Dripping, thinning, melt injection, metasomatism: Geochemical consequences of small-scale convection under continents

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Through a variety of physical mechanisms, the lower lithosphere is thought to be recycled into the mantle, thinning the lithosphere and creating compositional differentiation. Lithospheric thinning has been inferred from increases in crustal heat flow in specific regions, rapid regional uplift, and from the appearance of signature high-potassium magmas [*e.g.* 1-5]. Seismic studies also support ductile delamination in specific areas [*e.g.*, *6*].

Geochemical arguments appear to require foundering of crustal and mantle lithospheric materials to balance elemental budgets. Though continental crust and mantle are complementary reservoirs with respect to most trace elements, the continental crust is too felsic to be derived directly from the mantle [7,8]. A possible solution is the loss from the continental lithosphere through delamination of mafic residues from fractionation of mantle melts. The same process would explain the significant fractionation of thorium and lanthanum in continental crust, when they are unfractionated during the processes of subducting sediments and producing arc magmatism [9].

A spectrum of physical mechanisms have been proposed for this small-scale convection. The greatest discriminator among them appears to be rheology, that is, how ductile is the material that is sinking away? The most brittle material might sink away in the shape of a plate, while the most ductile drip off as fluids. The feasibility of these processes depends upon composition, pressure, and temperature, and all these combine to affect the surface expression and compositional ramifications, from recycling differentiated compositions back into the mantle, to producing melt that might erupt.

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Origin and evolution of volatiles in rocky airless bodies

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Large planetesimals or asteroids, the Moon, and Mercury form a size continuum of airless bodies, but their formation histories are thought to be significantly different. While planetesimals formed from relatively lower energy accretionary impacts, they themselves continued to accrete gravitationally in more and more energetic impacts to build larger planets such as Mercury, and finally to produce the giant Moon-forming impact on the young Earth that resulted in the Moon. Despite the significant impact energy that went into producing the Moon, it was not completely dried and devolatilized during its formation [e.g., 1-3].

Part of the original evidence for a dry Moon, overturned by these recent measurements of volcanic materials, was the depleted K/U ratio compared to the Earth [4]. In contrast, Mercury shows a K content similar to the Earth and Mars, and thus may not be as depleted in volatiles as the Moon [5]. Similarly, measurements of meteorite compositions [6] indicate that neither primiive nor differentiated planetesimals were completely dried. Thus, the building blocks (planetesimals), the final planets (Mercury), and their impact debris (the Moon) all retained some fraction of their original volatile content.

In differentiated planetesimals and in the Moon and Mercury the silicate portions of the bodies were likely processed through a magma ocean stage [7]. Retention of volatiles is less likely in a planetesimal interior than it is in a planetary magma ocean. Internal heating from short-lived radiogenic aluminum 26 in small early planetesimals drives off volatiles from planetesimals above a certain size [8].

Factional solidification in a planetary-sized magma ocean, in contrast, can retain some volatile fraction inside the planet through partitioning with solid phases and sequestration of interstitial melts. Model results for these processes will be compared with measurements from the Moon.

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