

Welcome to Vibrationdata

Acoustics • Shock • Vibration • Signal Processing

June 2006 Newsletter

Aloha!

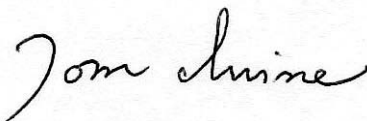
The theme of this month's Newsletter is the ability of the natural geophysical world to either generate or conduct sound and vibration waves.

The image at the upper right is a prototype underwater buoy used in Wood's Hole in the late 1960s. The photo is courtesy of Tom Rossby. The sphere housing the electronics and battery has a diameter of 1m, with the transducer hanging below. The float was designed to detect sound waves in the ocean's "deep sound channel." The first article discusses sound propagating in this layer.

The image at the lower left is the eruption of the Kavachi Submarine Volcano in the Solomon Islands, taken by Pamela Brodie, 2000. Underwater volcanoes and earthquakes generate T-waves, as discussed in the second article.

The third article describes glacial ice quakes which are occurring at an increasing rate due to global warming.

Sincerely,



Tom Irvine
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Feature Articles



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SOFAR Channel by Tom Irvine

Introduction

SOFAR is an acronym for “Sound Fixing and Ranging.”

The SOFAR channel is a continuous layer in the deep ocean where sound waves are focused, thus providing a mechanism for a long-range communications system. It is also referred to as the “deep sound channel.”

The depth of this channel varies in different oceans depending on the salinity, temperature, and depth of the water. It may be anywhere from 600 to 1500 meters below the surface, depending on these variables.

Discovery of the SOFAR

William Maurice Ewing, a Columbia University geoscientist, discovered the SOFAR Channel during World War II.

Ewing recognized that sound waves tend to bend downward as they travel at shallow depths. Conversely, the waves bend upward as they propagate at deeper depths. He thus theorized that waves should be able to travel great distances, if the sound source was located at the proper depth in the ocean. He further realized that low-frequency waves are less vulnerable than higher frequencies to scattering and absorption.

Ewing then calculated that at a depth between 1000 and 1500 meters, the waves would become “trapped” between forces sending them upwards and forces sending them downwards, allowing them to propagate almost indefinitely through this channel.

Researchers performed a test that successfully verified this theory. They set off an underwater TNT explosion in the

Bahamas at a depth of 1500 meters, which was easily detected by receivers 2,000 miles away on the coast of West Africa.

Military Uses

The immediate benefit of this discovery was that it provided a means for locating downed pilots during World War II.

The U.S. Navy set up a network of hydrophones throughout the Pacific Ocean.

A downed pilot floating in a life raft would release a device, which would sink to the depth of the SOFAR channel and then implode. This device was actually a simple, hollow sphere. It imploded due to the water pressure at the desired depth. Note that water pressure increases with depth. In addition, the sphere may have had an explosive charge to enhance the sound output, but this design feature has not been confirmed.

The Navy would then be able to locate and rescue the pilot, using the hydrophone data from the resulting sound waves.

The military has only recently declassified some of the general information about this location system. Most of the details remain secret. Whether this system was actually used in a successful rescue has not been disclosed.

The reason for the secrecy was that the same hydrophone network was used to track Soviet submarines during the Cold War. The system might also have been used to detect explosions from underwater nuclear weapons tests.

This monitoring program was called the Sound Surveillance System or SOSUS

Scientific Uses

Aside from military applications, scientists measure sound propagating through the SOFAR channel to study underwater earthquakes, volcanoes and whales. This group of scientists includes researchers from the National Oceanic and Atmospheric Administration.

In addition, oceanographers used SOFAR floats in the 1970s to measure and track oceanic currents. The floats were free-drifting underwater buoys.

The floats sent out acoustic pulses, typically at 260 Hz.

Moored listening stations at known locations received the sound signals. The position of each float was determined using time of arrival of the signal at three or more hydrophones.

SOFAR floats worked at ranges of up to 2500 km, which is about half-way across the Atlantic Ocean.

In recent years, SOFAR floats have been replaced by new designs that communicate their positions via satellite links.

An example is the RAFOS (SOFAR spelled backwards) Float. The transmitters are moored and the receivers mobile and drifting at depth in this system.

The drifting receivers drop a ballast weight after a period of time and rise to the surface. Once there, they transmit their data to satellites, which in turn transmit the data to scientists on land.

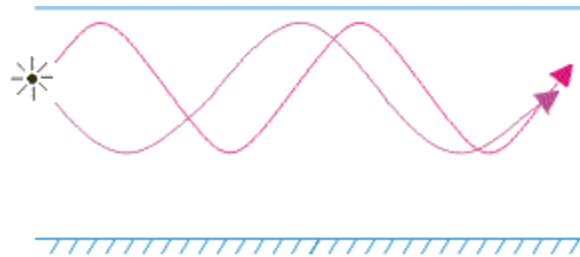


Figure 1. Image Courtesy of NATO Undersea Research Centre

The figure shows two refracted rays in red. The sound directed upward is refracted down by temperature gradients, and the sound directed downward is refracted up by pressure at depth.

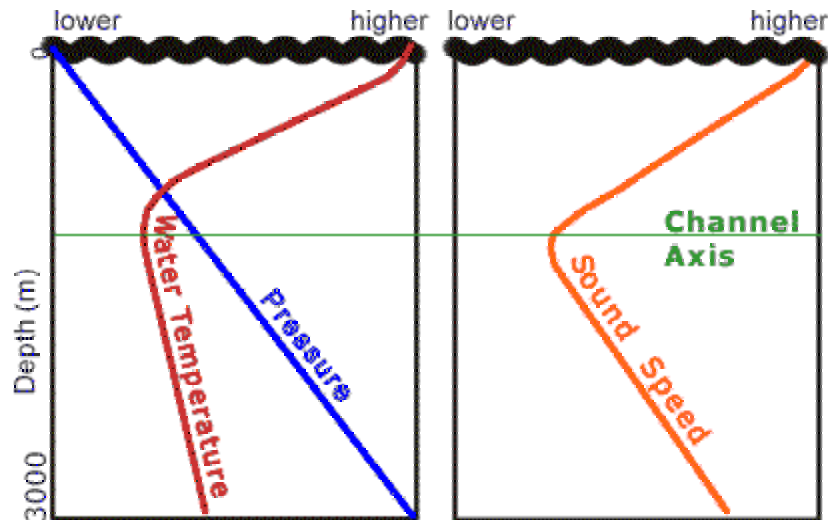


Figure 2. Image courtesy of NOAA

SOFAR Channel Technical Description

The ocean is divided into horizontal layers. The speed of sound is greatly influenced by temperature in the upper layers and by pressure in the deeper layers.

The speed of sound decreases as temperature decreases.

The speed of sound increases as the pressure (depth) increases.

The two effects do not cancel, however.

The "channeling" of sound occurs because there is a minimum in the vertical sound speed profile in the ocean caused by the changes in temperature and pressure.

The principle of sound propagation is that sound rays always bend towards the region of lower sound speed.

The refraction of sound waves from higher velocities above and below the sound channel axis thus bends the sound back towards the axis. Sound energy is refracted towards the axis of the sound channel away from the surface and the bottom of the ocean.

Furthermore, sound propagates in the SOFAR channel without interacting with either the sea surface or seafloor. These sound waves thus travel with relatively little attenuation beyond that due to geometric spreading.

Seismo-acoustic T-waves by Tom Irvine

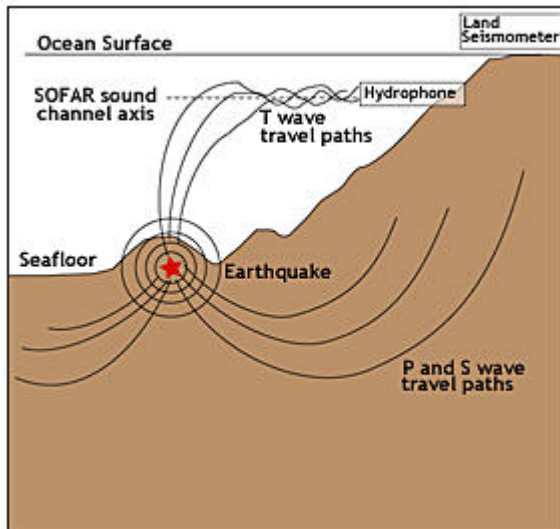


Figure 1.

Introduction

Underwater earthquakes and volcanoes generate three types of waveforms.

Primary or P-waves are the fastest seismic waves, and they propagate through solids and liquids.

Secondary or S-waves travel only through solid materials, at a slower speed than P-waves. Seismologists locate and study earthquakes by measuring the magnitude and timing of these two types of waves.

Tertiary or T-waves are the slowest of the three types.

T-wave Generation and Propagation

Seismic events at the seafloor generate energy that is transmitted into the ocean water column. Some of this energy becomes focused within the SOFAR channel and can be recorded by

hydrophones located in the channel. The SOFAR channels serves as a waveguide, as discussed in the previous article in this newsletter.

The resulting seismo-acoustic waves can travel thousands of kilometers within the SOFAR channel.

Furthermore, T-waves can be partially converted to other seismic waveforms at a continental or insular shoreline. T-waves can thus be recorded by seismic stations in the vicinity of the coastline.

T-waves are described by some sources as “seafloor rumbling.”

Discovery

Daniel Linehan reported a class of seismic waves in the early 1940s that were observed only on coastal and island seismic stations.

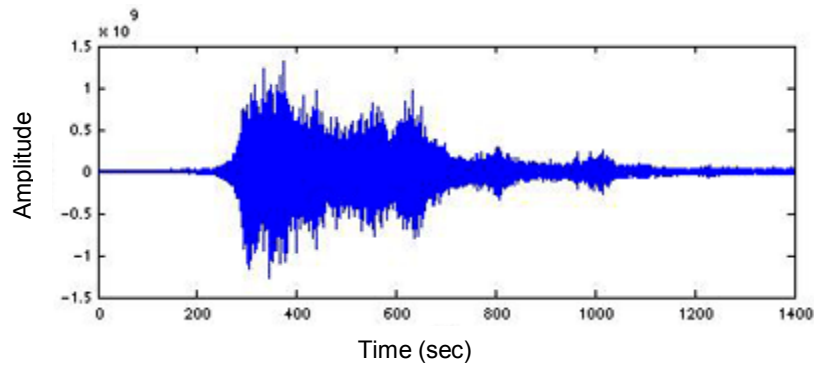


Figure 2. Image Courtesy of Columbia University

Ivan Tolstoy and Maurice Ewing gave an explanation of T-waves in 1950. They recognized that the phase arrival times recorded on land seismometers were consistent with ocean sound velocities and occurred only with events that permitted ocean propagation paths.

2004 Sumatra Earthquake T-waves

The T-waves for the Sumatra earthquake were captured by hydrophones located at Diego Garcia, more than 1700 miles (2740 km) from the epicenter. The measured sound pressure time history is shown in Figure 2.

Resonating Bubble Cloud

Researchers Jacques Talandier and Emile Okal analyzed some seismic recordings from French Polynesia, as reported in Scientific America, August 1997 issue. They noticed some “monochromatic” seismic signals, typically between 3 and 12 Hz, with a lack of overtones.

The signals were due to oceangoing T-waves, which were particularly active in 1991 and in the early months of 1992. The duration of individual blasts lasted from a few seconds to several minutes.

The researchers ruled out earthquakes and whales as the source of the T-waves.

They eventually determined that the waves originated at an underwater volcanic ridge in a poorly surveyed region of the South Pacific. New probing showed a flat-topped undersea volcano that rose to within 130 meters of the surface.

Talandier and Okal realized that undersea volcanoes at shallow depths were capable of producing T-waves, where the pressure is low enough that bubbles can form in the hot lava.

Another scientist, Bernard Chouet, noted that “interesting things” can happen in a mixture of water and steam. Sound waves normally travel at about 1500 meters per second in seawater, but they can slow to one meter per second in a cloud of bubbles generated by the steam from a volcano.

The cloud becomes sandwiched between the top of the seamount and the ocean surface, forming a resonant cavity. The cavity behaves as an organ pipe, with acoustic waves reflecting back and forth between the boundaries. A standing wave could thus be generated. The standing wave would emit a fundamental tone with overtones, but the gas bubbles would damp out the higher frequency overtones.

Finally, Talandier, Okal and Chouet note that the resonant bubble cavity explanation remains a theory.

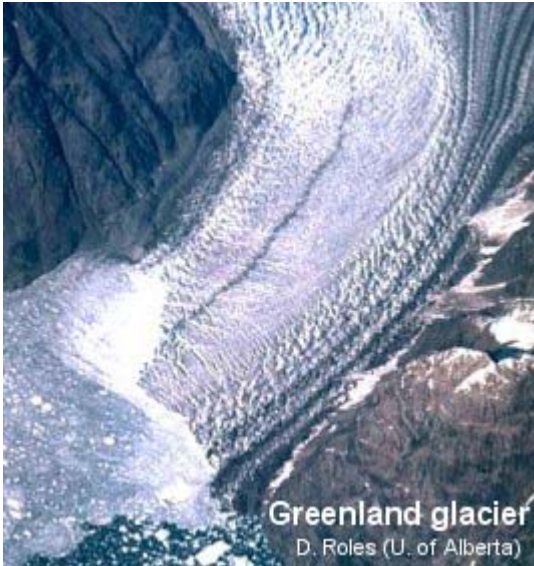


Figure 1.

Ice Quakes by Tom Irvine

Introduction

Göran Ekström, a geophysicist, has studied low-frequency seismic signals originating in Greenland's glaciers.

He also found that these seismic waves mostly occurred during the warmer summer months when portions of the ice melt. Note that tectonic earthquakes do not have the same "seasonality" as these glacial quakes.

Mechanism

Ekström's research team includes Victor C. Tsai, Meredith Nettles and others.

These scientists suspect that liquid water is pooling underneath the glacial ice to the point that the thin layer of water at the glacier's base allows the whole ice mass to slip slightly. The water provides lubrication.

The researchers believe that the resulting "ice quakes" are the vibrations generated

by a large mass of ice moving as much as 10 meters (33 feet) in under a minute.

The movement can be described as skidding or sliding. It is also referred to as "stick-slip." The resulting scraping of the ice against the rocky ground is a source of low-frequency elastic waves.

Ekström makes an analogy to an ice cube sliding on a slightly tilted rock surface: "This ice cube will start sliding slowly and then pick up speed," he says. Then "the glacier gets caught again as friction increases, and it slows down." The shallow slope lengthens the events.

Magnitude and Duration

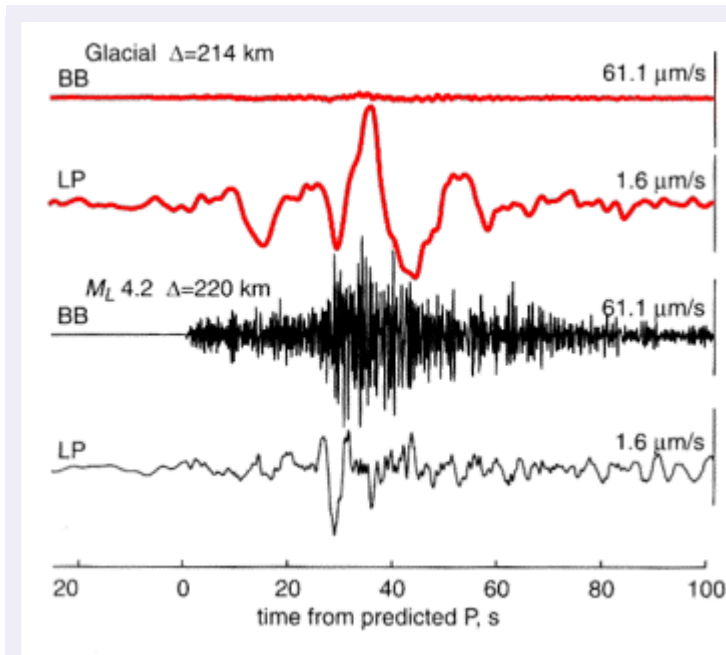
The magnitude of these glacial quakes can be substantial. An ice slab roughly the size of Manhattan Island, and as tall as the Empire State building, slipping 10-meters (33 feet) causes a magnitude 5 quake.

Furthermore, the ice quake duration can last thousands of seconds whereas a normal earthquake might last hundreds of seconds.

Frequency of Occurrence

Ekström and his colleagues analyzed glacial seismic records back to 1993. They found a sharp increase in the number of quakes recorded in recent years. All 136 of the best-documented slips were traced to glaciated valleys draining the main Greenland ice sheet. A few others occurred in Alaskan glaciers or on Antarctica.

Ekström reports that these glacial quakes ranged from six to 15 per year from 1993 to 2002, then jumped to 20 in 2003, 23 in 2004, and 32 in 2005. This rate increase matches an increase in Greenland's temperatures.



Two seismic records from the Dall Glacier area of Alaska. The upper two traces (in red) are the broad band (BB) and long-period (LP) records of the M 5.0 event of September 1999.

The lower two traces (in black) are the BB and LP records of an M 4.2 earthquake in the same area.

(after Ekström et al., 2003)

Figure 2.

The image in Figure 2 is courtesy of <http://www.mala.bc.ca/~earles/ice-quakes-oct03.htm>