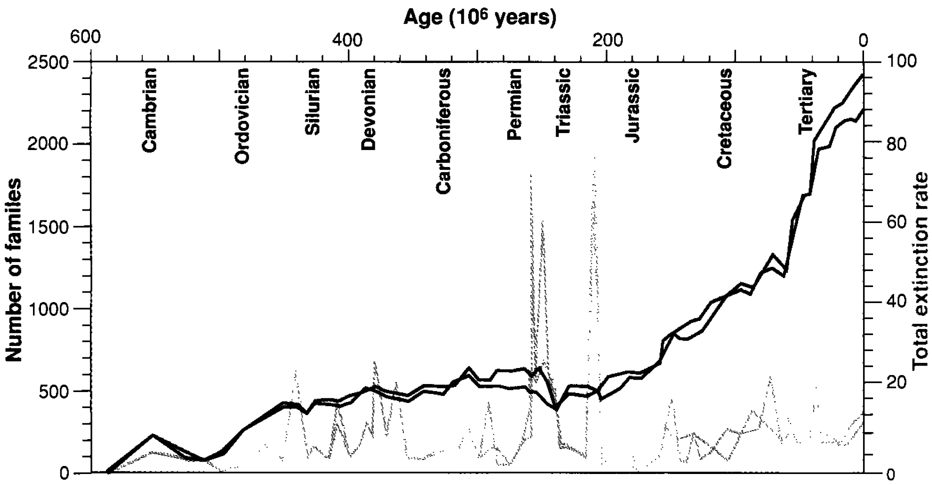

Extinctions in the past. Past major extinctions have produced transient dips in the proliferation of the number of families on Earth. The present human-generated mass extinction may have a more protracted outcome.

Nee and May focus on the entire tree of life in evolutionary terms, asserting that if 80% of the tree survives an extreme mass extinction like the Late Permian crash, there is little loss of "evolutionary history." True, the mass extinctions in the prehistoric past have pruned only 5 to 10% of the perhaps half billion species that have existed (see the figure). But these crash episodes can exert a strongly directional influence on subsequent evolution (*5*). Much depends of course on which species get the chop—whether clumps of species or species at random. For instance, the demise of the dinosaurs in the Late Cretaceous is a main reason why we are here to assess their fossilized remains.

The Nee and May report not only probes evolutionary history but prompts thoughts about the evolutionary future. Regrettably the latter remains a black hole of research, even though the next few decades seem set to impose a profoundly depletive hiatus on certain basic processes of evolution. A grand-scale fallout of species generally leaves homogenized biotas with generalist species in the ascendant, to the detriment of the more numerous specialist species. In contrast with the aftermath of prehistoric mass extinctions, human-dominated landscapes will encourage the generalist species to proliferate—all the more so as natural controls (predators, parasites) are preferentially eliminated. The upshot could well be a "pest and weed" ecology, with all that implies for evolutionary history.

At the same time, we are probably witnessing an end to the evolution of vertebrates larger than a few kilograms. More significant still, we are eliminating the evolutionary powerhouses of tropical forests and wetlands, these being regions that have supplied the majority of new species in the prehistoric past (*6*). This could well delay the biotic recovery by several million years beyond the "par" period of 5 million years for a postcrash phase. There is a host of such front-rank questions (*7*), yet they remain almost entirely unaddressed.

What does all this say for conservation planning? Should we continue with our overwhelming emphasis on saving as many species as we can, particularly the charismatic mega-vertebrates? Or perhaps we should try to limit future damage by safeguarding evolution's capacities for speciation, origination, and other forms of renewal. These two aims are far from congruent. The greatest evolutionary potential is manifested by invertebrates; their huge reproductive scope supplies abundant resources for natural selection to work on. Perhaps invertebrates should receive differential support from conservationists, in contrast to the whales, elephants, rhinoceroses, and the like, which, producing only a handful of offspring in a lifetime, are comparatively dead ends for speciation purposes.

Within a generation we may commit the biosphere to a grand-scale depletion that will disrupt evolution for at least 200,000 generations, or 20 times as long as humans have been a species. The number of people affected could be on the order of 500 trillion (on the basis of an average global population of 2.5 billion people), or 10,000 times more humans than have existed thus far. These are challenging times to be an evolutionary biologist. Although we are far from generating many definitive answers about future evolution, we should take a better crack at pinning down the right questions.

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SEISMOLOGY

Tsunamigenic Sea-Floor Deformations

Costas Synolakis, Philip Liu, George Carrier, Harry Yeh

As important as it is for hazard mitigation, the calculation of three-dimensional tsunami inundation in real time remains a formidable undertaking. Recent advances in hydrodynamics (*1*) triggered by the availability of high-resolution field and laboratory data have demonstrated that—given reasonable initial data—the predictions of runup heights are correct to first-order, and therefore, attention has been focused on the effects of the seismic predictions of the fault parameters used for model initialization.

The National Science Foundation recently sponsored a workshop (*2*) to examine the state-of-the-art of interfacial seismology and its interface with tsunami hydrodynamics. One objective was to ascertain which quantitative features of the early sea-floor deformation can be inferred from teleseismic data, with what accuracy they are believed to be known, and the scientific basis of these inferences. Another objective was to discuss recent developments in the deployment of real-time bottom pressure recorders and seismic instrument arrays for real-time monitoring of tsunami generation, as well as the

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implementation of their data into real-time warning.

Hiroo Kanamori (California Institute of Technology) opened the workshop with an overview of the tectonic motions that generate tsunamis and defined the relevant physical fault parameters. Seismological data provide estimates of the seismic moment (that is, the magnitude M_w), fault width (W), fault length (L), fault slip (D), and rupture duration (L/V), where V is the rupture velocity. For most large subduction zone earthquakes, these parameters have been estimated reasonably well (see table). Kanamori asserted that the rupture time is small in comparison to typical tsunami propagation time scales, for all except perhaps the giant events, and is likely unimportant in the actual tsunami generation.

Certain earthquakes referred to as tsunami earthquakes (3) have slow faulting motion and very long rupture duration, at least three times longer than those listed in the table. These earthquakes probably occur at shallow depths within the sedimentary structure, where entrapped layers with lower rigidity cause greater slip for a given seismic moment. Because of the extreme heterogeneity, accurate modeling is difficult, resulting in large uncertainties in estimated ground deformation. Worse, the spatial and temporal patterns of submarine slumping are presently poorly understood, and it is often difficult to differentiate between slumping events and tsunami earthquakes from teleseismic records.

Tsunami coastal effects are greatly affected by the specific details of the earthquake rupture pattern. Eric Geist [U.S. Geological Survey (USGS)] explained how slip variations in the strike direction lead to variations in tsunami amplitude parallel to the wave front that are preserved during local propagation (4). Slip variations in the dip direction lead to changes in the tsunami wave form, producing N waves (that is, leading waves shaped like the letter N), whose polarity affect runup dynamics.

Necessary as it is for correctly initializing tsunami models, determining the time history of sea-floor surface elevation remains elusive, for it relies on an understanding of the basic physics of earthquakes. Tom Heaton (California Institute of Technology) discussed Reid's elastic rebound theory and argued against it, using common sense fracture-mechanics considerations; he pointed out that the deformation area estimated from aftershocks often is twice that estimated from geodetic data, begging the question, which one is the more realistic estimate.

Without before and after bathymetric data, the only method for validating the predictions of fracture models on the sea-floor deformation is the inversion of seismic, geodetic, or hydrodynamic data. Apostolos Papageorgiou (Rensselaer Polytechnic Institute) presented results from a recent inversion of the M_w = 9.2 Great Alaskan Earthquake of 1964. The rupture scenarios used were based on the slip model inferred recently by joined inversion of tsunami and geodetic data. The qualitative characteristics (that is, variation of intensity with time) of the synthesized ground motion in Anchorage were shown to be consistent with eyewitness accounts, raising the possibility of simulating correctly the time history of sea-floor deformation for study of historic events.

Hydrodynamic inversion uses runup or tidal gauge data as input for determining the initial sea-floor displacement that generated the wave motion. Although there have been significant advances, the criteria for regularizing what is an ill-posed problem remain lacking. Nobuo Shuto (Tohoku University) and Kenji Satake (Geological Survey of Japan) have pointed out that the geographic distribution of records is perhaps more important than the actual number, although a threshold number of data sources for useful inversions is as yet undetermined.

M_w	W (km)	L (km)	D (m)	η (m)	L/V (s)
7	30	70	0.6	0.16	23
8	80	200	2.7	0.70	70
9	240	600	9.0	2.30	200
9.5	250	1000	27.0	7.00	330

Estimates of fault parameters for tsunamigenic earthquakes. Here, η is the corresponding vertical sea-floor displacement.

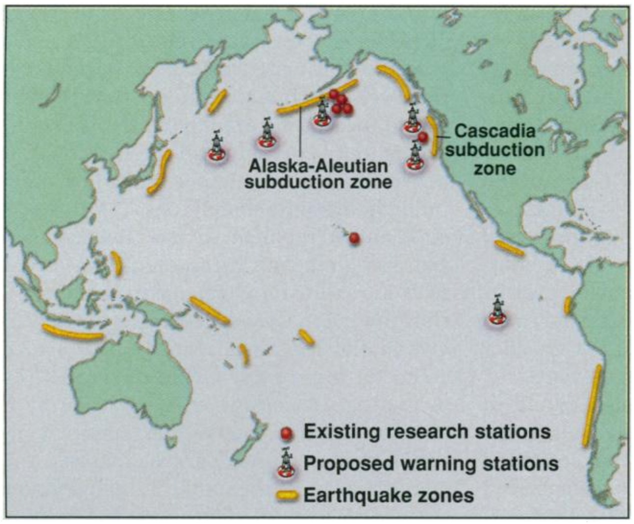
Currently, all tsunami hydrodynamic models use the Harvard CMT solution, the relation for the seismic moment $M = LW\mu D$, where μ is the rigidity, and elastic dislocation theory for predicting the sea-floor displacement. An important issue is the accuracy to which different fault parameters are calculable in real time and as a function of time. The seismologists at the workshop were blind-polled as to their best guesses of the errors in the estimates of the fault parameters for tsunamigenic events, which rely exclusively on teleseismic records. Even though there is scant evidence for validating fault data in subduction zones (SZs), the guesses were unexpectedly similar: The short-term errors range from 25 to 50%, except for the length and width, where they may be as high as 75%; the error in the distribution of slip and its strikewise variation may be as high 90%. Errors in longer term estimates are lower by a factor of 2. The best guesses for the rigidity for SZ events varied from 5×10^{11} to 10×10^{11} dyne/cm^2.

The rise time τ remains elusive; it is defined as the ratio of the barrier interval (a measure of the heterogeneity of the fault plane) over the rupture velocity V, a stable parameter estimated to be 0.7 to 0.9 of the S-wave velocity. It is conjectured that τ can be determined within a factor of 2 for SZ events, except for the pathological silent events, but that its estimate is unimportant to first-order for hydrodynamic simulations.

A major problem in real-time tsunami warning is recognizing an anomalous event such as a tsunami earthquake. Emile Okal (Northwestern University) discussed how to extend the real-time estimation of source characteristics of the TREMORS model by measuring the seismic energy carried by P waves (5). When coupled with routine real-time estimates of M_w, Okal compares the characteristics of the source at high and low seismic frequencies. On the basis of analysis of the major SZ events of the past few years, it appears possible to uniquely identify tsunami earthquakes as those with a deficiency of up to two orders of magnitude in the ratio of seismic energy E to its moment, E/M. When implemented into TREMORS, this method could automatically identify exceptionally efficient tsunami generation in adequate time for warning.

Two major current developments in real-time tsunami warning are TriNet and CREST. TriNet is a wide–dynamic-range seismic network being constructed jointly by the California Institute of Technology, USGS, and the California Division of Mines and Geology. Kanamori asserted that if ground-motion data longer than 100 s can be retrieved, then the sea-floor deformation can be estimated quickly and provide key information for near-field tsunami warning; however, the systems' ability to detect such long-period strong ground motion has not been tested.

The Consolidated Reporting of Earthquakes and Tsunamis (CREST) was initiated in 1996 through the tsunami hazard mitigation implementation plan of the National Oceanographic and Atmospheric Administration (NOAA). According to Dave Oppenheimer (USGS), the USGS will be upgrading the seismic equipment and monitoring facilities of seismic networks operating in Cascadia, Alaska, and Hawaii, with 24-bit data loggers and broadband and strong-motion sensors. A total of 60 CREST sites will be installed or upgraded in the U.S. Pacific states. This equipment will provide rapid, reliable, and relevant seismic data to



Existing and planned tsunami monitoring stations. The network focuses on regions posing a direct threat to coastal communities of the United States. Research stations do not report in real time. Two of the six real-time reporting stations are scheduled for deployment in July 1997.

the tsunami warning centers that will be exchanged among them by way of the Internet and dedicated intranets.

In 1986, NOAA's Pacific Marine Environmental Laboratory started measuring tsunamis in the Pacific with the use of bottom-pressure recorders (BPRs), which store data but do not report in real time; the systems were deployed for up to 15 months at water depths of up to 5 km and can detect 1-mm changes in sea level that last longer than 2 min. Frank Gonzalez (NOAA) discussed NOAA's plans (6) to deploy a six-buoy tsunami monitoring network of a real-time reporting version, for operational hazard assessment and warning (see figure). The first two buoys are scheduled for deployment in 1997, south of the Shumagin Islands in the Alaska-Aleutian SZ and west of the Cascadia SZ.

The installation of BPRs for real-time warning has also been progressing in Japan, where the National Research Institute for Earth Science and Disaster Prevention (NIED) has installed an optical submarine cable for earthquake and tsunami monitoring in Sagami Bay; S. I. Iwasaki (NIED) explained that its main objective is the inference of the sea-floor displacement for real-time warning.

Overall, despite significant advances over the past 5 years, the following issues remain troublesome, and progress is needed for reliable tsunami warnings. (i) There is lack of quantitative information on sediment layers overlying tsunamigenic faults and about how these layers affect directly the generation of tsunamis. (ii) A consistent methodology for differentiating between submarine slumping and tsunami-earthquake events needs to be developed. (iii) The distribution of friction in the fracture zone of tsunamigenic events needs to be better calculated either through measurement or theory. (iv) The effects of onshore small-scale topography and focus-inducing large-scale bathymetry and areas at risk from exceptional runup need to be further identified to allow for more targeted real-time warnings. (v) Better methods for identifying the strikewise and slipwise slip distribution need to be developed.

Yet, there is wide consensus that the seismic moment, the hypocentral location, and the dip and strike angles, if known from fault characteristics, are reliably determinable in the short term for first-order initialization of hydrodynamic computations and are sufficient for differentiating between small and large events, except in the Okal-style atypical events. The key for better data, better warnings, and faster results is the deployment of strategically located BPRs with redundancy built in and the use of satellite communications as soon as cost-effective.

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NOTA BENE: CANCER BIOLOGY

The Importance of Telomerase

The ends of chromosomes are capped with specialized sequences, generally multiples of TTAGGG. These nucleotides are synthesized by the ribonucleoprotein telomerase to complete the ends of the chromosomes during DNA replication, a task beyond the capacity of the usual DNA polymerase. Another, more glamorous function has also been ascribed to telomeres: Because many mammalian cells do not express telomerase, it has been suggested that the resulting telomere shortening during cell division eventually results in chromosome instability, causing the "aging" and death of the cell (*1*); the corollary to this notion is that the almost ubiquitous expression of telomerase in tumor cells may be a necessary contributor to the transformed phenotype, allowing the cells to go through round after round of division without losing their telomeres (*2*).

In a paper in a recent issue of *Cell* (*3*), researchers tested these functions of telomeres in mice by generating strains of animals lacking the RNA component of telomerase, which effectively eliminates any telomerase activity. Some of the features of these mice confirm the expected. Careful analysis of cultured fibroblasts from the transgenic mice by fluorescence in situ hybridization shows that about 4.8 kb of telomeric DNA is lost with each cell division and that there are a large number of chromosomal abnormalities. Nevertheless, for at least six generations, the mice survived.

What of telomeres and tumors? Fibroblasts from the mice missing telomerase are perfectly able to form tumors after transformation with oncogenes; this is true even for cells with profoundly shortened telomeres. Perhaps, like yeast, tumor cells have other ways of maintaining the ends of their chromosomes (*4*). This result takes some of the shine off the notion that telomerase is essential for tumorigenesis and, as the authors suggest, may indicate that telomerase activation is passively coselected as tumors develop.

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