

# Natural (geologic) sounds in the oceans: volcanoes, earthquakes, and landslides

Jacqueline Caplan-Auerbach, Western Washington University

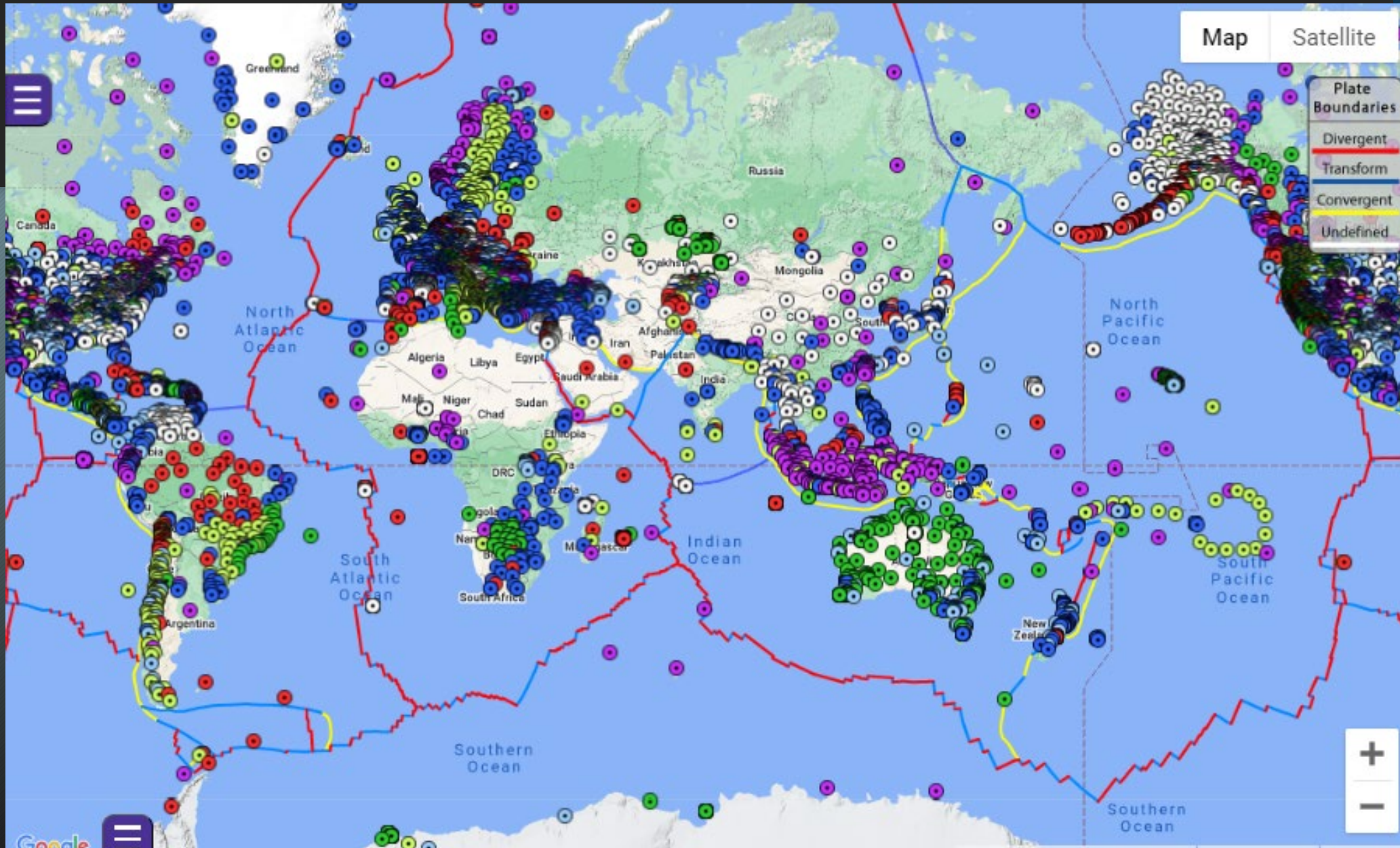
With thanks to collaborators C. Atkins, D. Bohnenstiehl, W. Chadwick, O. Costa, J. Drobiarz, F. Duennebier, R. Dziak, C. Fox, M. Louis

# What geologic processes make sound in the oceans?

- Earthquakes
  - T-phases
  - Seismic phases
- Landslides
- Volcanoes
  - West Mata
  - Kilauea
- Glaciers

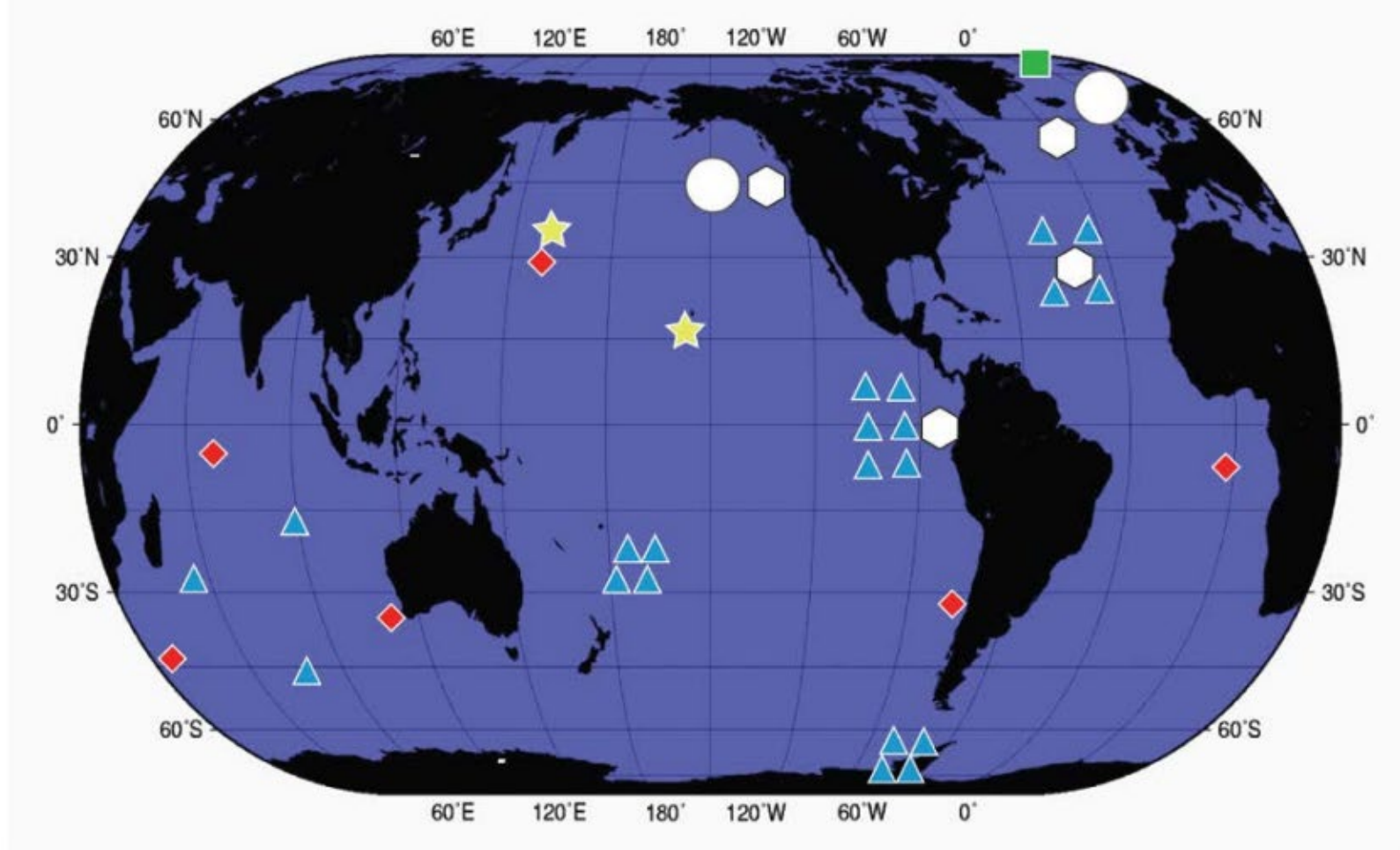
But we don't always know what we're listening to.

# Current global seismometer network



# Stations with hydroacoustic channels (permanent)





U.S. Navy SOSUS Hydrophones  
(real-time)



NOAA - Autonomous Hydro-  
phones (delayed time)



Spinnaker Array and other  
Arctic hydrophone deployments



U. Hawai'i MILS  
Hydrophones (1960s)

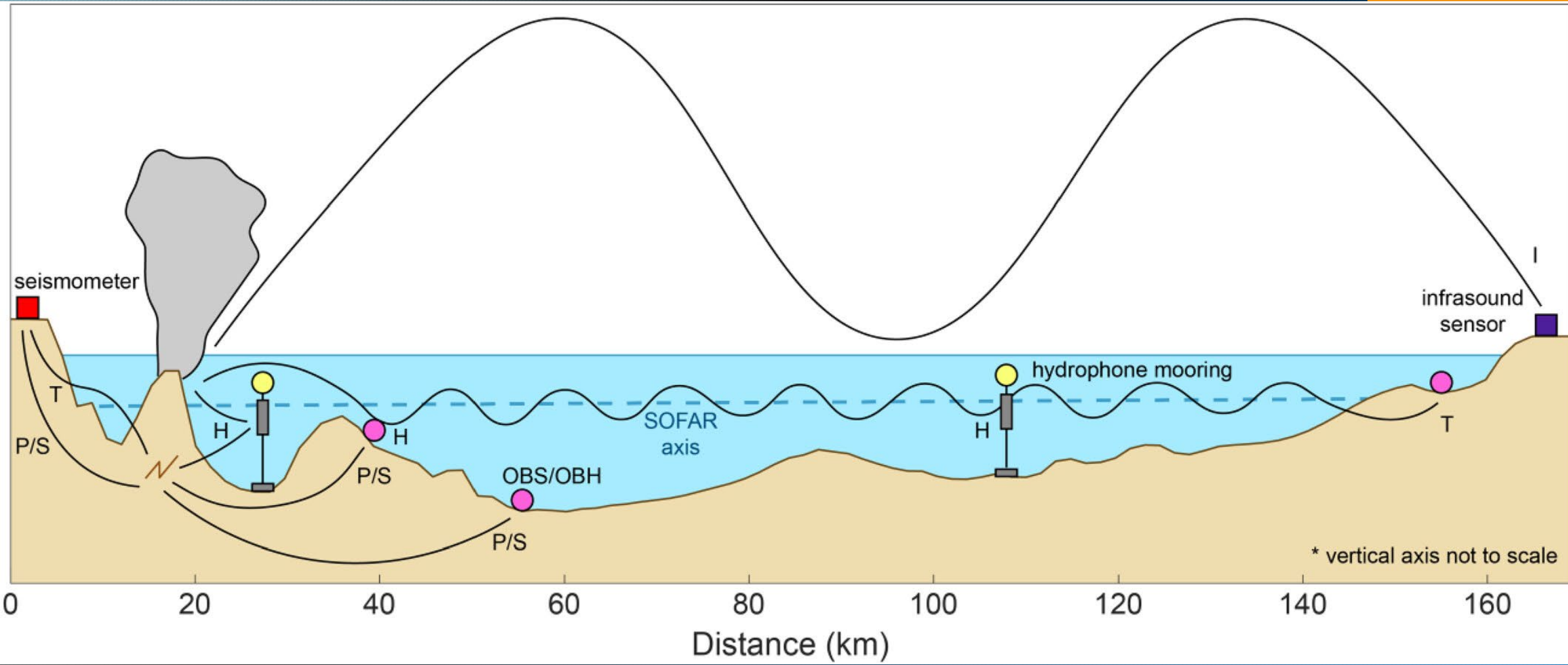


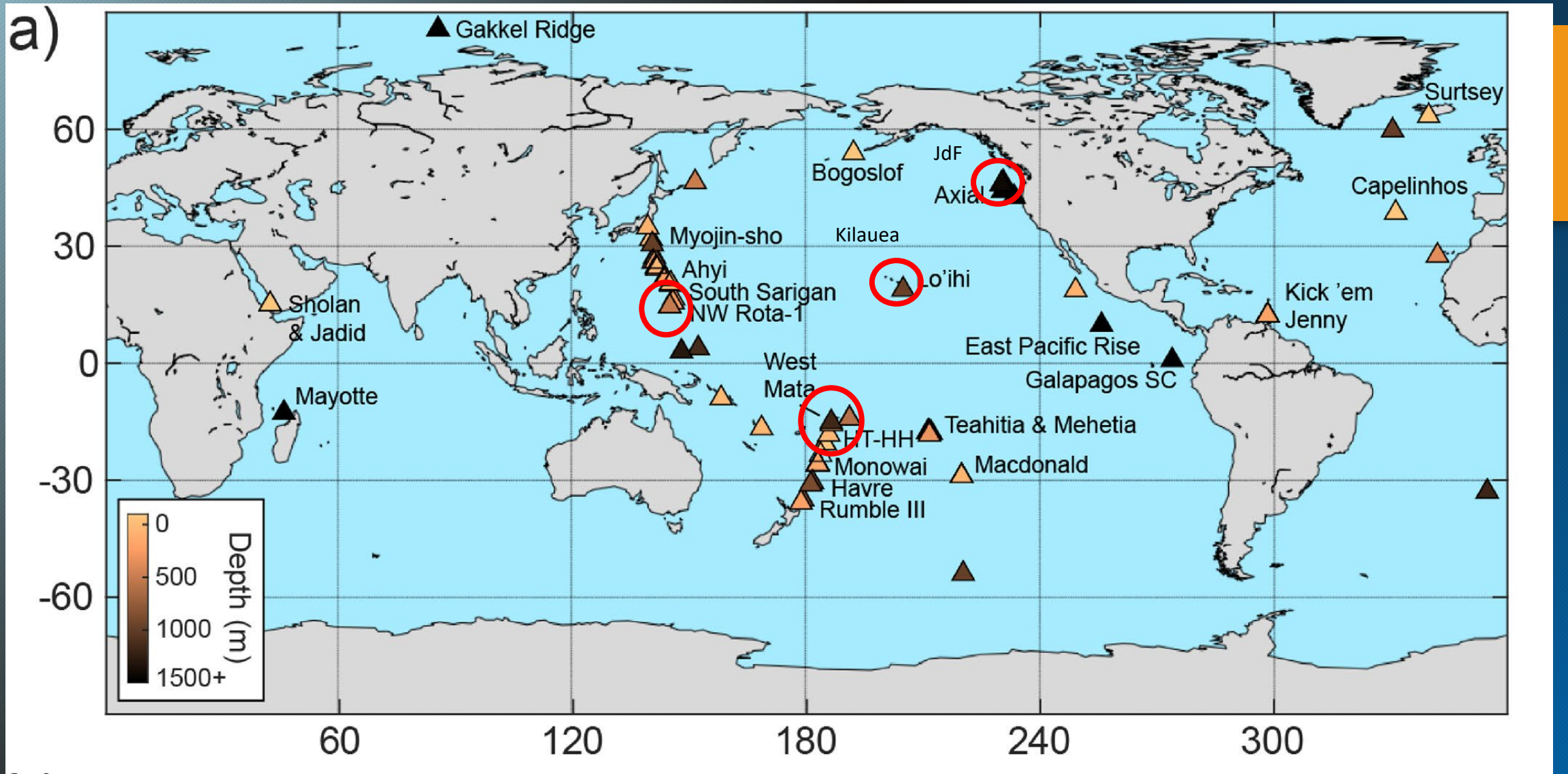
International Monitoring  
System Hydrophones (real-time)



Ocean-Bottom Hydrophone and  
Sonobuoy Studies

# Why do earthquakes make sound in the sea?

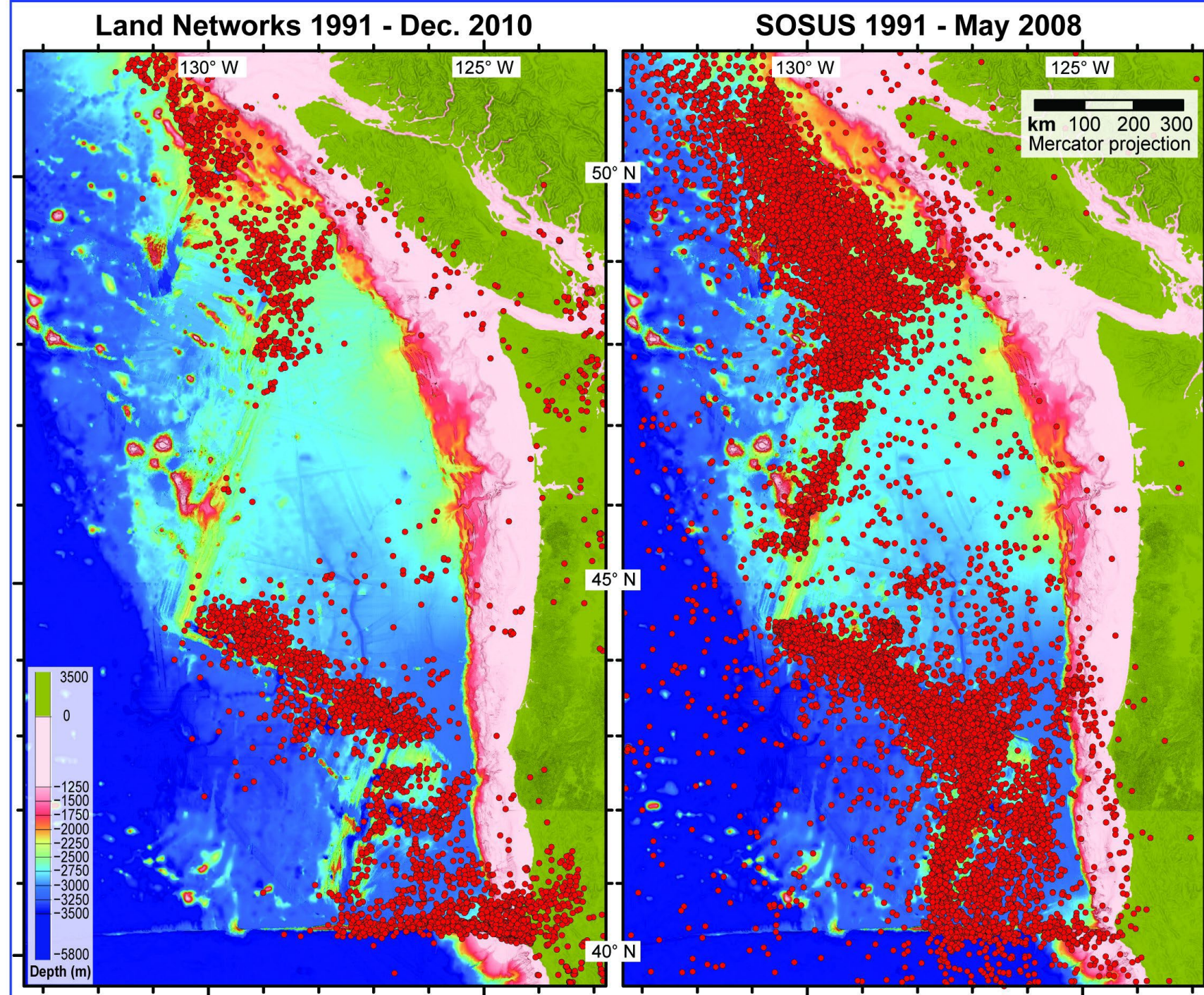




# SOund SUrveillance System/T-phase Monitoring System

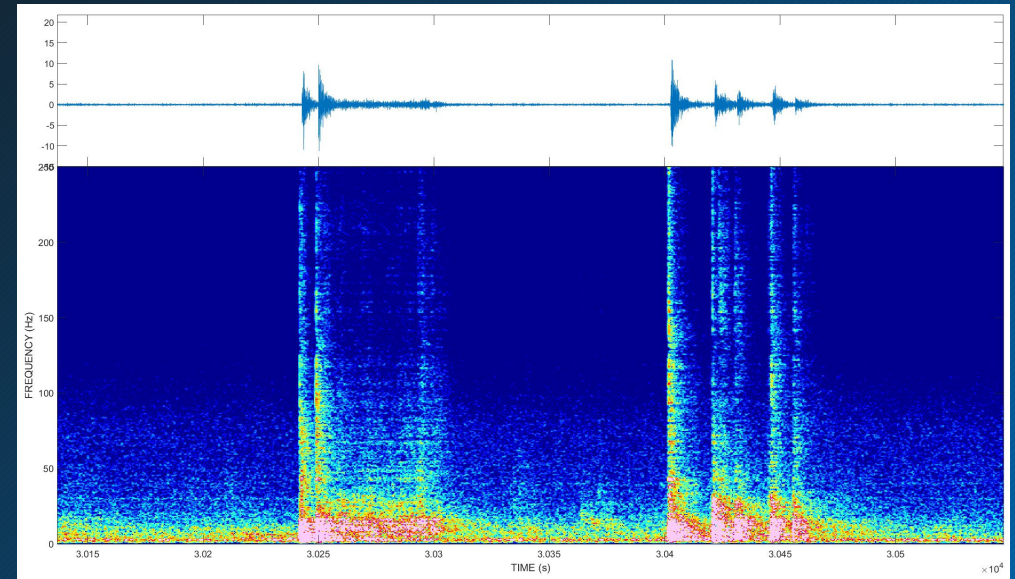
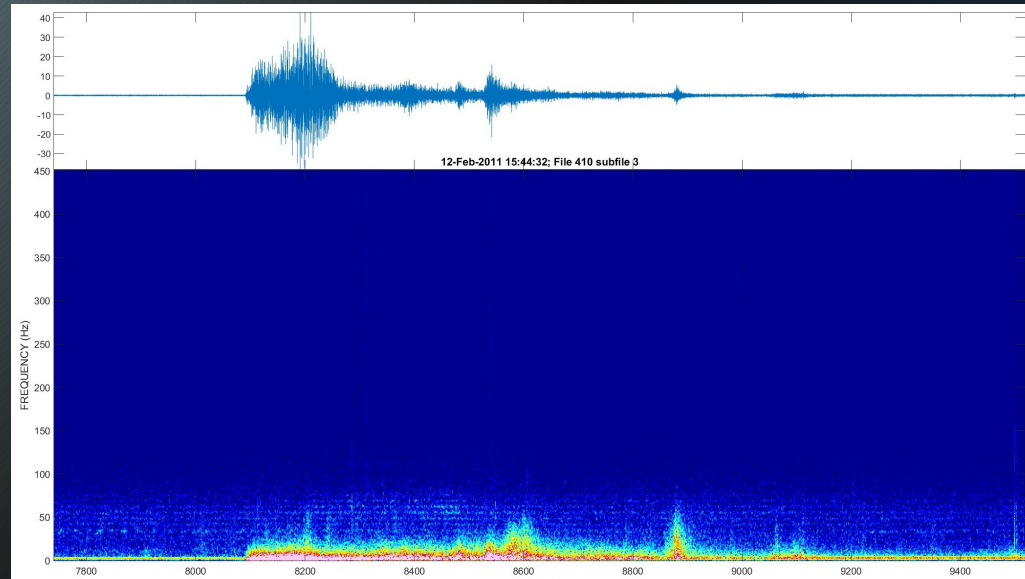
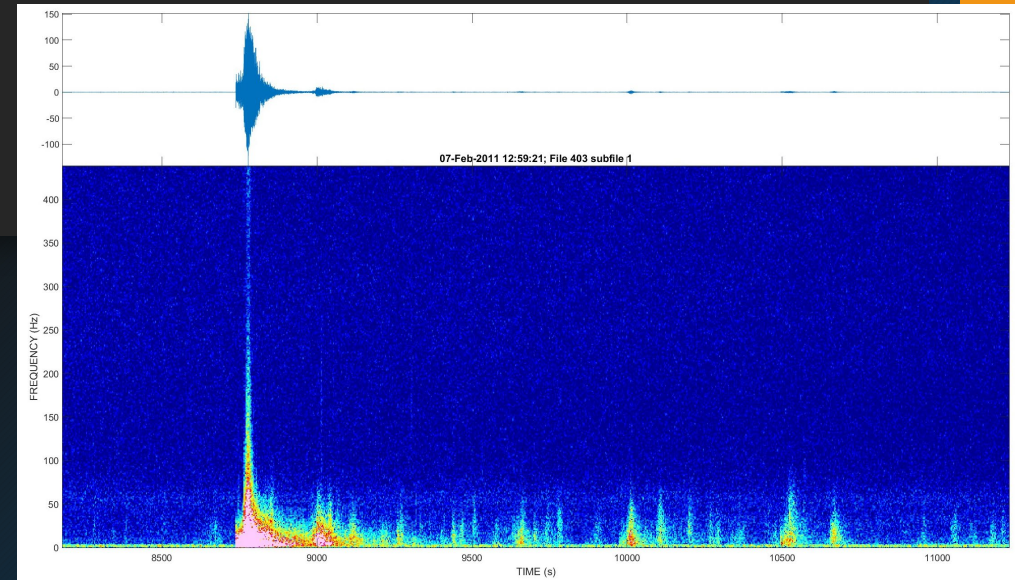
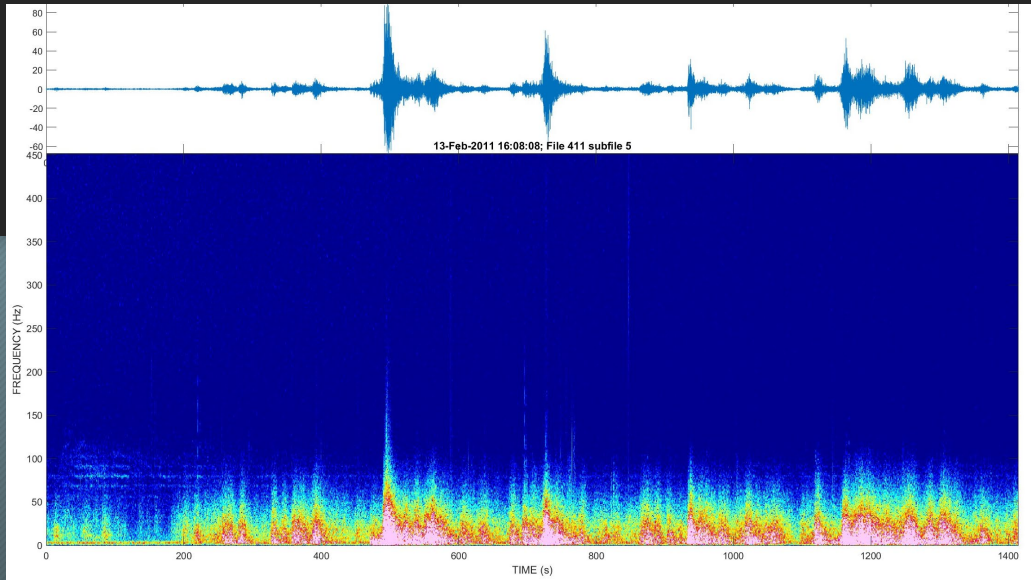
- Extends earthquake location to small, offshore quakes
- Dramatic increase in number of earthquakes
- Detection of submarine eruptions, tectonic events

Dziak et al., 2011

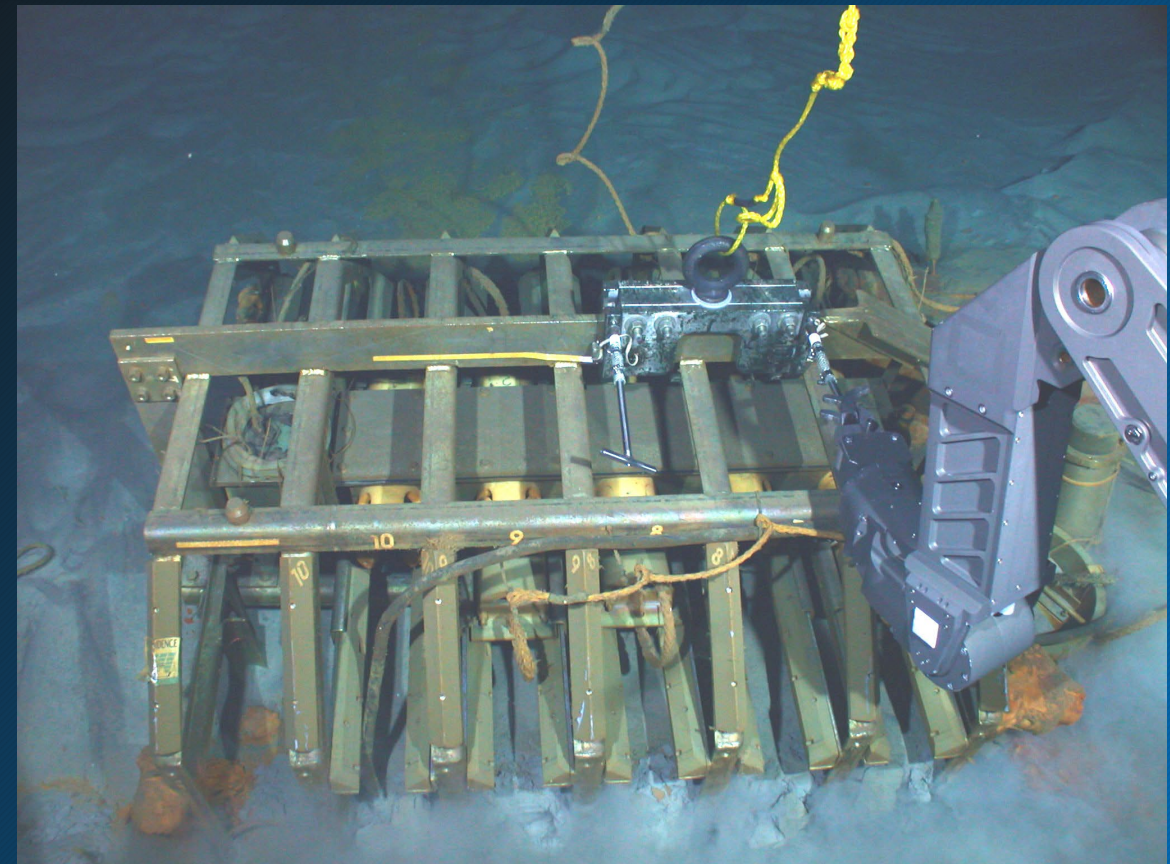
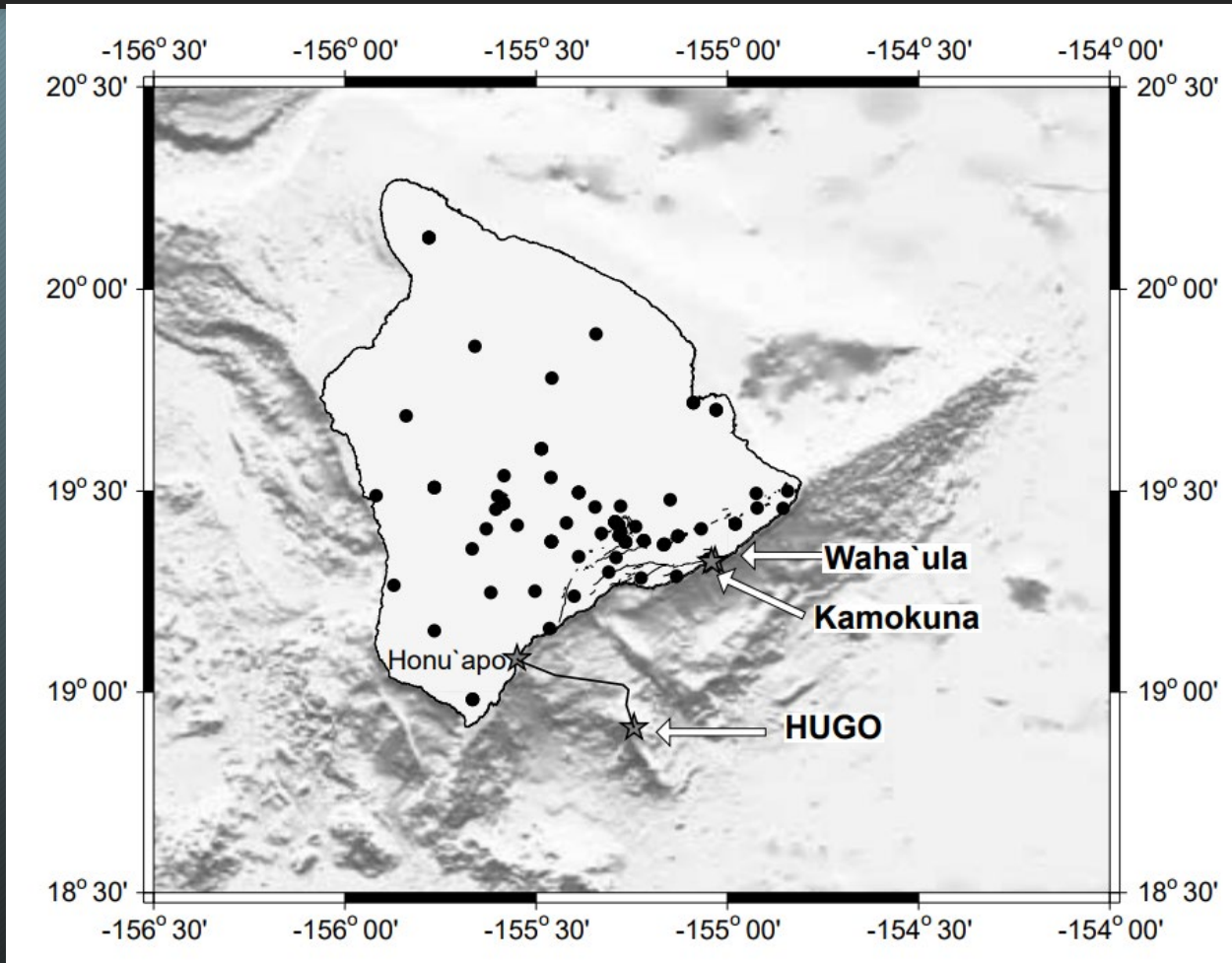


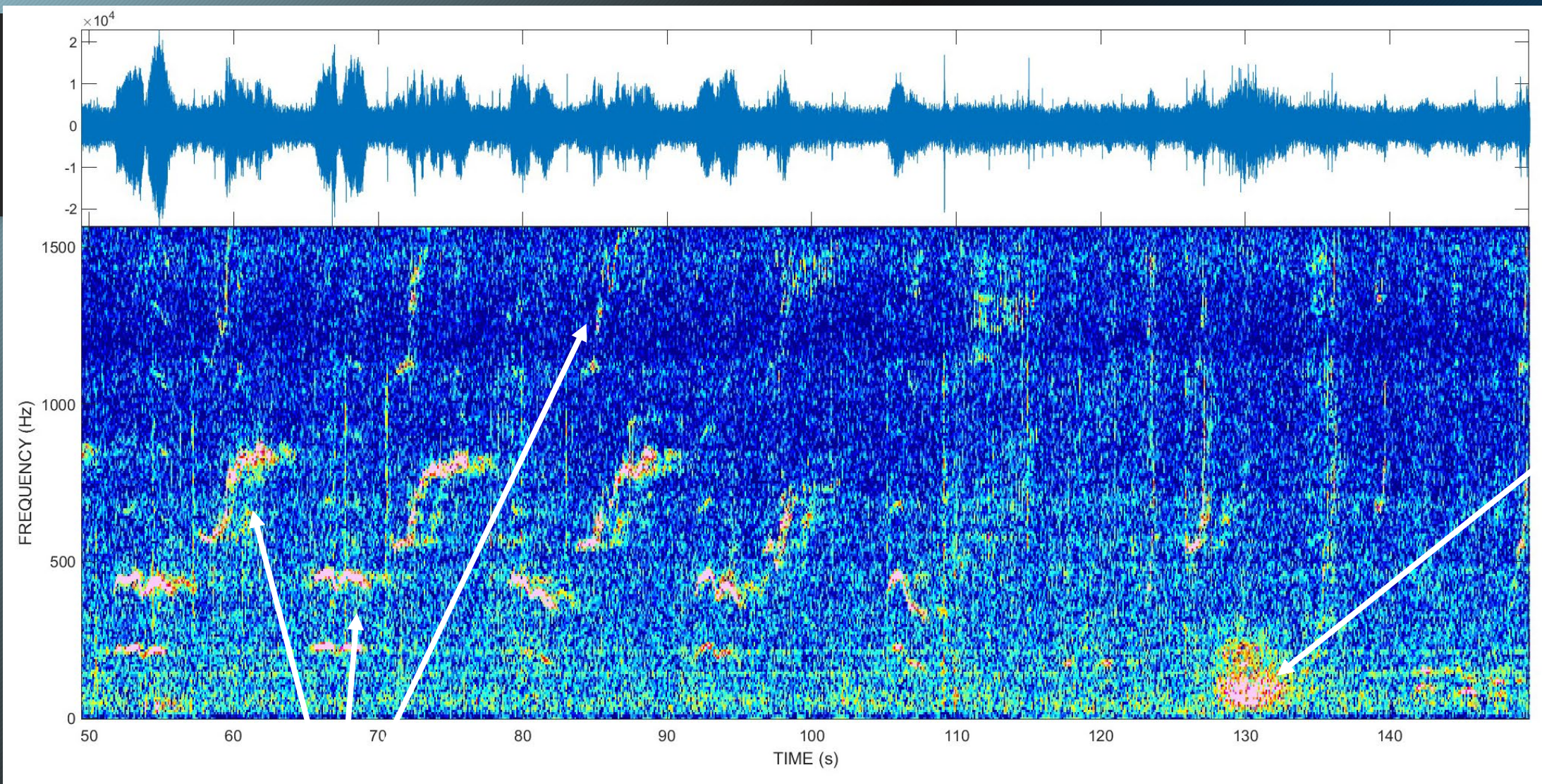


# Ubiquitous earthquakes in the Lau Basin (Tonga)



# HUGO: the Hawai`i Undersea Geo-Observatory

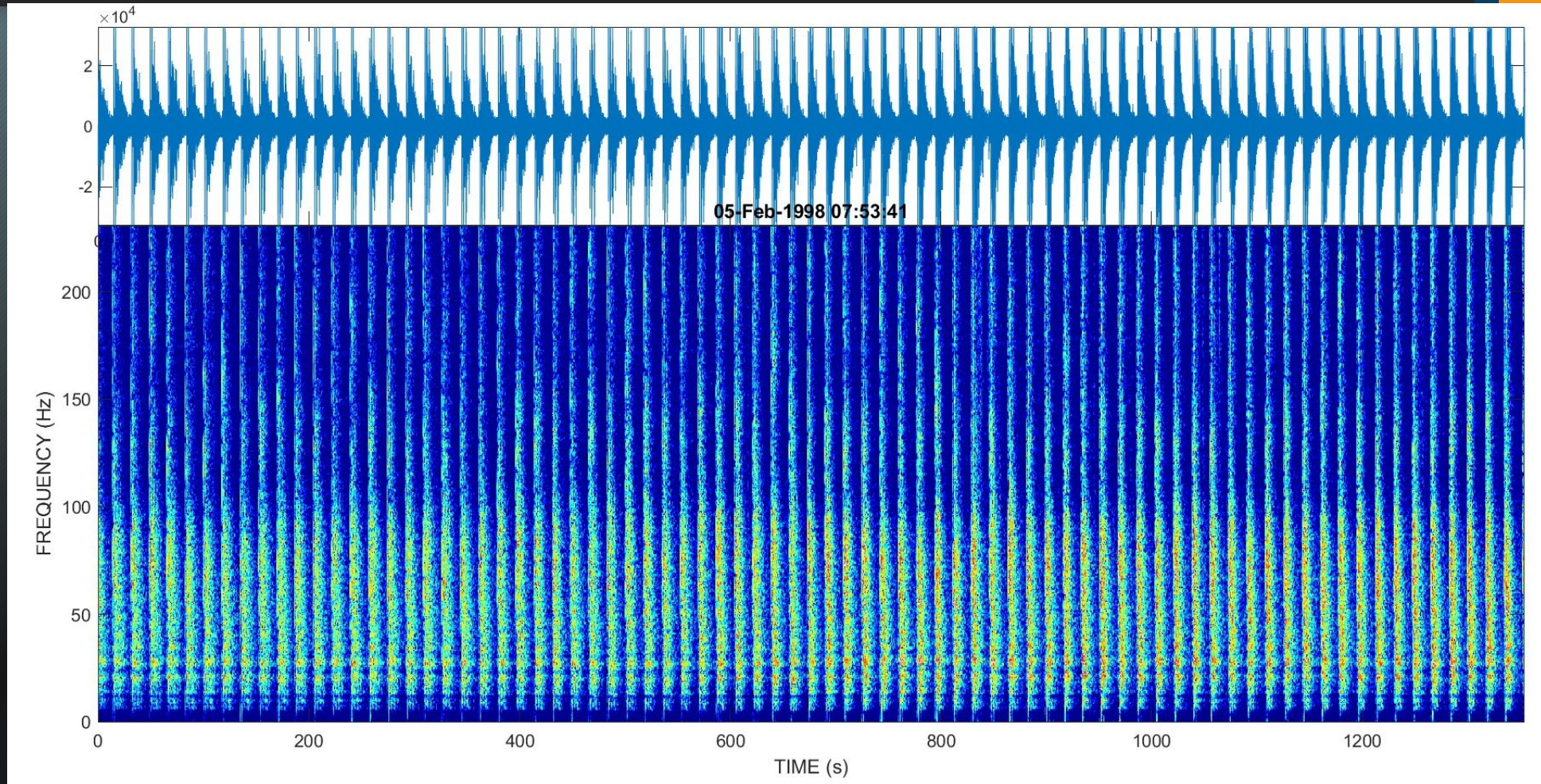




Whale song

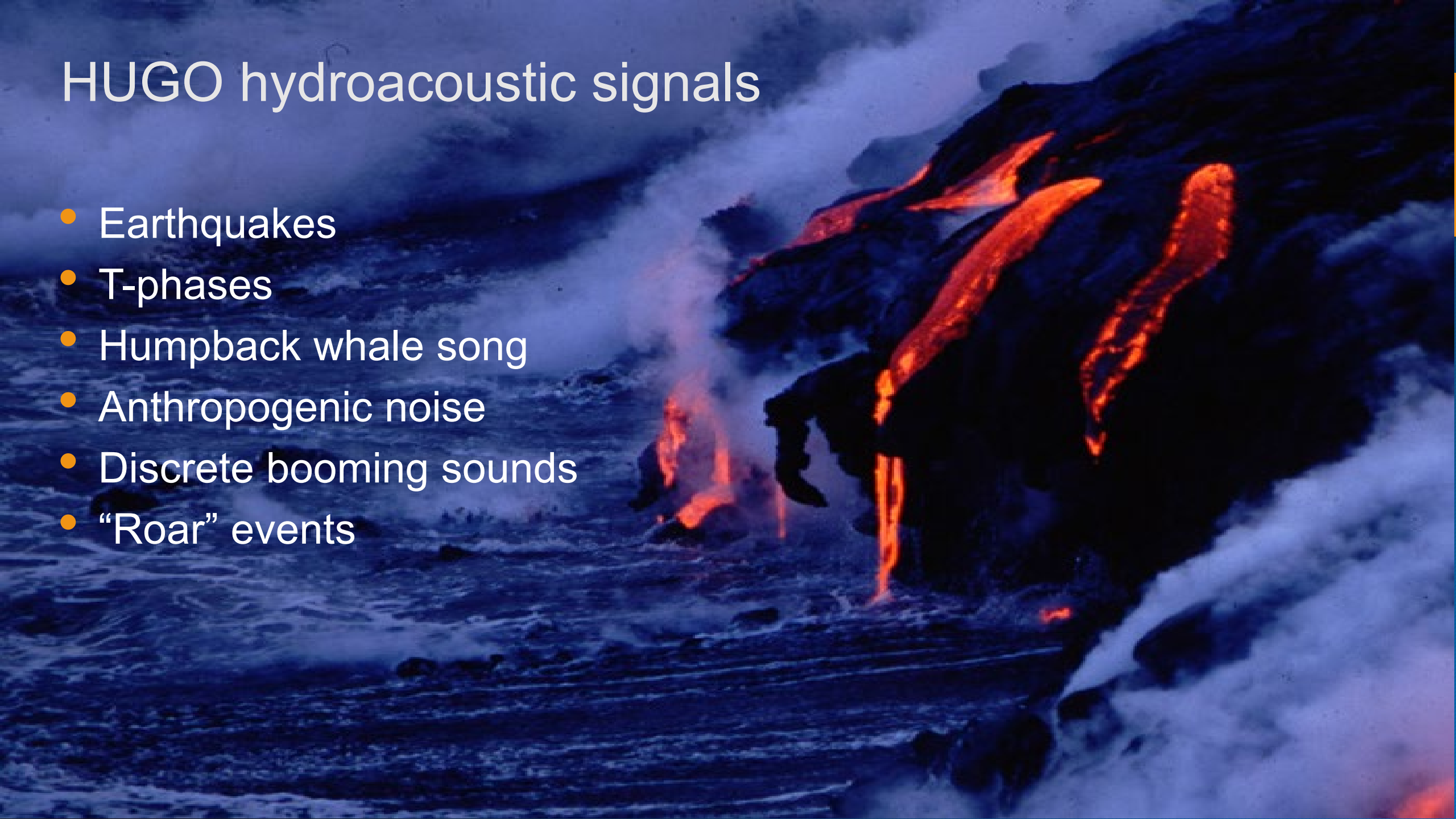
T-phase

# Seismic airguns recorded by HUGO (one person's signal is another's noise)

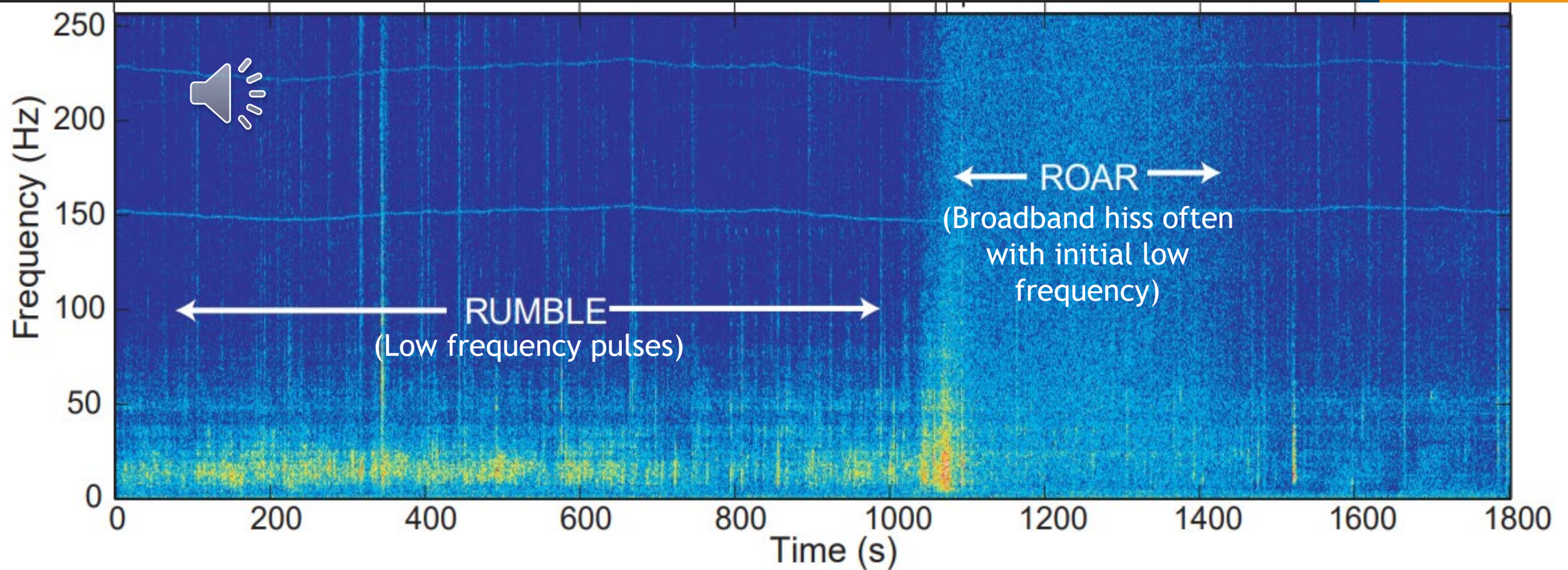


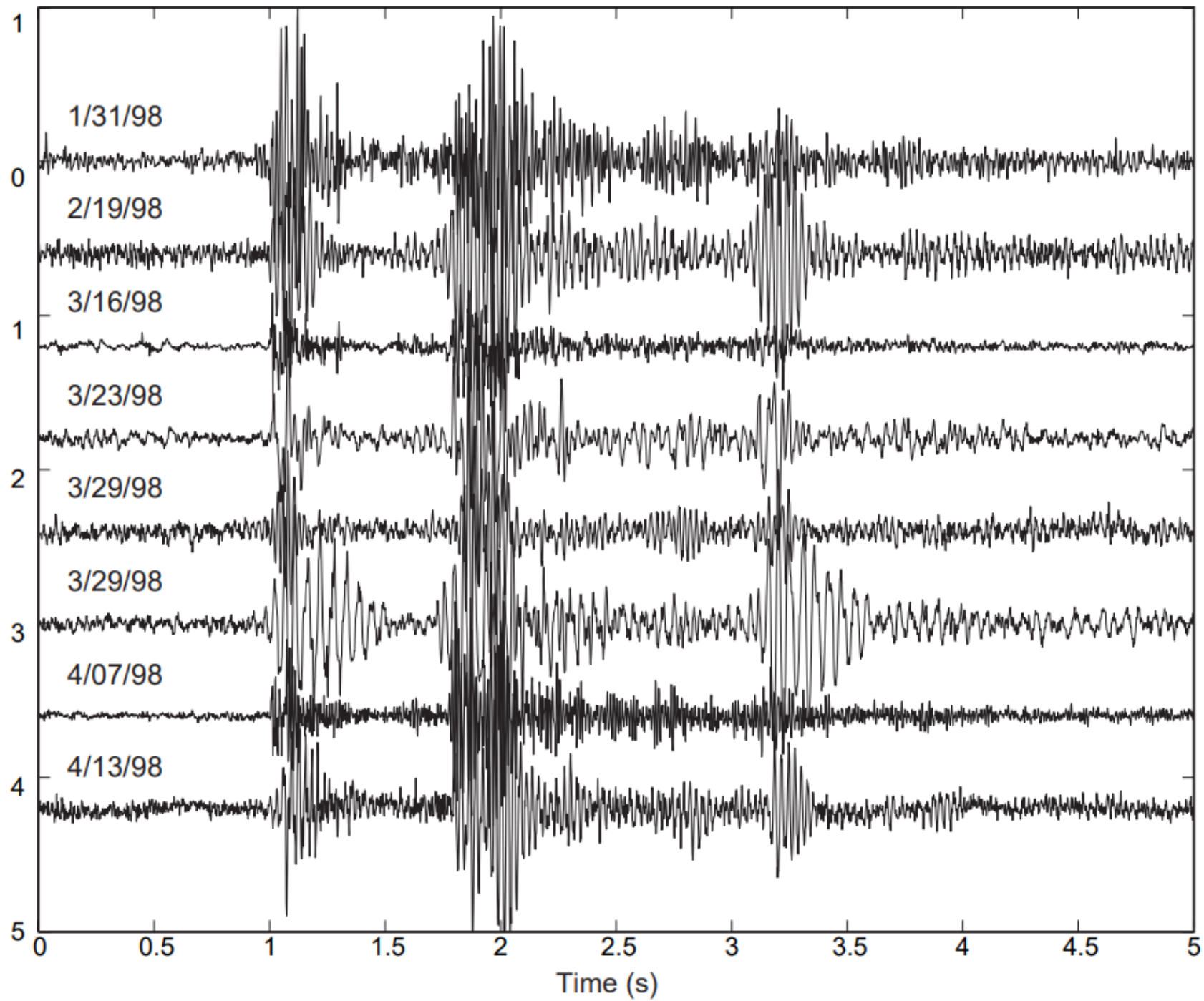
# HUGO hydroacoustic signals

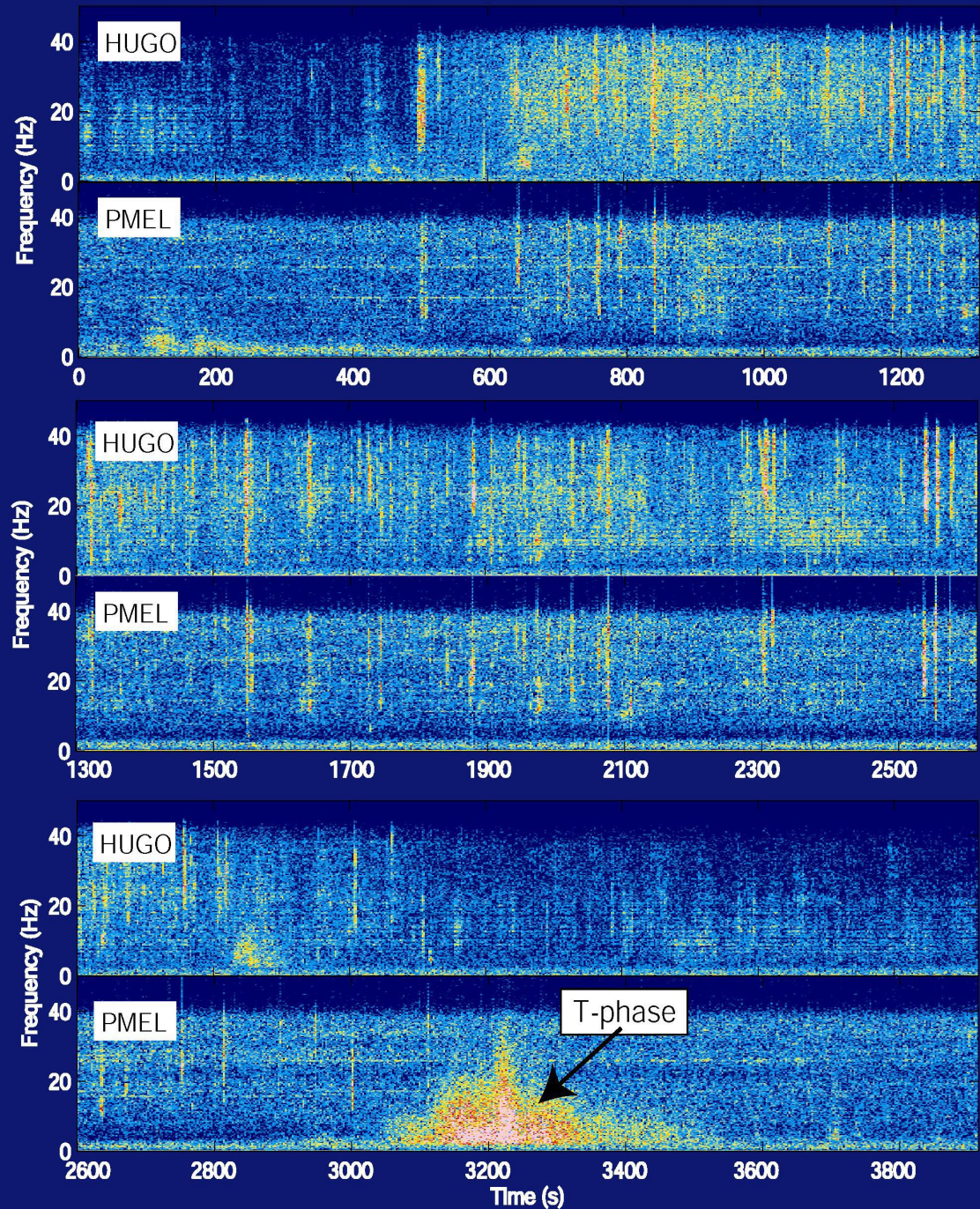
- Earthquakes
- T-phases
- Humpback whale song
- Anthropogenic noise
- Discrete booming sounds
- “Roar” events



# Serendipitous science





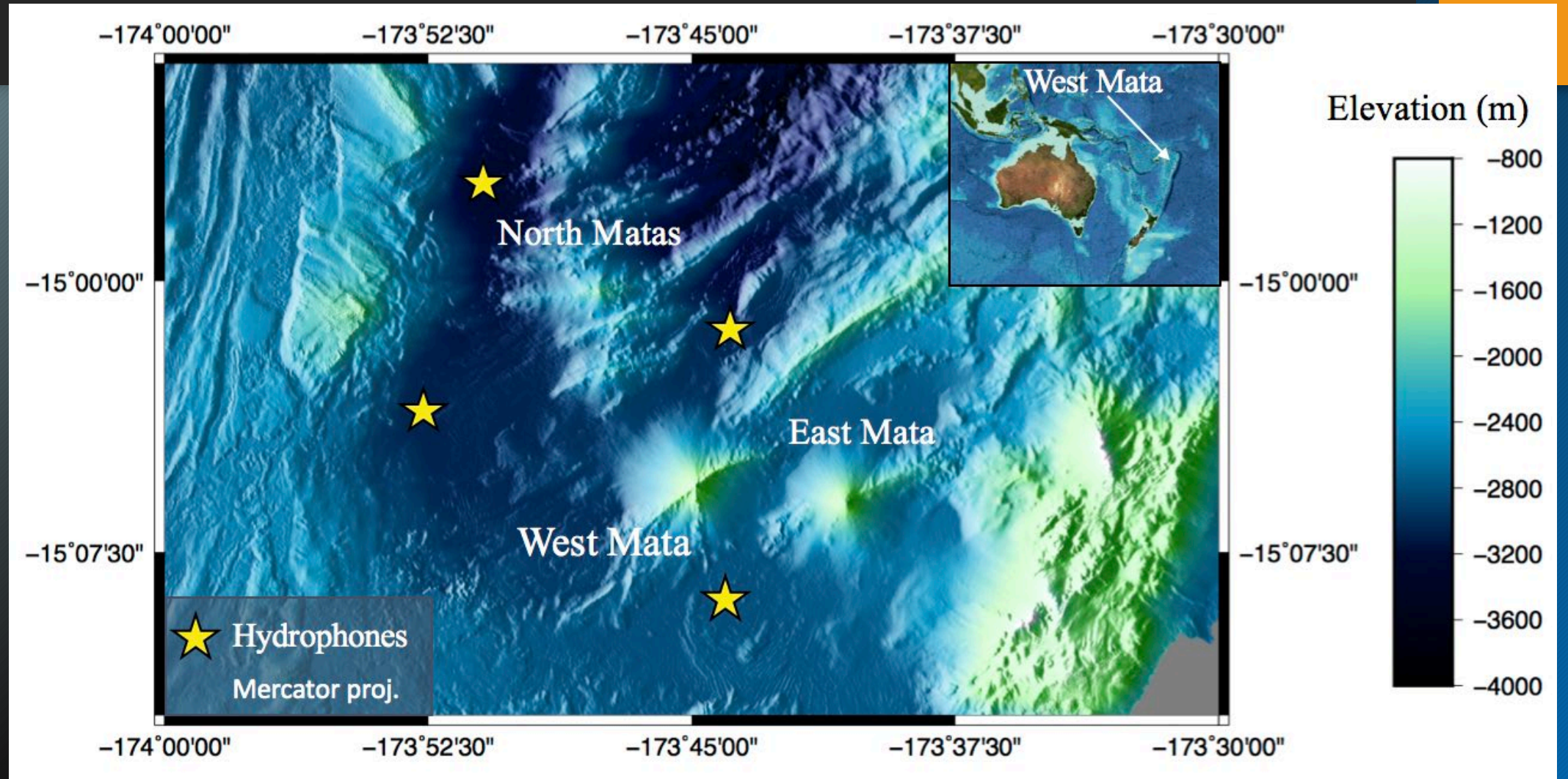


“Roar” events recorded by the HUGO hydrophone found to correlate with bench collapses at the coast of Kilauea volcano: these are the sounds of submarine landslides.



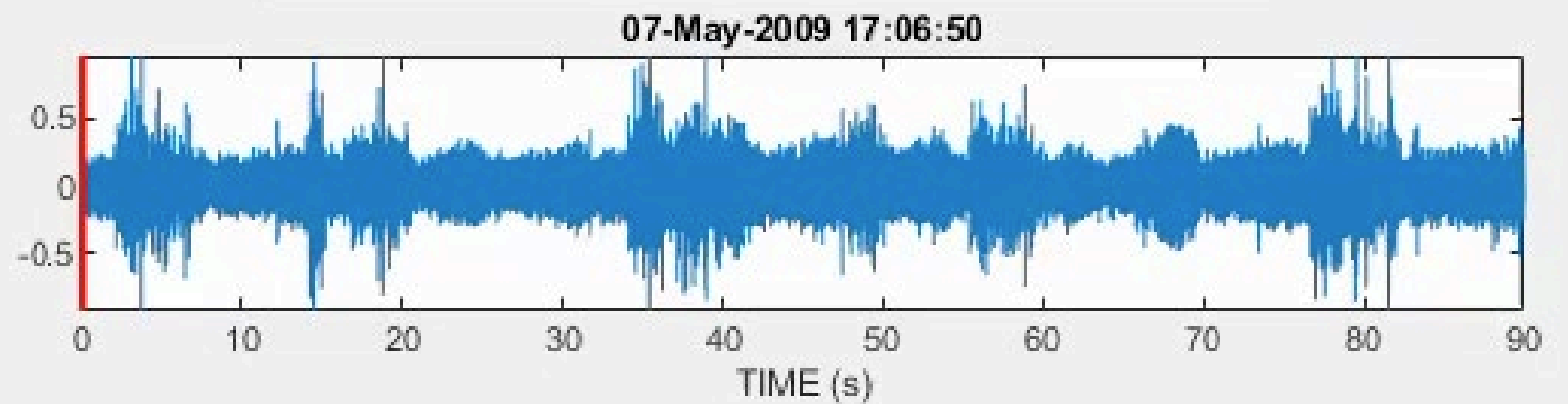


# West Mata volcano, Lau Basin



# West Mata

Hades Vent: bubble bursts generate short, discrete acoustic signals



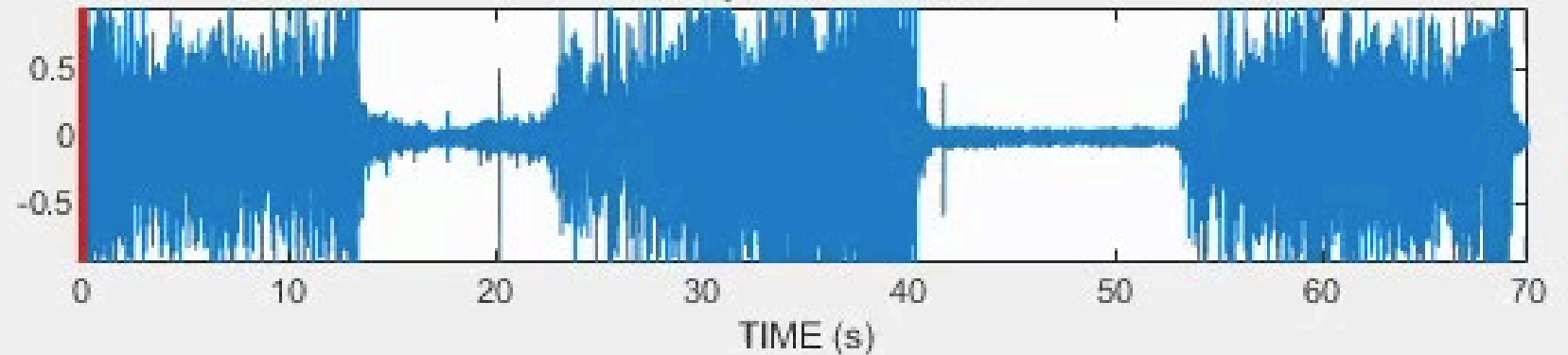
# West Mata

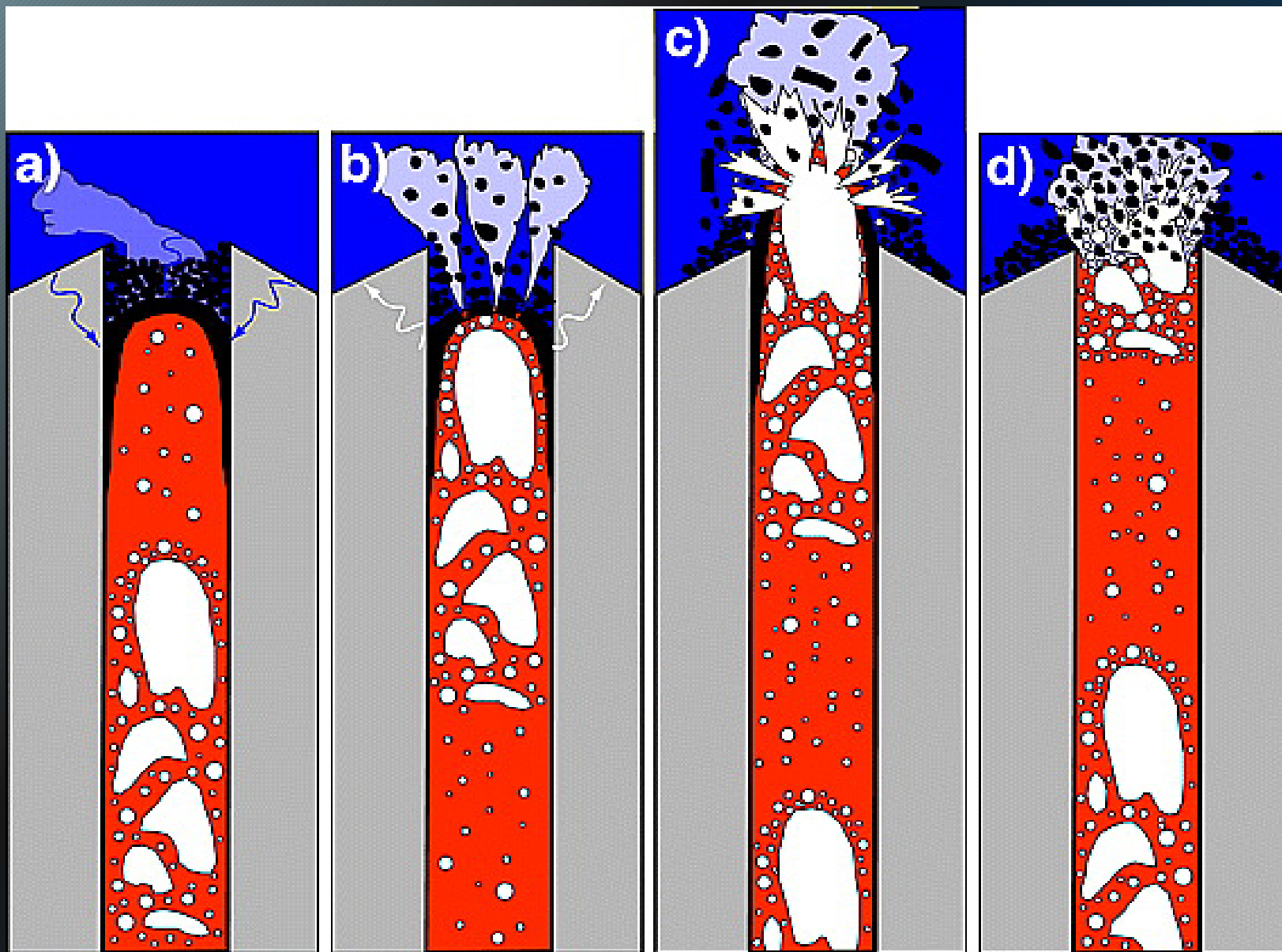
Prometheus Vent:  
long lasting (tens of  
seconds to tens of  
minutes) broadband  
signals

17:20:18.003

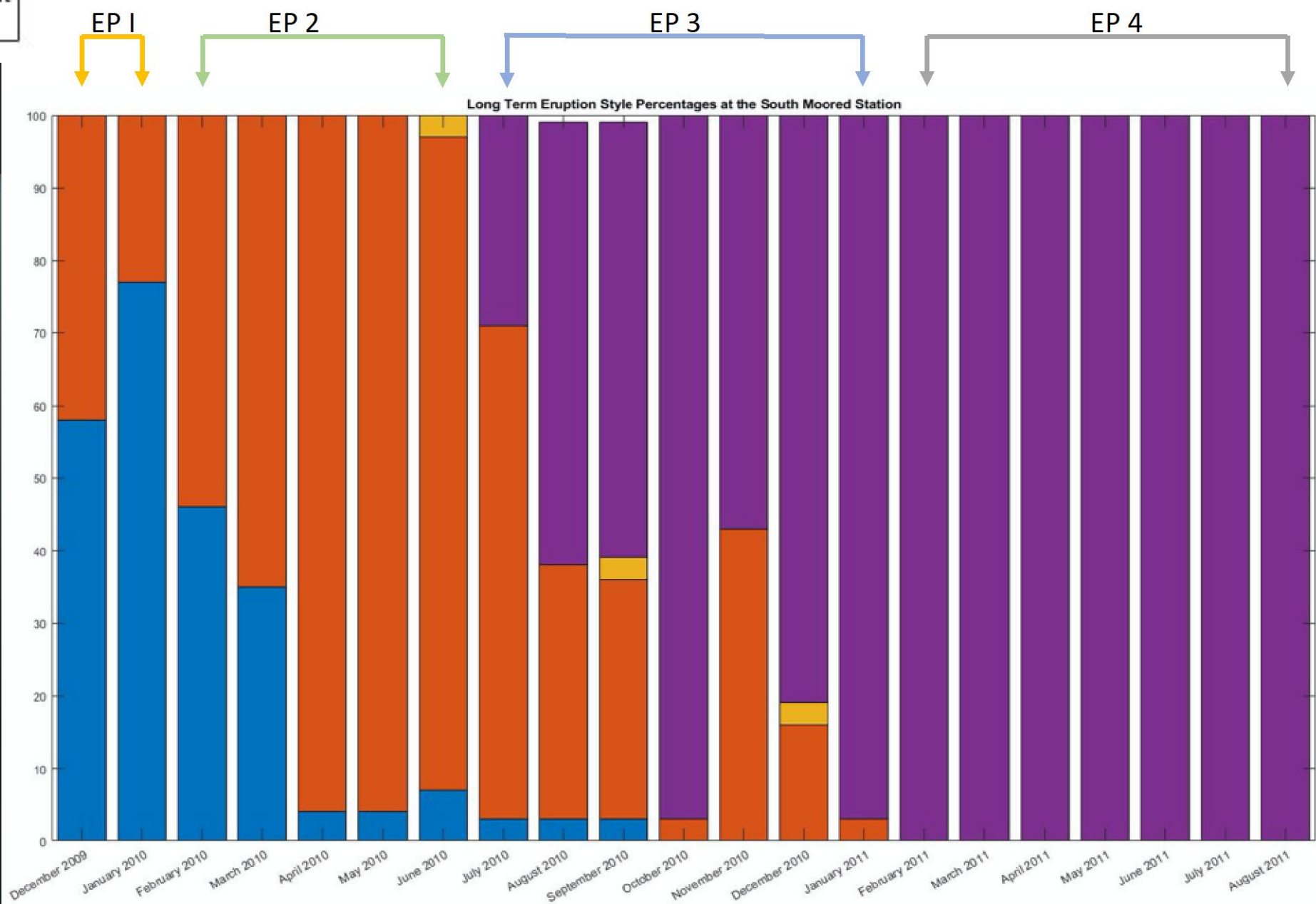
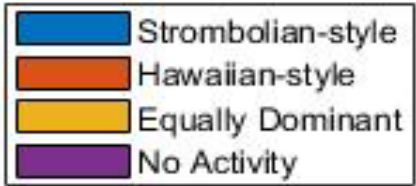


06-May-2009 17:20:18

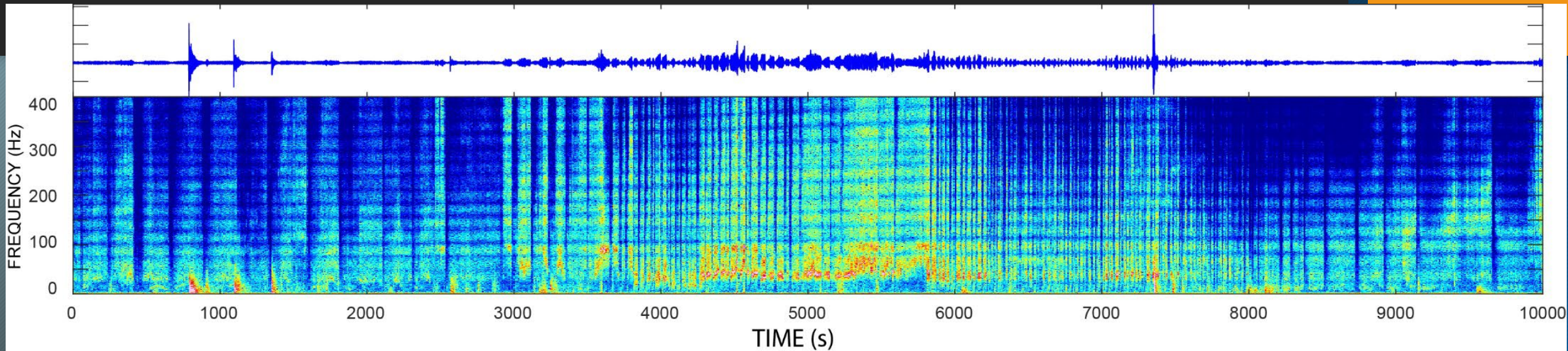




# Long-Term Eruptive Phases



# West Mata, 4/11/10



Weak, long duration  
(100-300 s) diffuse  
events

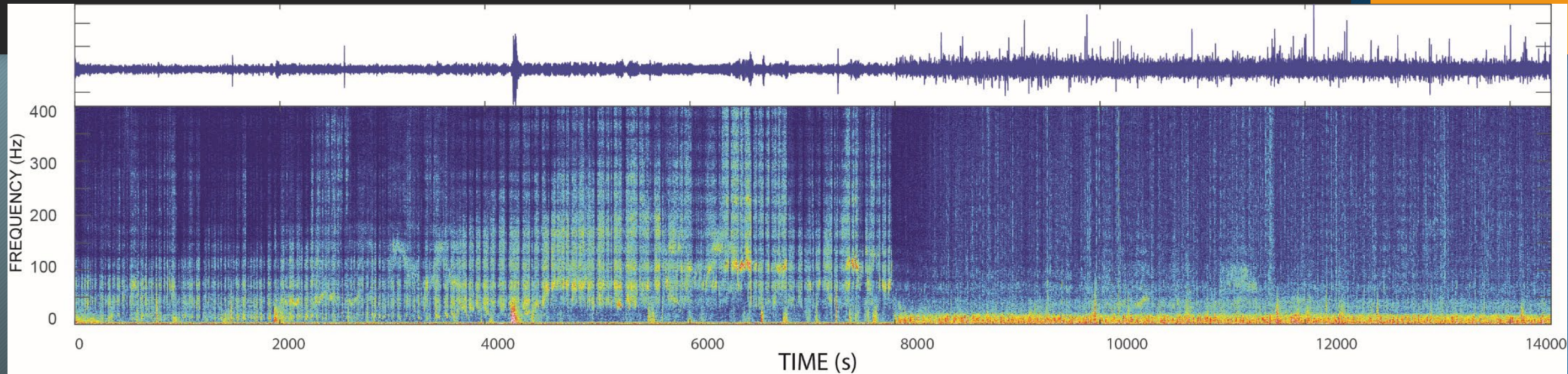
Events increase in amplitude,  
durations drop, then  
gradually increase; tremor  
observed

Short duration  
(10-30 s) signal;  
tremor variable

Weak, long  
duration  
events return

Changes in slug size, gas content

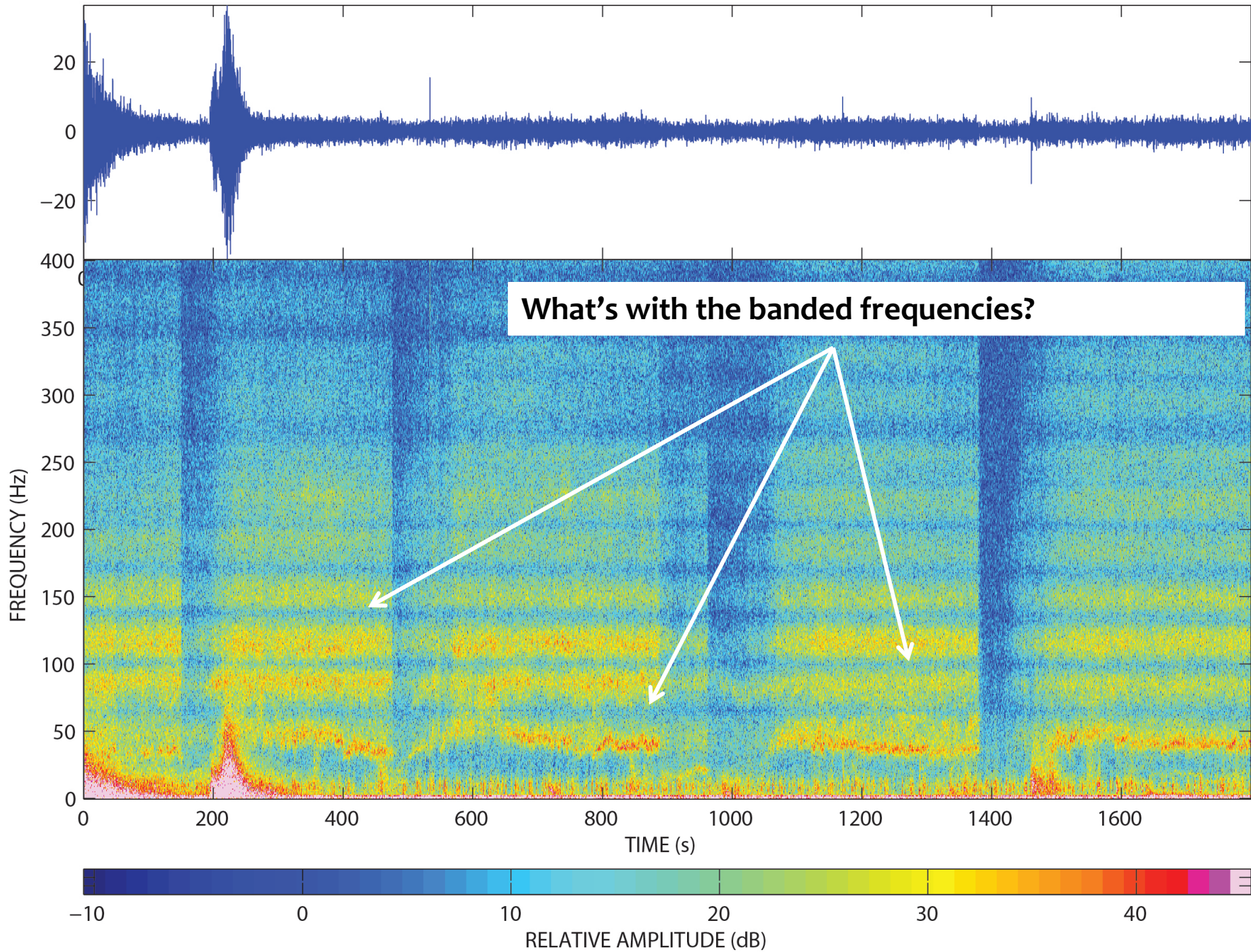
# West Mata, 2/26/10



Broadband signals of variable duration,  
some exhibit tremor

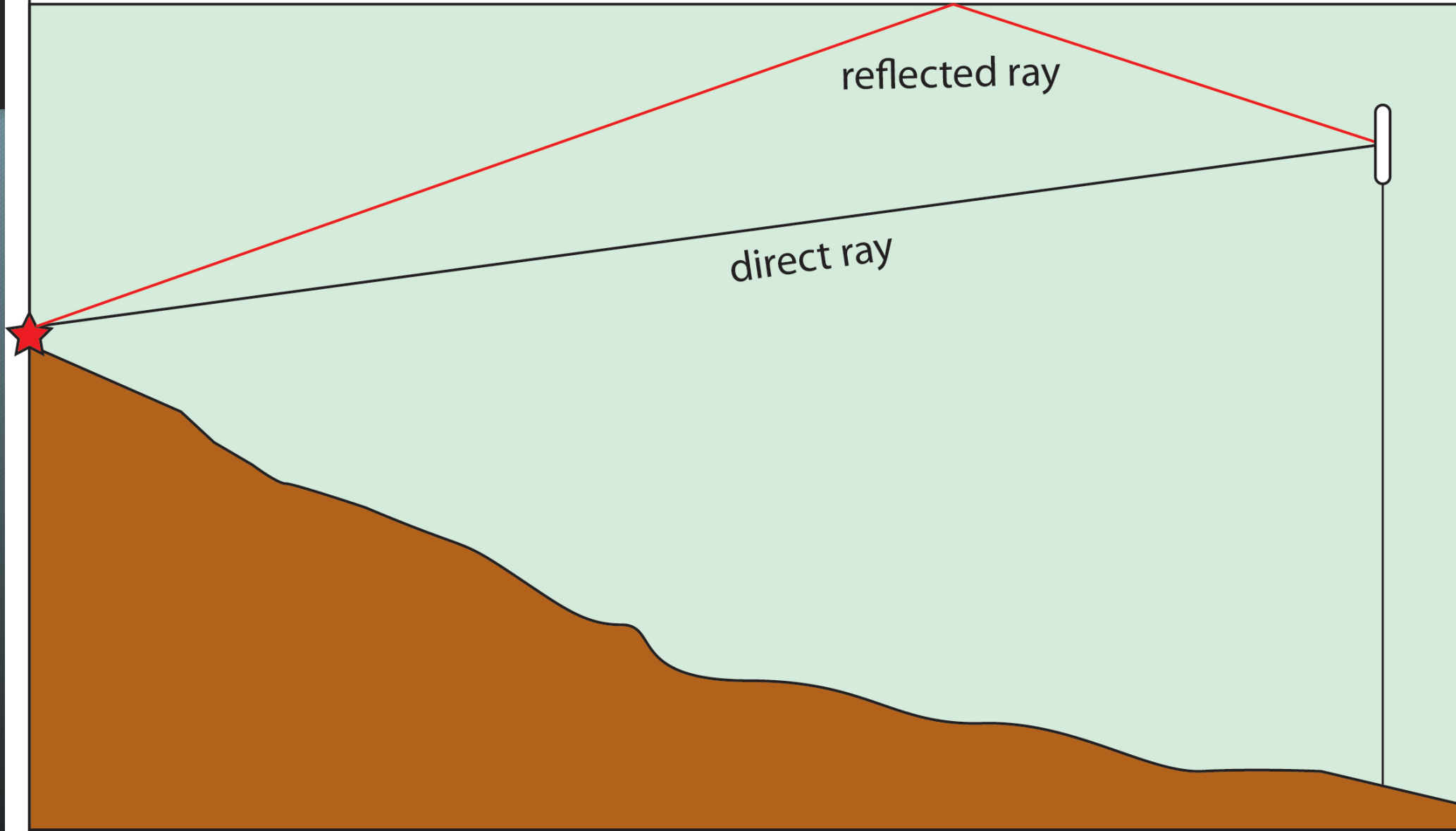
Rapid shift to low frequency pulses

Change from bubbly flow to slug (Strombolian) flow?  
Change in gas content or magma ascent rate

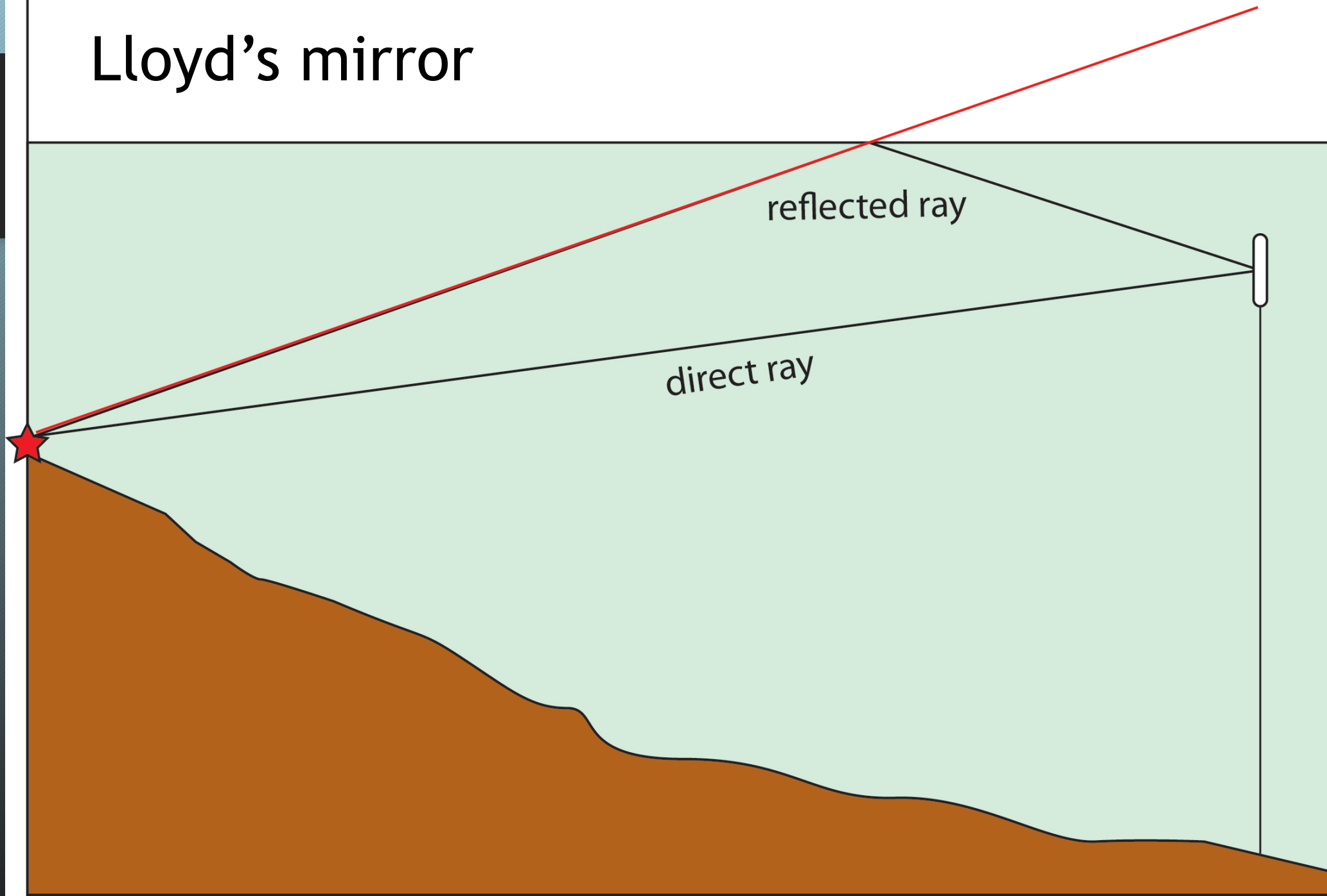




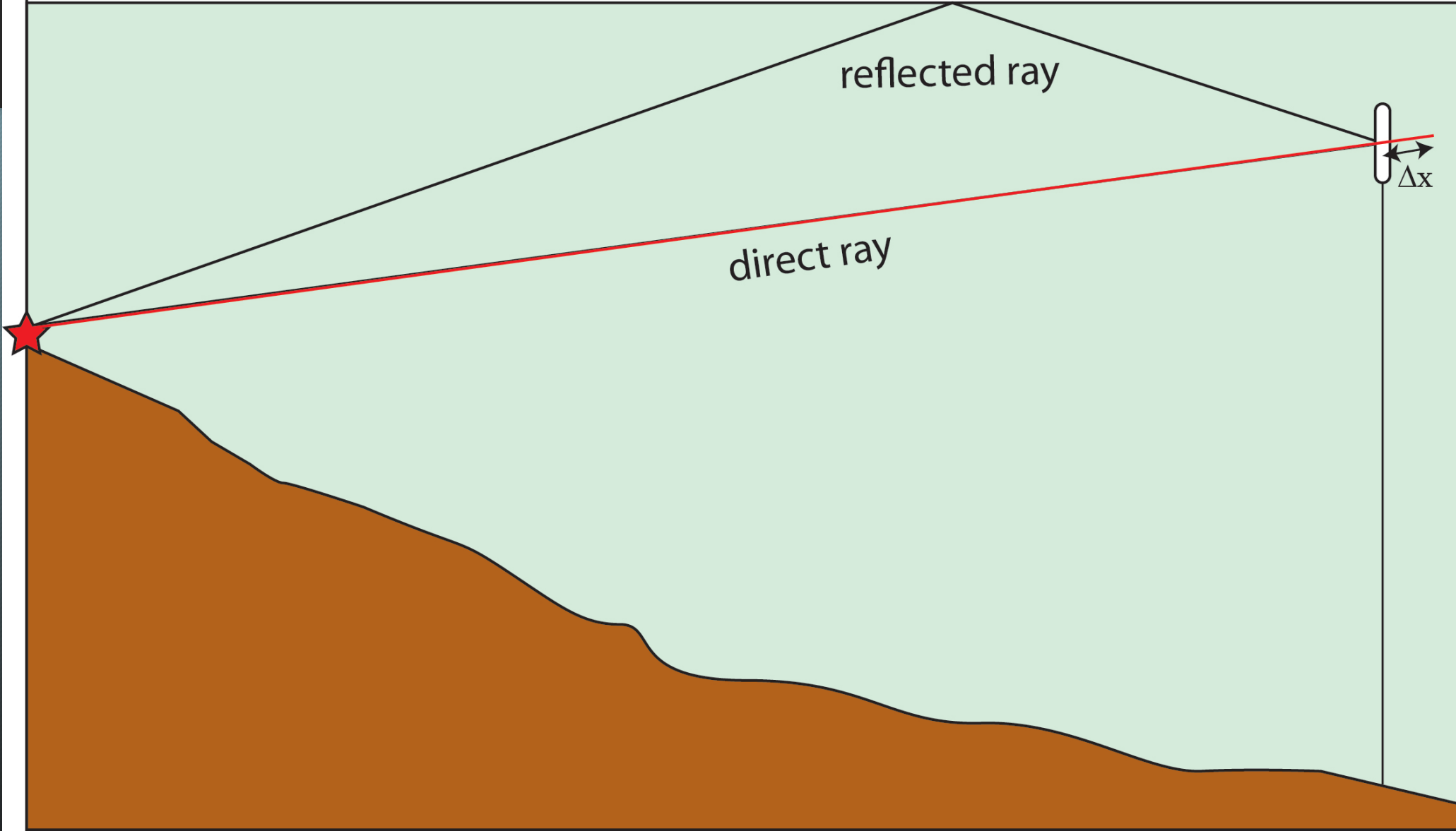
# Lloyd's mirror



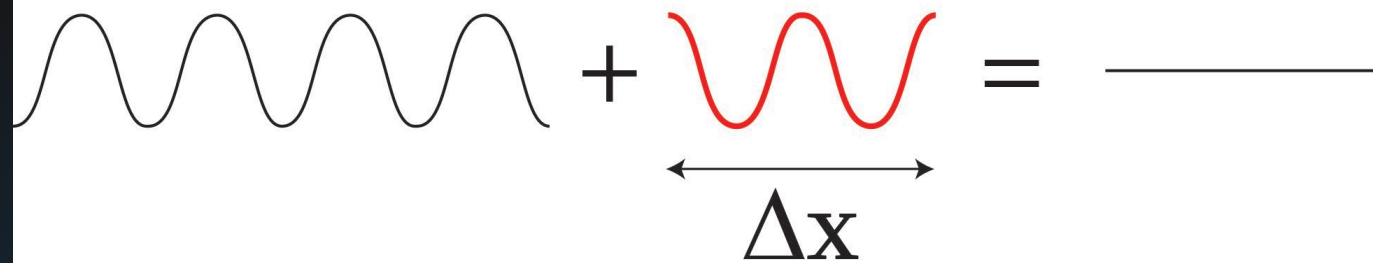
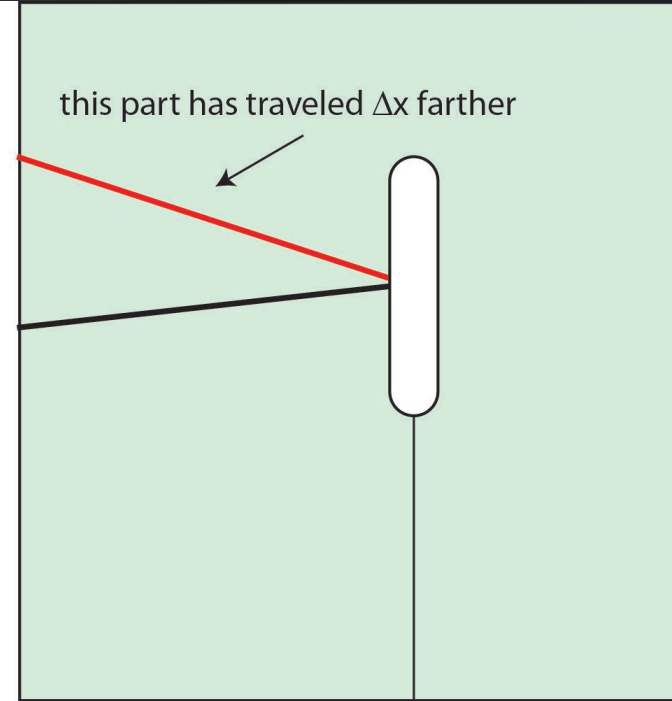
# Lloyd's mirror

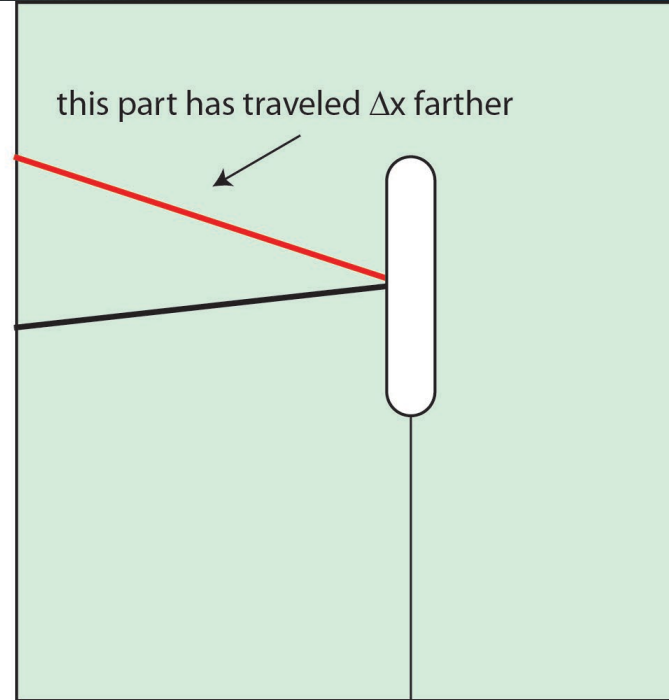


# Lloyd's mirror



Waves of this frequency  
will cancel out (quiet)



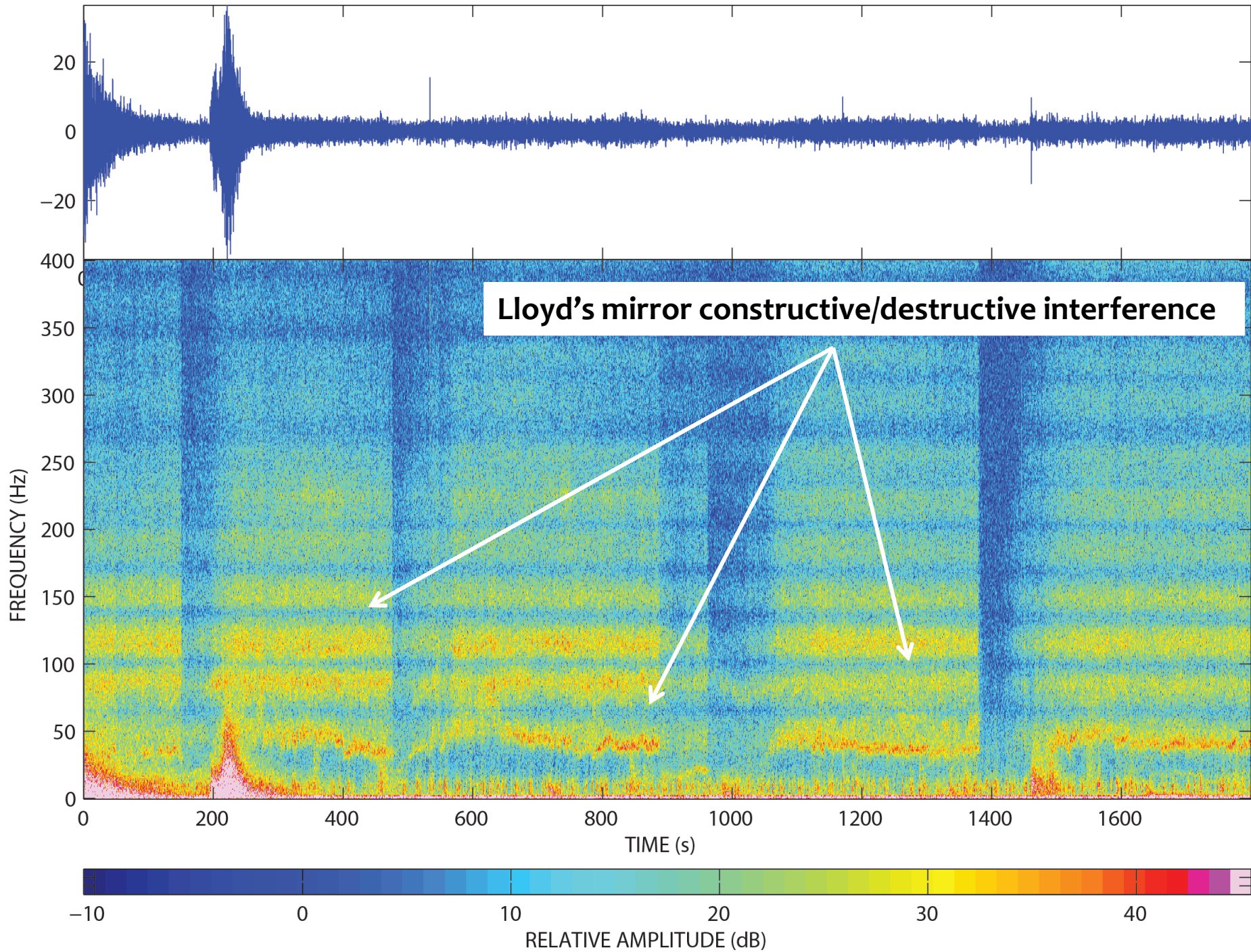


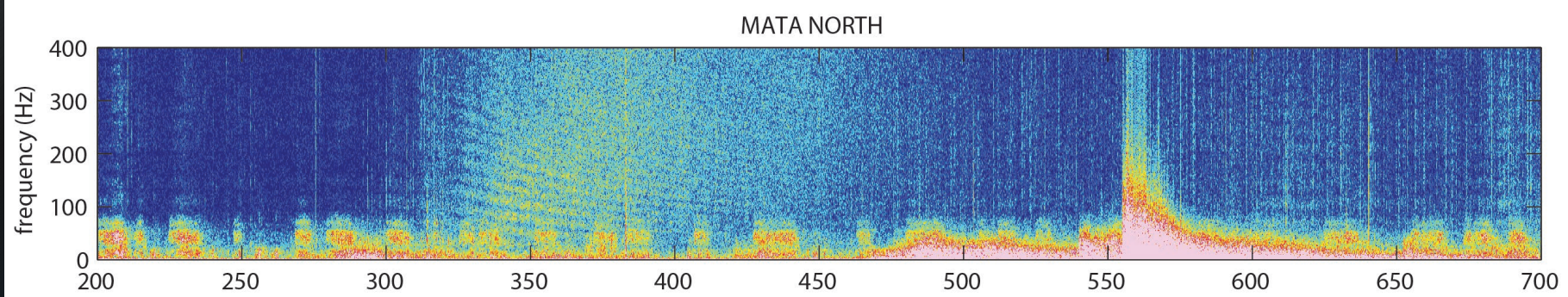
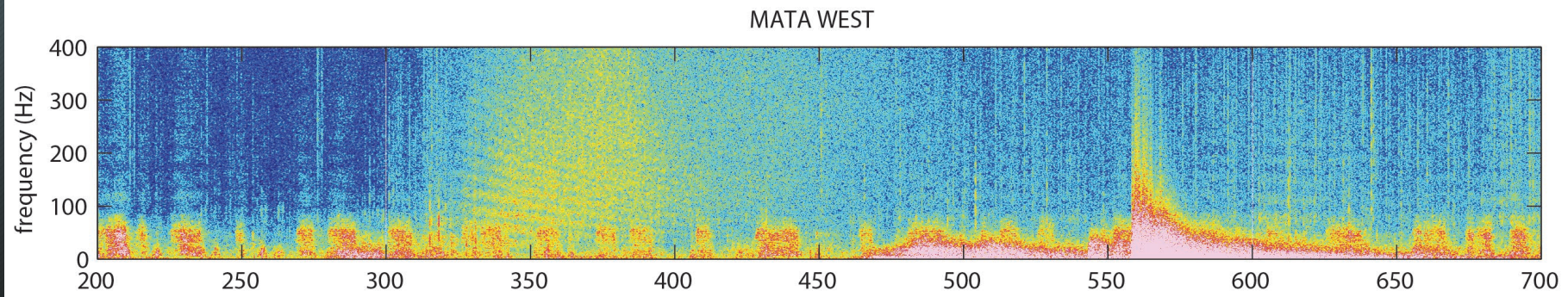
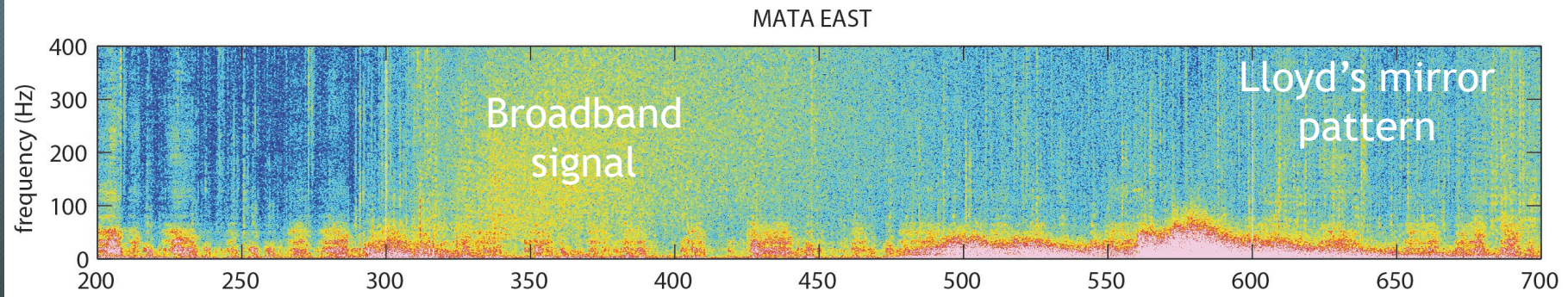
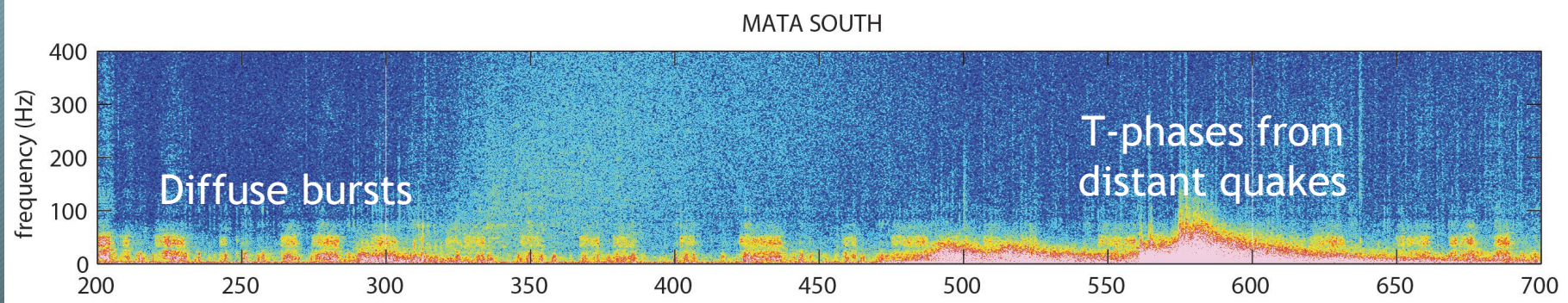
Waves of this frequency  
will cancel out (quiet)

Diagram illustrating destructive interference. A black sine wave is added to a red sine wave that is out of phase by half a wavelength. The result is a flat line. The path difference  $\Delta x$  is indicated by a double-headed arrow below the red wave.

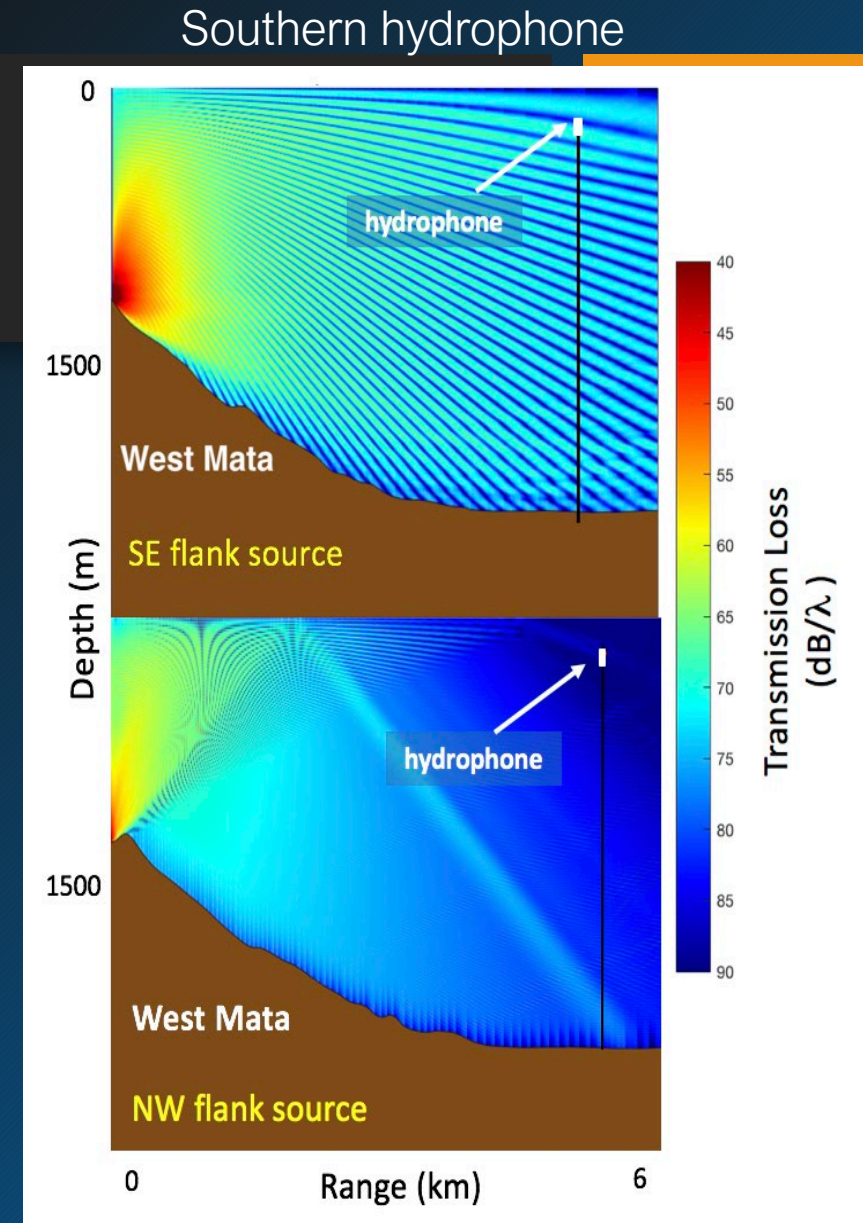
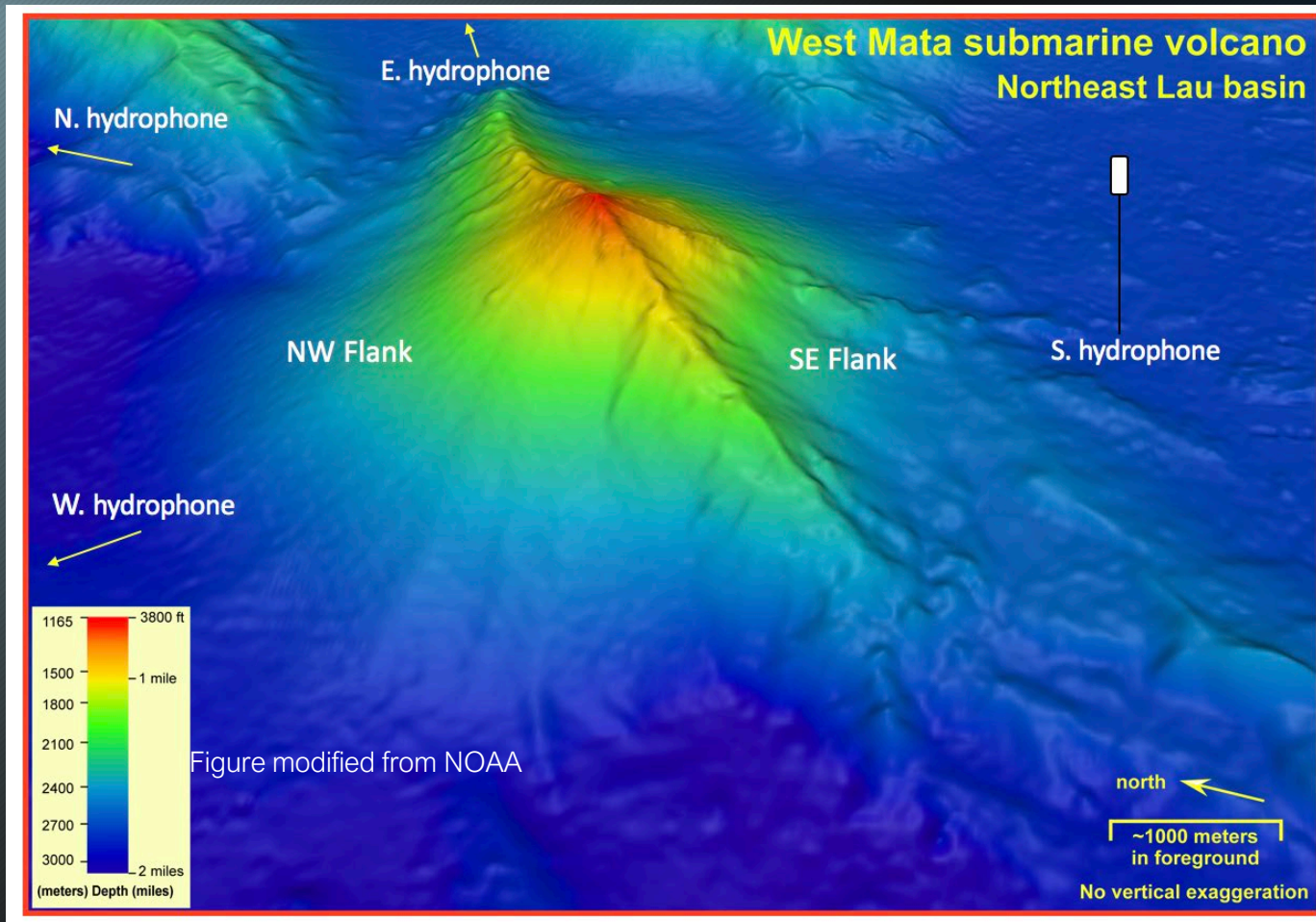
Waves of this frequency  
will add (amplify)

Diagram illustrating constructive interference. A black sine wave is added to a red sine wave that is in phase. The result is a larger black sine wave. The path difference  $\Delta x$  is indicated by a double-headed arrow below the red wave.

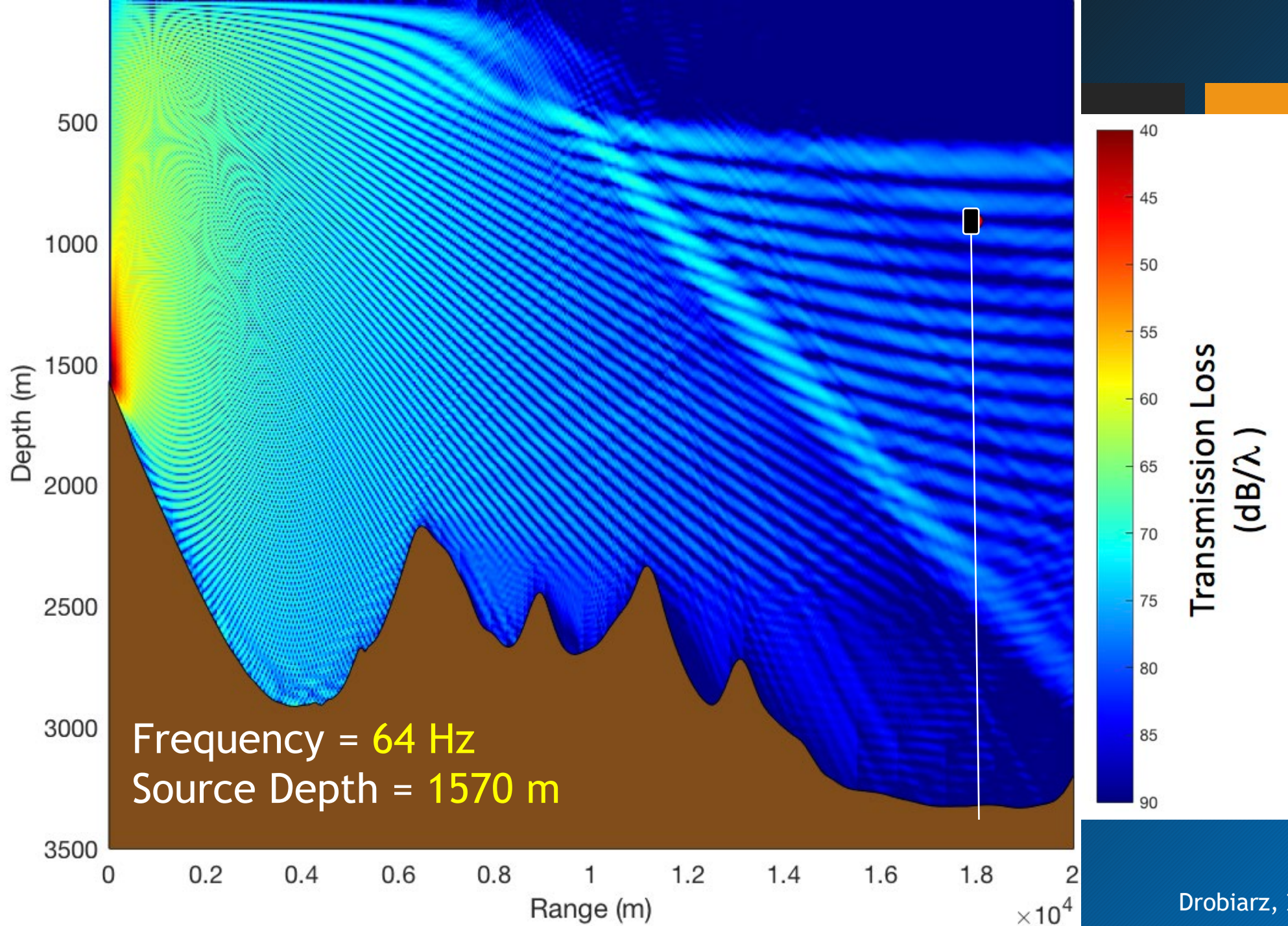


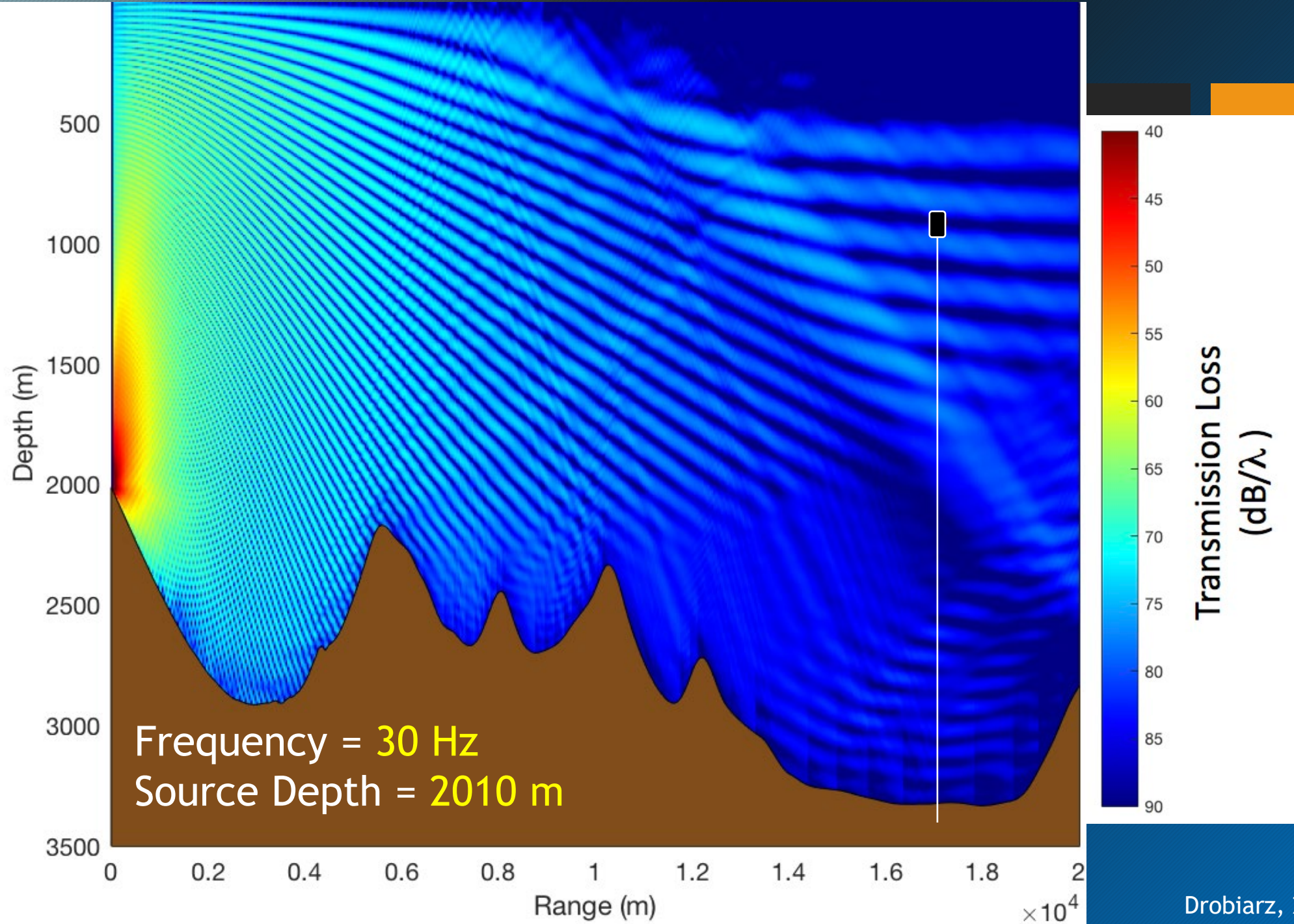


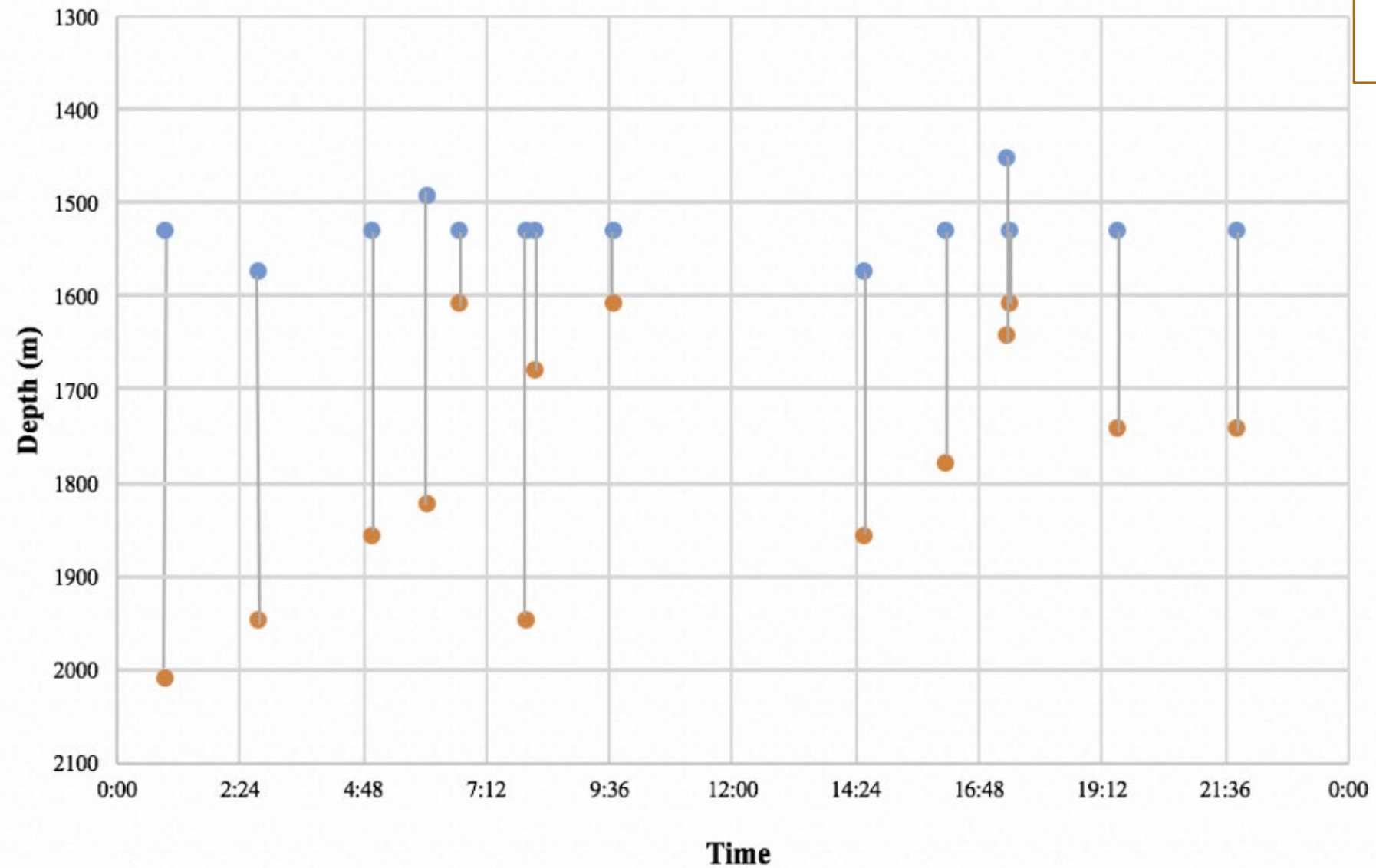
# Only some hydrophones show the Lloyd's mirror effect



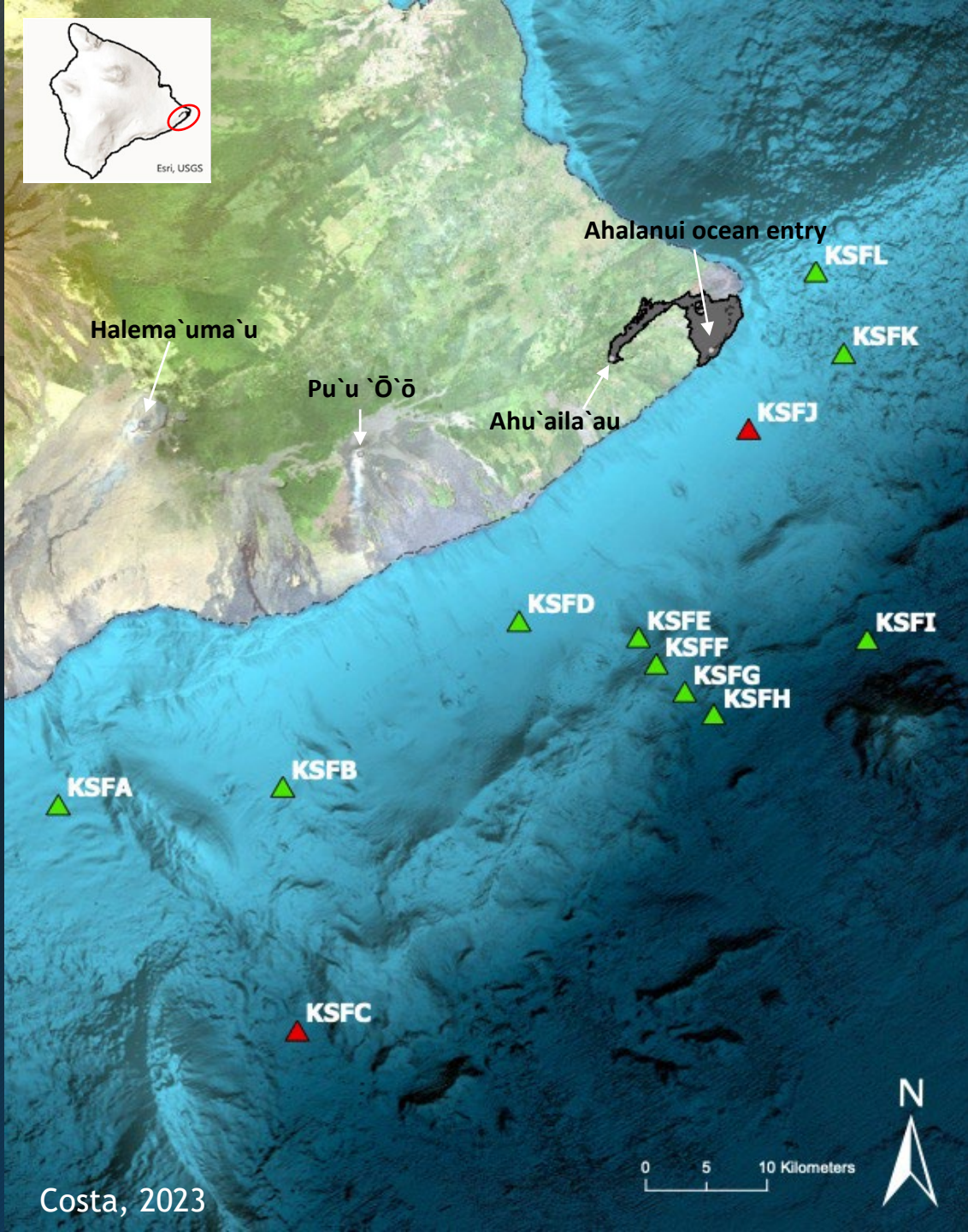


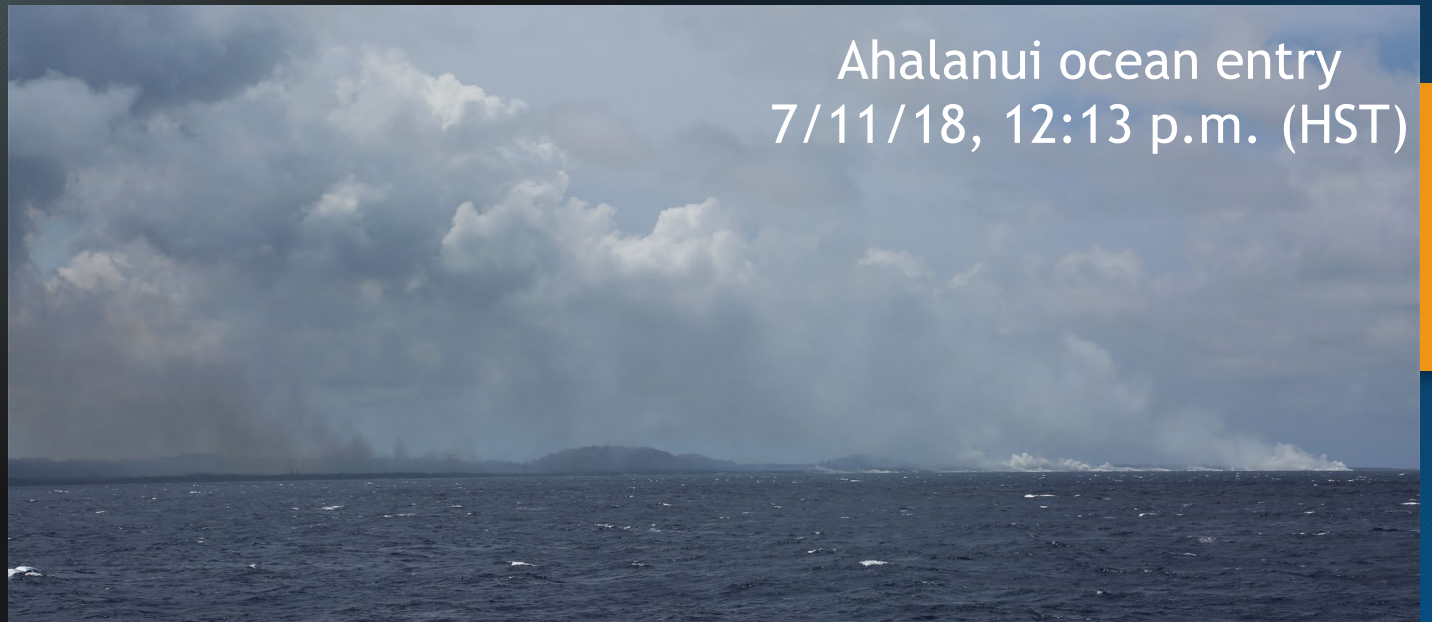
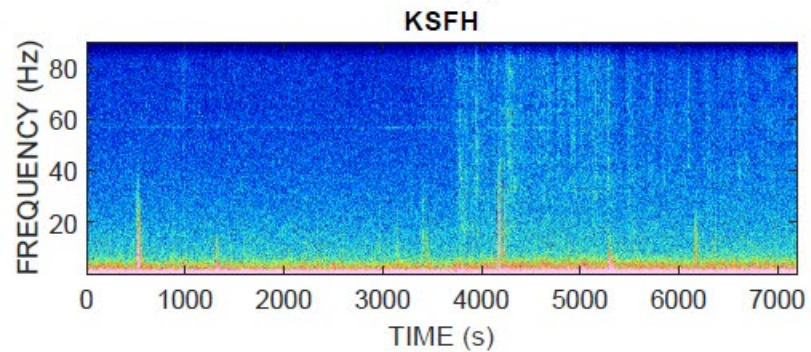
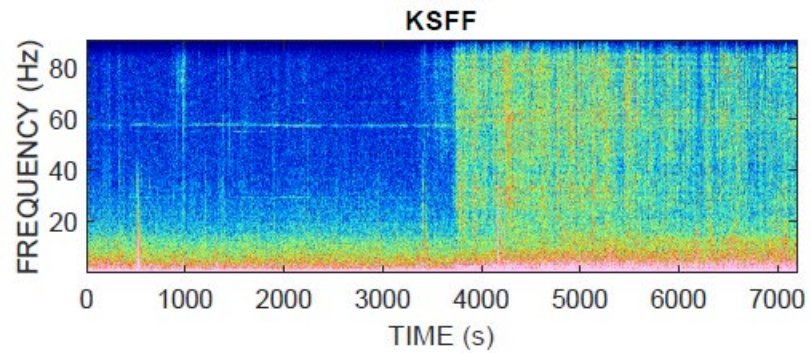
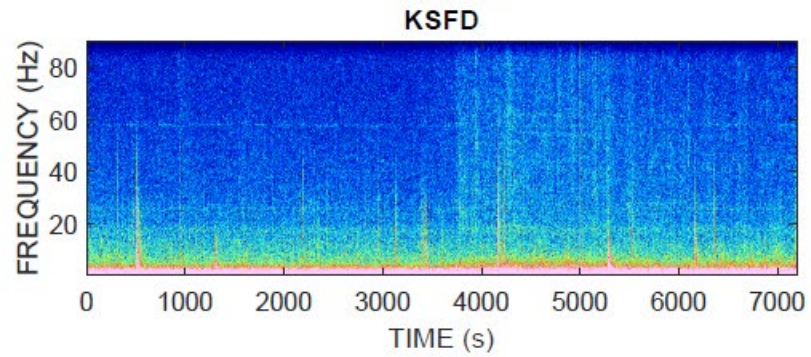
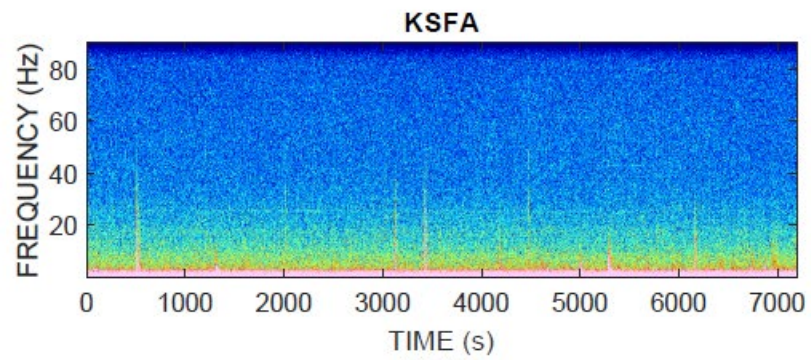


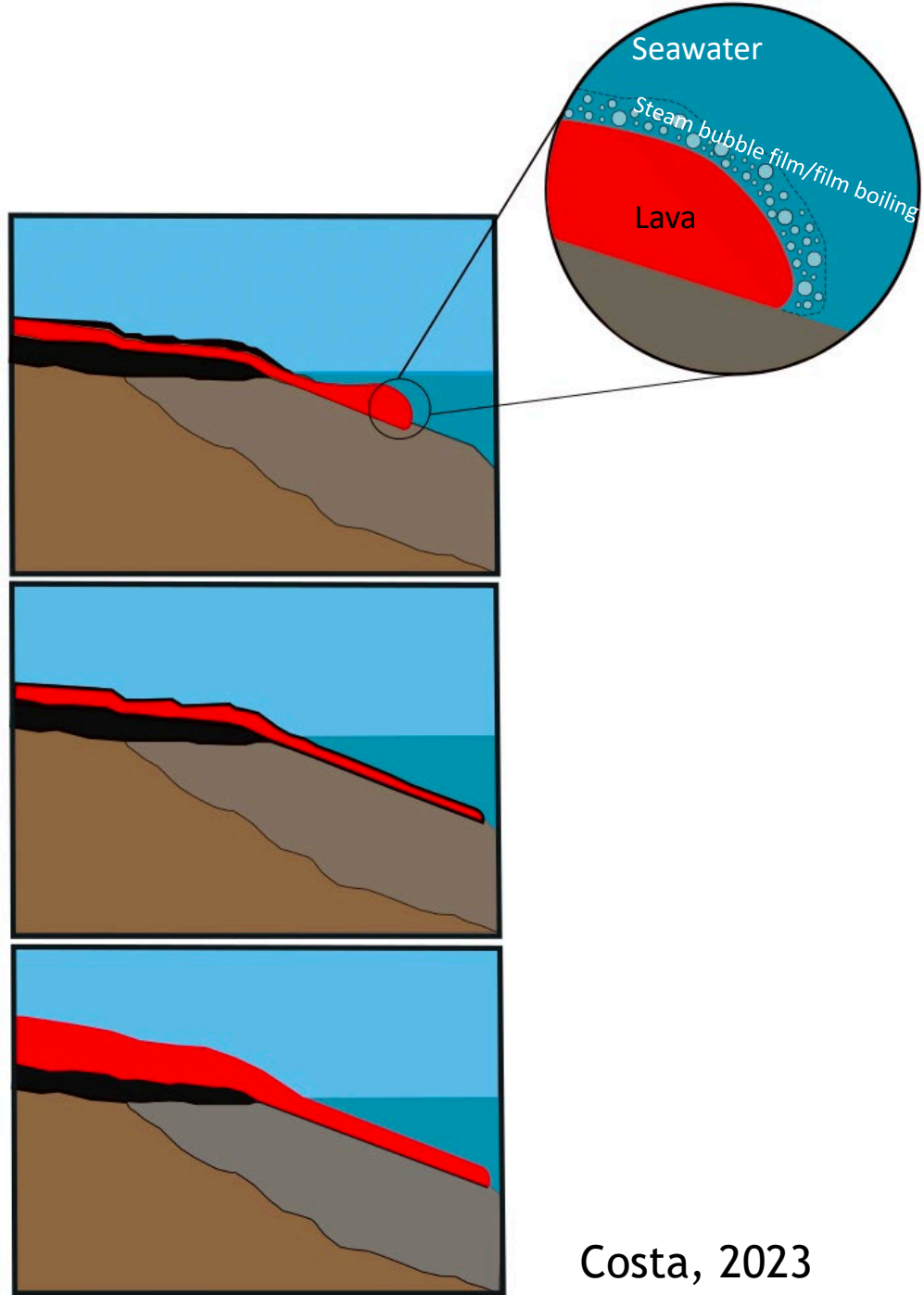




# How is lava emplaced offshore at Kilauea?



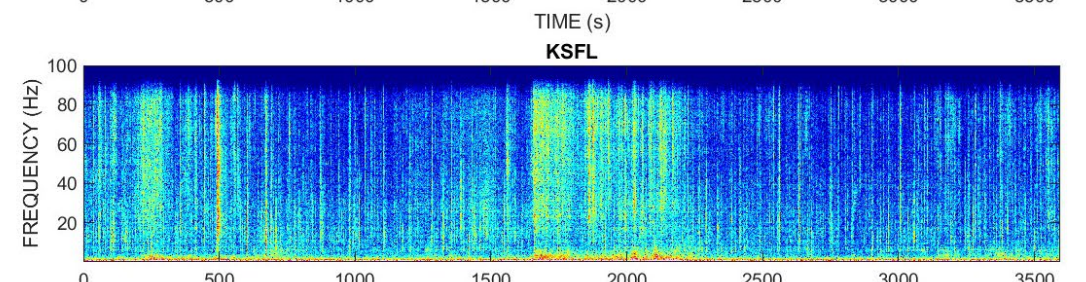
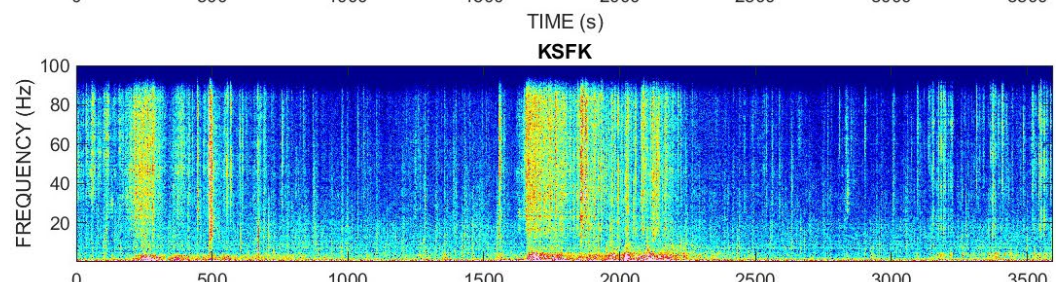
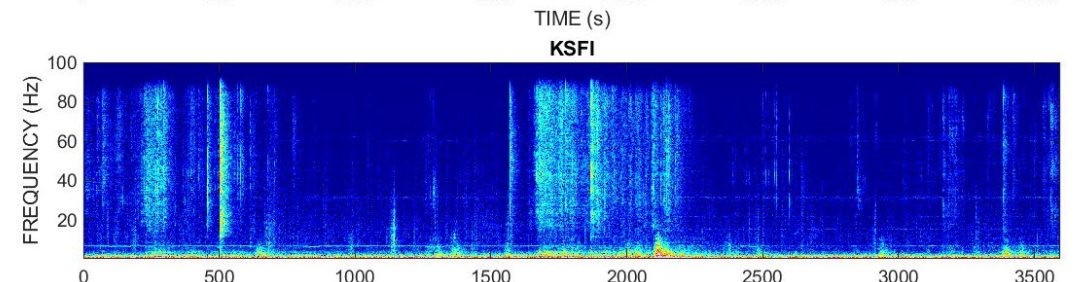
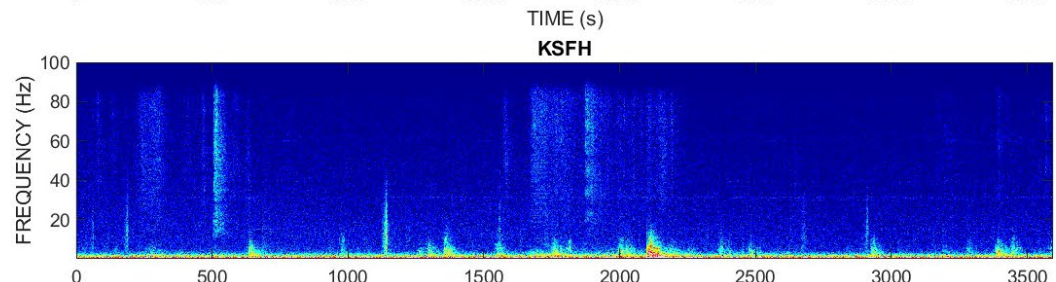
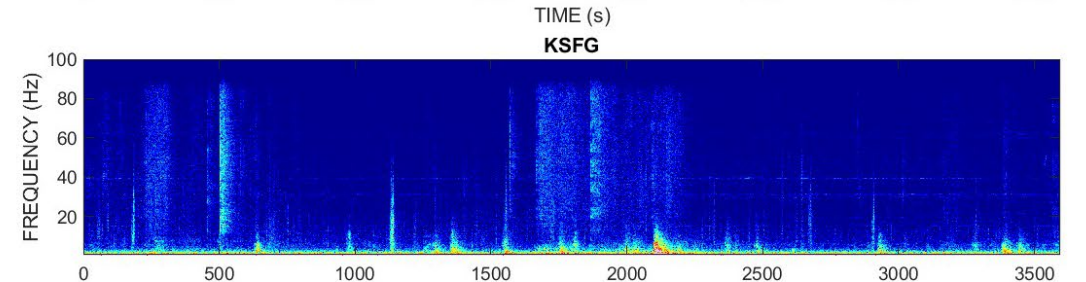
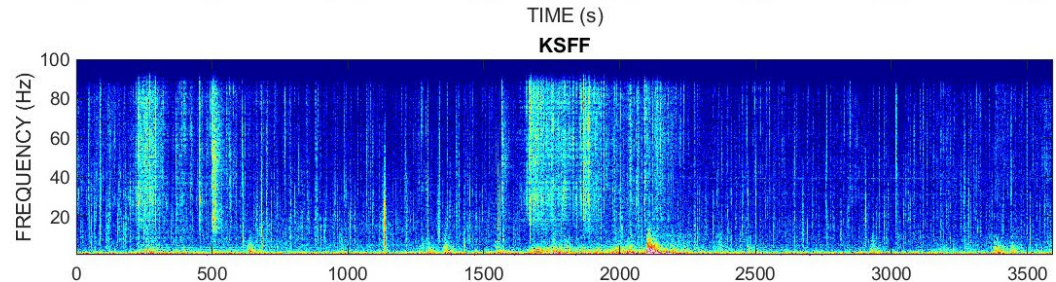
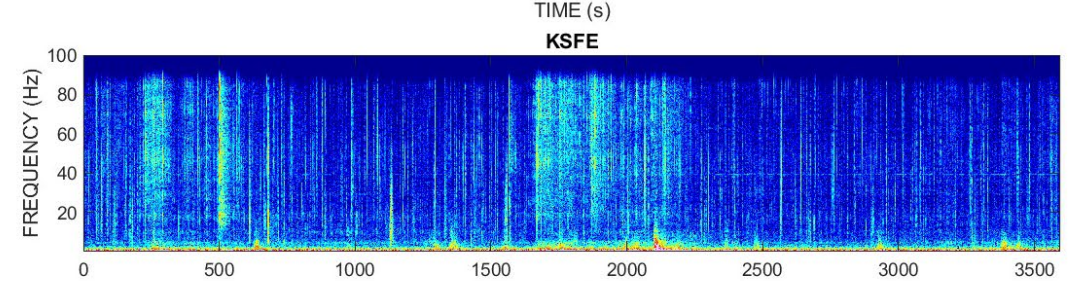
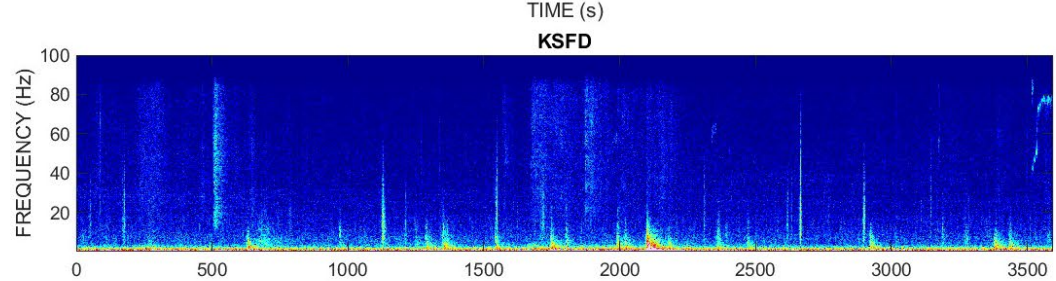
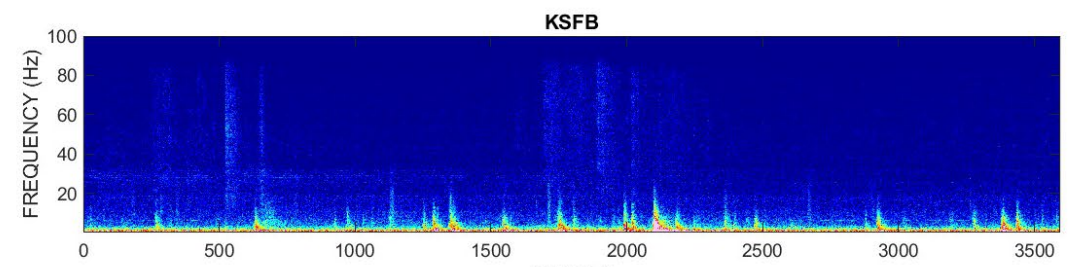
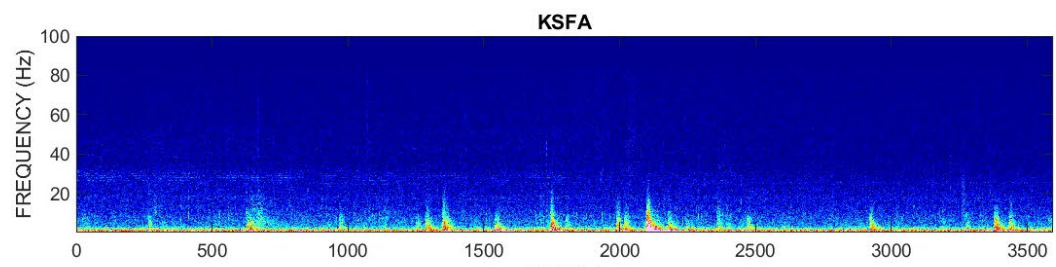




Costa, 2023



Video from Sansone et al. 1990; Pele Meets the Sea

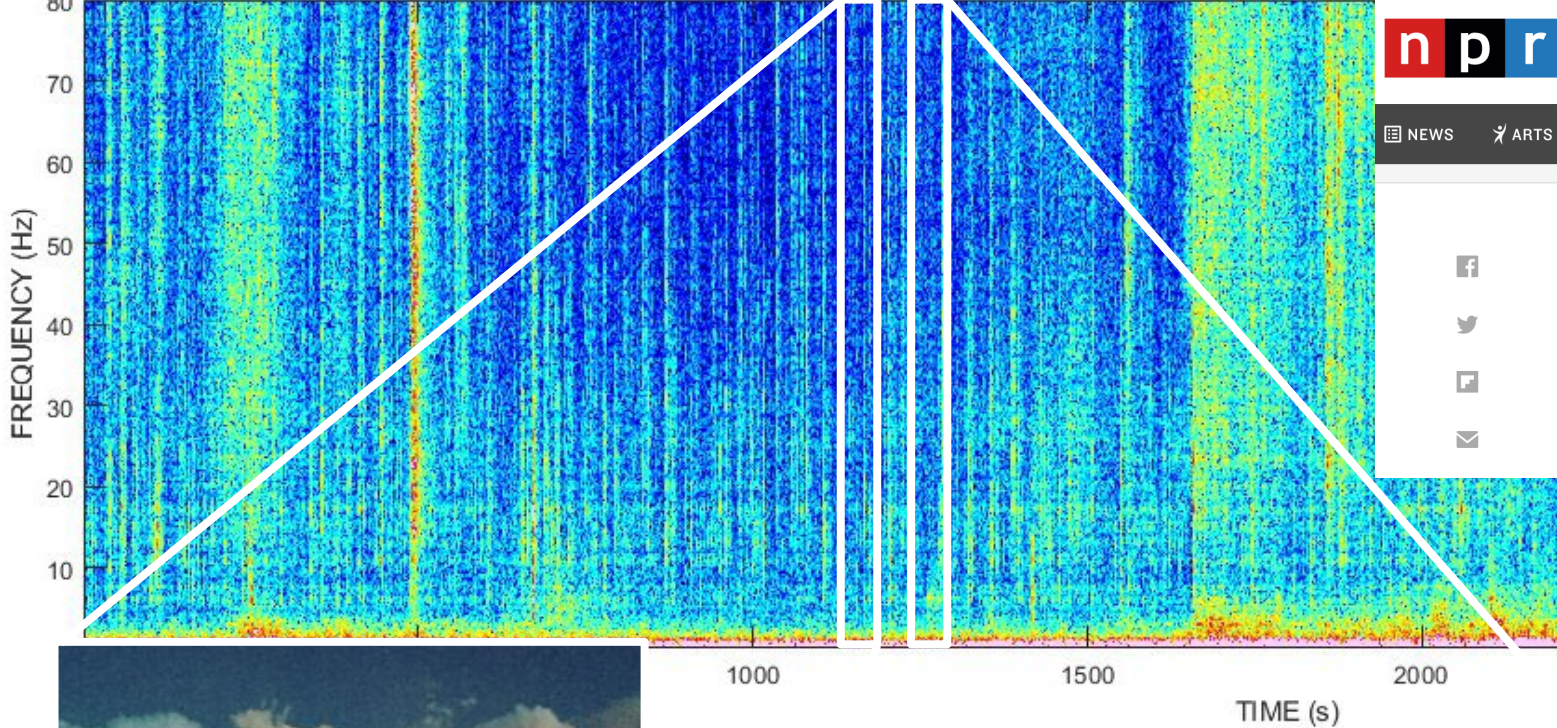


NATIONAL

# Kilauea 'Lava Bomb' Hits Tour Boat; Explosion Injures 23

July 16, 2018 · 7:53 PM ET

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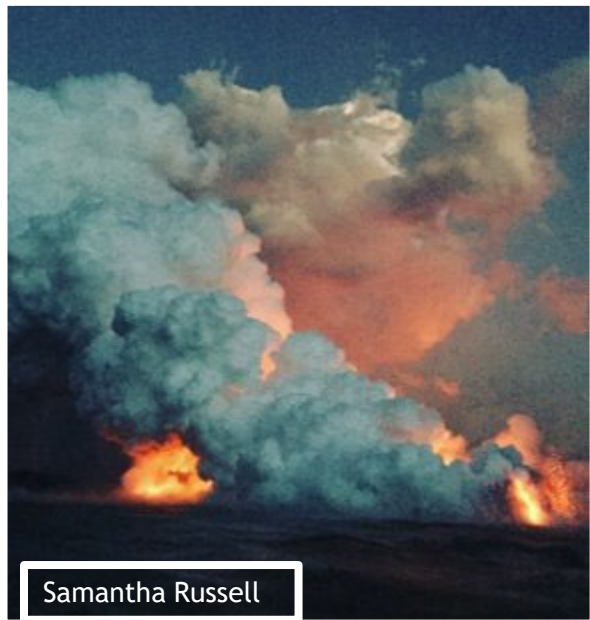
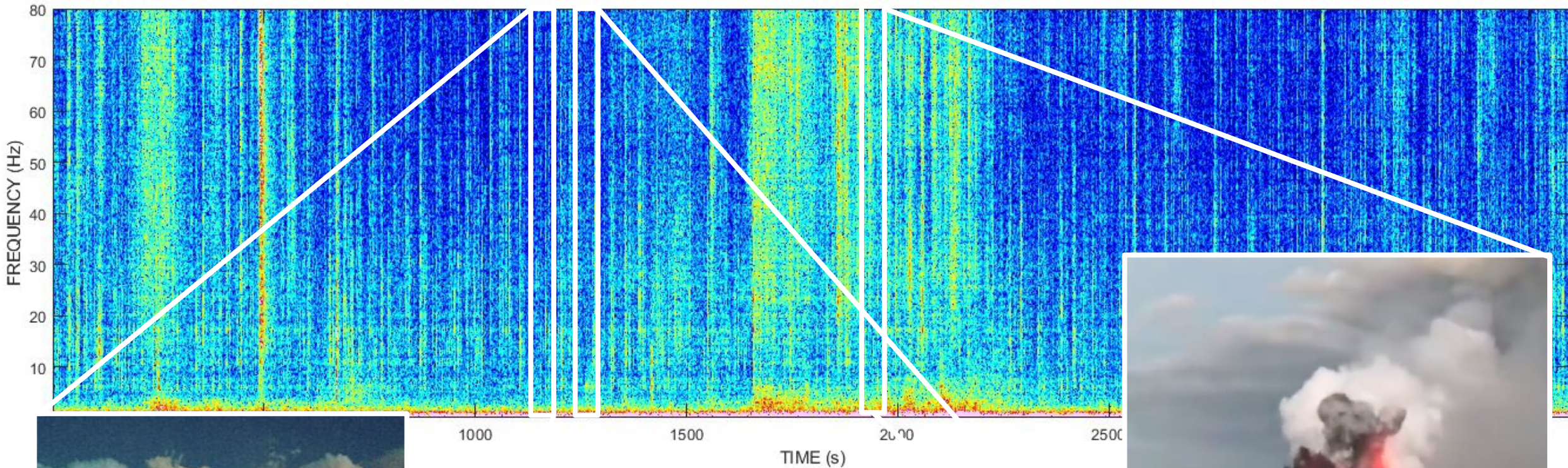


Samantha Russell



Will Bryan, courtesy of CBS Pittsburg

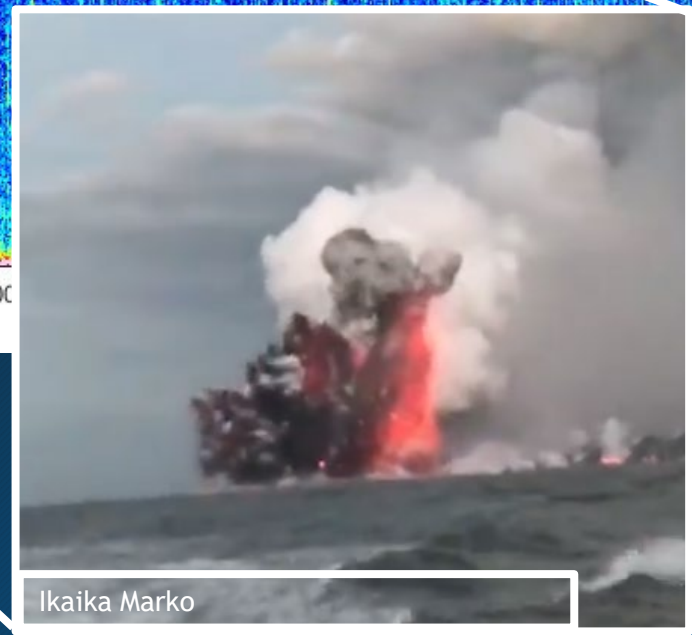




Samantha Russell



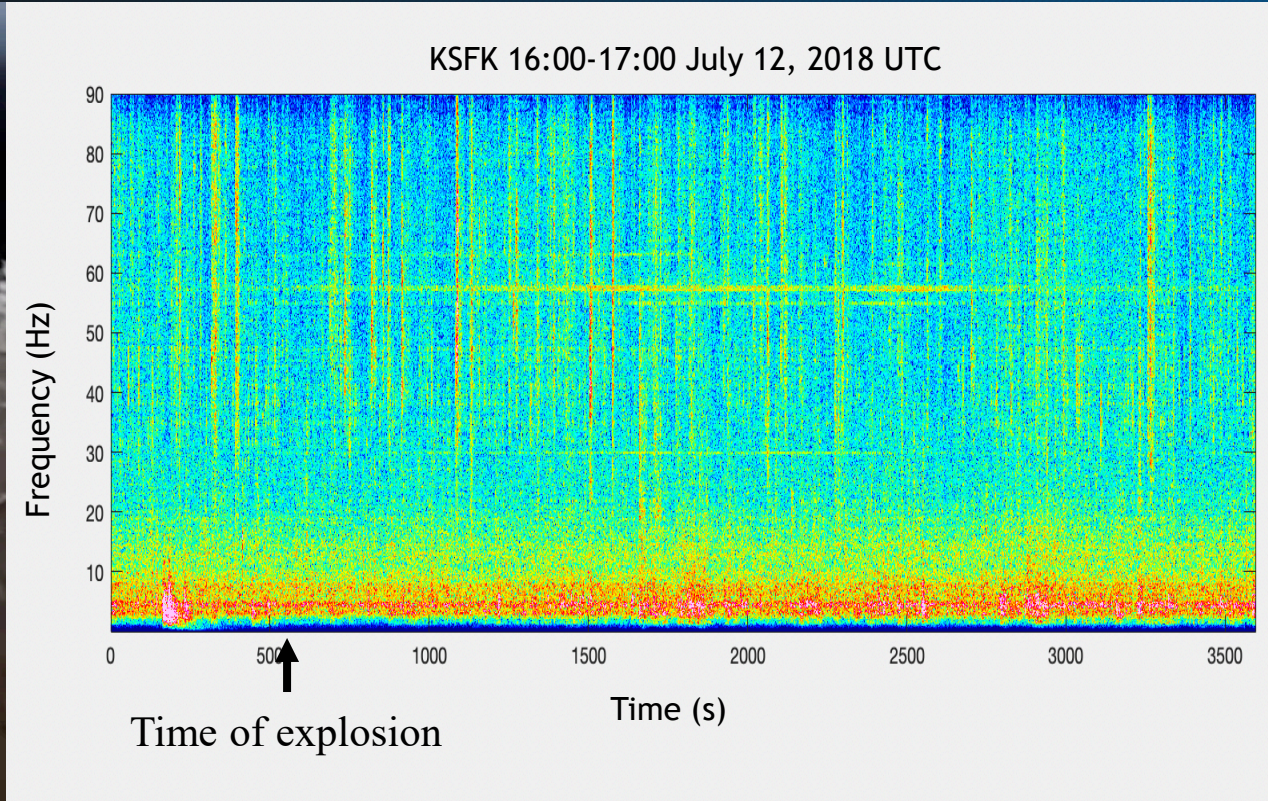
Will Bryan, courtesy of CBS Pittsburg



Ikaika Marko

# Lava-water explosions not heard by hydrophones

- Lava water explosions breached through the water
- But do not appear in hydroacoustic data

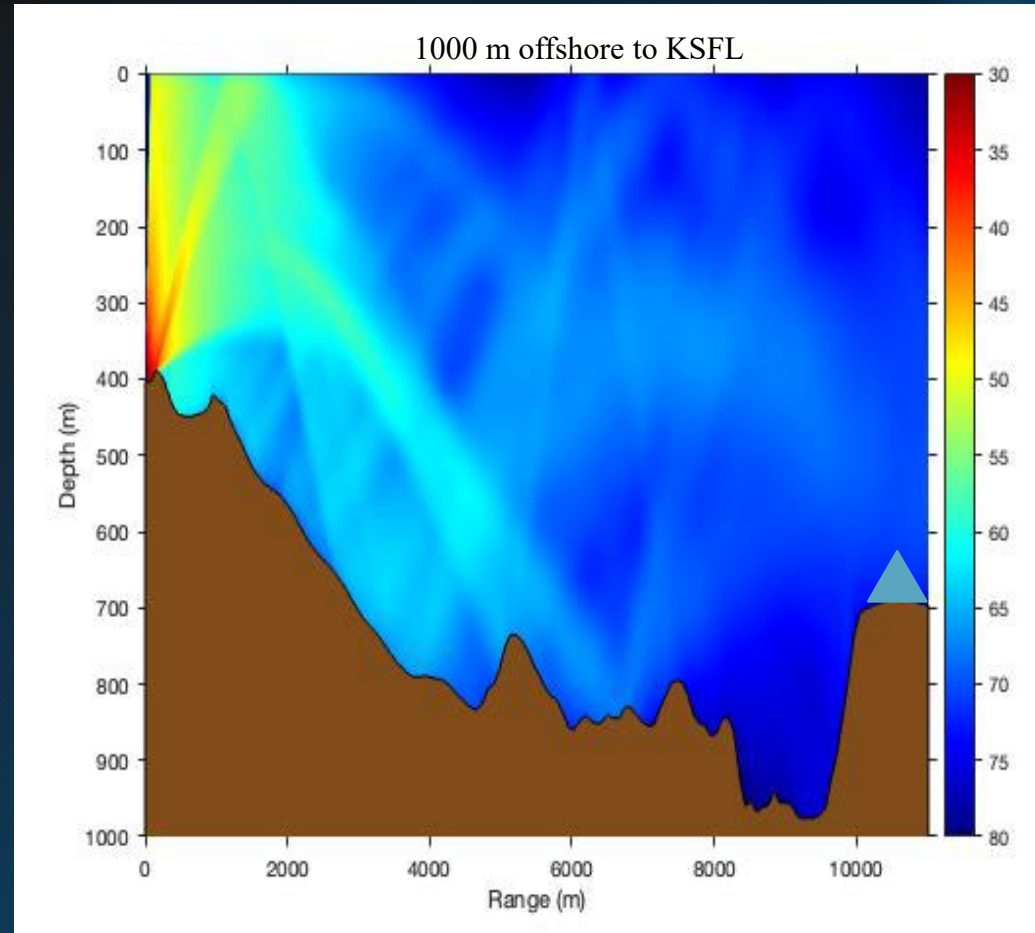
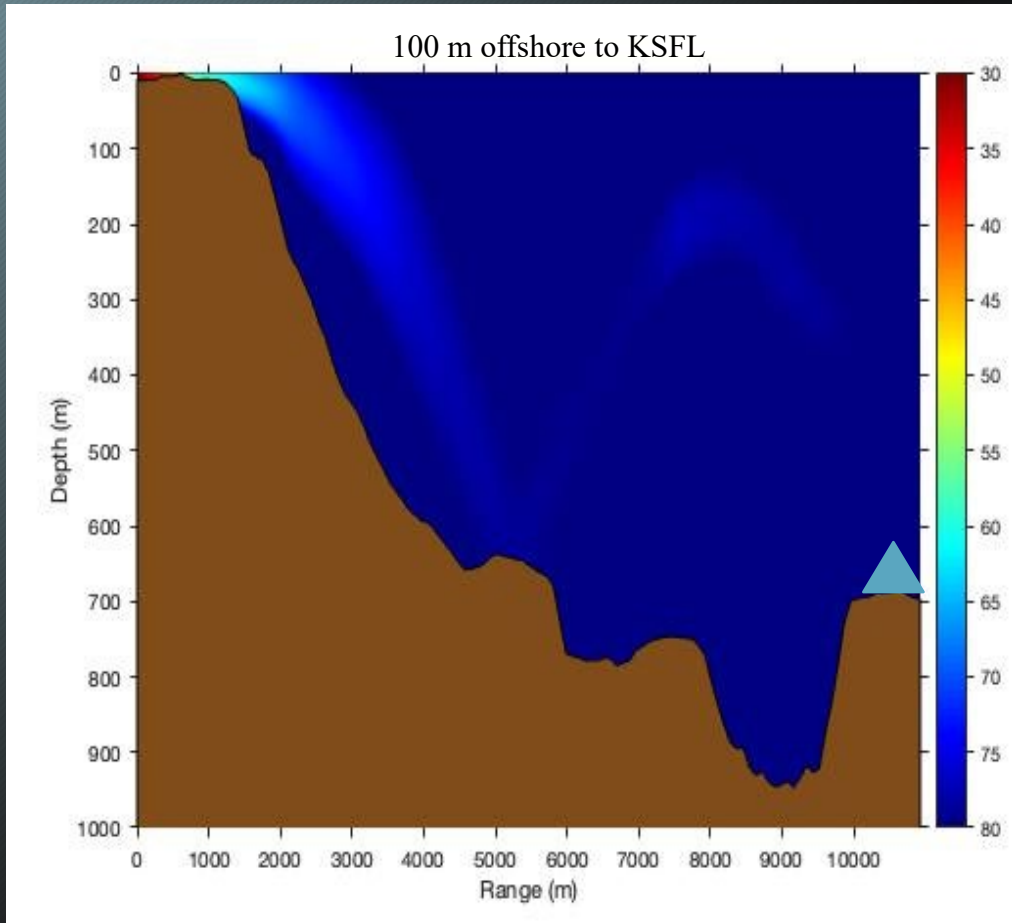


None of these explosions has an obvious hydroacoustic signal.

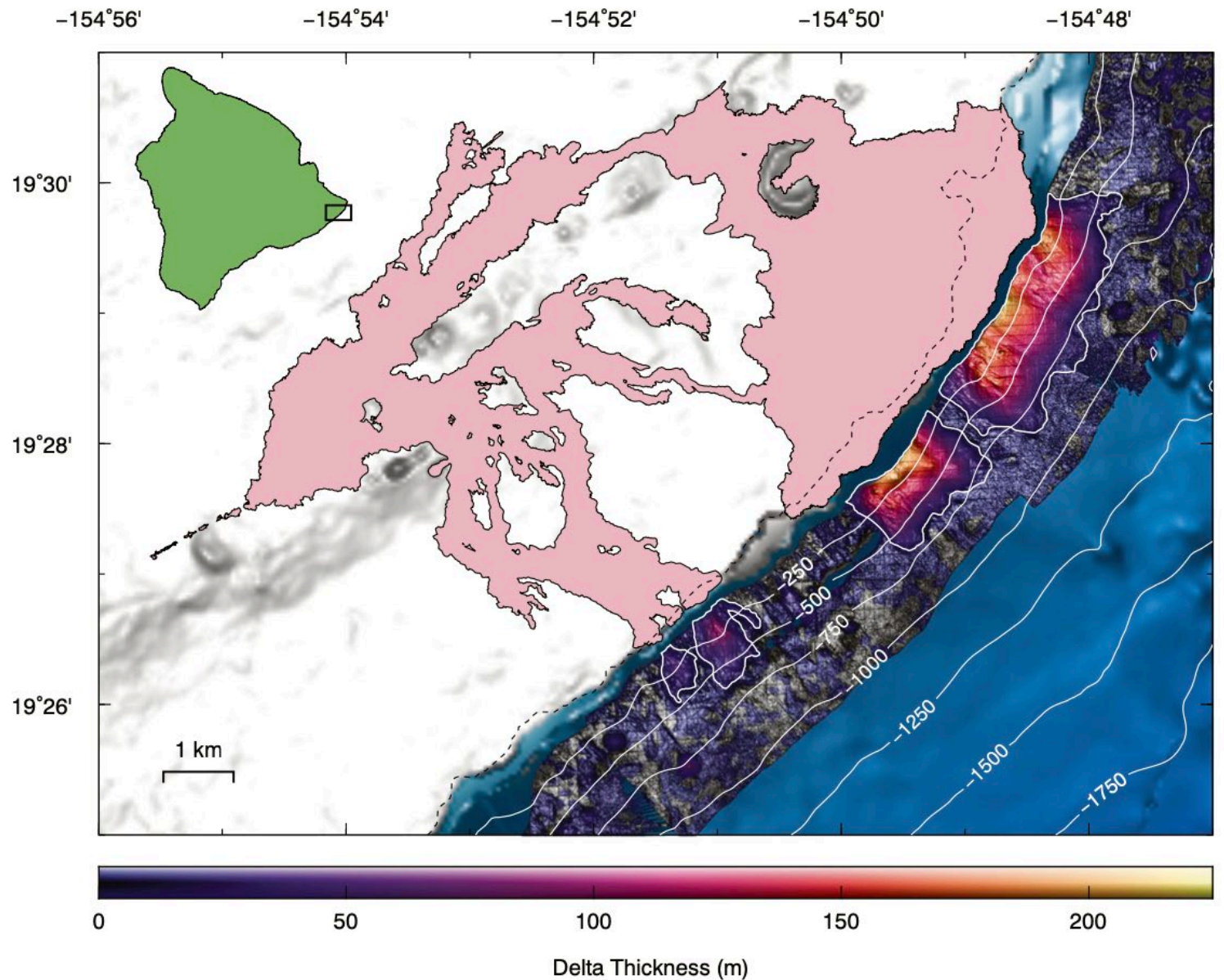
Major hydroacoustic signals are not associated with visible coastal lava-water interactions.

Signals must have to propagate well offshore before they can be detected by the hydrophone array.

# Why don't we hear sound from the coast?

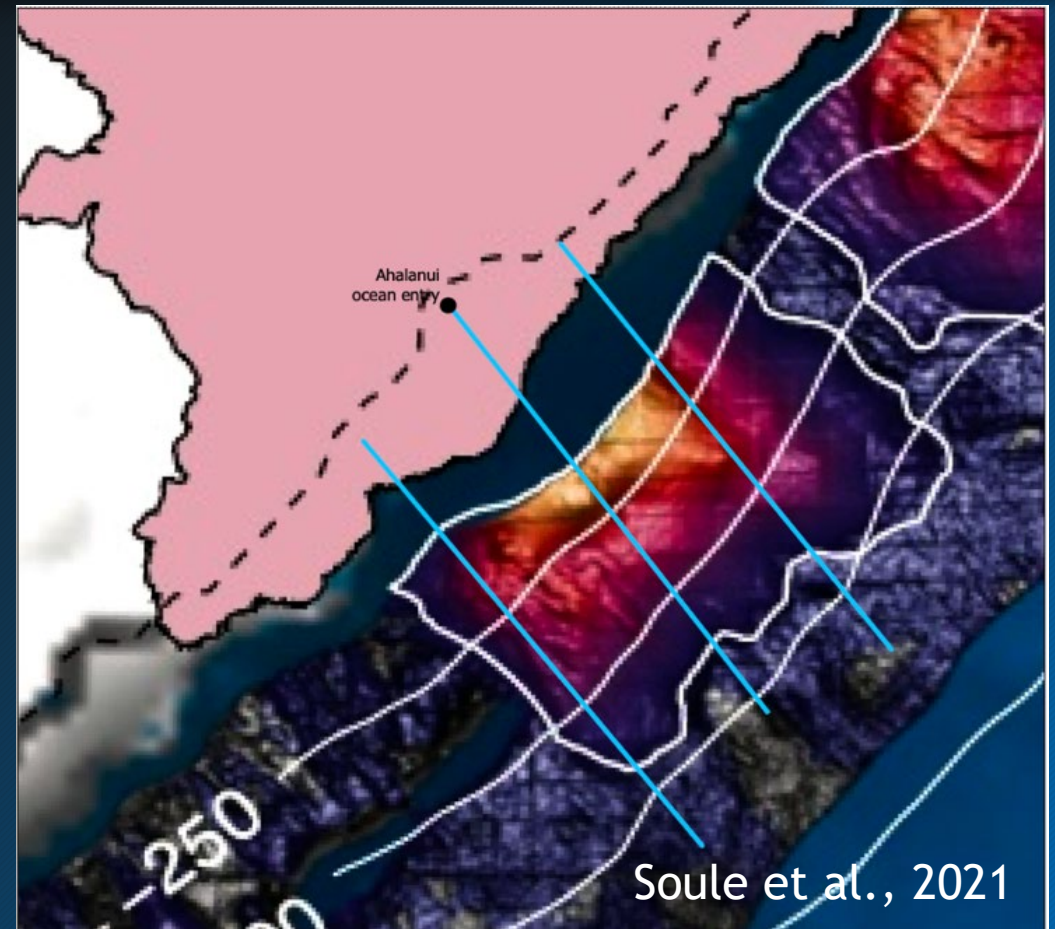
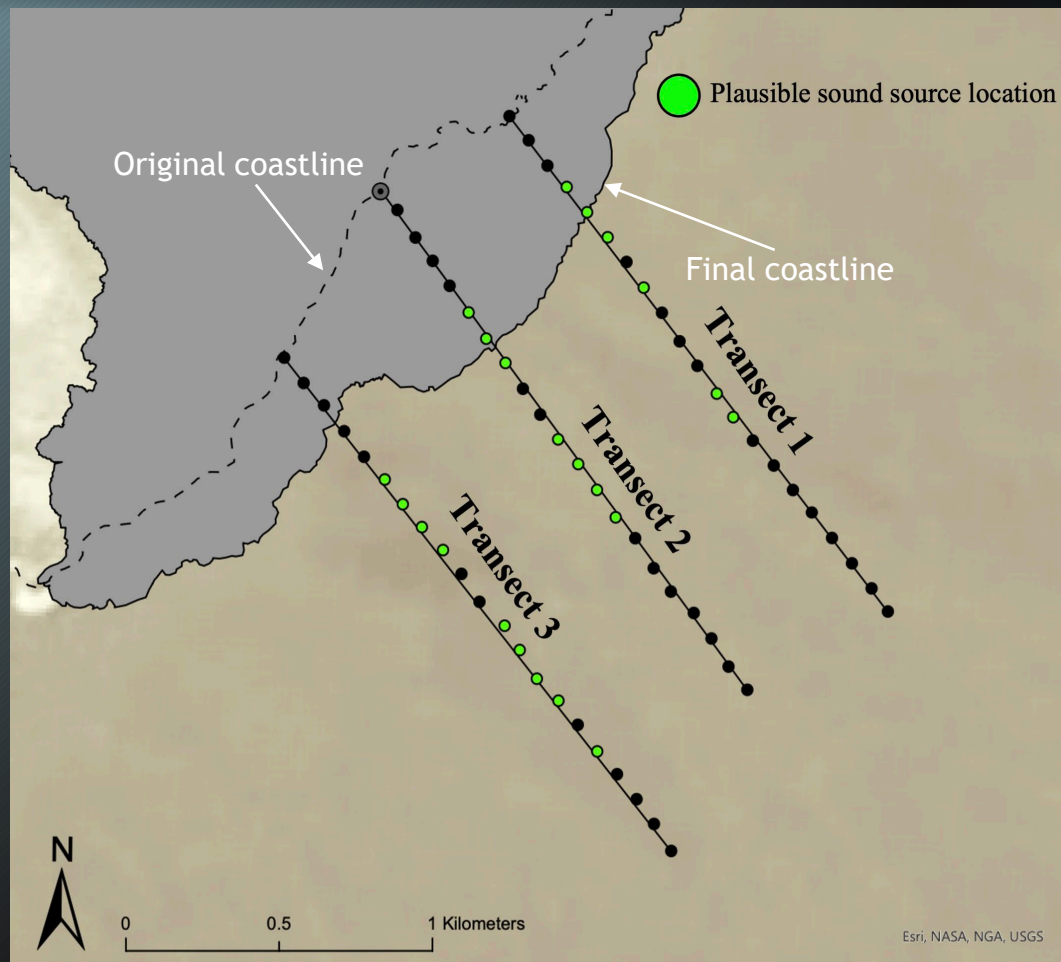


Where is lava  
emplaced  
offshore?

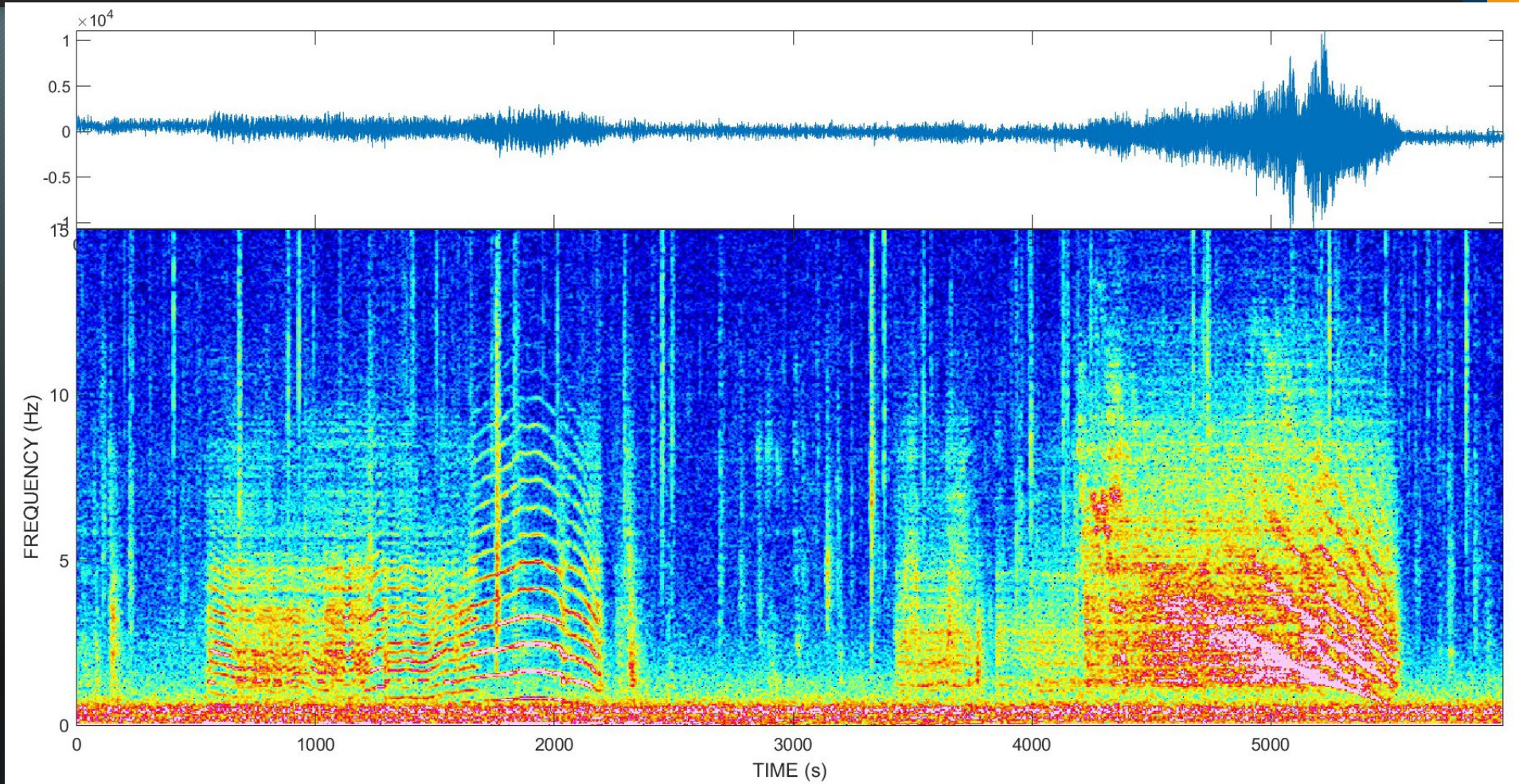


Soule et al., 2021

# Where is lava emplaced offshore?



# One more crazy sound: recorded at Mount Erebus volcano, Antarctica





Signal recorded hydroacoustically: locations by Talandier et al. (2002) confirm the sound source is iceberg B15 dragging on the seafloor.



# Conclusions:

Detection of earthquakes using hydroacoustics dramatically expands our understanding of offshore earthquakes, volcanic activity, and plate tectonics.

Submarine landslides have a characteristic acoustic signal that can be used to distinguish them from other natural submarine processes.

Hydroacoustic signals can provide a continuous window into eruption behavior at erupting submarine volcanoes.

*Sometimes you just don't know what you'll hear until you start to listen.*

Questions?

