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Quantifying sample-size-dependent geochemical variations for understanding the whole Earth composition through geoneutrino observations

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Geoneutrinos are anti-neutrinos emitted from beta-decays of uranium (U) and thorium (Th) in the Earth, and provide a direct constraint on the chemistry of the whole Earth. The surface geoneutrino flux has been determined with high precision at the KamLAND detector in Kamioka, Japan [1]. The observed geoneutrino flux involves contributions from the mantle and crust. Because U and Th are enriched in the crust, the crust near the detector contributes significantly to the observed geoneutrinos. Therefore, to constrain the whole-mantle chemical composition from observed geoneutrinos, it is necessary to subtract the contribution from the nearby Japan crust.

To constrain the contribution from the Japan crust, we developed a quantitative method to construct a 3D U-Th distribution of the crust by combining seismic velocity structure data with geochemical data from crustal rocks [2][3]. The derived 3D compositional map exhibited significant errors, preventing us from constraining the mantle composition.

Based on multiple chemical analyses, including LA-ICP-MS, of granite samples obtained by dense grid sampling, we found that these errors are related to sample-size-dependent compositional variations. Although our target is km-scale space, compositions are analyzed from small-size samples. It means that simply using compiled geochemical data to model km-scale variation leads to an overestimation of compositional variation, because compositional variation at the sample and rock-body scales is also involved.

To quantitatively constrain sample-size-dependent compositional variations, we develop a novel analytical method and conduct new statistical modeling. We conduct a modeling using a geochemical database with location information [4] to separate compositional variation within the rock body from that between rock bodies. We also developed a new observational method to quantify heterogeneity within the sample. This method uses an emulsion film to record alpha and beta decays from the rock sample, enabling us to determine the distribution of radioactive elements within the sample with high precision.

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