

Food for a Volcanic Diet

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Chemical analyses of lava can now reveal the nature of the rocks deep in the Earth that melted and rose to generate specific volcanoes.

Volcanic eruptions have the power to reshape Earth's landscape, alter climate, and affect life. To understand how this works requires that we go deep into the Earth to learn exactly what kind of rock melts to produce magmas, and the chemistry of this source rock. These are fundamental problems in geology, and they are also among the most difficult to understand. In this week's *Science Express*, Sobolev *et al.* (1) describe a method for identifying some of these source rocks. We can think of them as food for volcanoes in the sense that they melt to provide the magmas that can erupt to the surface. To understand what Sobolev *et al.* have done and the ramifications that go beyond Earth science, we need to start with a refresher in geology.

Earth's mantle consists mostly of peridotite, a rock rich in the mineral olivine $(\text{Mg,Fe})_2\text{SiO}_4$. When peridotite partially melts, the liquids collect to magmas that rise to the crust, give off gases like SO_2 , CO_2 , and H_2O , and solidify to basalt, a rock rich in the minerals clinopyroxene $\text{Ca}(\text{Mg,Fe})\text{Si}_2\text{O}_6$ and plagioclase $(\text{Ca,Na})(\text{Al}_{1-2}\text{Si}_{2-3})\text{O}_8$. Portions of these outer layers can be recycled back into the mantle at subduction zones and below thickened continents (see the figure). The recycled basaltic crust is transformed to a new rock called pyroxenite, so-called because it is rich in the mineral clinopyroxene $\text{Ca}(\text{Mg,Fe})\text{Si}_2\text{O}_6$. It may pile up on Earth's core, or be mixed back into the mantle with structures that have been described as marble cake (2), plum pudding (3), spaghetti (4), and gumbo (5) (see the figure). Volcanoes like those of Hawaii can melt from source rocks consisting of peridotite and/or pyroxenite from recycled crust. Sobolev *et al.* describe a method for identifying this rock based on the chemistry of lavas on volcanoes.

Sobolev *et al.* determined that many volcanoes melted from recycled crust, a conclusion that is not new (6). However, there has always been some ambiguity with past methods of identifying recycled crust based on the isotope and trace-element geochemistry of lavas at the surface. New interpretations suggest that many oceanic islands melted from mantle peridotite that had been modified by melts that flowed through it (7, 8), a process called metasomatism (9). Because

it makes no difference to an atom of lanthanum, for example, whether it ends up concentrated in the crust or metasomatized peridotite, using it as a tracer can be ambiguous and nonunique (7, 8).

A breakthrough came when Sobolev *et al.* (10) showed that the nickel contents of many olivine crystals in Hawaiian lavas were higher than those expected from melts of peridotite, and they preferred to explain this with a recycled crust source instead. But a lingering ambiguity is that a high nickel content in olivine can also arise when peridotite is enriched in pyroxene by melt-rock reaction (11). Supporting evidence for the recycled-crust interpretation (10) comes from the calcium contents of the Hawaiian lavas, which are too low to be easily explained by melting peridotite (12). Nickel and calcium are therefore telling the same story. That is, the main shield-building lavas at Hawaii were melted from a pyroxenite source rock that required the involvement of recycled crust as proposed by Sobolev *et al.* (10). The authors go further in that they examine the problem that arises when nickel, calcium, and manganese are used, and they extend the analysis to a larger population of volcanoes. Their results, together with other recent studies (7, 8, 11), show that it is unlikely that a single rock type will be an appropriate source for all oceanic volcanoes. For example, recycled crust is an important source rock for the Hawaiian islands (1, 10, 12), whereas metasomatized peridotite is the source rock for the Cook islands (7). An outstanding question is whether peridotite sources become metasomatized by melted recycled crust (13) or in some other way (7, 8).

Future studies might allow us to transform our picture from hypothetical models to actual three-dimensional views showing the size and distribution of recycled crust in the mantle. The implications go far beyond geology. For example, it may be no surprise that Sobolev *et al.* (1) identify pyroxenite as the rock that melted to produce the Siberian Traps. This was a magmatic flood on land so massive in scale that it triggered the largest mass extinction of life on Earth, some 250 million years ago (14). Although the exact causal links remain poorly understood in detail, one can reasonably imagine a different outcome if the mantle diet had less pyroxenite and more peridotite. Under these circumstances, less magma would have been produced and

made available for eruptive flooding, and Earth's biosphere could have evolved along different pathways.

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Models of Earth's crust and mantle. Oceanic crust (brown) is solidified liquid that forms by partial melting of mantle peridotite (green) at oceanic ridges; together with sediment, oceanic crust can be recycled back into the mantle at subduction zones (2, 3, 6). Continental crust (brown) forms at subduction zones, and can be recycled when it thickens by delamination (5, 15). All crust (brown) is transformed to pyroxenite (brown) when recycled. Green arrow denotes melting peridotite. Red arrow denotes melting pyroxenite. Recycled crust may be distributed uniformly throughout the mantle, or it may be concentrated in certain hemispheres or depths. Crustal thickness is exaggerated for clarity, but ranges from ~6 to 40 km at the present time. Recycling is expected to reduce crust to dimensions ranging from micrometers to kilometers.

