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Plume-type Ophiolites, Large Igneous Provinces and Geology of the Earth-like Planets

ISHIWATARI Akira*

Center for NE Asian Studies, Tohoku Univ., Japan

Plume-type is a new branch of ophiolite classification introduced by Dilek and Furnes (2011; GSAB, 123, 387-). Its most typical example is the komatiite-basalt-gabbro-wehrlite assemblage that is exposed on the Gorgona Island off Colombia, South America and is interpreted as a part of the Caribbean large igneous province (LIP). Analogous rock assemblage occur in the accretionary complexes in the circum-Pacific orogenic belts such as in Japan (Ishiwatari and Ichiyama, 2004; Int. Geol. Rev., 46, 316-; Ichiyama and Ishiwatari, 1985; CMP, 149, 373-; Ichiyama et al. 2006; Lithos, 89, 47-; 2007; Island Arc, 16, 493-; 2008; Lithos, 100, 127-; 2012; Geology, 40, 411-), western USA (Greene et al., 2009; J. Petrol., 50, 467-), and also in the central Asian orogenic belt in Mongolia (Erdenesaihan et al., 2013; JMPS, 108, 303-). They are characterized by abundance of ultramafic volcanic rocks such as komatiite, meimechite, and ferropicrite, scarcity of residual ultramafic rocks, and geochemistry with relative abundance of HFSEs and siderophile elements (including PGEs).

The problem of plume-type ophiolite is that the product of plume magmatism is not only present in the oceanic areas but also common in the continental areas. Flood basalt plateaus (traps), regional dike swarms and layered intrusions may be continental counterparts of the plume-type ophiolites. Genesis of the plume-type ophiolites should be considered in reference to those continental examples. It has been known that there are distinct two types among the continental LIP magmatism; one is characterized by a dry (H_2O-poor, OIB-type) magma without negative Nb anomaly (e.g. Ethiopia), and the other is characterized by a wet (hydrous) magma with distinct negative Nb anomaly (e.g. Siberia) (Puffer, 2001; Geology, 29, 676-). The latter resembles island arc magmas, and reactivation of an island-arc mantle sourcehas been proposed forSiberian magmatism (ibid.). The extremely large volume of the Siberian magmatism (>107 km^3) suggests massive presence of such a wet source in the mantle. This implies possibility of the wet plume origin of some "supra-subduction zone (SSZ) ophiolites". The high temperature/pressure nature of the mantle source of the plume-type ophiolite is suggested by the abundance of ultramafic lavas, highly magnesian olivine phenocrysts, and trace element patterns corresponding to the presence of garnet in the residue (Ichiyama et al., 2012 and references therein). In the pressure-temperature field of the mantle (Fig. 1), the plume-type ophiolite represents higher temperature and pressure of melting (Line D) than the other ophiolite types

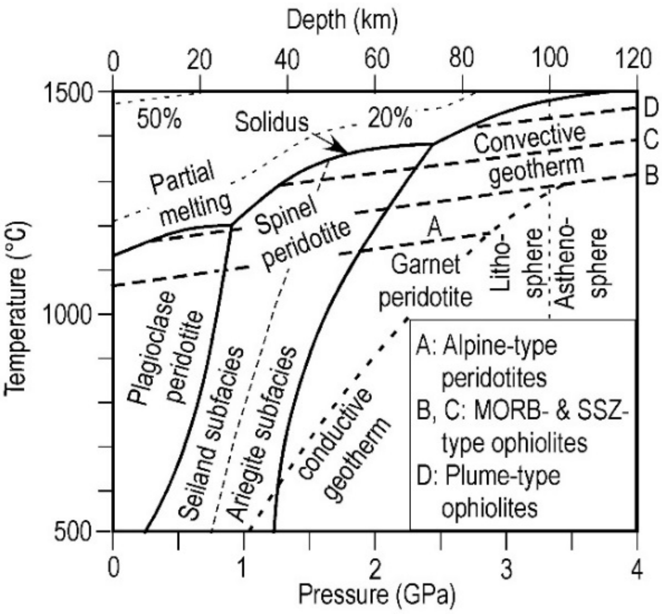

Fig. 1. Pressure-temperature diagram of the Earth's mantle showing sub-solidus mineral assemblages, supra-solidus melting degrees, convective and conductive geotherms, approximate lithosphere-asthenosphere boundary, and possible P-T paths of the mantle material of the alpine-type peridotites and various types of ophiolites (A-D). Geotherms and boundaries are mainly after Gill 2010; Igneous Rocks and Processes, Wiley-Blackwell. Temperature of large mantle plumes may exceed 1600°C.

* Corresponding author. E-mail: geoishw@cneas.tohoku.ac.jp

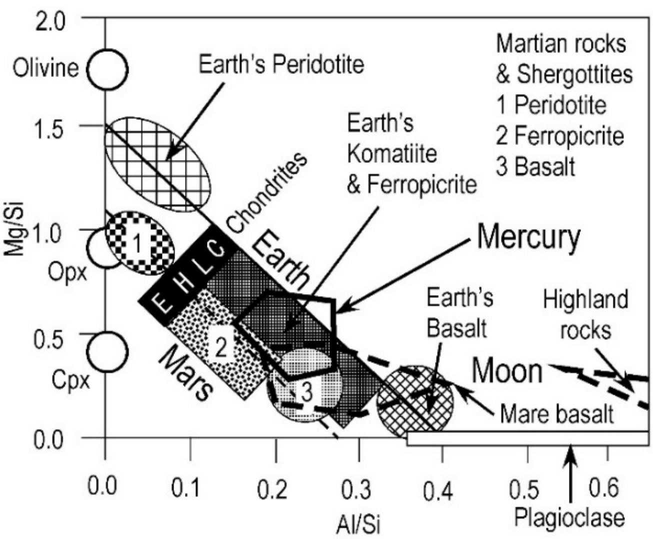

Fig. 2. Al/Si-Mg/Si diagram of the mafic-ultramafic rocks of the Earth, Mars, Mercury and Moon. Chondrites and major rock-forming minerals are plotted for reference. See text for discussion.
Data sources: Mercury and Moon: Nittler et al. 2011; Science, 333, 1847-, Mars: Gellert et al. 2006; JGR, 111, E02S05; Fleischer et al. 2010; JGR, 115, E00F05; Zipfel et al. 2011; Meteoritics & Planet. Sci., 46, 1-; Lodders, 1998; ibid., 33, A183-), Earth; Arndt, 2008; Komatiite, Cambridge, Filiberto et al. 2008;Icarus, 197, 52-; Ichiyama et al. 2012; Geology, 40, 411-. For ophiolitic peridotite and basalt data sources, see Ishiwatari 1985; CMP, 89, 155-; Dilek and Furnes, 2011; GSAB, 123, 387-.

(C or B) and alpine-type peridotite solid intrusions (A).

Moreover, recent progress of planetary geology revealed that the surface rocks of Mars (including Martian meteorites), Mercury, and Moon's maria (excluding plagioclase-rich highlands) closely resemble each other in abundance of picritic rocks, and thoserocks (ferropicrite, komatiite, etc.) of theplume-type ophiolites of the Earth also closely resembletheir extra-terrestrial counterparts (Fig. 2; e.g. Filiberto et al., 2008; Icarus, 197, 52-). Martian rocks are richer in Fe than those of the other planets, but some of the Earth's ferropicrite closely resemble Martian rocks.The unique feature of the terrestrial rocks may be high concentration of Ti and other HFSEs and low concentration of Cr and Mn. This may be due either to difference in original bulk-planet chemistry or to unique tectonic-magmatic processes in the Earth's mantle such as recycling of the subducted ocean crust.

The Earth's rocks are extensively differentiated to Mg-poor melt (basalt) and Mg-rich residue (peridotite) from the original chondritic source (Fig. 2) possibly by repeated, long-term, plate tectonic (shallow mantle) melting processes, and the intermediate (chemically near-chondritic) picrite-komatiite rocks occur only rarely. However, in the other planets where plate tectonics does not work, the plume-induced, deep melting has produced voluminous olivine-rich picrite-komatiite melts. The plume-type ophiolite provides terrestrial analogue for the magmatic rock assemblage on the surface of the other silicate planets of the Solar System.