Geochemical constraints on mantle sources for volcanic rocks from Mt. Melbourne and the western Ross Sea, Antarctica

Mi Jung Lee*, (mjlee@kopri.re.kr), Jong Il Lee†, Taehoon Kim‡, and Keisuke Nagao§

1Division of Polar Earth System Sciences, Korea Polar Research Institute (KOPRI), Incheon 406-840, Korea

ABSTRACT

We report geochemical and isotopic data (Sr, Nd, Pb) of submarine samples from the Terror Rift Region and subaerial lavas from Mt. Melbourne Volcanic Field (MMVF) in the western Ross Sea. The MMVF samples can be subdivided into Groups A and B based on their temporal and spatial distribution. All samples are alkaline, ranging from basanite to trachybasalt, and exhibit an HIMU-like isotopic signature (206Pb/204Pb = 18.510–19.683, 40Ar/39Ar = 0.70300–0.70398, δ14Nd = 0.51284–0.51297) and trace element affinities (e.g., Nb/U = 25–35, Nb/La = 5–13). The Terror Rift submarine lavas (0.46–0.57 Ma) display a distinct trend, with more primitive geochemical characteristics (higher MgO (7.2–9.8 wt%), and CaO (9.9–11.9 wt%) and stronger HIMU signature than those of MMVF basaltic samples. Results from a rare earth element (REE) model suggest that the Terror Rift submarine lavas are derived from small degrees (1–2%) of partial melting of an amphibole-bearing garnet peridotite mantle source. Incompatible trace element ratios (e.g., Ba/Nb = 6.4–13.2, La/Yb = 14.4–21.2) and isotopic compositions of the MMVF Group A and B volcanics suggest derivation from higher degrees (2–5%) of partial melting of a garnet peridotite source and strong influence of an EMI-type mantle source. The stronger HIMU signature of the Terror Rift submarine lavas appears to be related to smaller degrees of partial melting, suggesting preferential sampling of the HIMU component in the less partially melted rocks from the Cenozoic NVL magmatism. In contrast, the higher degree of MMVF A and B magmas can be explained by greater interaction with heterogeneous lithospheric mantle, resulting in a diluted HIMU signature compared with that of the Terror Rift submarine lavas.

Fig. 1. Regional location map of the Northern Victoria Land and sampling sites.

Fig. 2. Total alkalis vs. SO2 diagram for basalt from the Mt. Melbourne volcanic field and Terror Rift Region (the framework is after De Bari et al., 2005). Abbreviations: TRDR, Terror Rift Dredge basalts; MMVFA and MMVFB, Mt. Melbourne Volcanic field Group A and B basalts.

Fig. 3. Ba/Nb vs. La/Nb ratios. Data for McMurdo Volcanic Group basalts from the Northern Victoria Land (McKee et al., 2009) and Helge Birk Land basalts (MBL, Porter et al., 2006) are displayed together for comparison. Data field for Austral-Cook Island, SI, Helena lavas, which are known as representative HIMU-CIBs, Tristan da Cunha (EMI) and Tahiti-Society (EMII) are compiled from Tilton et al. (2010). Sr-Nd-Pb is from Zindler and Hart (1986). The Sr-Nd-Pb isotope data of the Terror Rift submarine samples forms an array between the MORB and EMI endmembers, with a slight enrichment in Pb relative to Sr and Nd.

Fig. 4. Sr-Nd-Pb isotopic compositions for the MMVF basalts and Terror Rift submarine lavas from NVL, Antarctica. Data sources for NVL and MBL samples are the same as in Fig. 1. MORB-PAR (Pacific Antarctic Ridge) are from Vlastelic et al. (1999). End-member mantle components are from O’Nions and Zindler (1994). The data for the Terror Rift samples are comprised of 1–2% melting of a garnet peridotite mantle source that shows greater compatibility for REE than Nd (e.g., amphibole: Dyb = 2.7, Tb = 2.5; Chauvin et al., 1994).—Modelling an amphibole-bearing garnet peridotite source produced a closer fit to the compositions of the Terror Rift samples in the Dyb vs. La/Yb and La/Nb vs. Dyb. The degree of partial melting for the Terror Rift samples is consistent with ~1–2% melting of an amphibole-bearing garnet peridotite source that shows greater compatibility for REE than Nd (e.g., amphibole: Dyb = 2.7, Tb = 2.5; Chauvin et al., 1994).—The MMVF Group A and B samples are comparable with those of the EMI-endmember mantle sources, indicating an influence of a HIMU-like mantle component with the depleted MORB-like source to the magma generation. To explain isotopic compositions of the MMVF Group A and B basalts, a third enriched component is required.

Fig. 5. Calculated partial melting curves assuming non-modal batch melting of spinel, garnet and amphibole-bearing garnet lherzolite. Phase proportions in solid and melt modes for a hypothetical spinel lherzolite used for model calculations are ol0.578 + opx0.27 + cpx0.119 + sp0.033 and ol0.1 + opx0.13 + sp0.03 for a hypothetical garnet lherzolite ol0.598 + opx0.211 + cpx0.115 + gt0.115 and ol0.05 + opx0.20 + cpx0.30 + gt0.45, respectively. Phase proportions in solid and melt modes for a hypothetical amphibole-bearing garnet lherzolite are ol0.514 + opx0.213 + cpx0.123 + gt0.075 + amp0.075 and ol0.05 + opx0.20 + cpx0.30 + gt0.20, respectively. Respectively, Modelled and REE distribution coefficients of McMurdo SO30000 (Hofmann et al., 1991).—The spinel and garnet peridotite mantle compositions are from Tang et al. (2006). The amphibole-bearing peridotite composition is from McCoy-Went et al. (2004). Abbreviations: ol, olivine; opx, orthopyroxene; cpx, clinopyroxene; sp, spinel; gt, garnet; amp, amphibole.

Conclusions

1. The Terror Rift submarine and MMVF Group A and B samples are alkaline, ranging from basanite to trachybasalt, and show the CIB-like patterns of trace element distribution, with a prominent depletion in K and Pb. Compared with the MMVF Group A and B basalts, the Terror Rift submarine samples have lower SiO2 and Al2O3, higher MgO and CaO, higher ratios of more to less incompatible elements (La/Yb, La/Sm, Nb/Y, Th/Yb, and U/Pb), and more radiogenic Pb and Nd and less radiogenic Sr isotopic compositions.

2. The K/Ar ages suggest that MMVF Group A and B and Terror Rift submarine lavas represent products of three distinct magmatic episodes. MMVF Group A samples show the youngest ages, ranging from 0.1 to 0.3 Ma. The Terror Rift samples have the oldest ages, from 1.25 to 1.34 Ma, and the Terror Rift samples have ages of 0.46–0.57 Ma.

3. REE modeling and the isotopic compositions of the Terror Rift samples suggest that they were derived from low (1–2%) partial melting of an amphibole-bearing garnet peridotite mantle source with preferential melting of a HIMU-like component in metasomatized lithospheric mantle. In contrast, the geological characteristics of the MMVF Group A and B basalts reflect the large geographic scale of sampling (higher 2–5% of melting) of heterogeneous lithospheric mantle and could be explained by the consequence of mixing and averaging of melts involving depleted MORB-like, HIMU-like, and EMI-like components.

4. We consider that edge-driven convective flow under the thinned lithospheric mantle of NVL toward the thick Antarctic Craton may have allowed upwelling of hot asthenospheric melts and triggered local melting of metasomatized veined lithospheric mantle.