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Subduction Processes and a New Hypothesis for "Top-down Hemispherical Dynamics" of the Earth

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Water-rock interactions reduce the rock strength, and possibly produce weak plate boundaries, inducing active plate tectonics. Water-rock interactions may also have geochemical impacts, causing the unique differentiation of the Earth (e.g., formation of granitic continental crust and hydrothermal ore deposits). However, how water actually interacts with the rocks and circulates within the solid Earth to contribute to material differentiation and dynamics has been poorly constrained. In this paper, we present numerical models of water and element transport in subduction zones, as well as global geochemical evidences for water and the associated element cycling in the mantle. Then we compare these geochemical evidences with the geophysical observations and modeling to propose "top-down hemispherical dynamics" for the whole Earth's interior.

Water-rock interaction may significantly reduce the viscosity of rocks [1], and affects the subduction zone dynamics. Hydrated subducting slabs release water as the slabs are heated up, which hydrates the bottom of mantle wedge just above the subducting slab, to form a serpentinite layer. In this case, the slab-wedge mechanical coupling is reduced, and weakens the wedge corner flow, decreasing the slab surface temperature. The serpentinite layer is stabilized to extend deeper, enhancing mechanical decoupling between the slab and the wedge. This positive feedback has a large impact on the overall thermal-flow structure and magmatism in subduction zones [2]. We compare the model results and the observations such as position of arc magmatism, heat flow and seismic structures to constrain the actual structure and dynamics.

Water may enhance elemental transport once a fluid phase is formed and
migrates, which potentially causes specific elemental fractionation. We have constructed two-dimensional models of trace element transport in subduction zones, incorporating (i) slab subduction-dehydration, (ii) fluid migration and its reaction with the convecting mantle, (iii) melt generation and (iv) associated elemental partitioning among the solid, aqueous fluid and melt [3]. This model predicts various trace element abundances in solid, fluid and melt, and shows that significant variability in terms of trace element ratios is produced in subduction zones and can be brought down to the deep mantle. The trace element variability must affect long-term radiogenic isotopic evolution of the mantle (e.g., Sr, Nd and Pb isotopic compositions). Recently, a global isotopic structure has been found based on a statistical analysis of a large geochemical data set including MORB, OIB and arc basalts [4]: the eastern mantle hemisphere is enriched in subducted aqueous fluid components compared to the western hemisphere. Magnitude of the radiogenic ingrowth for the hemispherical structure suggests that it has been mostly developed within the last several hundred million years. These observations can be explained by focused subduction towards the supercontinent (Rodinia, Gondwana and Pangea), which has created the large-scale mantle heterogeneity. A strikingly similar pattern is found for the seismic velocity structure of the inner core [5,6]. Such hemispherical structures may be key to understanding the global dynamics of the Earth. We propose that the focused plate subduction governs the flow and thermal structure of the deep interior, in a "top-down" manner.

References: [1] S. Karato, H. Jung, Philos. Mag. 83, 410 (2003). [2] S. Horiuchi, Ph.D. thesis, U. Tokyo (2013). [3] A. Ikemoto, H. Iwamori, Earth Planet. Space, in revision. [4] H. Iwamori, H. Nakamura, Geochem. J. 46, e39 (2012). [5] S. Tanaka, H. Hamaguchi, JGR 102, 2925 (1997). [6] L. Waszek et al., Nature Geo.4, 264 (2011).

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