discharge to the streams, the composition of stream water alone is not sufficient to determine routing and residence times.

If the findings of Brooks and colleagues can be generalized, they will require substantial revision of the accepted conceptual models for runoff generation and biogeochemistry on hillslopes. A much more compartmentalized system incorporating wetness-dependent interconnectivity will have to be used in models, and nutrient flow-paths will consequently be diverted. But the extent to which the findings can be generalized is uncertain. Hints of similar behaviour have been published for semiarid hillslopes in the southwestern United States[9]. However, many climate regimes do not have such pronounced seasonal disparities in water availability and the soil matrix may exchange with the fast flow paths on a more frequent basis. Also, many geological settings may not produce soils that are sufficiently fine-grained to absorb infiltration when dry and then resist it when wetted up. Even this mechanism for retention is hypothetical and detailed soil-physics and tracer studies are necessary to confirm it.

Despite numerous questions that remain to be answered, the results of Brooks and colleagues[1] are intriguing and open a new way towards a better understanding of the fate of water in the landscape. ❐

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EARTH'S INTERIOR

Intraplate upwelling


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The pre-Columbian Sinagua people, who occupied the land of present-day northern Arizona until about 1425, probably witnessed the final burst of volcanism in the San Francisco volcanic field. At some point between AD 1064 and 1150, Sunset Crater formed through the last eruption in this landscape dominated by more 600 volcanoes. Unusually, the volcanoes are located well within the interior of the North American plate.

The causes of volcanism in the middle of tectonic plates are hotly debated. Intraplate volcanism, away from obvious magma sources such as spreading ocean ridges or subducting plate margins, could result from upwelling of an anomalously hot mantle plume that impinges on the Earth's uppermost rigid layer. Yet many features of the San Francisco intraplate volcanic field (and others) do not fit the mantle-plume hypothesis.

A variety of non-plume mechanisms to generate intraplate volcanism have been proposed. One example is so-called lithospheric drips, where a block of cooler, dense rock sinks from the Earth's uppermost layer, generating a return upward flow of buoyant, hot, mantle material. Another possible mechanism is edge-driven convection, where the variable thickness of a tectonic plate creates relief on the boundary between the rigid lithosphere and the underlying ductile asthenosphere, enhancing small-scale convection and driving mantle upwelling.

Both of these mechanisms require density contrasts — either between the brittle lithosphere and the ductile asthenosphere or within the asthenosphere itself — to produce enhanced convection and upwelling of hot mantle rock. Yet, many examples of intraplate volcanism are not associated with density heterogeneity. Clinton Conrad, at the University of Hawaii, and his research team propose a mechanism that results in enhanced upward mantle flow without this requirement (*Phys. Earth Planet. Inter.* doi:10.1016/j.pepi.2009.10.001; 2009). Using numerical modelling they show that viscosity variation alone can induce increased upwelling, if subject to shear motion, in a mechanism they call shear-driven upwelling.

Viscosity contrasts can occur in the same locations as density contrasts. Variable thickness along the base of the highly viscous lithosphere can form an indented cavity that fills with less viscous asthenosphere. Alternatively, pockets of lower viscosity asthenosphere can form within normal asthenosphere owing to anomalies in thermal patterns, melting, or volatile or fluid content. The low viscosity cavities or pockets are exposed to a velocity shear that is generated by the relative motion between the convecting mantle and the overlying tectonic plates. Conrad and colleagues' numerical modelling results indicate that, under this imposed shear, viscosity variations within a cavity or pocket can generate increased mantle upwelling of up to ~1 cm yr^{-1}, causing partial melting and the generation of magma that erupts as surface volcanism.

The idea of shear-driven upwelling provides a neat alternative to existing models for volcanism where it is least expected. Whether it was indeed responsible for the generation of the San Francisco volcanic field remains to be shown.

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