NEWS

Seismic Imaging of the Ocean Internal Structure: A New Tool in Physical Oceanography?

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Reflection seismics has been intensively used for the last four decades by marine geologists and geophysicists for imaging Earth structures below the seafloor. Because their subject of interest is below the sea bottom, solid Earth scientists do not usually consider the seismic signal propagating in the water column and most often do not even record it, in order to save data storage space.

Two physical oceanographers, *Gonella and Michon* [1988], first reported internal waves revealed by reflection seismics in the northeastern Atlantic. Only recently, though, has the scientific community realized the importance of this issue, after *Holbrook et al.* [2003] published reflection seismic sections of the water column off Newfoundland, Canada, showing reflectors related to the major oceanographic front between the Labrador Current and the North Atlantic Current.

Up to now, the ocean has been discretely sampled using conductivity-temperature-depth (CTD) profiles that only provide vertical sections of the water column at discrete locations. The spectacular results of *Holbrook et al.* [2003] suggest that it is possible to map continuously the ocean internal structure using conventional, vertical reflection seismics. This could pave the way for new perspectives in physical oceanography, most particularly for studying the fine-scale structure of thermohaline intrusions, internal waves, and eddies.

Presently, the existing seismic and hydrological data sets need to be examined in order to assess the full potentiality of seismic imaging and define the best parameters for new data acquisitions. For physical oceanographers, relating discrete hydrological soundings to seismic images, and seismic images to oceanographic processes, are important questions that need to be addressed. Also, the definition of the seismic source parameters and the availability of numerical methods for modeling synthetic seismograms are major issues for geoscientists.

To illustrate the potentiality of high-resolution sources, here are presented new reflection seismic data collected in February-March 2004, during the Lobestory cruise of R/V *L'Atalante*. This cruise was conducted off the Brazilian margin, to study the internal structure of the distal, deep-sea fans of the Amazon River. The seismic source consisted of six SODERA mini-GI airguns (3 x 24 and 3 x 15 cubic inch, respectively) firing every 10 s and producing a signal

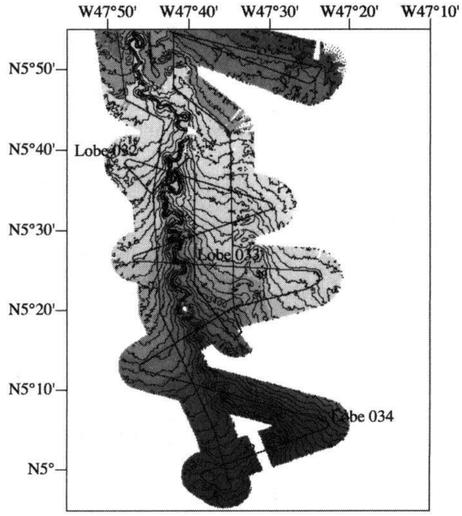

Fig. 1. Ship track superimposed on the bathymetric map of the submarine meanders of the Amazon River, based on the data collected with R/V L'Atalante *in February-March 2004, during the Lobestory cruise. The signal propagating in the water column was recorded along the six seismic lines, labeled from 49 to 54. Stars indicate the location of XBT (Expandable Bathy-Thermograph) profiles recorded with R/V* L'Atalante. *Original color image appears at back of this volume.*

with frequencies ranging between 50 and 250 Hz.

A total of six seismic sections (five across and one along the strike of the Amazon submarine canyon) recorded the signal propagating in the water column (Figure 1). All of these sections exhibit a series of reflections that actually originate at the thermocline. Along profile LST051 (Figure 2), for instance, the strong reflector observed near 150 ms two-way time (twt), that is, 108 m below sea level (bsl), corresponds to the top of the thermocline, while the reflective band between about 240 and 310 ms twt (that is, about between 180 and 230 m bsl) is clearly related to the base of it.

It is interesting to note that reflectors of lower amplitude appear in some places below the reflection that originates from the top of the thermocline, at about 190 ms (about 138 m bsl). This reflector corresponds to a little "kink" observed below the top of the thermocline that is likely to indicate slight increases in salinity (see the CORIOLIS program Web site at http://www.ifremer.fr/coriolis/cdc/floats/cdcFloats.asp; float number 3900139 recorded data near the study area at the time of the cruise).

As the Lobestory cruise was dedicated to geology, only a limited amount of data were collected with seismic signal propagating in the water column. This data set, however, is a new demonstration test, confirming that the seismic signal may provide high-resolution information on the fine-scale, internal structure of the ocean water masses. Reflection seismics yields continuous images of the water column, while vertical soundings are discrete. The two techniques are thus complementary.

Interdisciplinary programs can be proposed with objectives as wide as the water masses mixing within the oceans, submarine sediment erosion processes, and the deep structure of ocean margins, in areas having geologic and oceanographic interest. For instance, by the Mediterranean Outflow Waters area, in the Gulf of Cadix, west of the Gilbraltar Straight, is an area of major interest for physical oceanography [e.g., *Carton et al.*, 2002]. It is also a natural laboratory for studying the formation of mud volcanoes or gas hydrates, as well as tectonic processes related to the convergence of the African and Eurasian plates.

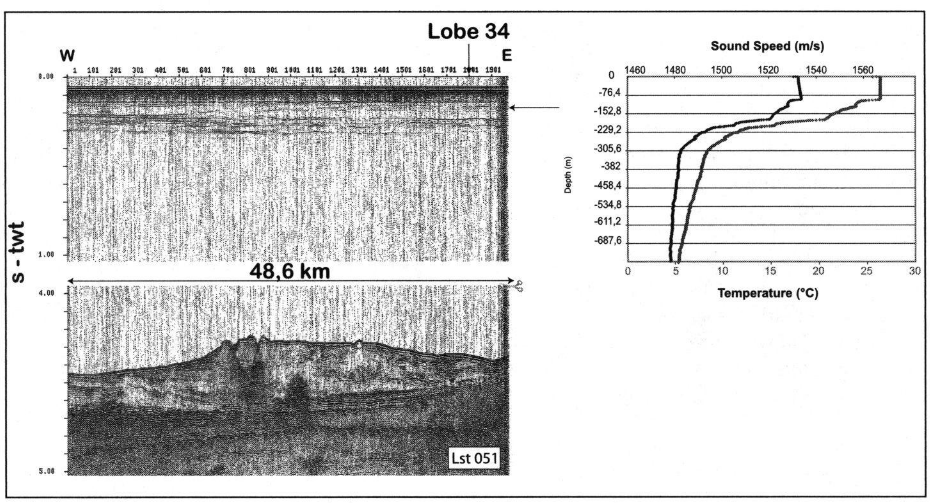

Fig. 2. (left) Seismic section Lobestory 51. The first reflector corresponds to the direct wave from the source to the receiver, which are separated by about 76 m. The reflectors below are generated by the internal sound speed structure within the thermocline. (right) The red curve represents the water temperature derived from the XBT collected at site 034 with R/V L'Atalante. *The blue curve is the corresponding, computed sound speed velocity. There is not a perfect linear correspondence between seconds two-way time (left figure) and depth (z) due to the source-receiver distance. Note the slight change in sound speed gradient, between 130 and 140 m below sea level, and the corresponding reflector in the seismic section (indicated by an arrow). Original color image appears at back of this volume.*

In addition, there are many other major oceanographic gateways (such as, for instance, the Faroe-Iceland Ridge gateway) that are of great interest, both in terms of geosciences and in terms of physical oceanography. The three-dimensional seismic structure of the Gulf Stream can also be studied through programs that could yield information on sediment transport processes in the North Atlantic. A new era begins in physical oceanography?

References

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FORUM

Meeting the Challenges of Natural Hazards In the Wake of the Tsunami Disaster

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In the wake of the 26 December 2004 Sumatra earthquake and tsunami, it is natural to ask ourselves what we could have done as scientists to help prevent or minimize the impact of this disaster. It is imperative, however, also to ask ourselves what we should be doing to mitigate the adverse impact of the next calamity.

AGU's Committee on Public Affairs, which I chair, is charged with advocating the contents of AGU position statements, one of which is entitled Meeting the Challenges of Natural Hazards. In that statement, AGU calls for three basic activities to reduce our vulnerability to natural disasters:

(1) fundamental research on Earth and space, and monitoring of natural hazards;

(2) dissemination of the relevant results to the public, especially vulnerable communities; and

(3) implementation of multidisciplinary efforts needed to apply effective mitigation strategies worldwide.

The first item we all do very well, but what about the next two? In this Forum, I lay out several challenges, and do so in the spirit of provoking discussion and comment that lead toward implementing the activities called for in the AGU statement.

First, as scientists we thrive on discussing our research with colleagues. Are we taking the time to engage all of our colleagues, especially those in areas around the globe particularly vulnerable to natural disasters? We all strive to demonstrate the wide breadth and scope of our research, especially in the global AGU community, but bringing the fruits of that research to bear on preventing natural disasters must flow through those who live where disasters may strike. Geophysical phenomena like earthquakes and tsunamis are studied and understood by scientists in regions all over the world, and the challenge is in communicating the most up-to-date scientific understanding to our colleagues and their neighbors who live in parts of the planet vulnerable to those hazards.

This does not necessarily preclude speaking directly to emergency managers, city planners, and those responsible for issuing warnings of an impending disaster. Indeed, global monitoring and warning systems require a coordinated worldwide effort for many natural hazards. Institutions and people responsible for zoning, issuing warnings, coordinating evacuations, and responding to emergencies are typically regional or local, and they require a closer working relationship with scientists who live nearby and who understand the regional context for communicating with the populace.

Are we as geophysicists doing enough to bridge the gap between monitoring natural phenomena and communicating risk to those who live in hazard-prone regions? The accurate prediction of certain phenomena such as earthquakes may never be achieved, yet we can certainly improve our forecasting of subsequent events triggered by an earthquake, including landslides, fires, and, of course, tsunamis. Doing so demands a cross-disciplinary and multidisciplinary approach to conducting our research, but also demands communicating our research results to the correct audiences. Contrary to popular belief, everyone who is interested in, and who could benefit from, our research does not attend AGU meetings, though perhaps they should.

Are we asking the right questions in our research proposals, and are we encouraging and giving credit to our colleagues who are working on problems that have the potential for more immediate benefit to society? And, are we asking ourselves how our current research is relevant to the mitigation of natural hazards? Certainly the recent earthquake and tsunami should compel us to reflect on our work. Fortunately, or unfortunately, the frequency, spatial distribution, and consequences of natural hazards are both wide and diverse, from low-frequency/high-impact phenomena like the 26 December event, to high-frequency/lower-impact floods, severe storms, and other regularly occurring hazards. Research interests across AGU's broad and diverse membership encompass nearly every natural phenomenon that, when crossed with human population and infrastructure, is a potential natural disaster. By working together, surely we can find ways to communicate to those who are in harm's way what we study and understand about nature's extreme events.

In the wake of the 26 December disaster, plans are under way to organize a tsunami warning system for the Indian Ocean similar to the existing system linking 26 Pacific Ocean nations. We should contribute to that effort as geophysicists who study the Earth system. But that is just one step. We need to increase our efforts to disseminate what we know about natural hazards writ large, especially to those in vulnerable areas. In addition, Earth and space scientists need to be ready and willing to engage in coordinated approaches involving engineers, policy makers, builders, lenders, insurers, news media, educators, relief organizations, and the public to reduce the adverse effects of natural hazards.

—SOROOSH SOROOSHIAN, Chair, AGU Committee on Public Affairs

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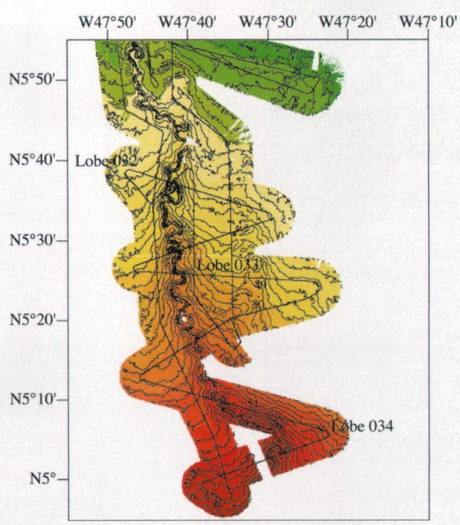
Fig. 1. View of the ocean when the water had reached its highest level at about 10:12 A.M. local time. This picture was taken 7 minutes after water was at its lowest level. The view is from the top floor of the beachside Triton Hotel, looking seaward over the reception area and across the swimming pool. Photo courtesy of Chris Chapman. See the Eos Electronic Supplement for additional photos: http://www.agu.org/eos_elec.000929e2.html.



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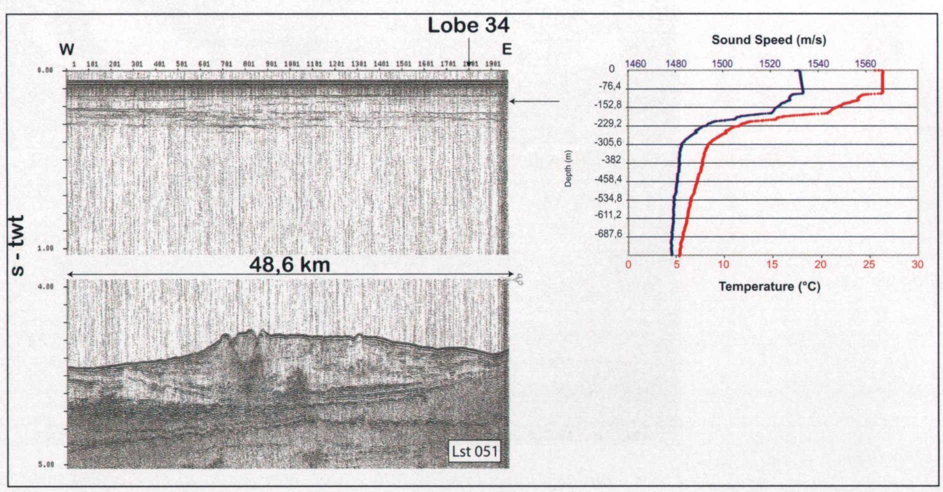

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