Photo © Intergovernmental Oceanographic Commission's International Tsunami Information Center, Hawaii, U.S.A.

Above, towering seismic sea wave, or tsunami, strikes the shore at Hilo (Hawaii). An instant after the photograph was taken by an unknown seaman on 1 April 1946, the man seen at left (arrowed) was swept to his death—one victim among 300 killed or injured that day in Hawaii. The tsunami had been triggered off five hours earlier by an underwater quake in the Aleutian trench 4,000 km. to the north. Right, capsized fishing boats and smashed buildings on a Japanese beach demonstrate the shattering force of tsunami waves generated in May 1960 by an earthquake in Chile 16,000 km. away.

TSUNAMIS ocean waves of death and destruction

EVERY island and coastal settlement in the Pacific Ocean area is vulnerable to the onslaught of seismic sea-waves, the destructive oceanic offspring of earthquakes (or seisms) and volcanic eruption.

Some call them "tidal waves", a name as misleading as it has been persistent; these great waves are not caused by tides. The Japanese, whose islands have felt the destructive power of the great waves for generations, give us the name used internationally: tsunami.

In 1868 and 1877 tsunamis devastated towns in northern Chile, and caused death and damage across the Pacific. A series of seismic sea-waves generated by the eruption and collapse of Krakatoa in 1883 killed more than 36,000 persons in the East Indies. Japan lost 27,000 lives to the wave of 1896, and 1,000 more to that of 1933. There have been hundreds more whose effects were less spectacular but which took many lives and did much damage.

Tsunamis occur most often in the Pacific. Around this immense ocean runs a zone of extreme seismic activity crowned by a volcanic "Ring of Fire."

This seismic belt extends along the major geologic faults, or fractures, and the deep oceanic trenches of South and Central America and the United States, turning westward along the Aleutian Island arc, then southward through Japan and the Philippine Republic; here it branches westward to Malaysia and Indonesia, and eastward through New Guinea, the southern island groups, and New Zealand.

The phenomenon we call "tsunami" is a series of travelling ocean waves of extremely long length and period. In the deep ocean, their length from crest to crest may be a hundred miles or more, their height from trough to crest only a few feet.

They cannot be felt aboard ships in deep water, and they cannot be seen from the air. But the kinetic energy—the energy of movement—represented by a tsunami is impressive: a tsunami "feels the bottom" even in the deepest ocean, and it appears that the progress of this imperceptible series of waves represents the movement of the entire vertical section of ocean through which the tsunami passes. In the deep ocean they may even reach speeds of over 900 km. per hour.

As the tsunami enters the shoaling water of coastlines in its path, the velocity of its waves diminishes and wave height increases. It is in these shallow waters that tsunamis become a threat to life and property, for they can crest to heights of more than 30 metres and strike with devastating force.

Tsunamis are believed to originate as displaced columns of ocean water, but the displacing agent has not been positively identified. Seismic or volcanic alterations of the ocean floor, provided they impart some vertical movement to the water column, may cause tsunamis. Submarine ava-

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by Ronald Fenton

lanches on the slopes of the Pacific trenches may also produce tsunamis.

Although it has been established that a relationship exists between seismic or volcanic disturbances and tsunamis, the nature of this relationship is not well-defined. Tsunami magnitude appears to be a function of earthquake magnitude and depth, water depth where the tsunami is generated and the extent to which the earth's crust is deformed by the earthquake. But the combined effect of these factors is still imperfectly understood.

The speed of tsunamis varies with water depth, and it is this relationship which permits prediction of tsunami arrival times at all points in the Pacific Ocean area.

A tsunami warning system and an international tsunami information centre serving all areas of the Pacific have been set up at Honolulu, capital of Hawaii. Their work has done much to reduce the hazards of the tsunami—the most destructive of all waves.

Using seismographs and tide-gauges scientists are able to predict almost exactly when a tsunami will arrive at a given seacoast since tsunamis are known to travel at speeds that may average from 650 to 800 kilometres an hour, the exact speed depending on the depth of water over which they pass.

But it is still not possible to predict what effect the topography of the ocean floor will have on a tsunami. It is not completely clear, for example, why a tsunami's wave may be of negligible size at one beach, and of giant proportions a few miles away.

What is certain, however, is that all tsunamis—like hurricanes—are potentially dangerous, even though they may not strike each Pacific coastline or do damage at each coastline they strike. So a constant tsunami watch has to be kept and the peoples of the Pacific alerted when the great waves roll across the world's largest ocean. ■

International warning system

THE Tsunami Warning System in the Pacific is an international co-operative operation designed to predict the arrival of seismic sea waves (tsunamis) and to alert countries throughout the Pacific region. In 1965 Unesco's Intergovernmental Oceanographic Commission set up an International Tsunami Information Center which now works closely with the Tsunami Warning System in the Pacific, operated by the United States Weather Service from a headquarters near Honolulu (Hawaii).

The International Information Center provides aid in the establishment of national tsunami warning systems and technical advice on the latest warning system equipment. It also maintains a computerized storage and retrieval system on tsunami data.

Unesco's Oceanographic Commission also established an International Co-ordination Group for the Pacific warning system which today numbers 15 member countries (1).

The first tsunami warning system in the Pacific was set up in Hawaii by the U.S.A. in 1948, two years after a destructive tsunami took the islands by surprise, killing or injuring over 300 persons and causing widespread damage. Subsequently, the need for a broader based international network was shown when major tsunamis swept across the Pacific—from a submarine quake off Kamchatka in 1952 and from others near the Aleutians (1957) Chile and Peru (1960) and Alaska (1964).

The present Tsunami Warning System in the Pacific operates primarily through two lines of detection. The first is a network of over 30 seismograph stations which pick up the shock waves of earthquakes and then determine their magnitude and location. If the shocks are strong enough and if the focus of the quake is under the ocean or close enough to it to disturb the ocean floor a tsunami may have been generated.

The warning system H.Q. in Honolulu reports the fact to all participant countries and issues a preliminary alert that includes the estimated time of arrival of a possible tsunami.

The system then turns to its second line of detection: a network of more than 50 tide stations where gauges record the cycle of the tides continuously. Such gauges record tsunamis as abnormal phenomena.

When confirmation is received by the Honolulu H.Q. it alerts all countries to the approach of a potentially destructive tsunami.

New operational methods are now being developed for the tsunami warning system. Use of the latest technology and instruments will reduce the time needed to evaluate the tsunami hazards. The system will use a large network of ocean bottom and shore based seismic and tsunami sensors to transmit data to Honolulu and will eventually rely on space communication satellites. ■

(1) Canada, Chile, China, Ecuador, France, Guatemala, Japan, Rep. of Korea, New Zealand, Peru, Philippines, Singapore, Thailand, U.S.A., U.S.S.R.