postulated high-potential gaps thus have been less seismically active than those with lower potential. This is not an artefact of region size, because the net areas of high-, intermediate- and low-potential regions differ by only 10%.

Kagan and Jackson apply several statistical tests to the gap hypothesis. They try a model in which earthquakes were twice as likely to occur in high-potential as in low-potential regions, and find that the data permit the hypothesis to be rejected at a confidence level above 95%. They similarly conclude that more than 90% of maps generated by assigning seismic potential to each zone randomly would predict the earthquake locations better than that of McCann and colleagues.

The apparent failure of the gap model is surprising, given its intuitive good sense. A natural question is whether the model is valid, but applicable only to larger earthquakes. Such tests are difficult, because the larger the magnitude, the rarer the earthquake, so earthquakes of magnitude 7 or greater are roughly ten times more common than those of magnitude 8 or more. Kagan and Jackson examine earthquakes over their ten-year period with magnitudes in excess of 7.5, and find one in the high-potential zones, three in the medium-potential zones, and five in the low-potential zones. So although the sample size is smaller, the gap model still seems unsuccessful.

Alternative

The alternative to the gap hypothesis is that earthquakes, rather than being quasiperiodic, occur in clusters. Kagan and Jackson consider the ratio of the standard deviation of the time between earthquakes to the mean time between them. If this ratio is less than 1, the process is quasiperiodic, whereas clustering would give a ratio greater than 1. Clustering has been suggested for the southern San Andreas fault, where over the past 1,500 years the mean period between events is 132 years with a nominal standard deviation of 105 years[8]. If earthquakes do cluster, the gap assumption of reduced seismicity after a large earthquake would not apply, presumably because not enough accumulated strain is released to preclude subsequent earthquakes.

Kagan and Jackson's results suggest that earthquake recurrence should be re-examined critically. Even if the gap concept proves to apply for great earthquakes, its utility for hazard assessment will be limited if it is inapplicable to smaller earthquakes which are still destructive. It may be that seismicity in some regions is quasiperiodic, whereas in others it clusters. The apparent failure of the gap model should thus spur further work in studies of fault processes. One key area is the interaction in space and time between slip on adjacent portions of faults[4,9]. There is also much to be learned about the fraction of the plate motion that does not occur as seismic slip: this fraction varies dramatically between plate boundaries[10] and can pose difficulties for identification of seismic gaps and estimates of recurrence times[11].

Assumptions

Kagan and Jackson's new study will do much to shape thinking on earthquake prediction. It demonstrates the need to pose forecasts in a form suitable for statistical testing, and to test them against subsequent data. For example, it would be meaningless to state that the gap hypothesis predicts only gap-filling earthquakes. Similarly, the authors note the need to test whether the observed quasiperiodicities at some plate boundaries exceed those expected purely by chance. Such testing, together with analysis of key assumptions used in forecasts[12], should help establish how useful probabilistic earthquake forecasts are. Because earthquakes on individual plate-boundary segments are infrequent by human timescales, centuries may be needed to provide a consensus.

Until then, inferences will still have to be drawn largely from the non-occurrence of earthquakes, a challenging prospect because *a priori* assumptions must be made. By way of analogy, fatal attacks by grizzly bears are more common in Montana than in New York. Does this indicate a 'bear gap' in New York so that an attack is now more likely there? Or does it represent a difference in intrinsic hazard? Depending on the assumptions made, either interpretation is tenable. □

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DAEDALUS

Icy blasts

A SPACE rocket needs to pack as much energy as possible into a given mass of fuel. Hydrogen and oxygen are about the best of stable fuels. Propellant chemists look longingly at such unstable substances as monatomic hydrogen, and the hydride and hydrogen-molecule ions, which would give maybe thirty times as much energy if only they could be captured. Daedalus now plans to make them by irradiating solid hydrogen.

He has been inspired by the 'matrix isolation' of unstable molecules. This technique incorporates suitable precursor molecules in a matrix of solidified gas near absolute zero, and then irradiates it with ultraviolet light. The molecules are created and trapped *in situ*. Daedalus calculates that ultraviolet light of wavelength 270 nm should split hydrogen molecules into single atoms. A wavelength of 70 nm could divide them into hydride and hydrogen ions. High-energy radiation could induce more drastic reactions still.

Solid hydrogen, of course, is merely the minimum-energy arrangement of equal numbers of protons and electrons. All possible reactions within it simply shift these charged entities into more energetic positions. Daedalus will encourage these shifts by maintaining a strong electric field across his frozen hydrogen. As the incoming radiation springs the particles out of their original sites, the field will prevent them just falling back in a recombination reaction. It will flick them away to lodge elsewhere. The final nightmarish product should be the most energetic distribution of protons and electrons that can be just stabilized by a temperature near absolute zero. It may still contain eighty-five per cent of normal hydrogen, separating and stabilizing its contents of high-energy atoms, ions and sites. This could still give it six times the energy of hydrogen–oxygen fuel (and twenty times that of TNT).

The result will be a bomb of appalling violence, ready to explode the moment its temperature rises the few degrees to its melting point. Even Daedalus does not recommend it for primary lift-off. But as a sustainer for long space journeys it is ideal. A spacecraft can call on sunlight or nuclear power for its energy; but its propellant mass is limited by what it can carry itself. A probe carrying pure hydrogen could use its power supply to freeze the gas and matrix-irradiate it into little pellets of hyper-energetic fuel. By exploding these at intervals in an expansion nozzle, it could generate enough thrust to drive around the Solar System as never before. Undignified expedients like swinging round Jupiter to gain speed might no longer be needed. David Jones