debates

18 March 1999

E-MAIL CONTRIBUTIONS

A case for intermediate-term earthquake prediction: don't throw the baby out with the bath water!

DAVID BOWMAN & CHARLES SAMMIS

As anyone who has ever spent any time in California can attest, much public attention is being focused on the great earthquake-prediction debate. Unfortunately, this attention focuses on deterministic predictions on the day-to-week timescale. But as some of the participants in this debate have pointed out[1,2] current efforts to identify reliable short-term precursors to large earthquakes have been largely unsuccessful, suggesting that earthquakes are such a complicated process that reliable (and observable) precursors might not exist. That is not to say that earthquakes do not have some 'preparatory phase', but rather that this phase might be not be consistently observable by geophysicists on the surface. But does this mean that all efforts to determine the size, timing and locations of future earthquakes are fruitless? Or are we being misled by human scales of time and distance?

As Robert Geller said in his earlier comments in this debate, 'the public, media and government regard an "earthquake prediction" as an alarm of an imminent large earthquake, with enough accuracy and reliability to take measures such as the evacuation of cities'. As Geller has pointed out on many occasions, this goal might be too ambitious. However, according to the categories of earthquake prediction defined by Ian Main in the introduction of this debate, most such efforts fall into category 4 (deterministic prediction). But what about forecasting earthquakes on the year-to-decade scale? Although 'predictions' over this timescale might not justify such drastic actions as the evacuation of cities, it would certainly give policy-makers as well as individual citizens sufficient time to brace themselves for the impending event, in much the same way that California was able to prepare itself for last winter's El Niño. With this paradigm in mind, forecasting on the year-to-decade scale would be immensely useful.

In recent years there has been the suggestion that even this goal might be inherently impossible. Central to this argument is the claim by many authors that the crust is in a continuous state of self-organized criticality[2-6] (and Per Bak's contribution to this debate). In the context of earthquakes, 'criticality' is defined as a system in which the stress field is correlated at all scales, meaning that at any time there is an equal probability that an event will grow to any size. If the system exhibits self-organized criticality, it will spontaneously evolve to criticality and will remain there through dissipative feedback mechanisms, relying on a constant driving stress to keep the system at the critical state. The implication of this model is that, at any time, an earthquake has a finite probability of growing into a large event, suggesting that earthquakes are inherently unpredictable.

However, this is contradicted by recent observations of the evolution of the static stress field after large earthquakes. In one of the first studies on this subject[7] it was found that the 1906 San Francisco earthquake produced a 'shadow' in the static stress field that seemed to inhibit earthquakes for many years after the M = 7.9 event. After this work, several other studies observed stress shadows after numerous events including the 1857 Fort Tejon[8,9] and 1952 Kern County[8] earthquakes. An excellent review of these and other observations of stress shadows after large earthquakes can be found in a recent issue of the Journal of Geophysical Research special issue on stress triggers, stress shadows and implications for seismic hazard[10].

In an earlier comment during this debate, Christopher Scholz discussed these stress shadows in the framework of self-organized criticality (Fig. 1B in his comment), and mentioned that this concept is equivalent to the 'seismic gap' hypothesis. However, it should be noted that recent years have seen the proliferation of models[11-17] that describe how the system emerges from these stress shadows. The hypothesis for this viewpoint (which has come to be known as intermittent criticality) is that a large regional earthquake is the end result of a process in which the stress field becomes correlated over increasingly long scale-lengths (that is, the system approaches a critical state). The scale over which the stress field is correlated sets the size of the largest earthquake that can be expected at that time. The largest event possible in a given fault network cannot occur until regional criticality has been achieved. This large event then reduces the correlation length, moving the system away from the critical state on its associated network, creating a period of relative quiescence, after which the process repeats by rebuilding correlation lengths towards criticality and the next large event.

The differences between these models for regional seismicity have important consequences for efforts to quantify the seismic hazard in a particular region. Self-organized criticality has been used as a justification for the claim that earthquakes are inherently unpredictable[2]. Models of intermittent criticality, in contrast, do not preclude the possibility of discovering reliable precursors of impending great earthquakes. Indeed, several modern models use this concept to predict observable changes in regional seismicity patterns before large earthquakes[16-18]. It can be argued that models of intermittent criticality not only hold the promise of providing additional criteria for intermediate-term earthquake forecasting methods but also might provide a theoretical basis for such approaches.

Although models of intermittent criticality might promise improved methods for intermediate-term earthquake prediction, we must be careful not to overstate their claims. Ideally, the scientific community and the public at large should approach these methods much the same way as weather prediction. It should be fully expected that forecasts will change through time, in much the same way that the five-day weather forecast on the evening news changes. However, this will require a fundamental shift in the way we as Earth scientists think about earthquakes. We must acknowledge that the Earth is a complicated nonlinear system and that even the best intermediate-term forecasts cannot hold up to the standards imposed by Geller in his comments earlier in this debate.

David D. Bowman and Charles G. Sammis
Department of Earth Sciences, University of Southern California, Los Angeles, USA.

References

1. Geller, R.J. Earthquake prediction: a critical review. *Geophys. J. Int*. **131**, 425-450 (1997).
2. Geller, R.J., Jackson, D.D., Kagan, Y.Y. & Mulargia, F. Earthquakes cannot be predicted. *Science* **275**, 1616-1617 (1997).
3. Sornette, A. & Sornette, D. Self-organized criticality and earthquakes. *Europhys. Lett*. **9**, 197 (1989).
4. Bak, P. & Tang, C. Earthquakes as a self-organized critical phenomenon. *J. Geophys. Res*. **94**, 15635-15637 (1989).
5. Ito, K. & Matsuzaki, M. Earthquakes as self-organized critical phenomena. *J. Geophys. Res*. **95**, 6853-6860 (1990).
6. Main, I., Statistical physics, seismogenesis, and seismic hazard. *Rev. Geophys.* **34,** 433-462 (1996).
7. Simpson, R.W. & Reasenberg, P.A. in *The Loma Prieta, California Earthquake of October 17, 1989--Tectonic Processes and Models* (ed. Simpson, R.W.) F55-F89 (*U.S. Geol. Surv. Prof. Pap*. 1550-F,

1994).
8. Harris, R.A. & Simpson, R.W. In the shadow of 1857-the effect of the great Ft. Tejon earthquake on subsequent earthquakes in southern California. *Geophys. Res. Lett*. **23**, 229-232 (1996).
9. Deng, J. & Sykes, L.R. Evolution of the stress field in southern California and triggering of moderate-size earthquakes. *J. Geophys. Res*. **102**, 9859-9886 (1997).
10. Harris, R.A. Introduction to special section: stress triggers, stress shadows, and implications for seismic hazard. *J. Geophys. Res.* **103**, 24347-24358 (1998).
11. Sornette, D. & Sammis, C.G. Complex critical exponents from renormalization group theory of earthquakes: implications for earthquake predictions. *J. Phys. I* **5**, 607-619 (1995).
12. Saleur, H., Sammis, C.G. & Sornette, D. Renormalization group theory of earthquakes. *Nonlin. Processes Geophys*. **3**, 102-109 (1996).
13. Sammis, C.G., Sornette, D. & Saleur, H. in *Reduction and Predictability of Natural Disasters* (*SFI Studies in the Sciences of Complexity* vol. 25) (eds Rundle, J.B. Klein, W. & Turcotte, D.L.) 143-156 (Addison-Wesley, Reading, Massachusetts, 1996).
14. Sammis, C.G. & Smith, S. Seismic cycles and the evolution of stress correlation in cellular automaton models of finite fault networks. *Pure Appl. Geophys.* (in the press).
15. Huang, Y., Saleur, H., Sammis, C.G. & Sornette, D. Precursors, aftershocks, criticality and self-organized criticality. *Europhys. Lett.* **41**, 43-48 (1998).
16. Bowman, D.D., Ouillon, G., Sammis, C.G., Sornette, A. & Sornette, D. An observational test of the critical earthquake concept. *J. Geophys. Res.* **103**, 24359-24372 (1998).
17. Jaum�, S.C. & Sykes, L.R. Evolving towards a critical point: a review of accelerating moment/energy release prior to large and great earthquakes. *Pure Appl. Geophys.* (in the press).
18. Brehm, D.J. & Braile, L.W. Intermediate-term earthquake prediction using precursory events in the New Madrid seismic zone. *Bull. Seismol. Soc. Am.* **88**, 564-580 (1998).

Contributions to this debate from readers are encouraged, by e-mail only, please, to debates@nature.com.

The rules are simple: contributions should be short and to the point. The moderator reserves right to select contributions to be posted on the site, and to normal editing for style, sense, length and, of course, good taste.