The fates of stars. In this Hertzsprung-Russell diagram, the main diagonal line denotes "main sequence" stars, which, like the Sun, burn hydrogen in their cores. Lines moving away from the main sequence are followed by stars after they have exhausted their hydrogen fuel supply. After a brief period of helium burning, most stars eventually reach the white dwarf cooling track—the last part of this evolution for stars of less than ~8 solar masses (M⊙). Asteroseismology has produced insights into the interior and evolution of a growing variety of stars (see shaded areas). The latest stars to yield some of their secrets are the β-Cepheids (red area)—massive main-sequence stars that are destined to become supernovae.

Quantification of the stress caused by the deep, slow earthquakes requires knowledge of the precise location and amount of the slow slip. Herein lies a problem. Static surface deformation from deep faulting provides only a blurry image of creep at depth. Moreover, the vertical deformation that is most useful for locating the creep is the least resolvable with GPS. As a result, stress drops have remained largely unconstrained, and the loading of the seismogenic zone by slow earthquakes has not been well quantified.

Such was the state of affairs until last year, when Obara discovered nonvolcanic tremor associated with subduction of the Philippine sea plate beneath southeast Japan (5). With the ultralow noise, bore-hole Hi-Net array, Obara was able to detect long-period seismic tremor at levels that on any conventional network would have gone unnoticed or been attributed to anthropogenic or other nontectonic sources. The signals Obara recognized were previously only found within active volcanoes, where they are generated by flow-induced resonance in magma-carrying conduits (6). Obara’s tremor, however, appeared to come from deep regions, at depths of at least 35 km, and well away from any known volcanic source.

Like their volcanic cousins, the signals described by Obara are emergent, that is, they mostly lack any isolated seismic P or S waves that can be used to locate their origin.
Interseismic deformation from subduction of the Juan de Fuca plate. The deformation vectors reverse themselves for 2 to 6 weeks every 14.5 ± 1 months during slow earthquakes. Tremor correlated with the vector reversals is detected to the north of the Olympic Peninsula.

Through cross-correlation of their filtered signal envelopes, however, Obara was able to estimate that their hypocenters fall along the 35- to 40-km depth contour within the subducting Philippine sea plate. At precisely this depth, the water-releasing dehydration from basalt to eclogite is expected to occur (7). It thus seems likely that the tremor originates from the forced flow of fluids that are released near the plate interface during metamorphic dehydration. But how is the tremor related to slow earthquakes?

Obara’s data show clearly that tremor occurs in regions of known slow earthquakes, but is absent in areas where no slow earthquakes have been detected. However, he did not show that tremor and slow earthquakes occur simultaneously. As Julian has pointed out (8), the Cascadia subduction zone off the western coast of North America, with its periodic and predictable slow earthquakes (see the figure) (9), is ideal for addressing the relation between slow earthquakes and Obara-type tremor. After detailed analysis of 10 years of seismic recordings from Vancouver Island, Rogers and Dragert now conclude not only that slow earthquakes and tremor are highly correlated, but that one is the hallmark of the other. Cascadia slow earthquakes are not silent; rather, they are accompanied by tremor that is notably absent when slow faulting is not occurring.

The slow earthquakes in the Cascadia subduction zone, and by extension everywhere around the world, thus seem to be moderated by fluid flow in or near the plate interface. As in southwest Japan, the Cascadia tremor peaks between 1 and 5 Hz, persists for days to weeks, migrates tens of km horizontally along the fault plane, and appears to both trigger and be triggered by adjacent conventional earthquakes. The tremor is not caused by near-simultaneous slip of large regions, as in conventional earthquakes, but probably by brine resonating the walls of the conduits through which it episodically bursts. The precise mechanism on how the fluid flow enables slow slip remains unclear, but may prove as simple as hydraulic pressure unclamping the fault walls that sandwich the fluid.

The correspondence established by Rogers and Dragert (1) provides an important new tool with which to study the slow earthquake process. Tremor can potentially be used to locate slow slip at depth more precisely than can static deformation measurements at Earth’s surface. With nearly 2000 new geophysical instruments coming online with EarthScope (10), the future promises better seismic locations, energy estimates, and source mechanisms, as well as tighter constraints on along-strike propagation of tremor and slip.

It may therefore be only a matter of time before the initiation of regular earthquakes is itself tied definitively to fault fluid flow, an idea that has been around for years. If this idea is proven to be correct, it probably applies to faults beyond those at subduction zones. Free-flowing brine has been detected in faults at depths below 10 km in the deepest boreholes on Earth (11). Like many other aspects of earthquake physics, discoveries first made in subduction-zone faults may prove to be applicable to all active faults—particularly those on which many of our cities are built.

**References**
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**Desperately Seeking Similarity**

Janis L. Dickinson and Walter D. Koenig

Ever since W. D. Hamilton pointed out that cooperation is facilitated by genetic relatedness (1), “kin selection” has held a central place in the study of social behavior. Although most cooperative societies comprise close relatives (2), there has always been a caveat to the logical conclusion that kin selection is the driving force in their evolution. Consider cooperative breeders such as the meerkat (Suricata suricatta) that have “helpers” providing care to young that are not their own. Although helpers are usually a breeder’s offspring from prior years, close genetic relatedness between the giver and recipient of aid is not necessarily crucial to the evolution of helping behavior. The importance of kinship relative to other more direct benefits of group living and cooperation is the subject of much debate. Two studies on pages 1947 and 1949 of this issue (3, 4) shed new light on this problem.

In support of kin selection, a preponderance of cooperative species have groups consisting of close relatives. One particularly notable experiment in a British bird species showed that returning helpers preferred to assist relatives over unrelated pairs at closer nests (5). Critics argue that cooperation among relatives arises as a side effect of delayed dispersal, which causes offspring to remain near kin. This viewpoint is advocated in recent reviews highlighting gains for helpers independent of aiding relatives (6, 7) and severe competition that reduces or eliminates kin-selected benefits.