Acoustic Detection of Submarine Eruptions

Fred Duennebier

GG 711

Nov 17, 2011

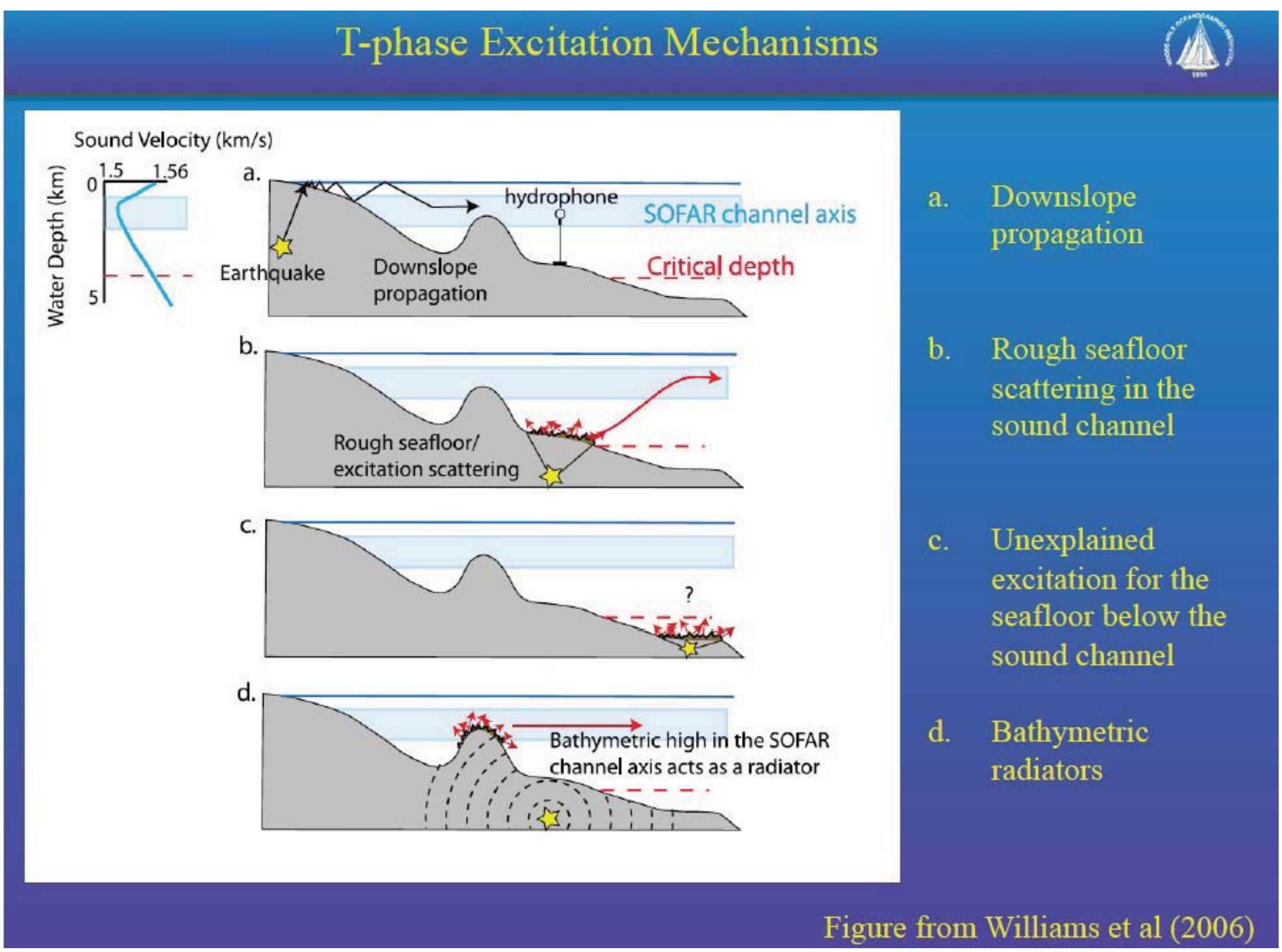
My background:

- Acoustics:
  - Earthquake T-Phases
- Seismology -
  - Moon, Mars, oceans
- Ocean Observatories:
  - Loihi, Mid Pacific, Station ALOHA
- End of Cheap Energy

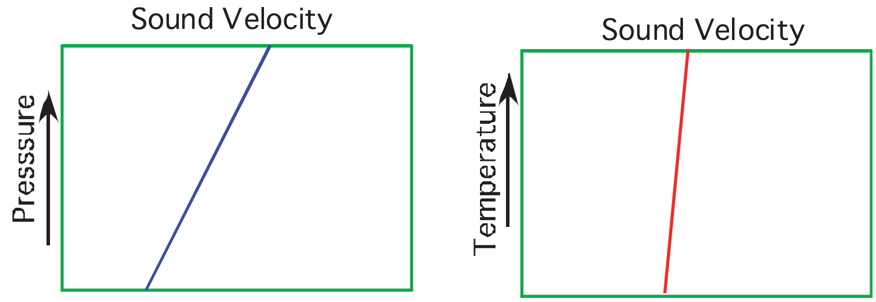
Deep Submarine Eruptions are DIFFICULT to detect.

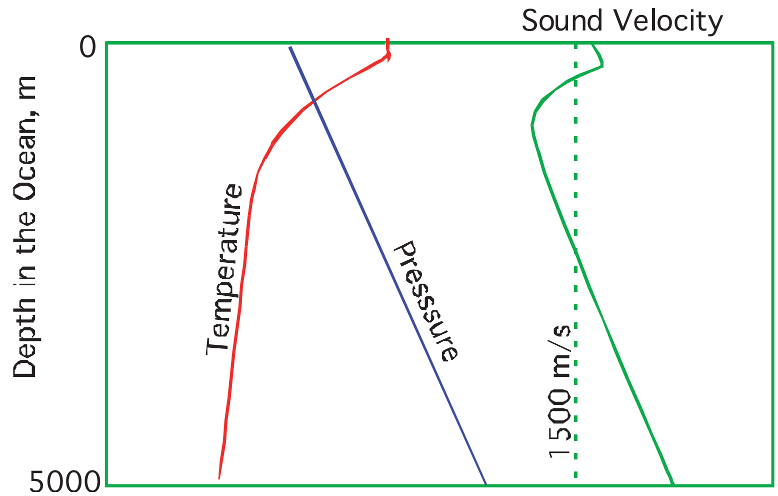
WHY?

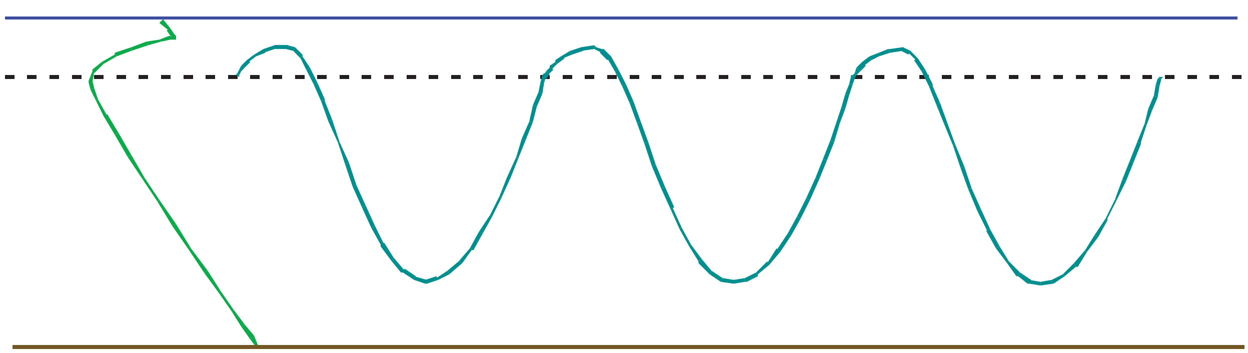
Often, it isn't the ERUPTION that's detected, but the associated earthquakes. As magma moves in the earth, generating new dikes and sills, earthquake swarms are generated, usually with a small "b-value", implying mostly small earthquakes.

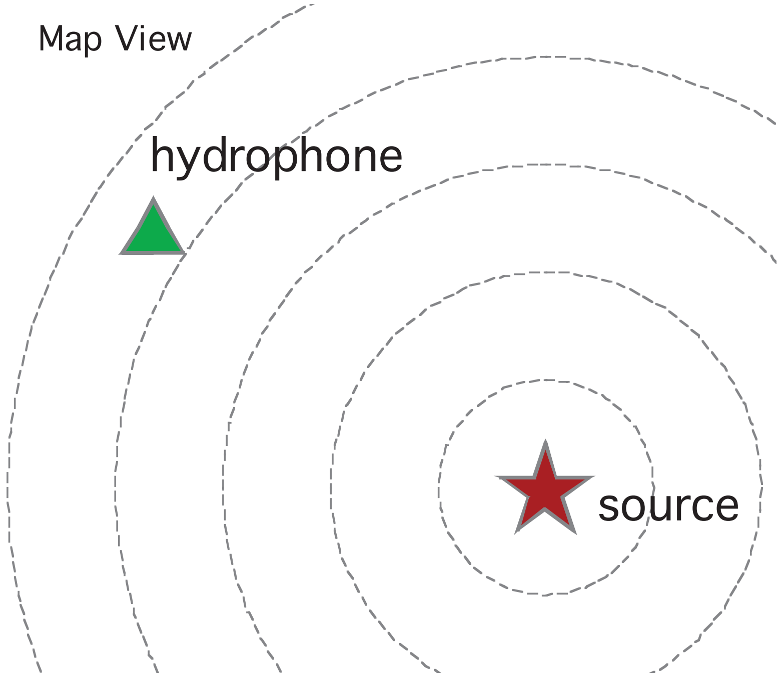


Another factor limiting the effectiveness of using sound to locate deep-ocean eruptions is the ocean sound channel.

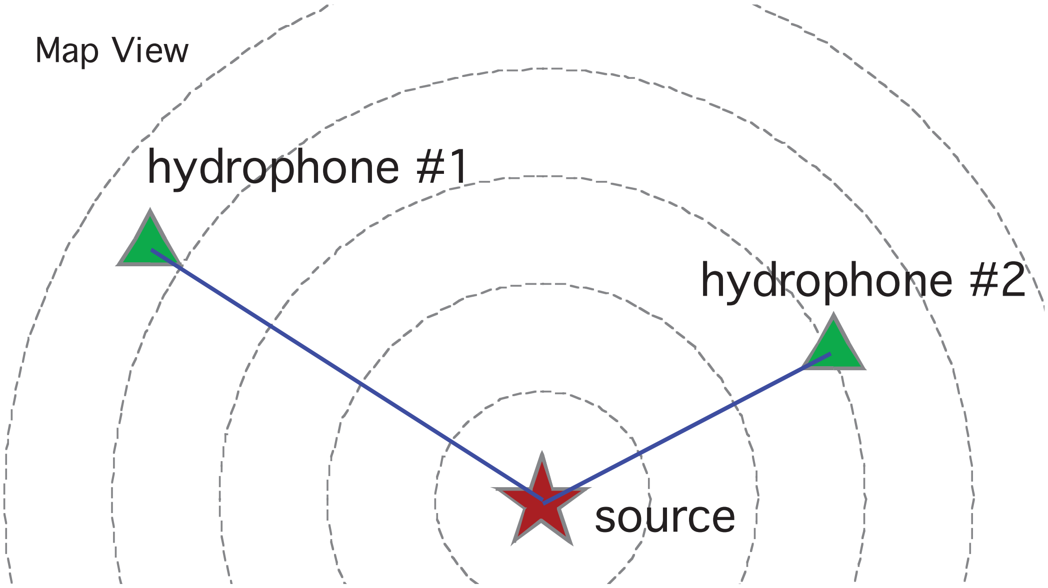








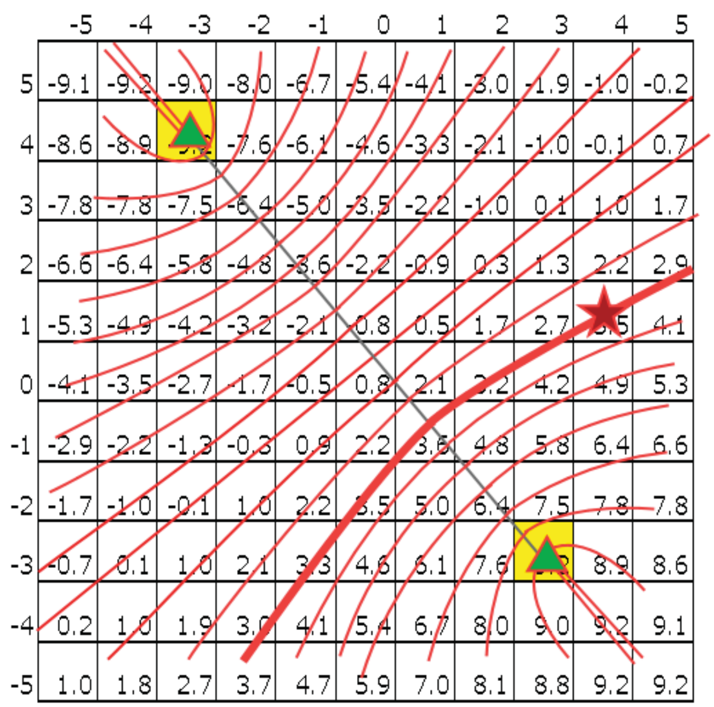
What can be learned about a source from a single hydrophone?



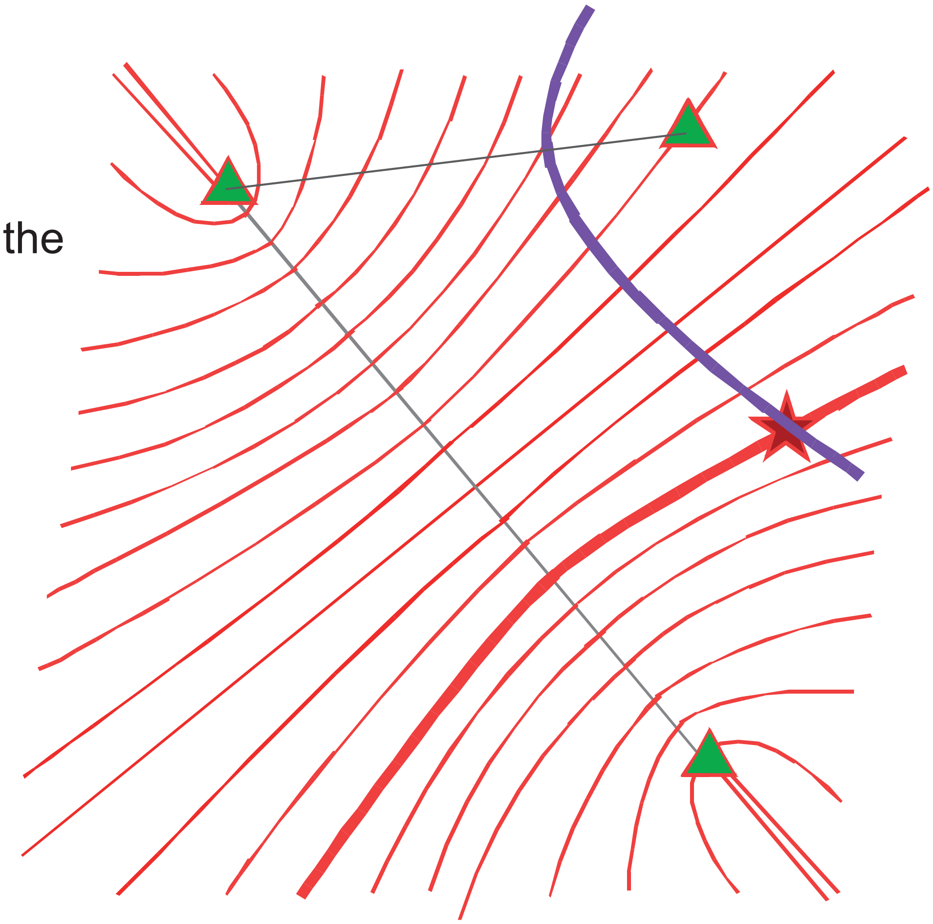
What can be used if the signal is detected on TWO hydrophones? The SPEED OF SOUND in water is nearly constant at 1500 m/s, so the DISTANCE to an object is proportional to the travel time.

With two hydrophones the source is constrained to lie on a curve where the ratio of the distances between the two hydrophones is fixed.

The curve is a **hyperbola**, and the source must lie on the line that describes all points that have the same arrival time difference at the two hydrophones.



Add a third hydrophone, and the location is found.



The T-Phase Project

From 1964-1972, the Hawaii Institute of Geophysics collected hydrophone data from arrays of hydrophones around the N Pacific to use for earthquake location. The hydrophones were publically used for air/sea rescue, but were likely used by the Navy for submarine monitoring.

During that time, the arrays also detected several swarms of volcanic events.

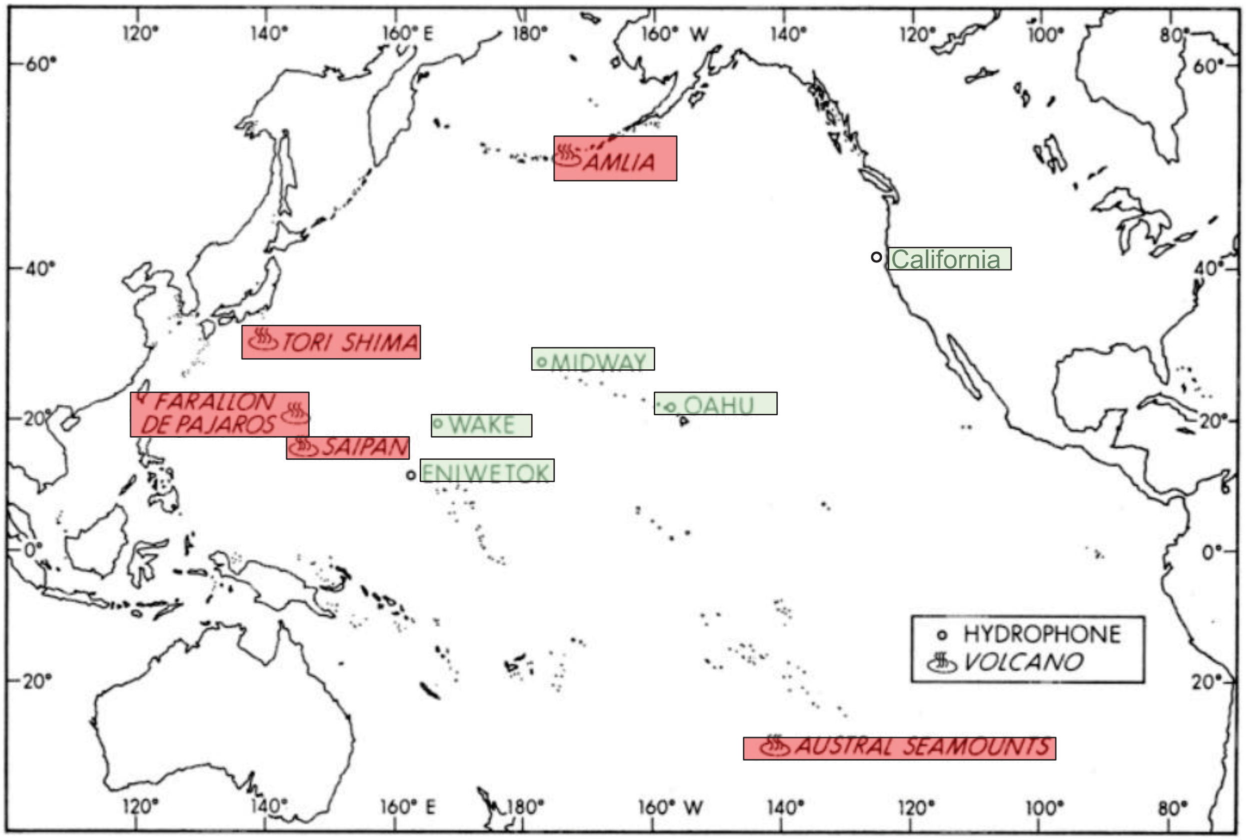


Fig. 1. Map showing the locations of the five occurrences of submarine volcanic activity

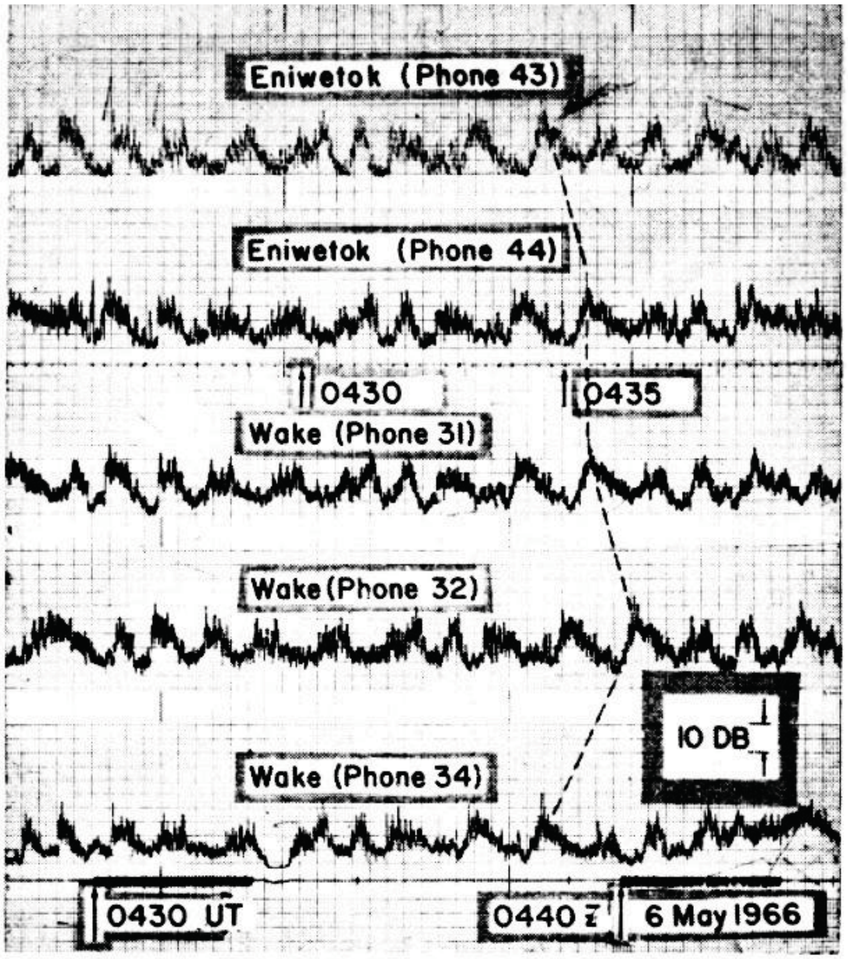
Journal of Geophysical Research Vol. 74, No. 2, January 15, 1969

Submarine Volcanic Eruptions Recently Located in the Pacific by Sofar Hydrophones[1]

Roger A. Norris and Rockne H. Johnson

Hawaii Institute of Geophysics, University of Hawaii
Honolulu, Hawaii 96822

Five sources of underwater sound having volcanic characteristics have been located in the Pacific Ocean by means of the Pacific Missile Range Sofar hydrophone network. Two are in the Mariana Islands, one in the Nanpo Shoto, one in the Aleutian Islands, and one at the southeast end of the Austral seamounts. The sounds range in duration from a few seconds (explosive) to weeks (periodic low rumblings). Sonagrams of some of these events show multiple bands as do those of underwater explosions.



: power-level records of the submarine eruption north of Saipan

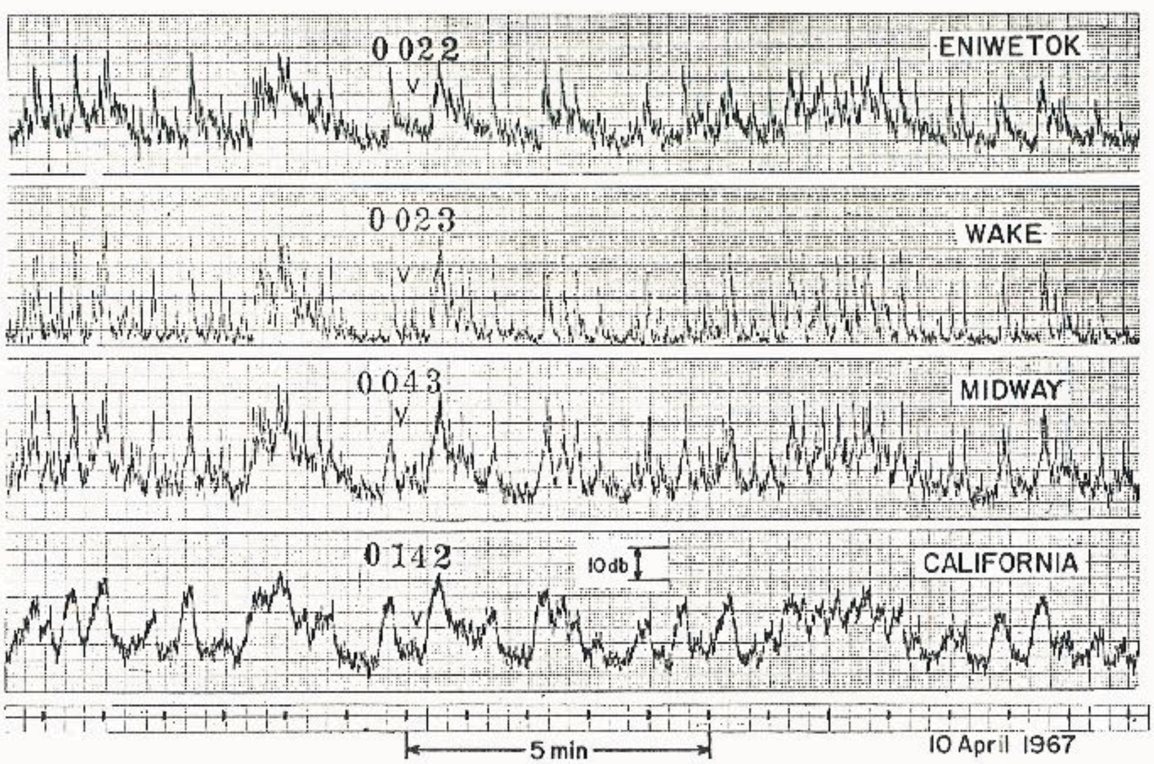


Fig. 7. Sound power-level records of the Farallon de Pajaros eruption about an hour before it ended.

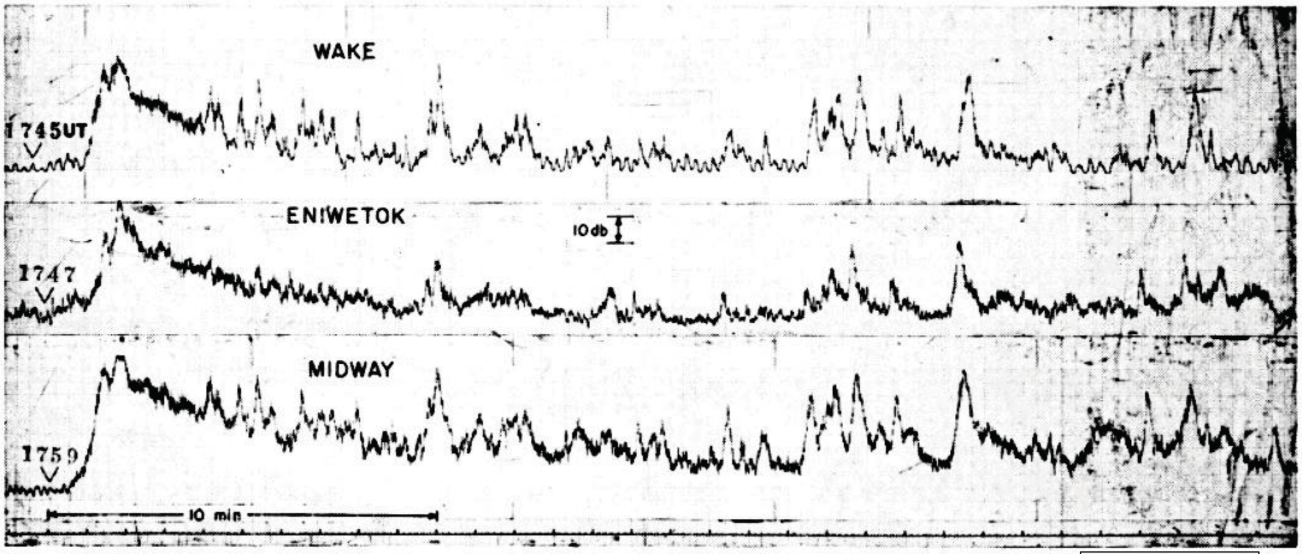


Fig. 2. Sound power-level record of the onset of the November 12–14, 1965, Tori Shima eruption as recorded by the Wake, Eniwetok, and Midway hydrophones.

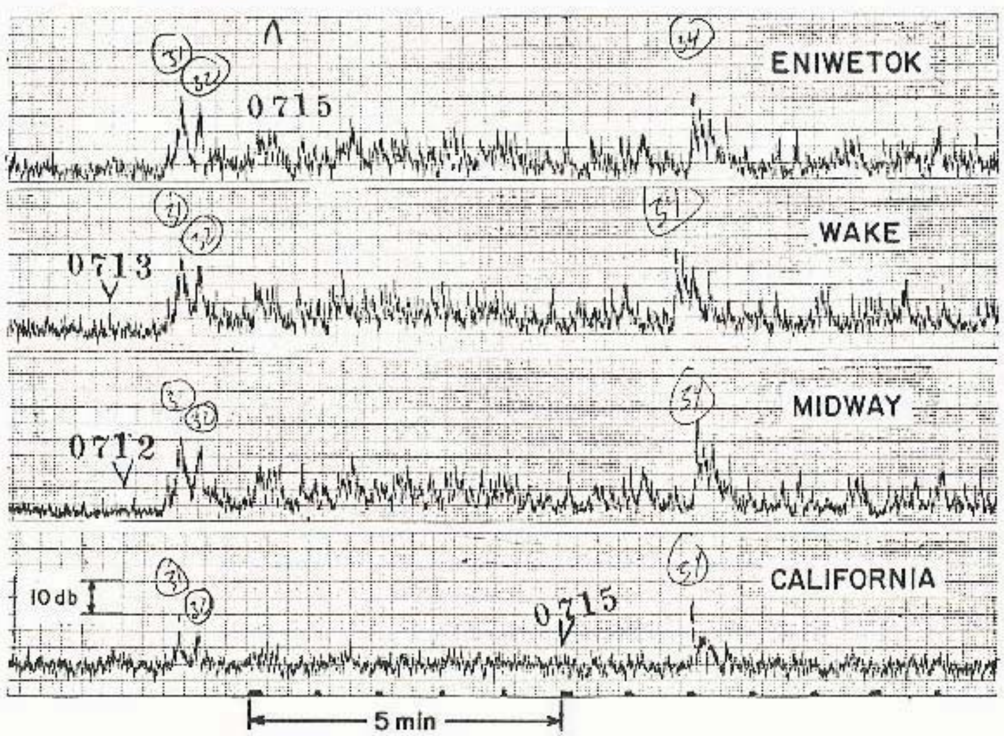
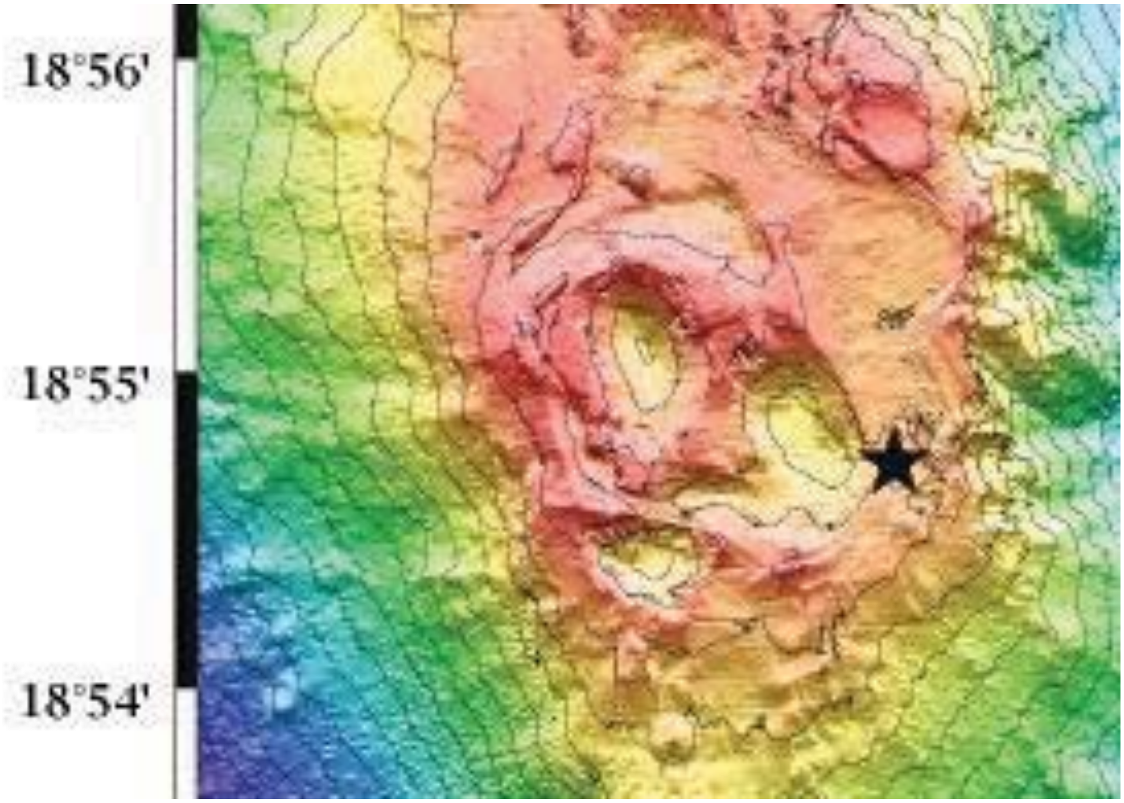
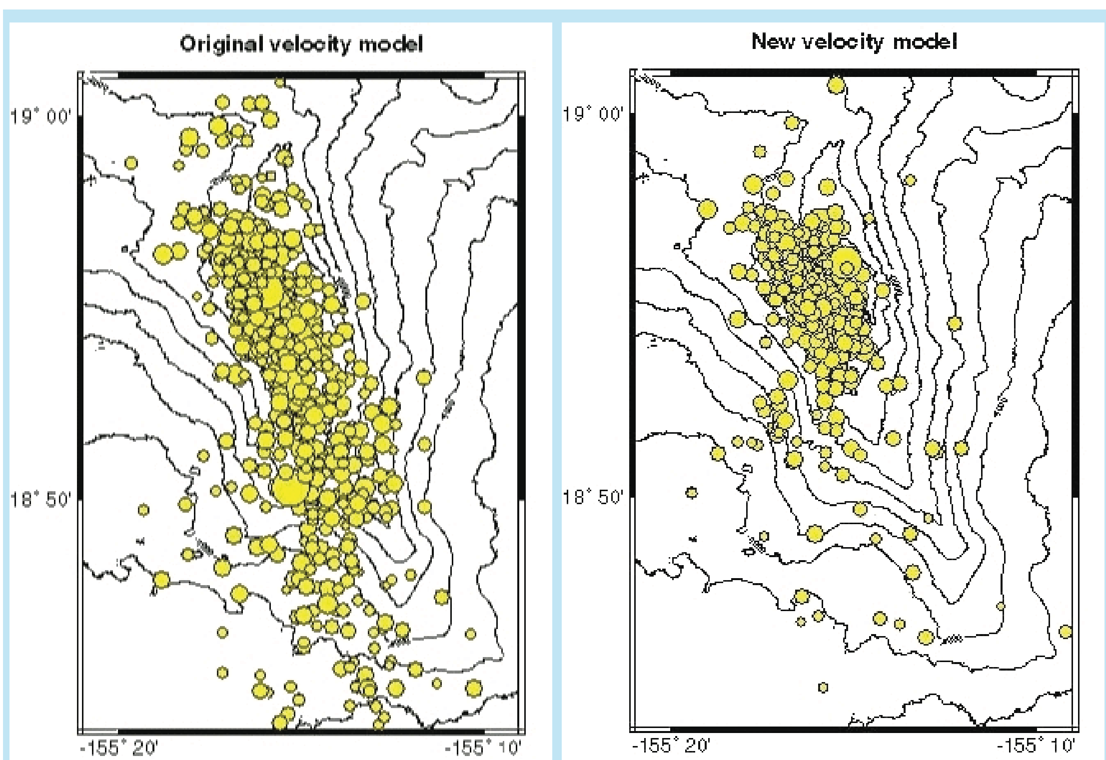


Fig. 11. Sound power-level record of the 29 May 1967 Austral Seamounts eruption near its beginning, as recorded by the Eniwetok, Wake, Midway, and California hydrophones.



Loihi Summit - Post 1996



1996 Loihi Swarm

HUGO Sounds

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 106, NO. B3, PAGES 4183–4206, MARCH 10, 2001

Monitoring Pacific Ocean seismicity from an autonomous hydrophone array

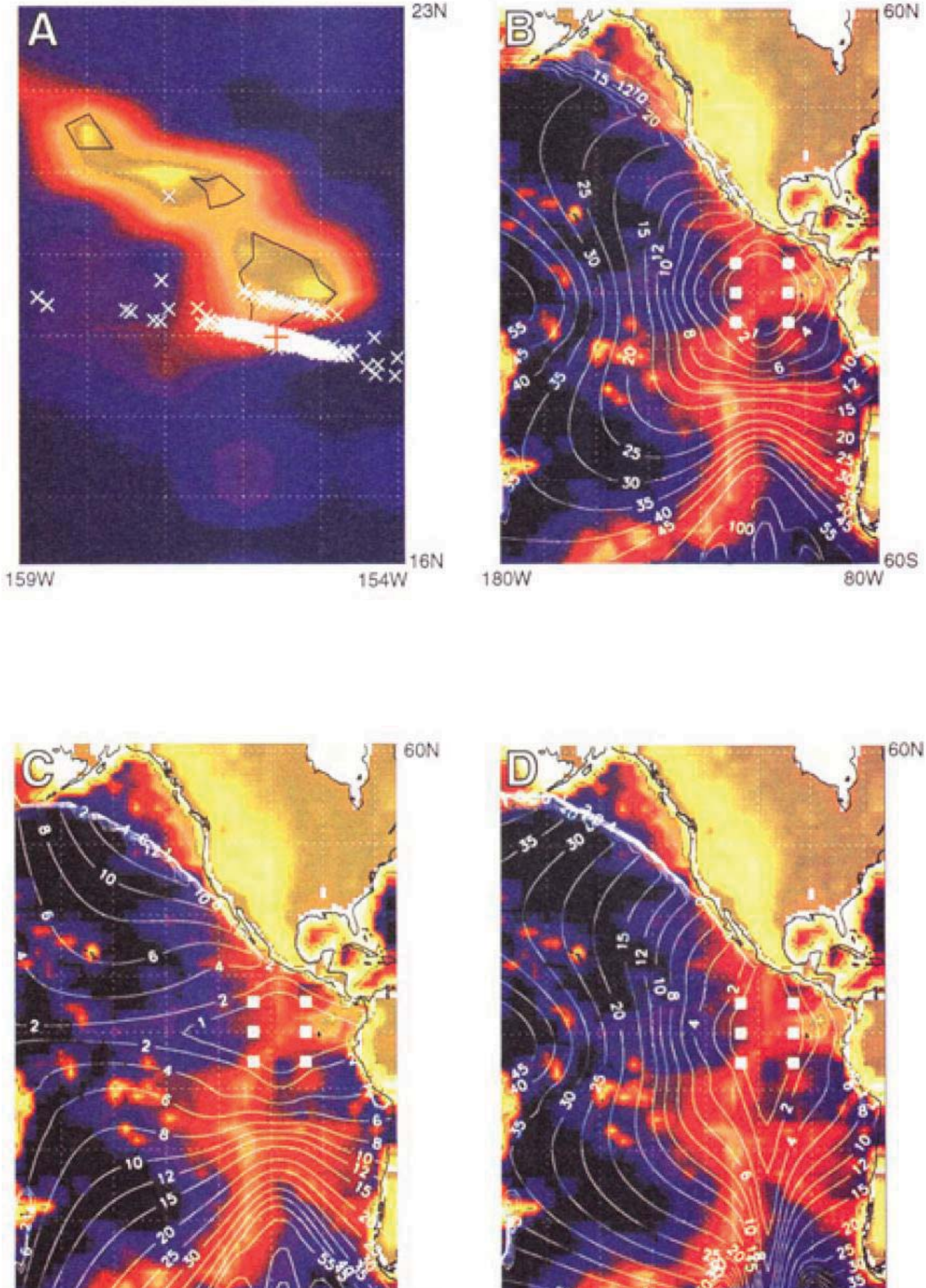
Christopher G. Fox

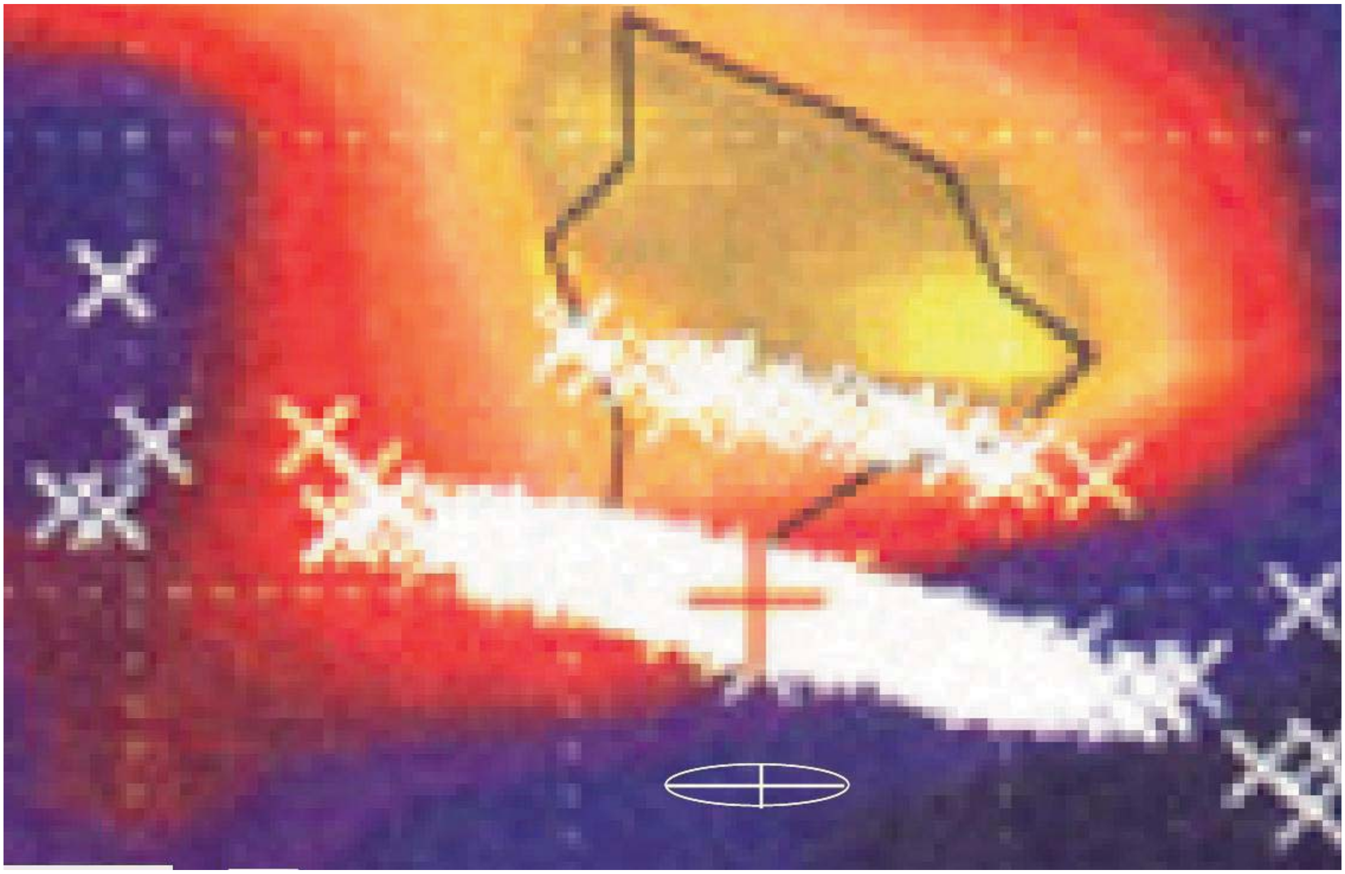
Pacific Marine Environmental Laboratory, NOAA, Newport, Oregon

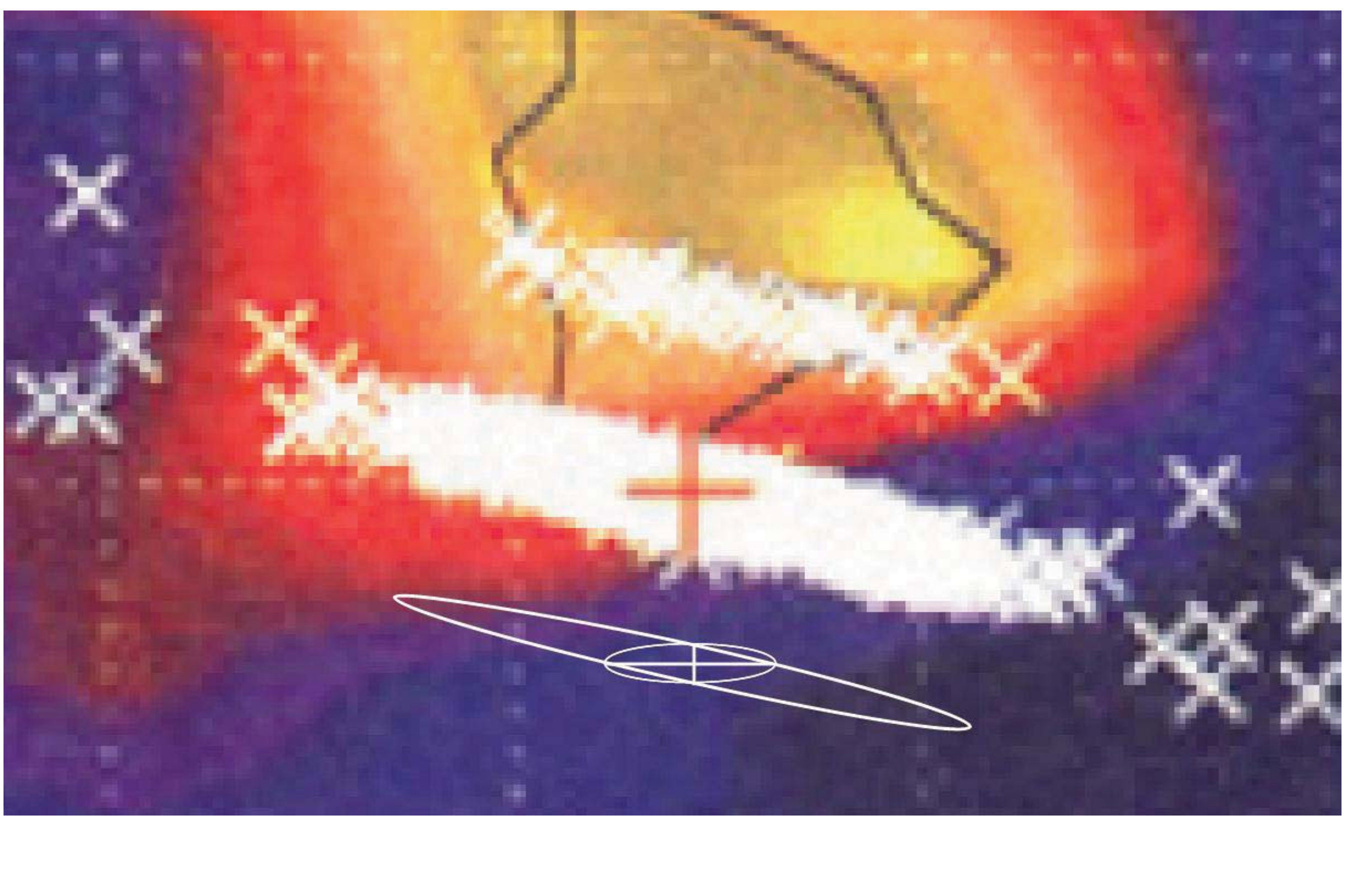
Haruyoshi Matsumoto and Tai-Kwan Andy Lau

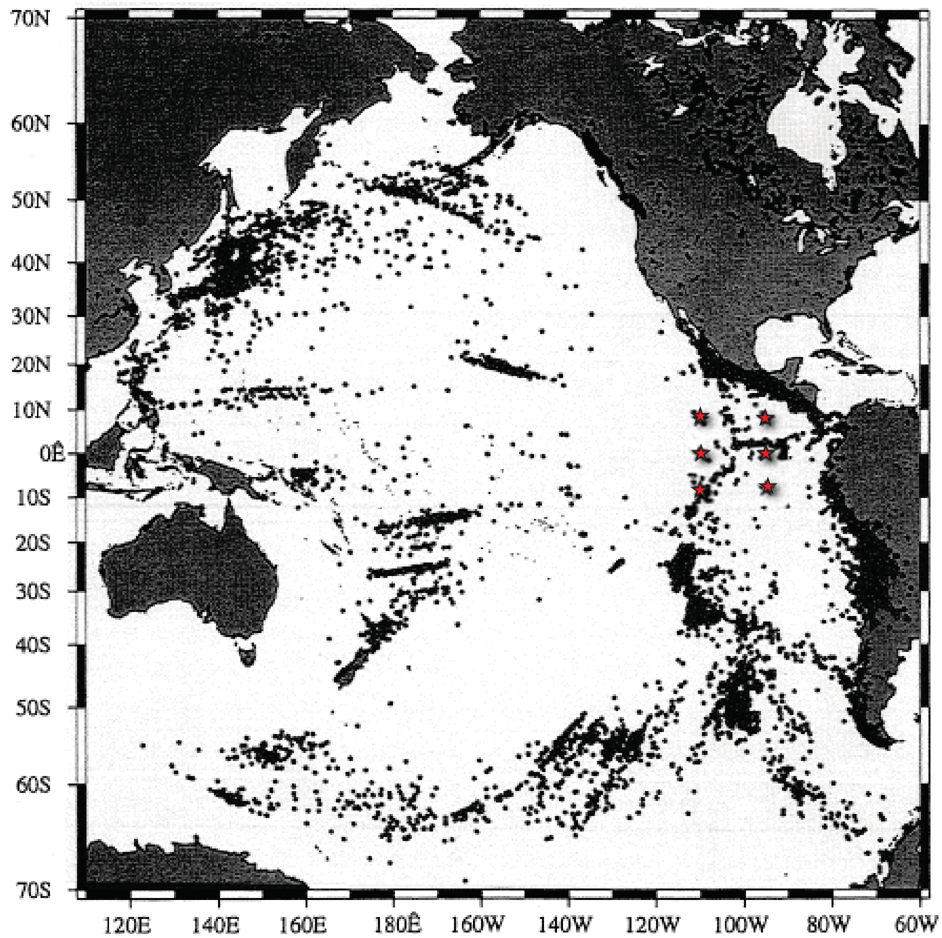
NOAA/Oregon State University, Cooperative Institute for Marine Resources Studies, Newport, Oregon

Abstract. Since May 1996, an array of autonomous hydrophone moorings has been continuously deployed in the eastern equatorial Pacific to provide long-term monitoring of seismic activity, including low-level volcanic signals, along the East Pacific Rise between 20°N and 20°S and the Galapagos Ridge. The instruments and moorings were designed to continuously record low-frequency acoustic energy in the SOFAR channel for extended periods and produce results comparable to those previously derived by using the U.S. Navy Sound Surveillance System (SOSUS) in the northeast Pacific. The technology and methodology developed for this

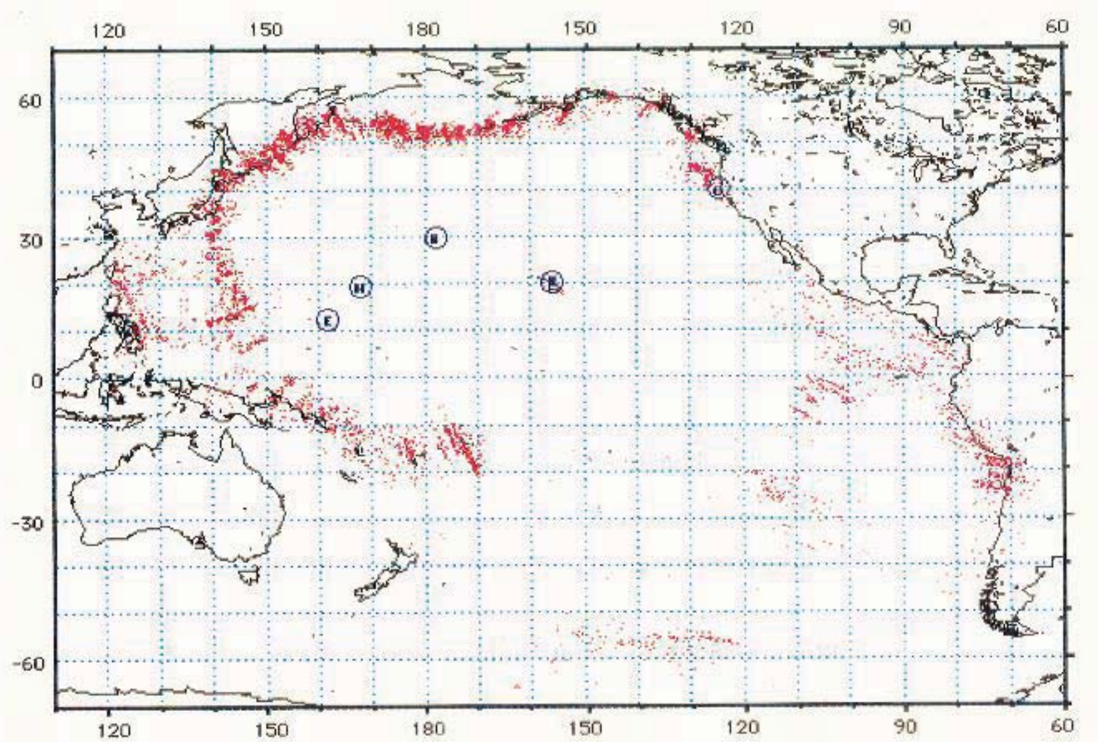

A
23N
16N
159W
154W
B
60N
60S
180W
80W
C
60N
60S
180W
80W
D
60N
60S
180W
80W







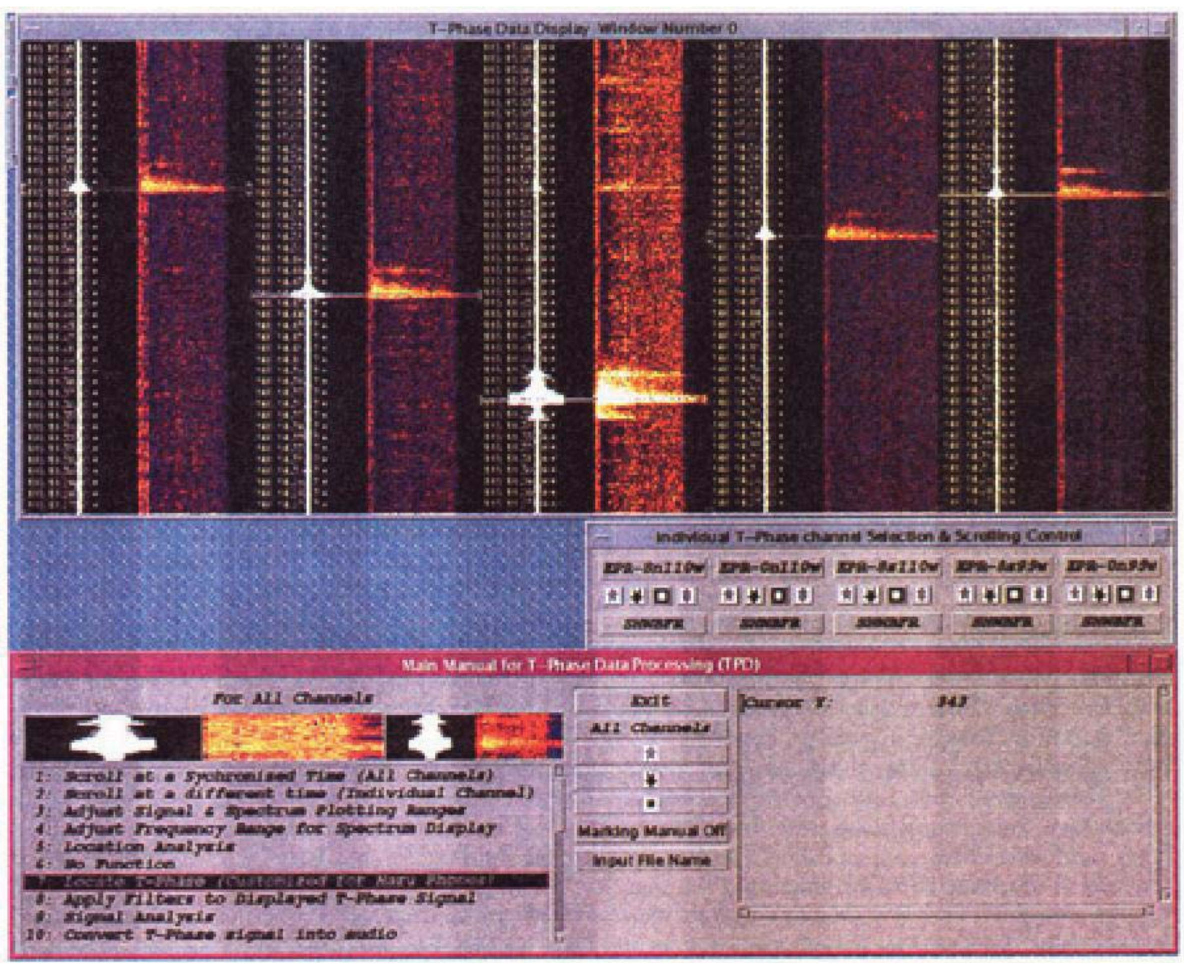
May 19, 1996-
May 19, 1999
seismicity from
PMEL equatorial
hydrophone
array. Note
distant sources
are aligned
along great
circles through
the hydrophone
array.

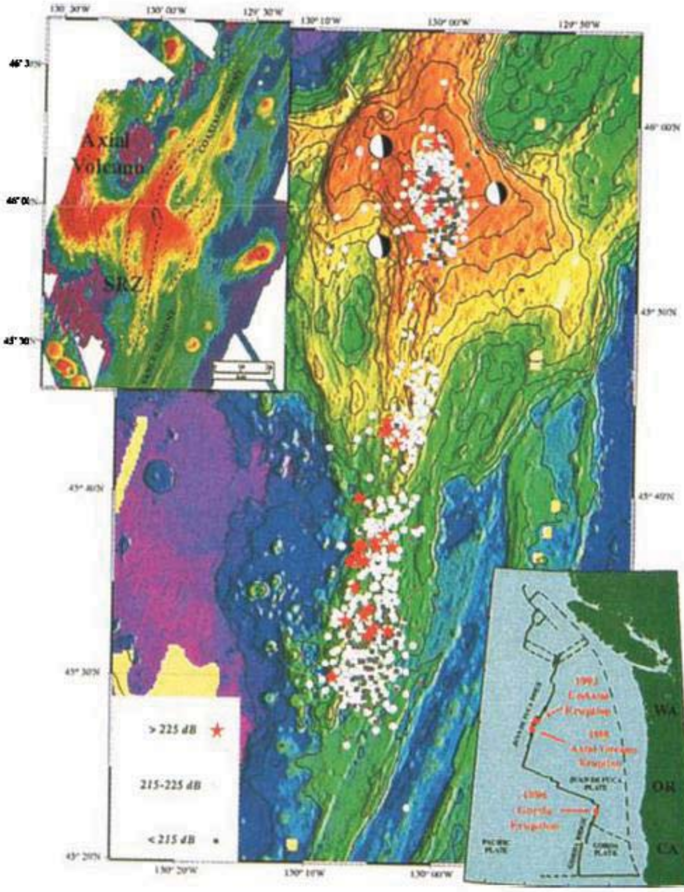


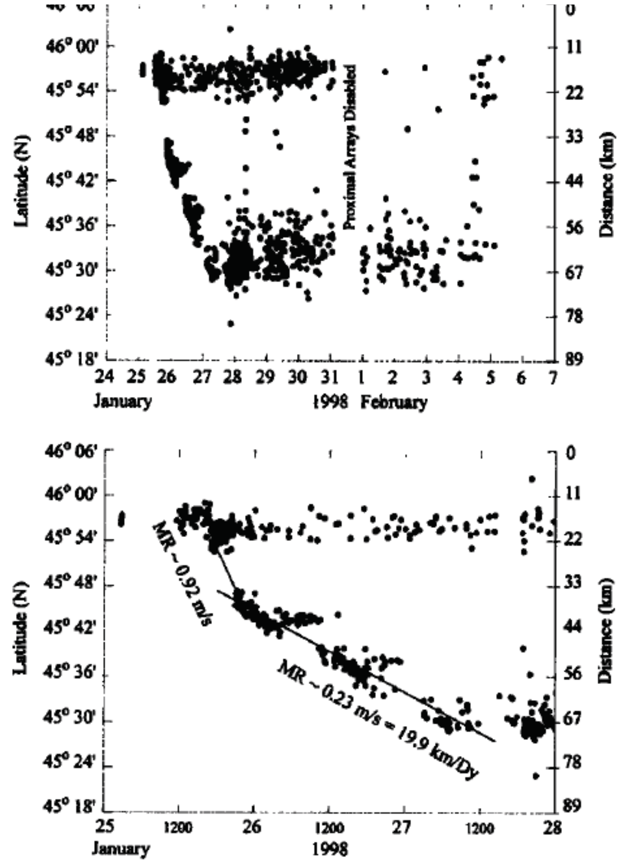
Compare this map from the T-Phase Project of the late 1960's with the previous map. The "error ellipses" point towards the center of the array.

A second detection and location method involves the use of closely spaced hydrophones in large arrays, and a process called BEAM FORMING. This is a method used by the navy for location of ships and submarines.

In the cold war, SUSUS arrays were placed on the ocean floor in many locations to note the passing of submarines across the oceans. Some of these arrays have been re-activated in a limited basis for location of earthquakes and volcanic activity, particularly in the Juan de Fuca area off the US NW coast.

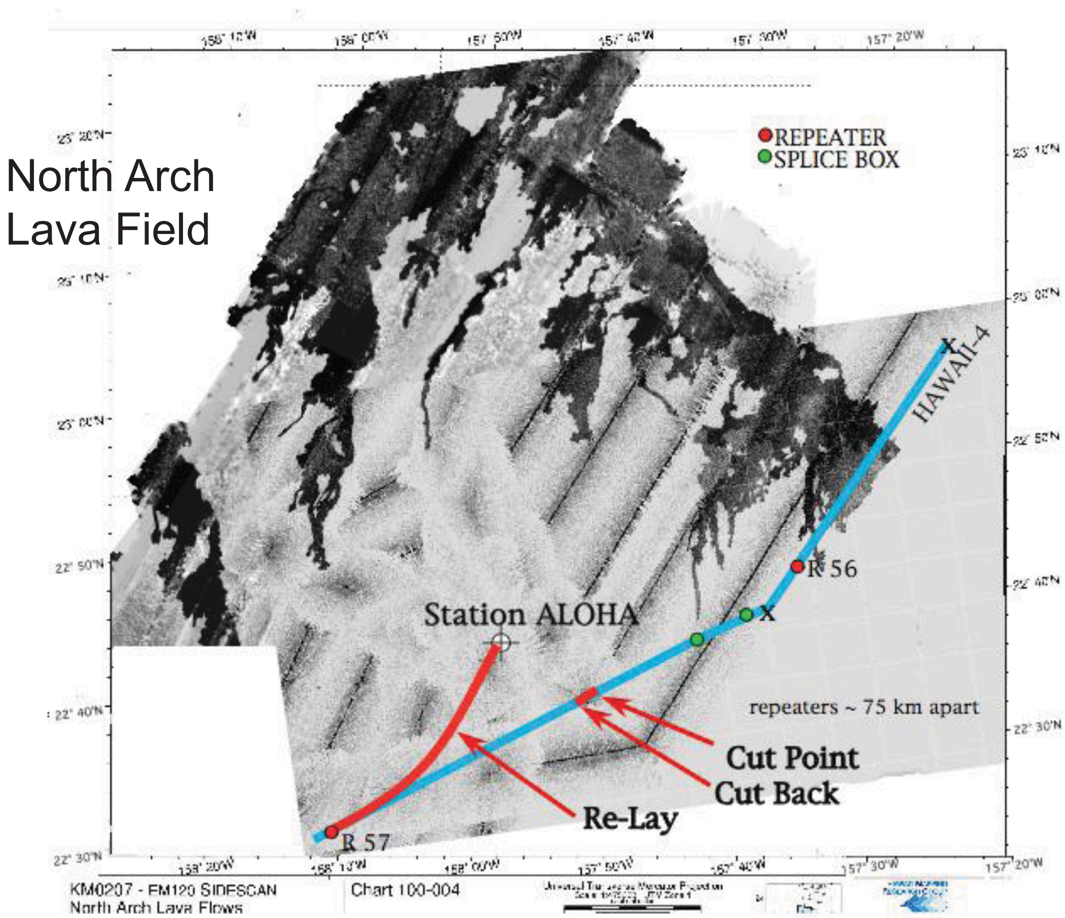


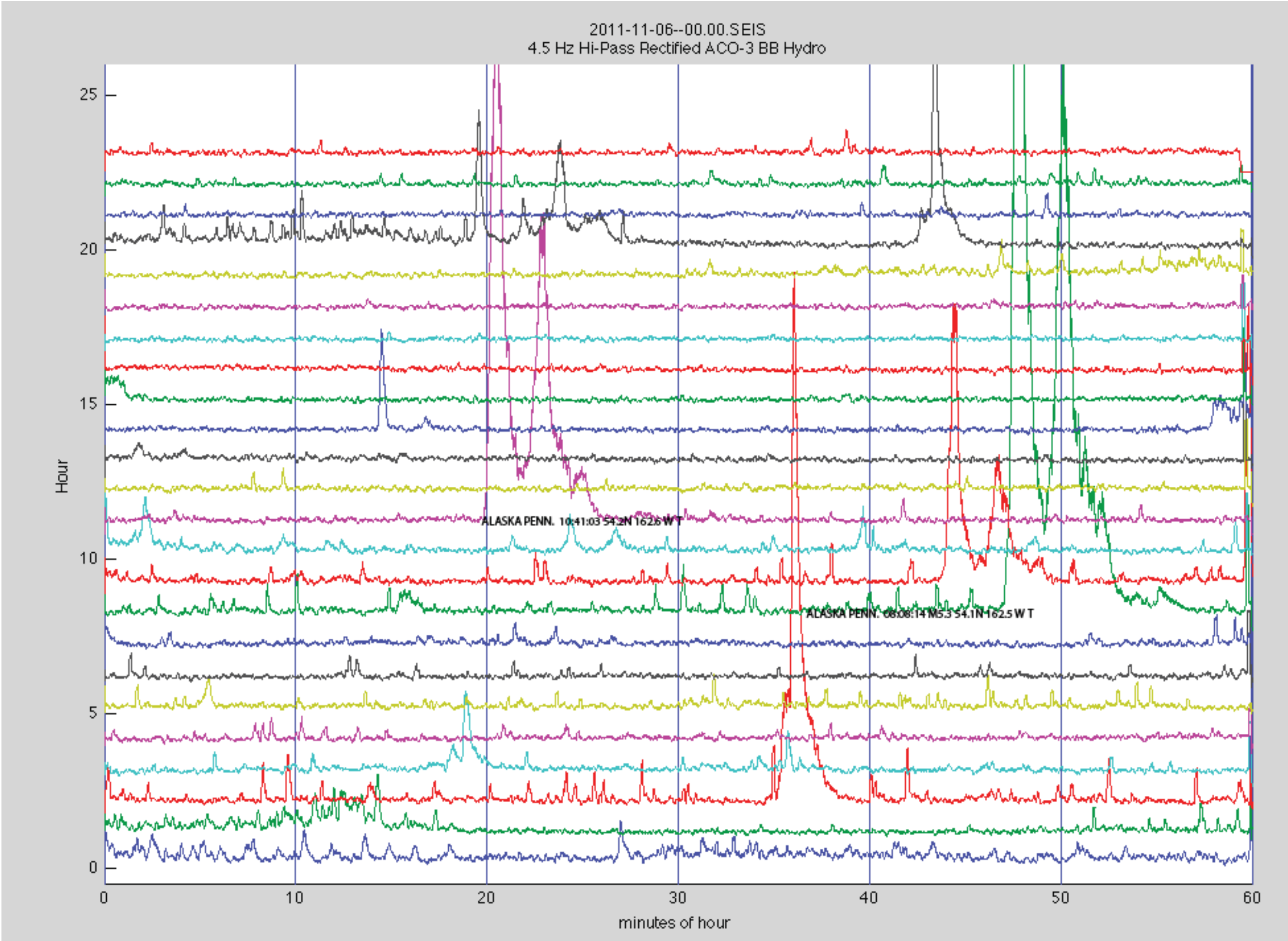


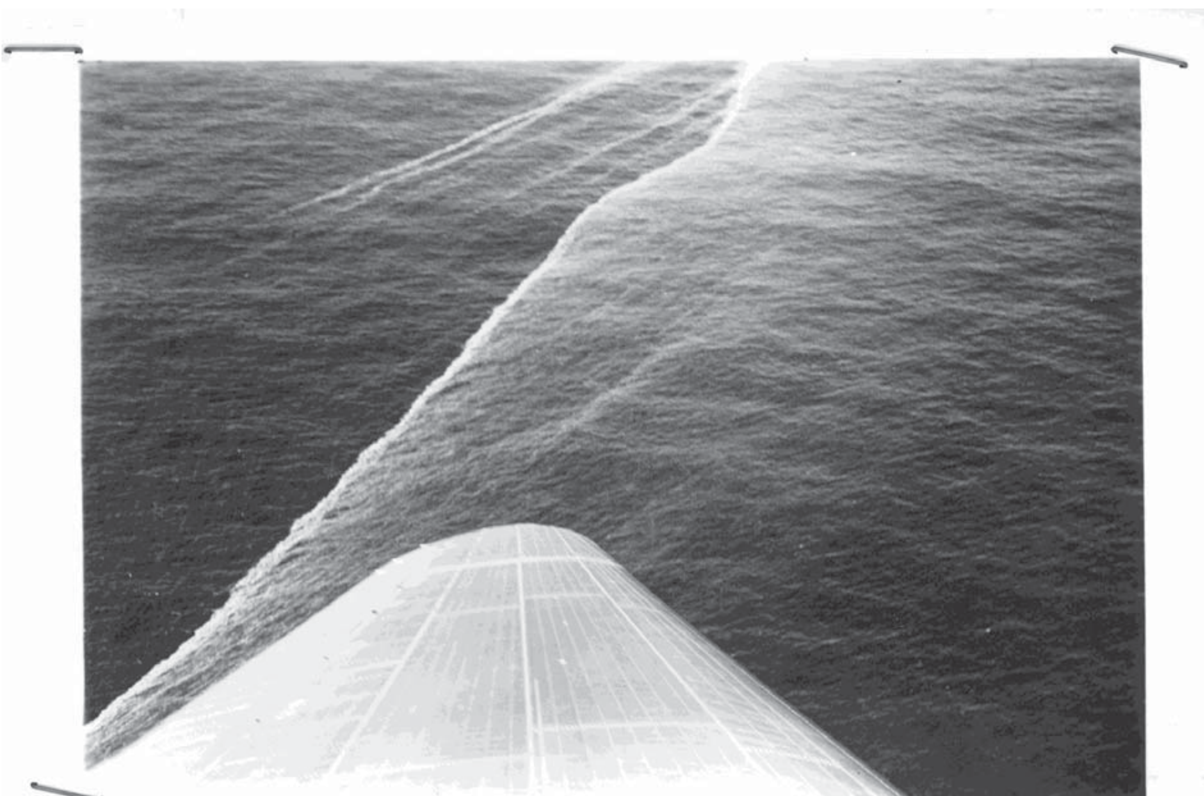


gure 3. Diagrams show earthquake distribution

Figure 1. Distribution of the 1037 located earthquakes on top of Axial Volcano bathymetry (100 m CI). Lower right map shows







Algae (?) in Kauai Channel
From Kodachrome by Don Smith, PRI, 7/12/56 - 56-461-GE

Bulletin of the Seismological Society of America, Vol. 86, No. 5, pp. 1529–1544, October 1996

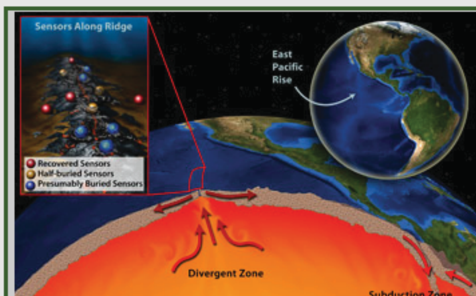
Monochromatic *T* Waves from Underwater Volcanoes in the Pacific Ocean: Ringing Witnesses to Geyser Processes?

by Jacques Talandier and Emile A. Okal

Abstract We analyze swarms of exceptionally intense and sustained *T* waves recorded during 1991 through 1994 at the Polynesian seismic array. The strongest swarm lasted 15 months and originated southwest of the Eltanin fracture zone, in the immediate vicinity of a documented seamount associated with a recognized volcanic chain branching out of the local segment of the mid-oceanic ridge. The Eltanin *T* waves are characterized by an exceptionally monochromatic spectrum featuring a single line (of a few Hertz frequency) in the range 2 to 80 Hz. While no similar characteristics had previously been observed in 25 yr of recording in Polynesia, comparable spectra were recorded during a 1993 swarm at the Revilla Gigedo Islands, following by 4 months a documented eruption of Socorro Island. In both cases, we interpret the *T* waves as evidence of a major underwater volcanic process. The existence of a single resonating frequency, and in particular the absence of any overtones, is generally not compatible with the now classical models of the resonance of a fluid-filled crack, and we speculate that the source of the phenomenon may be the oscillation of a bubbly liquid, which could result from vaporization of seawater in the presence of a large lava lake.

Scientists Catch Underwater Volcanic Eruption "In Action" in Pacific Ocean Depths

November 27, 2006



HI-RES

Oceanographers discovered an undersea eruption as it happened last spring.
Credit: Nicolle Rager Fuller, National Science Foundation

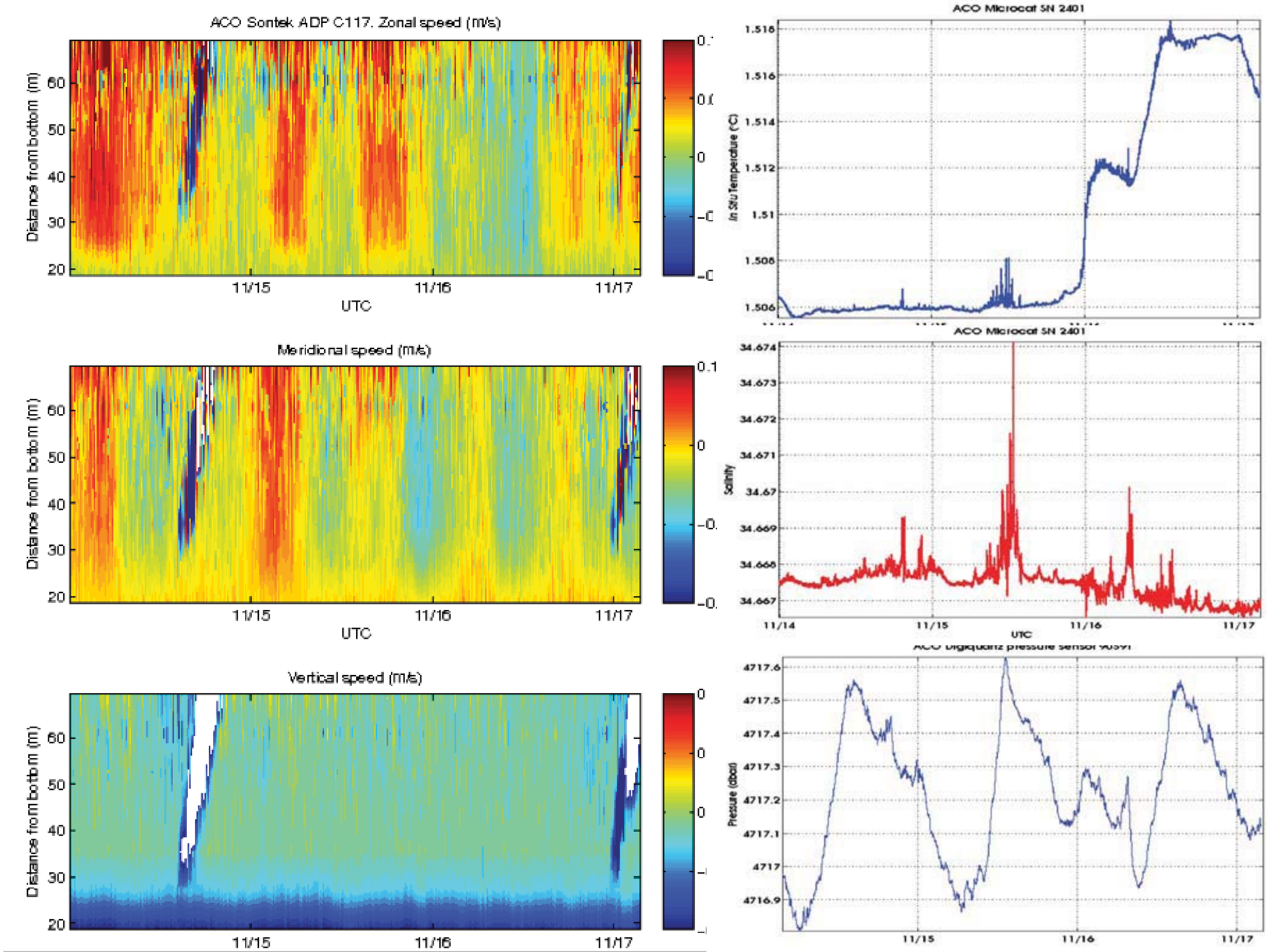
Nearly 2,500 meters beneath the surface of the Pacific Ocean, magma erupted onto the sea floor last January in a new episode of sea-floor spreading, an occurrence never before caught in progress by scientists.

Geologist Maya Tolstoy of the Lamont-Doherty Earth Observatory in Palisades, N.Y., lead author of a recent *Science Express* paper on the finding, said that earthquake activity on the sea bottom steadily increased from 2003 to 2005, and predicted that an eruption was imminent.

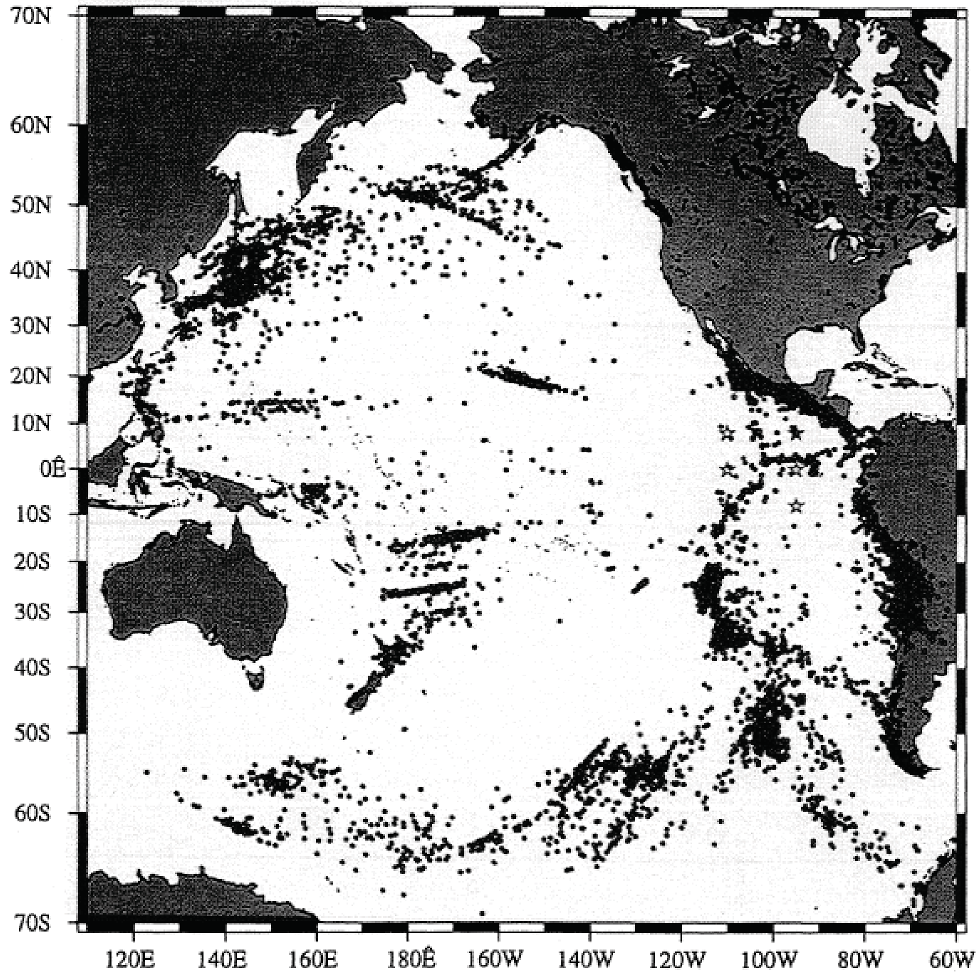
The research has "exciting implications that we may be able to anticipate future sea floor eruptions," said scientist James Cowen of the University of Hawaii in Honolulu, a co-author of the paper.

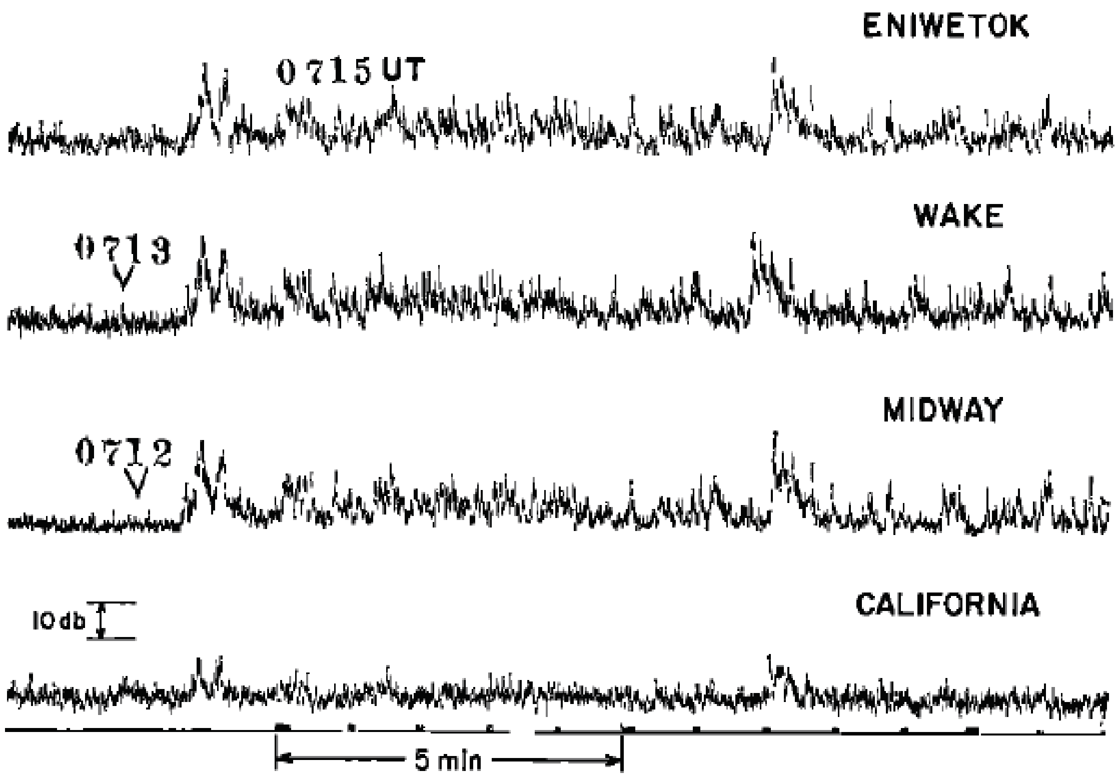
Scientists aboard the research vessel (R/V) *Knorr* confirmed evidence of the volcanic activity in April, 2006, when they tracked the locations of 12 ocean-bottom seismometers (OBSs) designed to monitor earthquake activity on the East Pacific Rise tectonic plate boundary, located south of the Gulf of California.

When only four of the 12 OBSs were recovered, the scientists became suspicious that a lava flow might have covered or damaged them. Although equipment malfunction was a possibility, the seismometers in previous experiments had been retrieved in 98 percent of deployments.



ACO Sontek ADP C117. Zonal speed (m/s)
Distance from bottom (m)
UTC
11/15
11/16
11/17
Meridional speed (m/s)
Vertical speed (m/s)
ACO Microcat SN 2401
In Situ Temperature (°C)
Salinity
Pressure (dbar)





...d power-level record of the May 29, 1967, Austral seamounts ...

$$\min \sum_{i=1}^{N} w_i (a_i - b_i)^2$$

where

w_i	weight (1 for unweighted solution);
a_i	recorded arrival time on hydrophone i;
b_i	predicted arrival time on hydrophone i;
N	number of hydrophones recording the event.

The predicted arrival time is calculated on the basis of an assumed location and origin time as

$$b_i = t + d_i/c_i$$

where

t	origin time;
d_i/c_i	travel time in seconds;
d_i	distance between hydrophone location i and assumed origin;
c_i	sound speed i along path from hydrophone to assumed origin.