NORTHRIDGE EARTHQUAKE

Which fault and what next?

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WHAT at first appears to be a semantic dispute between distinguished geologists about what to call Northridge's nemesis — the Pico or the Oak Ridge blind thrust fault — turns out to hinge on fundamental questions about where Los Angeles's most perilous fault might lurk[1,2]. The only point of accord is that, by whatever name, the fault segment that slipped in last year's magnitude 6.9 earthquake is not a major player in southern California's pantheon of buried or 'blind' faults.

Writing in a November issue of *Nature*, Davis and Namson[1] argued that the fault on which the 17 January 1994 earthquake struck is a 'back thrust' or splinter off the more ominous Elysian Park blind thrust fault. The Elysian Park thrust is several times longer than the Pico, and in Davis and Namson's view, slips at three times the Pico's rate and is thus capable of much larger earthquakes. When the Elysian Park thrust ruptures, for example, the famed Hollywood sign will heave perhaps a metre heavenwards. Yeats and Huftile, writing on page 418 of this issue[2], argue that the Northridge shock occurred on the east end of the Oak Ridge fault. They contend that the rate of slip of the Oak Ridge fault is three times that in the Ventura basin at Northridge and three times that of the Elysian Park thrust in Los Angeles. Thus they point to the Oak Ridge, which extends 70 km east from Northridge into the heavily populated Ventura basin and has shown a high rate of historical strain[3], as the most ominous threat.

Davis and Namson's[1] key argument is that the Santa Susana anticlinorium north of the earthquake is a fold uplifted by slip on the blind south-dipping Pico thrust it conceals. The south flank of the fold rose by about half a metre during the earthquake[4]. Davis and Namson regard the north-dipping Santa Susana fault, whose trace snakes along the south flank of the anticlinorium, as a shallow bedding-plane thrust passively folded by the Pico fault. The fold, and thus the Pico below, is in their view about 30 km long, disappearing about 10 km east of the Oak Ridge fault, and is unrelated to it.

Yeats and Huftile[2] counter that a 60-mgal trough in the isostatic residual gravity field of the Ventura basin[5] corresponds to the 15-km-deep sedimentary basin that abuts the downthrown side of the Oak Ridge fault[6], and argue that since the gravity trough extends without interruption to the San Fernando Valley near Northridge, so must the Oak Ridge fault. So although the mapped fault trace disappears 30 km from Northridge, the fault continues by stealth as a blind thrust. Yeats and Huftile regard the Santa Susana anticlinorium as the product of slip on both the Oak Ridge and Santa Susana faults. In their view, the fold disappears west of the Oak Ridge trace because the Santa Susana fault, rather than the Pico, terminates at that point.

Both studies, to my mind, could go further to bolster their arguments. Davis and Namson do not show a map of the Santa Susana anticlinorium; its western terminus relative to the Oak Ridge and Santa Susana faults is the keystone to their contention that the Pico stops east of the Oak Ridge fault. Similarly, Yeats and Huftile do not show the gravity field. In fact the 60-mgal trough shallows to 48

EARTHQUAKES

From California to Kobe

THE Kobe earthquake offers a chilling vision of the damage that the Northridge shock might have wrought had it struck beneath Los Angeles. Despite the larger size of the Kobe event (moment magnitude M_w=6.9 rather than 6.7), the Northridge earthquake shook the ground harder. Two factors explain the heavier toll at Kobe. The Japanese shock ruptured towards and then through the port and industrial city. In contrast, the Northridge event struck beneath a suburban setting and ruptured away from Los Angeles. And the heavy industry and dense housing sited on soft soil and landfill at Kobe proved a tragic combination, whereas Northridge is underlain by stiffer soils. Unfortunately, Kobe's predicament is all too close to conditions elsewhere, such as along the Hayward fault that rims the east margin of the San Francisco Bay, where another of the world's great ports lies waiting. The Hayward fault produced two shocks of magnitude around 7 during the nineteenth century, and so, like Kobe, could rupture again.

Earth scientists in Japan have made impressive progress in analysing the earthquake, and have generously distributed preliminary findings through the Coordinating Committee for Earthquake Prediction, chaired by Kiyoo Mogi of Nihon University, to which we are indebted. The Kobe event struck on the Arima–Takatsuki–Rokko fault system, one of the many shallow crustal faults in southwest Japan driven by the motion between the Philippine Sea and Eurasian plates. The fault lies 200 kilometres inland of the plate boundary, where two $M \approx 8$ earthquakes occurred between 1944 and 1946, and slips at about the same rate as the fault on which the Northridge earthquake struck, so earthquakes of magnitude 7 or over are rare. Seattle and Anchorage lie 250 and 350 kilometres, respectively, from their plate boundaries, and share some susceptibility to Kobe's fate.

The Kobe shock is a classic strike-slip earthquake, where each side of the fault moves sideways. The earthquake focus lies at the centre of an aftershock zone 50 kilometres long and 15 deep, a pattern reminiscent of the 1989 M_w = 6.9 Loma Prieta earthquake on the San Andreas fault. As much as 2 metres of surface fault-slip was found on Awaji Island southwest of the epicentre, typical of strike-slip earthquakes of this size. Some 6–12 hours before the main shock, four foreshocks of magnitudes 1.5–3 occurred at the future epicentre, similar to the 1992 Landers, California, earthquake (M_w = 7.3) and unlike the Loma Prieta shock. The Rokko strainmeter, a mere 25 kilometres northeast of the epicentre and within the aftershock zone, however, shows no discernible precursor during the month or hours before the rupture, at a level of 0.1 microstrain. This is consistent with experience in the United States for shocks of similar size, but is nevertheless disappointing. Nor was any precursory magnetic signal seen at an instrument 50 kilometres from the epicentre.

In 1916 a shock of magnitude M=6.1 struck within a few kilometres of the 17 January 1995 epicentre. Small shocks cluster along the future rupture zone on Japanese maps of 1980–91 seismicity, reminiscent of many strikeslip faults in the US, such as the Hayward and the New Madrid seismic zone. The shear strain rate along the fault, also used in California to help gauge the earthquake hazard, is higher than average for Japan, but not by much. The rate, about 0.3–0.4 microstrain per year near the fault, is similar to the San Andreas and associated faults in the US. Fourteen years ago, in *Earthquake Prediction — An International Review* (Maurice Ewing Series 4, AGU, 1981), Tokihiko Matsuda placed the Arima–Takatsuki–Rokko fault among seven inland fault zones that appeared to be late in their earthquake cycles, and that he thus, with quite extraordinary foresight, termed 'precaution' faults.

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