

## GEOPHYSICS

# Periodic Slow Earthquakes from the Cascadia Subduction Zone

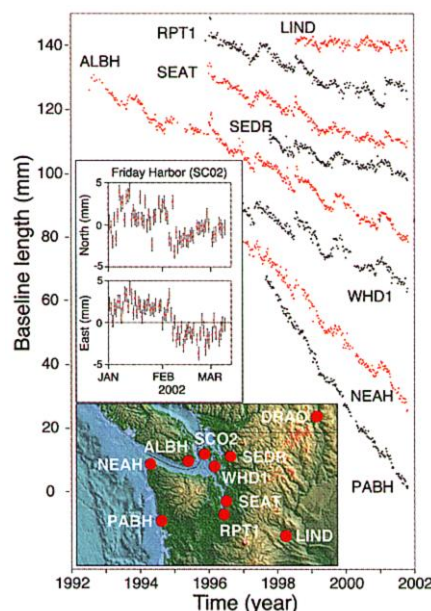
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Continuous geodetic measurements from convergent margins have shown that deep transient creep events can release large amounts of strain energy without detectable seismic shaking, and they are thus known as slow or silent earthquakes. Because subduction zones generate the largest earthquakes, seismic hazard assessment relies on understanding the degree to which slow earthquakes reduce the energy released by infrequent large earthquakes. We present data that indicate the periodicity of slow earthquakes in Cascadia and the current onset of such an event.

Along the Cascadia margin, great earthquakes (moment magnitude,  $M_w > 8$ ) have occurred over its 1500-km length from central British Columbia to northern California as the Juan de Fuca plate subducts beneath the North American plate (1–4). Since 1992, continuous global positioning system (GPS) monitoring of changes in station position have been used to monitor surface deformation associated with tectonic events (5, 6). In the fore arc that lies between the offshore plate boundary and the Cascade volcanoes, current interseismic deformation is dominated by northeast-directed contraction, the result of shallow convergence of the Juan de Fuca plate beneath the North American plate. During 1999, a sudden shift from fore arc contraction to short-lived extension led to identification of a deep slow earthquake (7).

Our analysis of GPS results from the Pacific Northwest Geodetic Array (PANGA) indicates that eight slow earthquakes have occurred since 1992. Both fore arc station positions in the global reference frame and precise baselines relative to Pentiction, British Columbia (DRAO), show episodic, discrete extension events superimposed on interseismic crustal shortening (Fig. 1). DRAO lies inland and is largely unaffected by convergence-related contraction. The transient reversals from secular contraction are consistent with southwest-directed fore arc motion that is both spatially and temporally coherent. Each event starts over a 3-week period and lasts 2 to 4 weeks at any one station. Propagation of the slow earthquake across the af-

fected region may last for 8 weeks. The slow earthquakes occur on average every  $14.5 \pm 1$  months over the past 10 years and typically begin in the Puget Lowlands near the arch in the downgoing Juan de Fuca plate. Observa-



**Fig. 1.** Time series for GPS stations along the Cascadia margin. Baseline lengths are from weekly station positions with respect to Pentiction (DRAO). (Inset) Time series shows daily positions for Friday Harbor (SC02) for 2002 in the global reference, illustrating the onset of the latest of the slow earthquakes.

tions at ALBH show similar displacements for each event. Yet the last three events have well-mapped displacement fields that differ across the network, implying differences in the fault area that failed. Modeling suggests creep of a few cm along the plate interface at depths of 30 to 50 km. Estimated moment release approximates a  $M_w = 6.7$  earthquake, consistent with previous analysis (7).

No corresponding periodicity characterizes the DRAO time series in the global reference frame or baselines between DRAO and other PANGA back arc stations, those that lie east of the volcanic front. Thus, tectonic, tropospheric, or monument instability signals

localized to DRAO itself are not the source of the transient reversals. The 14.5-month average recurrence is similar to the period of the Chandler resonance (8). Nonetheless, this resonance cannot explain the observed baseline changes or the sawtooth pattern in the time series.

We observe the onset of another slow earthquake that began on 7 February 2002 at Friday Harbor, Washington (Fig. 1; inset). Discrete offsets in the north and east components fit the pattern observed at nearby stations in previous events and are visible at this new station in the daily positions. The offset and partial recovery in the north component reflect propagation of a slow earthquake under the station.

The frequency of these slow earthquakes invites an assessment of the role of transient, aseismic creep events in the deforming Earth. Over the time scale of recurrence intervals for the plate interface, this mechanism may rival great thrust events for recoverable strain energy release. The four-dimensional deformation field determined over the past 10 years by GPS contains a rich record comprising permanent deformation overlain by an elastic strain field, which is ultimately recovered both during earthquakes and during frequent transient deformation events. The regular and cyclical nature of the transient events indicates that they are a fundamental mode of strain release in subduction zones.

## References and Notes

1. J. Adams, *Tectonics* **9**, 569 (1990).
2. K. Satake, K. Shimizaki, Y. Tsuji, K. Ueda, *Nature* **379**, 246 (1996).
3. B. F. Atwater, E. Hemphill-Haley, *Recurrence intervals for great earthquakes of the past 3,500 years at northeastern Willapa Bay, U.S. Geol. Surv. Prof. Pap.* **108** (1997).
4. D. K. Yamaguchi, B. F. Atwater, D. E. Bunker, B. E. Benson, M. S. Reid, *Nature* **389**, 922 (1997).
5. H. Dragert, R. D. Hyndman, *Geophys. Res. Lett.* **22**, 755 (1995).
6. M. M. Miller et al., *Tectonics* **20**, 161 (2001).
7. H. Dragert, K. Wang, T. S. James, *Science* **292**, 1525 (2001).
8. L. Xie, S. R. Dickman, *Geophys. J. Intl.* **121**, 117 (1995).
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