

Early planetary differentiation and volatile accretion recorded in deep mantle Xenon isotopes

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¹²⁹Xe, produced from the radioactive decay of extinct ¹²⁹I, and ¹³⁶Xe, produced from extinct ²⁴⁴Pu and extant ²³⁸U, have provided important constraints on early mantle outgassing and volatile loss from Earth^{1,2}. The low ratios of radiogenic to non-radiogenic xenon (¹²⁹Xe/¹³⁰Xe) in ocean island basalts (OIBs) compared to mid-ocean ridge basalts (MORBs) have been used as evidence for the existence of a relatively undegassed primitive deep mantle reservoir¹. However, the low ¹²⁹Xe/¹³⁰Xe ratios in OIBs have also been attributed to mixing between subducted atmospheric Xe with MORB Xe, obviating the need for a less degassed mantle reservoir^{3,4}.

We present new noble gas data from OIBs and MORBs that demonstrate for the first time that the lower ¹²⁹Xe/¹³⁰Xe ratios in OIBs are derived from a lower I/Xe ratio in the OIB mantle source and cannot be explained solely through mixing between atmospheric Xe and MORB-type Xe. As ¹²⁹I became extinct prior to 100 Myrs after the start of the Solar System, OIB and MORB mantle sources must have differentiated by 4.45 Ga and subsequent mixing must have been limited. Thus, if the Moon-forming giant impact led to large scale planetary equilibration, it must have happened within 100 Myrs of the start of the Solar System.

The new precise xenon measurements also allow us to compute the proportion of Pu to U-derived fission Xe. Our measurements indicate that the plume source has a higher proportion of Pu- to U-derived fission Xe, requiring the plume source to be less degassed than the MORB source and supporting the long-term separation of MORB and OIB mantle sources. These conclusion are independent of noble gas concentrations and the partitioning behavior of the noble gases with respect to their radiogenic parents.

Calculated I/Pu ratios for the plume source is lower than the MORB source. This suggests that early accretion was volatile-poor compared to later accreting material, supporting the hypothesis of heterogeneous accretion⁵. Overall, the noble gases suggest at least two separate sources of volatiles for Earth and require that 4.45 Gyrs of mantle convection have not erased the signature of Earth's early differentiation. Finally, if noble gases in OIBs are derived from the Large Low Shear Wave Velocity Provinces (LLSVPs), then our study requires LLSVPs to be stable features that have existed since the formation of the Earth and are not exclusively composed of subducted slabs.

[1] Allegre, et al. (1987) *EPSL* 81, 127-150. [2] Marty (1987) *EPSL* 94, 45-56. [3] Holland & Ballentine (2006) *Nature* 441, 186-191. [4] Trieloff & Kunz (2005) *PEPI* 148, 13-38. [5] Schonbachler et al (2010) *Science* 328, 884-887.

Sr-Nd-Hf-Pb isotopic constraints on the origin of alkalic basalts in the northern Cascade Arc

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Calc-alkaline basalts are the predominant primitive magmas in the Cascade Arc. However, the northernmost segment of the arc, the Garibaldi Volcanic Belt (GVB), shows a progressive northerly shift from calc-alkaline to alkalic basalts. At the northern end of the arc, hawaiite and basanite occur at Salal Glacier, Bridge River, and Mt. Meager volcanic complexes. The gradient in alkalinity is accompanied by a northerly reduction in the "arc signature" and increases in P and T of basalt generation. These trends may be related to the age of the subducting plate, which decreases by ~4 Myr, potentially leading to reduced slab inputs and consequently smaller melt fractions formed at greater depths [1]. We have obtained new high-precision whole-rock Sr-Nd-Pb-Hf isotope and trace element data on GVB basalts to geochemically characterize the mantle beneath each volcanic center and determine whether the geochemical gradients displayed by the basalts can be explained solely by changes in slab input or require multiple mantle components.

Relative to other primitive Cascade arc basalts, GVB basalts have lower ²⁰⁸Pb/²⁰⁴Pb at a given ²⁰⁶Pb/²⁰⁴Pb (18.67-18.92) and higher ϵ_{Nd} (3.8-8.5) at a given ⁸⁷Sr/⁸⁶Sr (0.70310-0.70396). The alkalic GVB basalts have the most depleted Pb isotopic ratios yet identified in the Cascade Arc. In Pb isotopic space, the GVB defines a linear array extending from Juan de Fuca MORB to subducting sediment in the northern Cascadia basin, which we interpret as a mixing line indicating variable sediment input to the mantle. A northerly La/Nb decrease from ~4.25 at Glacier Peak to ~0.78 at Bridge River confirms the reduction in arc signature, but an inverse correlation between ϵ_{Nd} and ϵ_{Hf} (8.7-13.3) indicates arc-parallel mixing between two isotopically distinct mantle sources, one dominating in the south and the other in the north.

Trace element modeling, phase equilibria and thermobarometry indicate that the alkalic GVB basalts segregated from the mantle at high pressures and MORB-like temperatures (up to ~2.7 GPa, 1475°C) and have garnet lherzolite residues. The mantle source is not modified by a subduction component and is isotopically depleted, yet it is enriched in incompatible elements. These correlations indicate either long-term mantle source depletion coupled with a recent metasomatic enrichment event, or extremely low melt fractions. In contrast, calc-alkaline basalts of the southern GVB (Mt. Baker, Glacier Peak) were generated near the base of the crust from depleted lherzolite or harzburgite metasomatized by sediment melt or fluid.

Because the alkalic basalts lack an arc signature, have a hot, recently-enriched mantle source, and are located at the termination of the currently subducting slab, we propose that they are generated by a "slab edge effect". Decompression melting is triggered by upwelling of asthenospheric mantle through a window between the active Juan de Fuca plate and near-stagnant Explorer plate [2,3].

[1] Green (2006) *Lithos* 87, 23-49. [2] Audet et al. (2008) *Geology* 36, 895-898. [3] Riddihough (1984) *J. Geoph. Res.* 89, 6980-6994.