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論文要旨

THESIS SUMMARY

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要旨（英文 800 語程度）
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The Hawaiian Islands have been an attractive target for geological research because of the active hotspot volcanism induced by the deep-rooted mantle plume. Studies of Hawaiian volcanoes have played a critical role in unraveling the mysterious nature and evolution of deep mantle structures. Peridotite xenoliths from the Hawaiian Islands serve as mantle residues and provide a unique opportunity to investigate refractory components in deep mantle plumes. However, the origin of these Hawaiian mantle xenoliths is controversial, with questions being raised as to whether they are derived from the plume, reflecting its chemical diversity, or are fragments of the Pacific plate unrelated to the Hawaiian plume. Given the complex interactions between the plume and the lithosphere revealed by geophysical and numerical studies, a comprehensive understanding of the lithospheric evolution beneath the Hawaiian Islands is essential to reveal the origin of these xenoliths.

For this purpose, I studied the microstructure, crystallographic preferred orientations (CPOs), mineral chemistry, whole-rock chemical composition, and isotopic composition (He, Ne, Ar, and Os) of Hawaiian mantle xenoliths from Ka‘ula Island, Kaua‘i Island, Salt Lake Crater (SLC), and Pal- Ka‘au (PK) vents. This dissertation contains seven chapters.

Chapter 1 provides a general introduction and review of deep Earth structures, the geochemical heterogeneity in the Hawaiian plume, the evolution of the Hawaiian lithosphere, and the geological insights into the controversial origins of the Hawaiian mantle xenoliths.

Chapter 2 involved the reconstruction of the lithostratigraphy of the Hawaiian lithosphere based on microstructure and mineral chemistry. Petrophysical and petrological analyses of the Hawaiian mantle xenoliths underscore the influence of reactive transport of plume-related melts on the recrystallization and re-fertilization of the Hawaiian lithosphere.

Equilibrium temperatures exhibit variability among sites, with the highest temperatures observed in the following order: Ka‘ula Island, Salt Lake Crater (SLC), PK vent, and Kaua‘i Island. Depth-related temperature variations within the Hawaiian lithosphere are likely responsible for the temperature variations observed in Hawaiian mantle xenoliths between these localities. The thermal gradient estimated from P-T conditions in SLC garnet pyroxenites provides pressures corresponding to equilibrium temperatures in Hawaiian peridotite xenoliths, yielding derived depths of ~1.5 GPa for Kaua‘i peridotites, ~1.7 GPa for PK peridotites, ~1.9 GPa for SLC peridotites, and ~2.0 GPa for Ka‘ula peridotites.

The depth-related chemical variation within the Hawaiian lithosphere is then constrained by a combination of microstructure, mineral chemistry, and whole-rock geochemistry (Chapter 3). The Kaua‘i peridotites, composed of refractory materials, correspond to the shallower layer of the Pacific lithosphere, while the PK peridotites, which have a fertile composition, correspond to the deeper Pacific lithosphere. However, it is still unclear why the Ka‘ula and SLC peridotites are both refractory and deep, which cannot be explained through the typical ridge-melting model. This suggests that plume-lithosphere interaction modified the bottom of the pre-existing Pacific plate, creating a highly refractory layer at the base of the Hawaiian lithosphere.

In Chapter 4, the analytical protocol and method for HSE and VCE abundances, along with Os isotopes, are developed for ultramafic samples. Following the developed method, the HSE geochemistry in the Hawaiian mantle xenoliths was investigated to understand the nature and ancient origin of the Hawaiian mantle xenoliths in Chapter 5. HSE abundances and Os isotopes in Ka‘ula and SLC peridotites are dominated by the highly depleted pattern (Pd/Ir <0.5) and unradiogenic Os isotope composition (^{187}Os/^{188}Os <0.126), respectively. In contrast, PK and Kaua‘i peridotites display flat HSE patterns and near chondritic ^{187}Os/^{188}Os ratios comparable to Pacific abyssal peridotites. Highly depleted HSE patterns and unradiogenic Os isotopes in Ka‘ula and SLC peridotites imply that these peridotites represent the ancient, recycled lithosphere within the Hawaiian plume.

Chapter 6 examines the noble gas systematics of the Hawaiian mantle xenoliths and discusses the nature of chemical heterogeneity and the genetic relationship between primordial and recycled material reservoirs. The study found that refractory and less-metasomatized peridotites have radiogenic ^{3}He/^{4}He ratios compared to the MORB mantle. Model calculations indicate that the ancient (> 1.0 Ga) residual mantle could host the radiogenic ^{3}He/^{4}He ratios observed in these coarse porphyroclastic peridotites. Consequently, the radiogenic ^{3}He/^{4}He ratios in the ancient residual mantle support the argument that recycling depleted oceanic lithosphere cannot account for the high ^{3}He/^{4}He ratios but may contribute to an isotopic end-member component characterized by depleted lithophile elements and radiogenic ^{3}He/^{4}He ratios.

In Chapter 7, a proposed model explains the evolution of the Hawaiian lithosphere, including the interaction between the plume and the lithosphere. This model has implications for the distribution of geochemical heterogeneity in the Hawaiian plume and deep mantle. The result obtained in this study has highlighted the petrophysical and chemical changes that occur in the Hawaiian lithosphere as a result of plume-lithosphere interaction. During the main shield stage, there is a significant influx of magma, which causes static recrystallization and refertilization. This modification, in turn, results in rheological weakening and increased intrinsic density. The plume residue, which is high-temperature, refractory, and buoyant, accumulates at the basal lithosphere, causing thermal and density instability at the lithosphere-asthenosphere boundary. The activated small-scale convection erodes and thins the lithosphere, which is then compensated for by the plume remnant. This process may explain the dichotomous nature and origin of the shallower and deeper parts of the Hawaiian lithosphere, as reflected in two distinct chemical composition groups of mantle xenoliths.

The presence of ancient and depleted signatures in the Ka‘ula and SLC peridotites suggests that the Hawaiian plume comprises refractory diapirs with intrinsic buoyancy. These diapirs consist of ancient, depleted, and recycled lithospheric mantle. The spatial correlation between two parallel volcanic chains and localities of two mantle xenolith groups implies a cogenetic relationship between the Loa and ancient depleted components within the Hawaiian plume. If the observed geochemical differences between Kea and Loa trends result from preferential sampling of the deep mantle reservoir, the Pacific Large Low-Shear-Velocity Province (LLSVP) may manifest as strong geochemical anomalies originating from ancient, subducted lithosphere composed of isotopically enriched recycled crustal material and depleted refractory lithospheric mantle. The persistent density and longevity of LLSVPs may be due to subduction of cool and dense oceanic lithosphere, conductive heating by the outer core, selective upwelling of buoyant refractory lithosphere as mantle plumes, and accumulation of dense crustal material at the lowermost mantle that promotes LLSVPs growth.