phasized the great need for better understanding of the exact structural changes produced in DNA, especially by chemicals, and the correlation of specific DNA changes with particular cellular events, whether cell-killing, mutagenesis, or carcinogenesis. Chemicals and radiation exposure may produce several alterations in DNA structure, not all of which are necessarily harmful to the cell.

Peter Cerutti of the University of Florida is one of the investigators who is working to identify and characterize the DNA lesions produced by various carcinogens. He points out that persistence of the lesions may help to determine their biological significance. For example, he has found that a highly carcinogenic derivative of benz[*a*]pyrene, a suspected human carcinogen that is widespread in the environment, causes a persistent chemical lesion in the DNA of mammalian cells. Cerutti thinks that such persistent, but nonlethal, lesions may be responsible for the development of mutations and also cancers.

The other diseases thought to be caused by defects in DNA repair are AT, Fanconi's anemia and, possibly, Bloom's syndrome. All of these conditions are characterized by a high incidence of both cancer and chromosome abnormalities. The actual defects in DNA repair have not been as well characterized as those in XP cells, although several investigators have detected repair deficiencies in some, but not all, cells derived from AT and Fanconi's anemia patients. These diseases, like XP, appear to be genetically heterogeneous.

Thus, there are still many unanswered questions concerning the postulated connection between DNA repair pathways and cancer. Nevertheless, as research into the intricacies of the mammalian pathways grows, investigators think that they will see a payoff both in terms of basic knowledge about the systems and of a better understanding of how DNA repair affects human susceptibility to cancer.—JEAN L. MARX

Tidal Waves: New Method Suggested to Improve Prediction

Tidal wave, or more properly, tsunami (soo nah' me) prediction is not a glamorous field of research today, as earthquake prediction is, but the stakes are still high. A large earthquake, the most common cause of tsunamis, in one part of the Pacific can create waves capable of suddenly inundating villages and cities on the coasts of both North and South America, Asia, and the islands in between. The destruction can be staggering. A tsunami in 1896 killed 27,000 people in Japan. One, in 1960, destroyed or severely damaged every Chilean town along 800 kilometers of coast. But tsunami prediction, a reality since 1948, has helped minimize the loss of life during the four major tsunamis that have crossed the Pacific since 1948.

The reliability of tsunami warnings has improved during the 30-year history of the Tsunami Warning System, now a cooperative international organization operated by the U.S. Weather Service, but problems still remain. Improvement has been due largely to increased experience and the expansion of the system's network of observation stations throughout the Pacific. Now, an innovation in the way that possible tsunami-generating earthquakes are monitored may soon help to reduce the number of false alarms and increase public cooperation in areas, such as Alaska and Hawaii, where the most rapid warnings are required.

The present observation network of the Tsunami Warning System (Fig. 1) allows experts to locate and measure the magnitude of large earthquakes that may cause tsunamis, as well as to detect a tsunami itself and follow its progress across the Pacific. The system includes seismographs and tide gauges that are installed throughout the Pacific and linked to the Tsunami Warning Center in Hawaii. If an undersea earthquake appears from seismological data to be large enough to cause a tsunami, a watch is issued, alerting threatened populations to the possibility that a tsunami has been created. If a tsunami is actually observed by the tide gauges in the system, a warning is then issued. Because most watches and many warnings are not followed by destructive tsunamis, the effectiveness of the system has at times been impaired.

One reason that some unnecessary alerts must be called is that a great deal remains to be learned about how tsunamis behave once they are formed. A tsunami, which is actually a series of waves, like ripples from a pebble thrown into a pond, moves quite predictably across the deep waters of the Pacific. Its great speed in the open ocean, about 800 kilometers per hour, contrasts with its small height of less than a meter. The variation of a tsunami's speed with water depth is well understood, so that arrival times thousands of miles from the earthquake can be accurately predicted.

Unfortunately, the size that a tsunami will be when it reaches land remains rather unpredictable. Eventually, it may rear up to as high as 30 meters within a few hundred meters of shore as it slows to about 50 kilometers per hour. Or it may disperse its energy before arriving at a particular beach and not cause any damage. Attempts to understand the basis of these differences have met with limited success.

The tide gauges of the warning system can record the passage of a tsunami (although it has nothing to do with the tides) and provide the first proof that a tsunami has been indeed created. But they cannot be used for predicting how large it will be at another location. In addition, initial tide gauge reports may not arrive at the warning center until 2 hours or more after the quake because of the travel time involved and the sometimes circuitous communication links with remote stations. Plans to link the network by a satellite have not yet progressed beyond a single experimental link.

An alternative to waiting for tide gauge reports would be to issue a warning solely on the basis of reports from several readily accessible seismograph stations. This is more rapid but considerably less reliable. It may take only a few minutes if the quake is within a dense network of instruments such as the one that comprises the Alaska Regional Tsunami Warning System. To predict whether or not a tsunami has been formed, the location and magnitude of the earthquake must be known. It is relatively easy to determine whether a quake is in the ocean, where it can cause a tsunami. Determining its magnitude is more difficult.

As a general rule, destructive tsunamis are generated by earthquakes of magnitude 8 or larger on the Richter scale. But not all tsunamis follow the general rule. For example, the 1946 Unimak Island quake in the Aleutians had a Richter magnitude of only 7.2 (about eight times smaller seismic wave amplitudes than magnitude 8.0), but it generated tsunami waves of 9 to 17 meters in Hawaii, killing 159 people.

Currently, the only way to avoid overlooking a dangerous earthquake is to put a conservative lower limit on the magnitudes that will trigger a watch. Any earthquake within the Pacific basin greater than magnitude 7.5 automatically initiates a watch. A warning is only issued for the Pacific if tide gauges detect a

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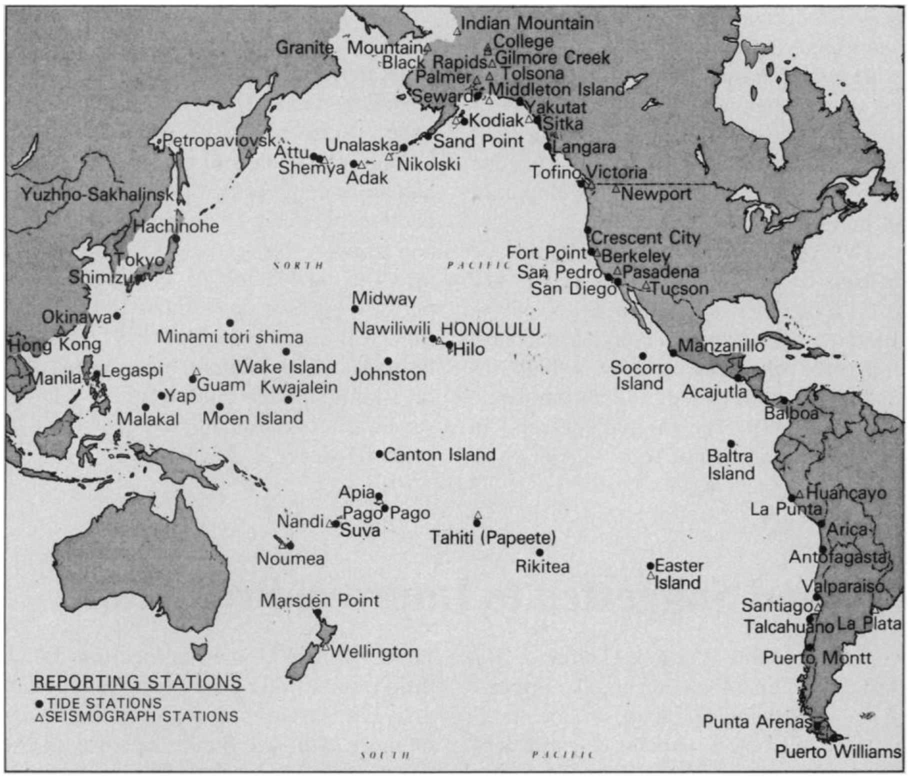

Fig. 1. Seismograph and tide gauge stations of the Tsunami Warning System. All stations report by various means to the Warning Center in Honolulu. The Alaskan stations also comprise the Alaska Regional Tsunami Warning System, organized for the rapid issuing of warnings to coastal Alaska and the Aleutian Islands. Several changes in station locations have occurred since this map was prepared, resulting in a net addition of two seismograph stations.

tsunami. No warnings have been issued by the Hawaii Warning Center since 1967, but there are about two watches each year.

When the threatened coastline is close to the location of an undersea earthquake, the only practical basis for a timely warning is seismological data. For example, the Alaska Regional Tsunami Warning System will issue a warning, not a watch, for an area within several hundred miles of any Alaskan coastal quake of magnitude 7.0 or greater, rather than the usual 7.5. In the last 10 years, the Alaska Warning Center has issued three warnings, but no significant tsunamis were generated.

These necessarily numerous watches and warnings can reduce public confidence in the warning system. A striking example from the earlier years of the warning system is the 1960 Chilean tsunami. In spite of being warned 6 hours before the first wave arrived, 61 residents of Hilo, Hawaii, were killed. As a public tsunami information pamphlet puts it, the victims apparently believed that the warning had been "just another false alarm."

Many researchers believe that the reliability of tsunami predictions would be improved by the use of specially designed seismographs. A wide range of seismic waves with different periods can be produced by earthquakes, from the very short period waves resulting from the sharp snap of rocks under high stress to very long period waves due to the slower movements of large sections of the ocean floor. Because it is generally thought that the up or down movement of these large blocks causes most tsunamis, some researchers suggest that the strength of seismic waves of very long period would be the best guide to an earthquake's ability to generate a tsunami.

Most seismographs in use today are not sensitive to very long period waves. Thus, they cannot "see" that aspect of an earthquake thought to be most responsible for tsunamis. The familiar Richter magnitude scale, which is useful as a measure of ground shaking and possible damage to buildings, was first calculated from the amplitude of seismic waves with periods of only about 1 second. This scale is now derived from 20-second waves so that large earthquakes, which produce a larger proportion of long period waves than smaller quakes, can also be accurately measured. In the present Tsunami Warning System, shorter period waves are used to locate the earthquake, but 20-second waves are used to calculate the magnitude.

A number of seismologists and tsunami researchers, including James Brune of the University of California at San Diego and Hiroo Kanamori of the California Institute of Technology, believe that even 20-second waves do not accurately reflect the true magnitude of some earthquakes and that 100-second waves should be used instead. It has already been shown by the work of Brune, Kanamori, and others that a large part of the energy released by some large earthquakes goes undetected unless the movement that produces very long period waves is included in the calculation of its magnitude. For example, the Chilean earthquake of 1960 had a magnitude of 8.3 when calculated on the basis of 20-second waves, but its magnitude was 9.5, more than 10 times larger in wave amplitude and more than 60 times larger in energy released, when calculated by Kanamori's method that attempts to include the energy release represented by very long period seismic waves. It was this possible underestimation of magnitude that prompted tsunami specialists to include a safety factor of up to one magnitude unit (a factor of 10) in the seismological criteria for issuing watches and warnings. But National Oceanic and Atmospheric Administration scientist Harold Loomis at the University of Hawaii as well as other scientists now believe that many alerts would not need to have been called if very long period seismological data had been available.

Such data have begun to be collected, but it has not yet been integrated into the Tsunami Warning System. Very long period seismographs have been in use for more than 10 years, but only recently have any instruments been devoted to tsunami studies. Two very long period seismographs have been set up in recent months under a Soviet-American exchange program, one in Hawaii and the other on the Soviet island of Yuzhno-Sakhalinsk northeast of Vladivostok. These instruments incorporate recent technical advances that have reduced internal noise and increased resolution. Project IDA (International Deployment of Accelerometers) employs identical seismographs in the study of the excitation or "ringing" of the whole earth by large earthquakes. A third station is being created by the modification of a conventional instrument at the Alaska Warning Center in Palmer.

Now, tsunami specialists must wait for enough large earthquakes and any tsunamis that result to see whether very long period seismology can actually make a contribution to tsunami prediction.

—Richard A. Kerr