pox. The relevant risk is not only that individuals get infected in those settings, but that these individuals themselves promote subsequent transmission of the disease.

One solution to the lack of data about smallpox outbreaks is to gather data on influenza epidemics. Indeed, Halloran *et al.* use insights from influenza outbreaks to guide construction of their smallpox transmission model. But even for influenza outbreaks, data are limited. Huge studies that follow individuals closely enough to document their exposure and infection are very expensive. However, there is another promising but untried data source: nucleotide sequences of infectious agents taken from individuals with documented contact points in the transmission system. The idea is not to determine which individuals infected other individuals, but rather to fit transmission models to genetic distances (estimated using nucleotide sequence data) in a pathogen population.

The Halloran *et al.* model simulates a smallpox outbreak in a population of 2000 individuals. They find that under a number of conditions, more infections are prevented by extending vaccination beyond immediate social contacts. This supports the notion that targeted control measures will need to involve vaccination of a broader range of individuals. Future work will need to focus on scaling up the Halloran *et al.* model so that it effectively simulates a population as large as that of the United States. There are other kinds of information that will also be needed by policy-makers. For example, we need to determine ahead of time the most important data to collect during a bioterrorist attack. How will the various new vaccines proposed for development fit into simulated control efforts like those examined in the Halloran *et al.* and Kaplan *et al.* studies? Neither study will put to rest the current debate over the best policy for protecting the U.S. population against a bioterrorist attack. But publication of these studies may help to orient future research that will provide the information needed by policy-makers.

References

1. M. E. Halloran, I. M. Longini Jr., A. Nizam, Y. Yang, *Science* **298**, 1428 (2002).
2. E. H. Kaplan, D. L. Craft, L. M. Wein, *Proc. Natl. Acad. Sci. U.S.A.* **99**, 10935 (2002).
3. J. P. Fox, L. Elveback, W. Scott, L. Gatewood, E. Ackerman, *Am. J. Epidemiol.* **94**, 179 (1971).
4. S. Wolfram, *A New Kind of Science* (Wolfram Media, Champaign, Il, 2002).
5. J. S. Koopman, S. E. Chick, C. P. Simon, C. S. Riolo, G. Jacquez, *Math. Biosci.* **180**, 49 (2002).
6. P. Rohani, M. J. Keeling, B. T. Grenfell, *Am. Nat.* **159**, 469 (2002).
7. M. E. J. Newman, *Phys. Rev. E* **66**, 016128 (2002).
8. J. S. Koopman, G. Jacquez, S. E. Chick, *Ann. N.Y. Acad. Sci.* **954**, 268 (2001).

PERSPECTIVES: GEOLOGY

Serpentinite Seduction

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Serpentinite, a valued green decorative building stone and the official California state rock, forms through hydrothermal alteration of peridotite, the rock of Earth's mantle. It is common in ophiolites, which are exposed fragments of oceanic crust and subjacent mantle.

It has been assumed that serpentinite is widespread in oceanic plates undergoing subduction (*1–3*). If true, this would have important implications for earthquake and volcano activity in subduction zones. During subduction, water is released from serpentinites by metamorphic dehydration reactions. It has been suggested that serpentinite provides a particularly fertile water source for magma generated in subduction-related arc volcanoes (*1*). Furthermore, water released by metamorphic dehydration could trigger subduction-zone earthquakes (*4*).

In concert with previous studies (*2, 3*), Dobson *et al.* contend on page 1407 of this issue (*5*) that earthquake hypocenters in the lower segments of double seismic zones (see the figure) can be attributed to serpentinite dehydration. Is serpentinite indeed widespread in the subducted oceanic plates, or is it a green herring?

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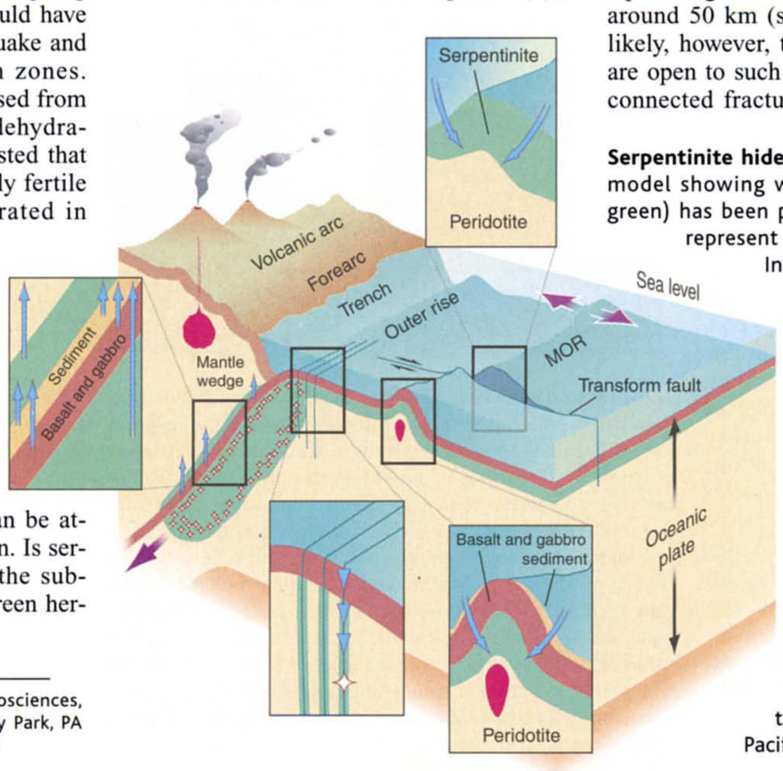
In the nonsubducting Atlantic oceanic plate, serpentinite is common where transform faults intersect and offset the slow-spreading Mid-Atlantic Ridge system. Hydrothermal circulation of seawater transforms the shallow peridotites into serpentinite. Seismic data suggest that the serpentinite may be 2 to 3 km thick (*6*).

In contrast, with rare exceptions (*7*), serpentinites are virtually nonexistent in the fast-spreading ridges of the Pacific oceanic plate and in ophiolites believed to be associated with fast-spreading centers (*8*). Nonetheless, serpentinization of oceanic mantle entering subduction zones around the Pacific (where most of Earth's subduction occurs) has been postulated to arise from infiltration of seawater into transform faults (*3*) or along deep faults at the "outer rise" where oceanic plates bend upon entering subduction zones (*2*).

The formation of serpentinite in the lower part of double seismic zones would require ingress of seawater to depths of around 50 km (see the figure). It is unlikely, however, that the outer rise faults are open to such depths, or that an interconnected fracture network allows deep



Serpentinite hide-and-seek. Plate tectonic model showing where serpentinite (dark green) has been postulated to form. Stars represent earthquake hypocenters. In the subducted plate, the hypocenters outline a double seismic zone. Large purple arrows indicate relative plate motion. Spreading occurs at the mid-ocean ridge (MOR). Blue arrows depict fluid ingress or expulsion. Magma is shown in red. Serpentinite along the transform fault is relevant to the slow-spreading Mid-Atlantic Ridge, whereas the other serpentinite locations are relevant to the Pacific plate.

penetration of seawater. Propagation of cracks and fractures necessary for fluid ingress would be inhibited by the large increase in rock volume accompanying serpentinization (*8*). The hypothesis that surface water is drawn to such depths by dilatancy (increase in pore volume) arising from seismic pumping associated with deep earthquakes (*2*) is difficult to reconcile with hydraulics.

Seismic tomography offers a potential way to image serpentinite remotely in subducted slabs. The ratio of P and S seismic wave velocities is directly proportional to Poisson's ratio (the ratio of longitudinal to transverse strain in a uniaxially stressed material). Serpentinite has an unusually high Poisson's ratio, providing a means to detect it at depth. It has been imaged in the mantle wedge overlying subduction zones (*9*). Serpentinite exposed in forearcs (*10*) (see the figure) provides direct evidence of its existence in mantle wedges.

However, the critical question here is whether serpentinite exists in subducted plates. Computing Poisson's ratio from seismic tomography, Omori *et al.* (*3*) suggest that substantial quantities of serpentinite exist to depths of ~50 km below the top of the subducted plate in northeast Japan. If this interpretation is valid, we require a credible mechanism for hydrating mantle peridotite to such depths.

Further evidence for or against serpentinite in subducted plates should come from detailed seismic tomography of areas with known serpentinite at depth (*10*). The serpentinite enigma is further compounded by uncertainties regarding the pressure-temperature conditions of serpentinite dehydration and the thermal structure of subduction zones (*3*).

The fluid required for mantle wedge serpentinization could derive from sources other than serpentinite in the subducted oceanic crust. Other sources might be metamorphic devolatilization of subducted marine sediments (*11*) and hydrothermally altered oceanic basalts (*12*). Dehydration of the mantle wedge serpentinites could then supply fluids to arc magmas (*13*). Comparison of the trace element and isotopic compositions of serpentinites exposed in forearcs (*10*) with those of the Mid-Atlantic Ridge and ophiolites (*14*) may help to determine whether arc magma fluids derive from mantle wedge or oceanic plate serpentinites.

In the distant future, a change in global dynamics may cause the Atlantic plate to undergo subduction. I postulate that the large amount of water released by dehydration of the subducted Atlantic oceanic serpentinites will then result in a significant quantity of arc volcanism and a lot of earthquake activity.

References

1. P. Ulmer, V. Tromsdorff, *Science* **268**, 858 (1995).
2. S. Peacock, *Geology* **29**, 299 (2001).
3. S. Omori *et al.*, *Bull. Earthq. Res. Inst. Univ. Tokyo* **76**, 455 (2002).
4. S. H. Kirby, E. R. Engdahl, R. Denlinger, in *Subduction: Top to Bottom*, G. E. Bebout *et al.*, Eds. (American Geophysical Union, Washington, DC, 1996), pp. 195–214.
5. D. P. Dobson, P. G. Meredith, S. A. Boon, *Science* **298**, 1407 (2002).
6. M. R. Muller *et al.*, *Earth Planet. Sci. Lett.* **148**, 93 (1997).
7. G. L. Frueh-Green, A. Plas, C. H. Lécuyer, *Proc. ODP Sci. Results* **147**, 255 (1996).
8. D. S. O'Hanley, *Serpentinites: Records of Tectonic and Petrological History* (Oxford Univ. Press, Oxford, 1996).
9. M. G. Bostock *et al.*, *Nature* **417**, 536 (2002).
10. P. Fryer *et al.*, *Geol. Soc. Am. Spec. Pap. 349*, 35 (2000).
11. D. M. Kerrick, J. A. D. Connolly, *Nature* **411**, 293 (2001).
12. ———, *Earth Planet. Sci. Lett.* **189**, 19 (2001).
13. H. Iwamori, *Earth Planet. Sci. Lett.* **181**, 41 (2000).
14. M. Scambelluri *et al.*, *Earth Planet. Sci. Lett.* **192**, 457 (2001).

PERSPECTIVES: CLIMATE CHANGE

Is the Hydrological Cycle Accelerating?

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Early studies of instrumentally detected climate change (*1–3*) mostly concentrated on the history of measured air temperature. More recent research has investigated the variability of other climatic factors such as irradiance (*4, 5*), water vapor (*6*), wind speed (*6*), and precipitation (*7*). In interpreting these data sets, researchers were conscious of the recent global warming and the expected consequences of the enhanced greenhouse effect.

One of these expectations was that evaporation would increase under a warmer climate. But in 1995, Peterson *et al.* reported a decrease in pan evaporation between 1950 and 1990, based on data from the United States and the former Soviet Union (*8*). The authors used data from a network of pan evaporimeters. These simple instruments consist of a water-filled pan, a device to measure the water needed to return the surface to a predetermined level, and a rain gauge (see the figure). They were first used in the 19th century, but only since 1951 have homogeneous data been available.

Peterson *et al.* (*8*) did not distinguish between pan evaporation and terrestrial and potential evaporation (*9*). They found the decreasing pan evaporation (and hence terrestrial and potential evaporation) to be in phase with the decreasing diurnal temperature range (daily maximum minus minimum temperature), which they related to increasing cloud cover. They thus concluded that evaporation had decreased in a warming climate.

In contrast, Brutsaert and Parlange (*10*) regarded the pan evaporation as fundamentally different from the terrestrial evaporation. They argued that the decreasing pan evaporation is a signal of increasing terrestrial evaporation, because the latter will cast moist air over a water-filled pan. The decreasing pan evaporation would then be an indication of an increase

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Installations of the water evaporation pan. (Left) A Canadian Class-A pan installed at the northernmost point on Earth where evaporation pans were used (79°25′N, 90°45′W). The pan is separated from the ground with a wood plank to avoid local effects from the ground. **(Right)** A Chinese pan at Hongwuyve, Tenshan Mountains. The pan is buried in an effort to minimize the effect of the exposed side wall.

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