EARTHQUAKES

Characteristic or haphazard?

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THE next time you gaze out of your window, only to find that the nearby lake has been drained and an excavation suitable for the foundations of the World Trade Center has been dug, don't call the city council. It's probably just a group of geologists dating prehistoric earthquakes on a fault passing underfoot. In their search to find sites with a longer and more precise history of past earthquakes, palaeoseismologists are being enticed underwater by the finely layered, carbon-rich strata of lakes and ponds, and they are digging not simple slices across faults but a deep labyrinth of excavations, tracing offset stream channels across fractures large and small. And they are benefiting from new on-site or 2-day-turnaround radiocarbon dating so they know at the outset if they have hit paydirt. Why bother? Because, as revealed at a recent meeting*, it is our best hope of finding out if large earthquakes are truly characteristic: in other words, whether events of the same size, or at least the same slip, recur on a given fault or fault segment[1-3].

Speaking like a rabbi whose role is not only to comfort the afflicted but also to afflict the comfortable, R. Muir-Wood (EQE, Gloucester) argued that given what is now known about fractal, chaotic and self-organized critical systems, it should be surprising to find any regularity in earthquake occurrence. Have we become too enamoured — too comfortable — with the utility of characteristic earthquakes, and the associated repeat time for such events? Despite an eloquent defence for their existence in the prehistoric record (D. Schwartz, US Geological Survey, Menlo Park; K. Sieh, California Inst. Technol.; T. Rockwell, San Diego State Univ.), there is no avalanche of evidence for a concept deeply embedded in probabilistic assessments of earthquake occurrence. Most convincing are trench excavations along some of California and Utah's major faults, where the displacement at a site is similar for several past earthquakes. The slip in the 1983 magnitude 7 earthquake on the Lost River fault in Idaho also looks identical to an event about 7,000 years ago. But few trenches uncloak more than two or three earthquakes, and flights of marine terraces in New Zealand, which record the sudden uplift associated with offshore earthquakes, do not paint a picture of similar-sized events[4]. What is needed is a much longer record of earthquake slip: hence the deeper excavations.

Whether the largest earthquakes on a fault recur with the same size is clouded by another phenomenon so widely reported at the gathering that it came close to a meeting mantra: clustering. In Iran, Italy, Greece, Turkey, New Zealand, China, California and Japan, historical earthquakes cluster in space and time, consistent with studies of instrumentally recorded shocks[5]. Rather than behaving as isolated events, earthquakes must thus interact. Mounting evidence points to one shock triggering the next by the transfer of stress[6,7]. But rarely is it possible to distinguish from trench logs whether near-synchronous displacements along a fault represent one large earthquake or a cluster of smaller ones spanning several decades. A series of trenches has revealed, for example, that nearly the entire fault that ruptured in the 1992 magnitude 7.4 earthquake in Landers, California, slipped about 5,500 years ago. Is the 1992 event therefore characteristic, or could a cluster of smaller shocks have struck along the fault during the earlier episode? Excavations also leave open the possibility that 500 km of the southern San Andreas fault ruptured in about AD 1480[3], which would yield an event of magnitude 8.1, 180 km longer than the magnitude 7.9 event in 1857 currently used to infer a maximum magnitude. But a cluster of three magnitude 7.6 events over 50 years satisfy the data as well, much as 725 km of the North Anatolian fault in Turkey ruptured in four large earthquakes during the Second World War. Thus assigning a maximum earthquake magnitude — and hence the maximum ground shaking — to a fault becomes harder to estimate from the prehistoric record if clustering is common. More precise age-dating is the only way out: hence the drained lakes.

Ironically, exciting progress has been achieved in tracking down the most concealed and elusive of earthquake sources: blind thrust and normal events in which the fault does not appear at the ground surface. Taking advantage of a lake repeatedly filled and drained by nature, M. Meghraoui (Univ. Cergy-Pontoise) dated seven prehistoric earthquakes at the site of the magnitude 7.3 shock at El Asnam, Algeria, from the damming of a river by co-seismic fold uplift[8]. At the Istituto Nazionale di Geofisica (Rome), researchers have carried out a systematic inventory of normal faults tracing the spine of the southern Apennines that are partially concealed by a former episode of compression, finding historical and prehistoric events separated by 1,000–3,000 years (see figure)[9,10]. Drawing from Iran's long and tragic historical records of earthquakes, M. Berberian (Najarian Assoc., New Jersey) identified numerous previously unknown blind thrust earthquake sources in the Zagros fold belt[11]. The 12 million people now living in Tehran are exposed to an earthquake potential in great need of study.

But such use of rich historical records

Fault segmentation, slip rate (S_r) and earthquake recurrence time (T_r) along the central and southern Apennine chain, Italy. Faults known from field observations or inferred from instrumental data are in red. Faults inferred from geological or historical data are in purple (*a*, high confidence level; *b*, low confidence). Shading marks weak zones with moderate seismogenic potential. Dates, where given, are for the last known event. (Courtesy of the Istituto Nazionale di Geofisica, Rome.)

*Active Faulting Studies for Earthquake Hazard Assessment, Ettore Majorana Centre for Scientific Culture, Erice, Sicily, 27 September–5 October 1995. Proceedings available by email from <Erice95@8800.ingrm.it>.

1. Schwartz, D. P. & Coppersmith, K. J. *J. geophys. Res.* **89**, 3051–3058 (1984).
2. Bakun, W. H. & McEvilly, T. V. *J. geophys. Res.* **89**, 3051–3058 (1984).
3. Sieh, K. *Proc. natn. Acad. Sci. U.S.A.* (in the press).
4. Ota, Y., Hull, A. G. & Berryman, K. R. *Quat. Res.* **35**, 331–346 (1991).
5. Kagan, Y. Y. & Jackson, D. D. *Geophys. J. int.* **104**, 117–133 (1991).
6. Stein, R. S., King, G. C. P. & Lin, J. *Science* **265**, 1432–1435 (1994).
7. Harris, R. A. *et al. Nature* **375**, 221–224 (1995).
8. Meghraoui, M. & Doumaz, F. *J. geophys. Res.* (in the press).
9. Valensise, G. & Pantosti, D. *Terra Nova* **4**, 472–483 (1992).
10. Pantosti, D., Schwartz, D. P. & Valensise, G. *J. geophys. Res.* **98**, 6561–6577 (1993).
11. Berberian, M. *Tectonophysics* **241**, 193–224 (1995).
12. Ambraseys, N. N. & Finkel, C. F. *The Seismicity of Turkey and Adjacent Areas: A Historical Review, 1500–1800* (Muhittin Salih EREN, Istanbul, 1995).

to elucidate earthquake occurrence[12] is, sadly and perhaps shamefully, rare. Muir-Wood and D. Giardini (Univ. Roma) remonstrated with the profession for devoting so few resources to seeking and husbanding our trove of historical earthquakes. These documents bear strongly on the issues of characteristic earthquakes, clustering and blind events, and because teasing science from diaries and church archives demands skills that few today possess, the historical treasure may be far more perishable than the strata in a trench. □

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