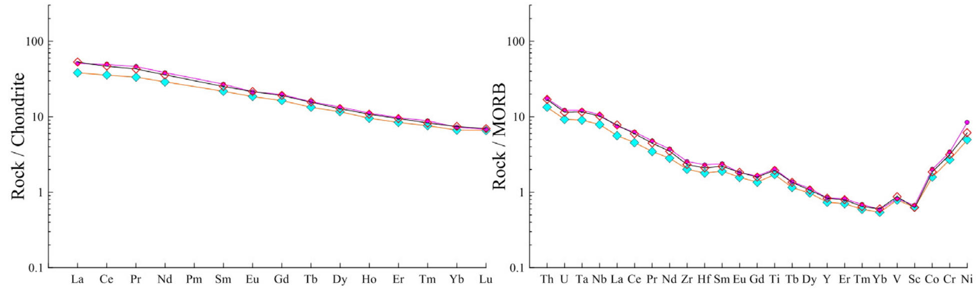

Fig. 1. Chondrite normalized REE pattern (left) and MORB normalized spider diagram (right) for the primitive mafic volcanics of the Raohe ophiolite.

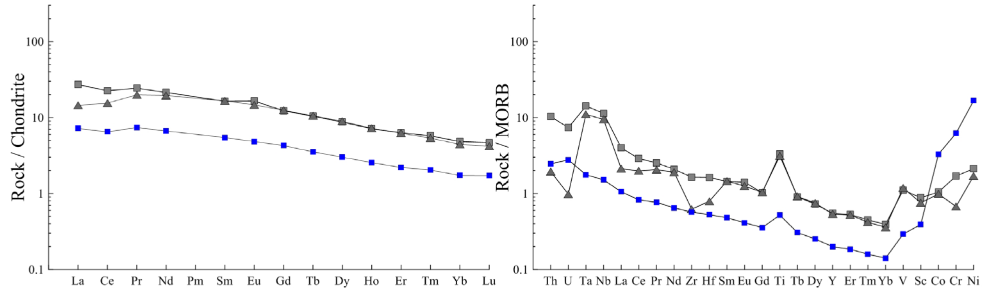

Fig. 2. Chondrite normalized REE pattern (left) and MORB normalized spider diagram (right) for the cumulative mafic and ultramafic rocks of the Raohe ophiolite.

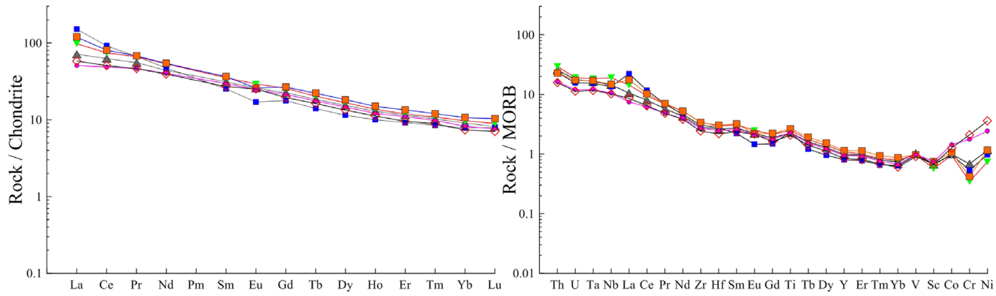

Fig. 3. Chondrite normalized REE pattern (left) and MORB normalized spider diagram (right) for the evolved mafic volcanics of the Raohe ophiolite.

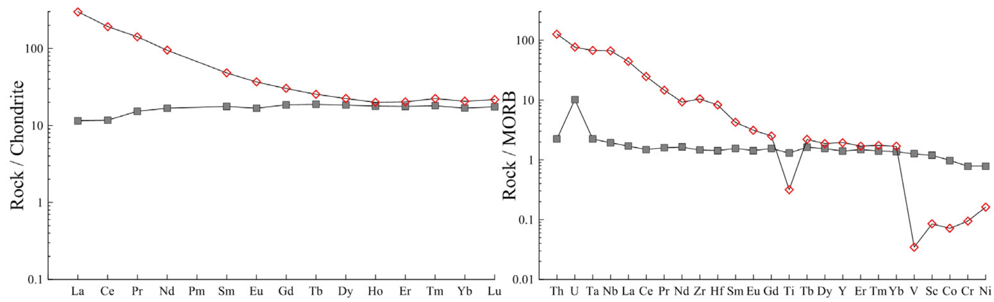

Fig. 4. Chondrite normalized REE pattern (left) and MORB normalized spider diagram (right) for the intermediate volcanics of the Raohe ophiolite.

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