

study is the treatment of surface production of organic matter, which is either held constant or forced to be consistent with the observed surface distribution of phosphate, a nutrient taken up by phytoplankton during photosynthesis. In a slightly more mechanistic model of the biological pump, atmospheric CO<sub>2</sub> concentrations show a strong sensitivity to ocean temperature, mediated mainly through remineralization<sup>4</sup>. This result supports the main conclusion of Kwon *et al.* that atmospheric CO<sub>2</sub> concentrations are highly sensitive to the pattern of deep-ocean remineralization.

Marine carbon cycle field programs of the 1990s, such as the Joint Global Ocean Flux Study, were motivated by the need to understand the ocean's role in regulating atmospheric CO<sub>2</sub> concentrations, and placed much emphasis on photosynthesis and the export of carbon from the euphotic zone. As a result of these highly successful campaigns, we have fairly robust mechanistic models of upper-ocean carbon cycling, that is, of photosynthetic uptake of inorganic carbon in the surface ocean. However, our understanding of the 'dark side' of the

marine carbon cycle — the conversion of organic to inorganic carbon below the euphotic zone — is poor. This is due, in large part, to a lack of direct measurements of remineralization.

Remineralization in the vast open ocean has been inferred from tracers, such as oxygen and dissolved organic carbon, and sediment-trap data. It is possible to determine the remineralization rate directly in shipboard or *in situ* incubations, much as one measures aquatic photosynthesis. But accurate remineralization rates are stymied for at least two reasons. First, remineralization rates, compared with photosynthetic rates, are relatively low, because they are distributed throughout a greater depth of the water column. Second, the presence of large background pools (oxygen and dissolved organic carbon) masks the remineralization signal during incubations. The latter problem could potentially be solved through isotopic labelling of the substrate, but this would be technically very difficult.

Kwon and colleagues<sup>1</sup> highlight the importance of understanding

remineralization if we are to get a handle on ocean-atmosphere CO<sub>2</sub> fluxes. Accurately measuring remineralization is a methodological challenge that lies with marine biogeochemists. Until this challenge is met, it will not be possible to develop robust, mechanistic models of the marine carbon cycle. Without a proper understanding of remineralization, Earth system model projections of atmospheric CO<sub>2</sub> concentrations will be missing an essential component. □

Raymond Najjar is in the Departments of Meteorology and Geosciences, Pennsylvania State University, 503 Walker Building, University Park, Pennsylvania 16802-5013, USA.  
e-mail: najjar@meteo.psu.edu

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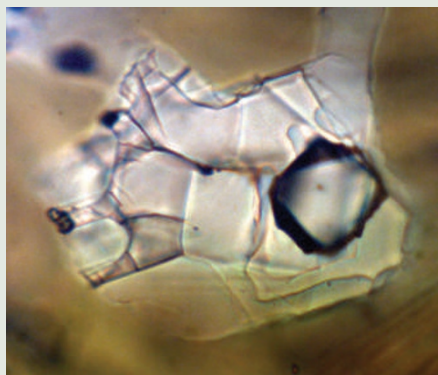
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## GEOCHEMISTRY

# Salt up the pipe

Among the more curious materials that occur naturally on the Earth are volcanic rocks called kimberlites. Unusually rich in magnesium, many of them also host notable quantities of elements as exotic as lanthanum. Kimberlite magmas are generated at great depths, and it seems that they just cannot wait to reach the Earth's surface: they literally drill their way up to form pipe-like bodies. And, if these peculiarities were not enough, they are the primary source of those dazzling objects that have been the source of much fascination and conflict — diamonds.

The Udachnaya-East kimberlite pipe in Siberia, less than a kilometre in diameter, contains an unusually high content of sodium and chlorine, far greater than other rocks of its kind. Kimberlites are rather susceptible to alterations that modify their original composition. Even though this pipe appears fresh there has been some debate about whether the saltiness of the magma that fed this pipe was inherited at the mantle source or imparted by the incorporation of sediments near the surface. Isotopic data obtained by Vadim Kamenetsky and colleagues seem to seal the case in favour



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of a salty mantle source (*Earth Planet. Sci. Lett.* **285**, 96–104; 2009).

A mineral called perovskite received particular attention from the researchers. Crystals of this mineral intermingle with those of salt in the Udachnaya-East kimberlite. Perovskite forms directly from the parent magma of kimberlites, and its isotopic composition is hence expected to reflect that of the kimberlite magma. If the magma composition were to be modified by incorporation of, say, salt-rich sediments, the isotopic composition of perovskite would change too — it would then fall somewhere

in between that of the parent magma and the contaminant.

It turns out that the strontium isotopic composition of perovskites from this particular kimberlite is very close to what would be expected for uncontaminated, primary magmas. This is borne out by the mineral relationships in the rock and various diagnostic elemental ratios, which reveal that perovskite and salt minerals grew from the same magma. When looked at in light of previous geochemical work by Kamenetsky's group (for example, *J. Petrol.* **49**, 823–839; 2008), it seems unlikely that the salt in this kimberlite had anything to do with the addition of crustal material.

The violent and rapid rise of kimberlite magmas to the surface is traditionally thought to be driven by large quantities of dissolved water. Intriguingly, the Udachnaya-East kimberlite magma shows evidence of having been poor in water. Perhaps, suggest the researchers, the answer is in the salt: it is the salty composition that imparts the high fluidity and propensity to rise up, both of which are required for kimberlite emplacement.

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