Geology and Geophysics for ASIAEX: Seismic Stratigraphic and Stochastic Analyses of High Resolution Seismic Data from the Continental Margins of the East China and South China Seas

Louis R. Bartek
Department of Geological Sciences, CB# 3315 Mitchell Hall,
University of North Carolina at Chapel Hill,
Chapel Hill, North Carolina 27599-3315
phone: (919) 962-0687 fax: (919) 966-4519 email: bartek@email.unc.edu

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LONG-TERM GOALS

Our research group is collecting and analyzing various levels of high-resolution seismic data and cores, for ground-truthing seismic facies, on continental margins with a spectrum of depositional boundary conditions. The long-term goal of this work is to develop stochastic models of variation of geotechnical and seismic property distribution on margins subjected to a spectrum of depositional regimes. We are also assessing the quantity of data required to recognize the nature of stratigraphic architecture of a continental margin. We refer to this as Minimum Data Density Analysis (MINDDA). The importance of being able to produce these stochastic models is that it provides a means of making predictions (with assignment of statistical risk) of the variation of geotechnical and seismic properties in areas where the only data that may exist for that margin at the time that a prediction is needed is information on physical oceanography or other gross descriptions of depositional conditions on the margin. In the ECS we have a regional data set that we are using for this purpose and we have initiated MINDDA and it appears as though we have established MINDDA for a number of stratigraphic elements of the East China Sea continental margin. However, there are some elements in which it is not clear that a data set that is required to establish MINDDA in the East China Sea (ECS) has been acquired. In order to provide a rigorous test of our hypotheses about MINDDA and geologic processes for the ECS system we acquired a data set consisting of geophysical data (seismic, chirp, and side-scan) and geologic data (cores) in a 40 by 55 km grid with profiles oriented parallel to depositional strike and dip in the ECS at a site where the geology consists of vertical stratification and lateral continuity of layers. Data collected in ECS area were subjected to seismic stratigraphic analyses; MINDDA and we are working on development of stochastic models of stratigraphic architecture variability. The data acquisition and analysis program in the ECS is providing control and the background data set required for the 2,001 acoustics experiment that is geared toward improvement of understanding of bottom interaction and sound propagation in continental margin environments.

As part of this project we were also supposed to conduct a study in the South China Sea (SCS). The SCS work was to provide geological constraints on bottom interaction for the ASIAEX volume interaction experiment in the area. However, international politics led to the loss of both of the area clearances we had to work in the ECS and SCS. Negotiations led to access to another area clearance the ECS but not in the SCS. The area clearance was for a reduced interval and the geology of the area in the ECS that was approved is quite different than the original area. We were able to acquire data in the SCS in March-April of 2003 and that effort is the subject of another report.

OBJECTIVES

- Initially we planned to acquire data in the ECS to support the ASIAEX bottom interaction experiment and in the South China Sea (SCS) to support the ASIAEX volume interaction acoustics experiment. Our geologic objective was to acquire a data set with a much tighter grid spacing in the ECS than our other data sets to test our hypotheses about ECS MINDDA that were developed on the basis of other grids in the ECS. The plan was also to acquire data in a location where the geology was relatively simple (vertically layered and with laterally continuous layers). We had identified such a site in the central ECS (an area defined by the following coordinates: 29°45'N and 127°00'W, 29°45'N and 125°00'W, 29°10'N and 127°00'W, 29°10'N and 125°00'W) and planned collect twenty profiles that were 55 km long, with a 2 km interval between profiles, and parallel to depositional strike. We also planned to collect ten profiles that are 40 km long, with a 4 km interval between profiles, and perpendicular to depositional strike. We had clearance from the Chinese government to work in this area, but international politics intervened just prior to our cruise and we had to move to a site that was southeast of this area from a mid-shelf site to an outer shelf site. However, we were still able to acquire the high-density grid of data in a manner that facilitates correlation of it with the existing regional ECS seismic profiles. The new area clearance was for a reduced time interval and the geology of the area in the ECS that was approved is quite different than the original area. However, the data acquisition and analysis program in the ECS is providing control and the background data set required for the 2,001 acoustics experiment that is geared toward improvement of understanding of bottom interaction and sound propagation in continental margin environments.
- Stochastic models of the "End-Member" systems (ECS and NE GOM) indicate that the spatial distribution of seismic facies are distinctly different from one another and there is a statistically significant relationship between the distribution of facies and processes. In order to refine our understanding of these relationships and test hypotheses about process-response linkages and acoustic property distribution we also need to acquire and analyze data from margins lying between our "End-Members". The new ECS site is in an area that is not dominated by large river systems and therefore has characteristics of a system with an intermediate boundary conditions.
- Conduct seismic stratigraphic and facies analyses on the data to identify the nature of the heterogeneity of the stratigraphic architecture of the margin.
- Quantify the nature of horizontal and vertical seismic facies heterogeneity within a sequence stratigraphic context, and develop stochastic models of seismic facies heterogeneity produced under depositional conditions described for the ECS.
- Use the data collected in the ECS ASIAEX project to augment our assessment the impact of the depositional processes from margins with extremely different boundary conditions on the stochastic models of vertical and horizontal distribution of seismic facies (and therefore geotechnical and acoustic properties).
- Use the data collected in the ECS ASIAEX project to assist with determination of the minimum data required to predict the distribution of seismic attributes on margins with various depositional boundary conditions. This will be accomplished by conducting sensitivity tests on survey spacing and associated changes in the distribution of mapped parameters.

APPROACH

The Carolina Seismic Imaging Lab (CSIL) of the University of North Carolina is researching the relationships between variations in sedimentary boundary conditions and the stratigraphy produced by these conditions. Limited work has been conducted on relating a quantified measure of the distribution of near-surface seismic facies and variability in depositional environment boundary conditions. The study area on the Western Pacific Continental Margin (WPCM) is a region with high sediment supply

(4 times the amount of sediment per year as the Mississippi River) and large magnitude hydrodynamic sediment transport processes (tidal currents and large waves from typhoons and storms associated with the winter monsoon), so that there may be a high degree of correspondence between the sedimentary processes active on the margin and the preserved stratigraphy. In other words it may be a situation where the sedimentary processes and recent stratigraphy may be in dynamic equilibrium. This situation may be rare today and it may be an "End-Member", but understanding this system is essential to understanding systems where the record of sedimentation is much less complete. In fact this area contrasts quite distinctively with many other continental margins (such as offshore Alabama, offshore Eel River, California, or offshore New Jersey).

The approach for this project is to: (1) acquire data from environments with a history of extreme depositional boundary conditions, (2) conduct sequence stratigraphic analyses of these data to identify units deposited within the same interval of time, and (3) conduct quantitative seismic facies analyses on the data sets so that the variations in seismic facies within each time-slice can be tracked spatially and later subjected to Analysis of Variance, Q-mode factor and binomial markov process analysis to identify non-random variations in seismic facies variability. This provides the stochastic model of spatial variability in acoustic property variability on the continental margin. We then test for sensitivity to survey spacing (MINDDA) by under and over sampling isochron maps of seismic facies and thickness of systems tracts at various intervals, overlaying the maps, measuring deviations in orientation of features, and their spatial magnitude and conducting statistical tests to determine when the differences are significant. We are conducting similar analyses when comparing the near-surface sonar facies distributions of the “end-member” continental margins.

We proposed to collect high quality (in a wide range of weather conditions) high-resolution seismic data 1,000 to 4,000 Hz. with 0.5 to 1 meter resolution using 15 cubic inch water guns and 50 cubic inch Generator Injector air guns and ITI solid streamers and our digital acquisition and real-time processing system. We also acquired digital chirp and side-scan sonar data for geologic analysis in conjunction with Dr. Steven Schock with his system and our Datasonics SIS-1000 system in intervals when there was a problem with his system. We used calibration hydrophones as well as tank calibrations of our transducers to obtain accurate measures of source output and streamer sensitivity as well as signal generators to calibrate all amplifiers so that we can calculate bottom loss and other bottom and sub-bottom acoustic properties. We also collected cores to provide ground truth for acoustic properties and to provide insight on geologic processes. We (Jim Miller of URI) borrowed an apparatus for measuring sound velocity of sediment in cores so we could measure sound velocities of sediment in cores on the ship. We have remeasured these acoustic attributes and done additional measurements of other geotechnical attributes in the lab since we returned. We are also conducting analyses of other sedimentologic attributes (composition (mineralogy and fossil content), sedimentary structures (x-radiography), texture (automated settling tube and laser particle size counter)) in the lab. Seismic stratigraphic and facies analyses are being conducted using Seisworks 2-D and the Kingdom Suite software. The results of these analyses will be subjected to our principal components and Markov analyses and MINDDA to help establish the linkage between process-response relationships and spatial distribution of acoustic properties.

WORK COMPLETED

- We acquired 1,765 km of high resolution and chirp sonar profiles in a grid that is parallel and perpendicular to depositional strike. Strike-oriented profile spacing is approximately 4 km. Time restrictions limited us to acquiring only two dip profiles. We have other dip profiles in the area from earlier surveys that can be used to correlate between strike-oriented profiles.

- Completed processing of seismic data.
- Completed loading of seismic data into stratigraphic interpretation workstation and completed stratigraphic analysis of the seismic data.
- Generated isopach and structure contour maps of important geologic intervals in the seismic data.
- Completed file format conversion on chirp sonar data so that it can be processed and integrated with other chirp data from the area on a stratigraphic interpretation workstation.
- Made additional geotechnical and acoustic property measurements on cores and began textural analyses and core x-radiography.

RESULTS

Examination of the1765 km of high-resolution seismic and chirp sonar data that were acquired during the survey reveals that the seafloor relief is minimal except at less than 10 locations in the SW portion of study area where small canyons were discovered. Sea level change in response to glacial volume created stratigraphic sequences in the area that bound by high amplitude reflections. We also discovered that an extensive, but thin veneer (2-4 m) of acoustically transparent sediment associated with transgressive intervals overlies most of the study area (a few areas lack the veneer). There are a few tidal ridges associated with the veneer and it is similar to other portions of the ECS. Beneath the veneer, the entire study area appears to be dissected by channel incisions associated with Lowstand intervals and the incisions range between 10-25 msec in depth. This part of the stratigraphy of the area is quite different from the rest of the ECS. The incisions overlie a laterally extensive unit (ranging between 25-75 msec in thickness) containing closely spaced, low to moderate frequency, parallel and extremely laterally continuous reflections. This unit is associated with Highstand intervals and is similar to the outer shelf of other portions of the ECS in that they are thick and laterally continuous. The orientation of the shelf edge varies from one interval to another creating relief on high amplitude sequence bounding reflections that may underlie relatively flat seafloor in the vicinity of the shelf edge. This may have an impact on sound scatter and backscatter in the ASIAEX ECS acoustics experiments.

IMPACT/APPLICATIONS

The scientific impact of this work is that it quantifies relationships between depositional boundary conditions and near-surface seismic/geotechnical properties distribution on continental margins. This therefore leads to more reliable estimates of these properties in areas where it is either difficult to acquire such data, or it is necessary to design a survey that will quickly provide needed insight, with a given level of risk of a bad prediction. It also leads to more successful design of transmission loss surveys and acoustics experiments on the role of bottom interaction on sound propagation in continental shelf environments. This obviously has impact in areas such as oil and gas exploration and production, environmental waste containment, and of course defense related issues on continental margins.

TRANSITIONS

Understanding the process-response relationship between depositional conditions and seismic facies distribution leads to improved understanding the nature of the heterogeneity of the distribution acoustic properties on a continental margin. The Naval Oceanographic Office has used the results of our analyses to design and conduct more successful transmission loss surveys on the WPCM. They also take data that we provide to them and integrate it into databases that they provide to the U.S. Navy for operations. Our data and analyses (maps) have also been used by members of the ASIAEX ECS acoustics experiment team (specifically Dr. Jim Miller of the University of Rhode Island) to constrain the impact of geological conditions on bottom interaction and sound propagation on the margin. We have also provided a contractor working for the Navy with data files for various horizons so that they could analyze results of data generated in Navy exercises.

PUBLICATIONS/PRESENTATIONS

Papers:

Miller, J.H., **Bartek, L.R.**, Potty, G.R., Tang, D., Na, Y.J. and Qi, Y., Sediments in the East China Sea, IEEE, Journal of Ocean Engineering, [in press].

Abstracts:

Miller, J.H., **Bartek, L.R**., Potty, G.R., Lazauski, C.J., Chen, C.-S., Westhoff, K. and Dahl, P.H., 2002, Geoacoustic measurements in the East China Sea, Asian Seas International Acoustics Experiment (ASIAEX) International Symposium, Chengdu, China, October 14 - 18, 2002, p. 20-21.