

Use of Stochastic Modeling of Stratigraphic Relationships in High Resolution Seismic Reflection Data for Prediction of the Distribution of Acoustic and Geotechnical Property Variability in Near Surface Sediments on the East China Sea Continental Margin

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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 develop stochastic models of variation of geotechnical and seismic property distribution on margins subjected to a spectrum of depositional regimes. 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. One focus of our research is on the East China Sea (ECS) margin where there are end-member conditions in terms of extremely high sediment supply, high tidal range, frequent and intense tropical and extra-tropical storms, and strong thermohaline currents.

OBJECTIVES

- Collect high-resolution seismic data on a margin with extreme depositional boundary conditions with objective of subjecting these data to sequence stratigraphic and seismic facies analyses to characterize the magnitude of the impact of variation in depositional regime on seismic stratigraphic architecture and seismic facies distribution.
- 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 above
- Assess 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)
- Determine the minimum data required to predict the distribution of seismic attributes on margins with various depositional boundary conditions by conducting sensitivity tests on survey spacing and associated changes in the distribution of mapped parameters.

APPROACH

University of North Carolina Seismic Stratigraphy Group (UNCSSG) is researching the relationships between variations in sedimentary boundary conditions and the stratigraphy produced by these conditions. Limited work has been conducted on relating 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). Thus far our attention has been focused on the inner and middle shelf environments. This investigation involves acquisition and analyses of data from the outer shelf and slope environment of the ECS. Therefore when this investigation is complete we will have characterized the entire margin.

UNCSSG is just completed an investigation of the 3-D variability of an area (the Alabama Shelf) with low sediment supply, microtidal conditions, and relatively infrequent storm events. Approximately 2,125 km of high-resolution (<1 m) Geopulse reflection seismic data were acquired within a 900 km² grid in an area that extends from ≈5 km offshore of the Alabama coast to the upper continental slope. We developed probability models of the distribution of seismic facies variability in this area and determined the minimum data density required to successfully make predictions of physical property distribution given the set of boundary conditions described above.

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. We will also investigate the utility of Fuzzy Logic in characterizing spatial variability of seismic facies in this system. This provides the stochastic model of spatial variability in acoustic property variability on the continental margin. We then test for sensitivity to survey spacing 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 are also using an "Acoustic Core" seismic processing system to calibrate our chirp and seismic data so that we can compute variations in velocity, density, impedance, reflectivity, and attenuation with depth. Results of these analyses will be integrated with the results of stochastic analyses of seismic facies so that we can use these investigations to produce models of variation of physical property distribution on continental margins.

WORK COMPLETED

- Data that we collected for this project includes 191 km of 210 cubic inch Generator Injector Air Gun data, 3,502 km of 15 cubic inch water gun data, 3,217 km of chirp and side-scan sonar data, and 6 cores from the East China Sea (ECS) and the Yellow Sea (YS) in our first cruise of 1999. During our second cruise of 1999 we surveyed the outer continental shelf and slope of the ECS margin and we collected 2,575 km of 50 cubic inch Generator Injector Air Gun data, 1,723 km of 15 cubic inch water gun data, 2,061 km of chirp and side-scan sonar data, and 11 cores. All of these data initially went to the Naval Oceanographic Office in Mississippi where they made duplicates of these data. We received the data at the end of 1999. Although we were successful at doing a lot of the processing of the seismic data while at sea we found that we needed to do additional processing of the data. This year we completed processing the data and loaded it onto workstations for seismic stratigraphic and facies analysis. New chirp seismic and sonar data collected in the WPCM study area and new cores will be integrated into an existing data base of cores and seismic data in the analysis of the stratigraphy of the area. We anticipate completing the seismic stratigraphic and facies analysis by early 2002.
- Upon completion of the seismic stratigraphic and facies analyses we will begin our stochastic analyses of the data set. Analysis of spatial variability of subsurface acoustic attributes of chirp sonar data collected during the 1999 cruises (reflection coefficients and attenuation coefficients) will be conducted using our Acoustic Core system. The “Acoustic Core” seismic processing system that was used to calibrate seismic data as it was acquired will be used to compute variations in velocity, density, impedance, reflectivity, and attenuation with depth. Results of these analyses will be integrated with the results of stochastic analyses of seismic facies so that we can use these investigations to produce models of variation of physical property distribution on continental margins. These results will also be compared with the analyses of the relationships of facies distribution with variations in depositional boundary conditions (from published literature) in the entire region.
- The data collected during the 99 surveys reduces the lateral interval between existing profiles on the ECS margin. These data will be integrated with the existing data sets and sensitivity tests on impact of survey profile spacing on successful prediction of property distribution on ECS will be conducted.
- We will continue with our comparison of results of stochastic models from margins with extremely different boundary conditions to assess the impact of the processes on development of stratigraphic architecture and distribution of near surface acoustic and geotechnical properties.

RESULTS

We recently completed the data processing phase of our work on this project. We are completing seismic stratigraphic analyses and we have learned from our initial examination of the data that the depth of the shelf /slope break (approximately 150-190 m) on the ECS margin has had a significant impact on sediment dispersal on the margin. The depth of the shelf/slope break is deeper than the sea level fall (120 m) associated with the last few glacial expansion events. A consequence of this situation is that there was very little bypass of sediment beyond the shelf/slope break during the Lowstand intervals. We do not see evidence of the large submarine fans in the Okinawa Trough that one would expect to find associated with a Lowstand event of two of the world's largest fluvial

systems. The slope also lacks the extensive slope failure features that are normally associated with high sedimentation rates. On the shelf we have found “fluvial” seismic facies that are laterally extensive (100’s to 1000 km along strike) and mounds on the outer shelf. We believe that these facies are the Lowstand deposits that are perched on the shelf due to the deep shelf/slope break. We have also observed extensive fields of large 2-dimensional bedforms on the outer shelf. These appear to be associated with northeastern traction transport of sandy sediment by the Kurishio Current. This transport mechanism may be responsible of significant transport of the sediment supplied by the river systems out of the basin. The stratigraphy on the outer shelf is much more complete relative to what we have observed in the inner shelf. Amalgamated Lowstand fluvial deposits with limited preservation of isolated patches of Transgressive and Highstand deposits dominate inner shelf stratigraphy, while the outer shelf has nearly complete Transgressive and Highstand units sandwiched between Lowstand deposits. Our efforts for the upcoming year will be devoted to verifying whether these initial observations are correct and developing stochastic models of the stratigraphy.

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 and modeling of sound propagation on the WPCM. They also include the data we provide in their databases that they generate for the operations of the U.S. Navy.

RELATED PROJECTS

This project is closely related to and ONR project titled “Statistical, Seismic Stratigraphic, and Facies Analyses and Synthesis of Data and Results from Cruises 331293, 221196, and 221296 on the Western Pacific Margin”, ONR grant number N00014-93-0921. This project focuses on conducting a similar set of analyses as described in this project to two seismic, chirp sonar, and cores collected during survey in 1993 and 1996 from the inner and middle shelf of the ECS and the Yellow Sea. Profiles from the 1999 survey of this project focus on the outer shelf and slope so the two projects complement each other and will give us a complete picture of the stratigraphic architecture of a high energy and high sediment supply continental margin.

PUBLICATIONS/PRESENTATIONS

Refereed Papers:

Bartek, L.R., Cabote, B.S., Young, T. and Schroeder, W., (in press), Sequence Stratigraphy of a Continental Margin Subjected to Low-Energy and Low Sediment Supply Environmental Boundary Conditions: late Pleistocene-Holocene Deposition offshore Alabama, USA, in John B. Anderson and Richard H. Fillon eds., Late Quaternary Stratigraphic Evolution of the Northern Gulf of Mexico Basin, SEPM Special Publication, Tulsa, OK, v., p.____.

Wellner, R., and **Bartek, L.R.**, resubmitted, The Link Between Base Level, Climate, Shelf Physiography and Large Incised Valley Development: A Modern Example from the East China Sea, Geological Society of America Bulletin.

Abstracts:

Moss, C.C. and **Bartek, L.R.**, 2001, Controls on the Bimodal Distribution of Broad Incised Valley Fill on the Yellow Sea Continental Margin, Chapman Conference on the Formation of Sedimentary Strata on Continental Margins, June 17-19, 2001, Ponce, Puerto Rico, p. 29.

Bartek, L.R., Cabote, B.S., Lucas, J.L., Moss, C.C., Seitchik, A.M., Warren, J., and Wellner, R., 2000, Stochastic Models of Stratigraphic Heterogeneity Produced by Variation in Environmental Boundary Conditions in Modern and Recent Depositional Environments: A Tool for Development of Reservoir Framework, Invited Abstract, American Association of Petroleum Geologists Hedberg Symposium "Applied Reservoir Characterization Using Geostatistics", December 3-6, 2000, The Woodlands, Texas, p. 19-22.

Flaum, J.A., Keen, T.R., and **Bartek, L.R.**, 2000, Modeling the Stratigraphy that Evolves in the Transgressive Systems Tract of Continental Margins with High Sediment Input and Frequent and Intense Storms, Geological Society of America Annual Meeting, Reno, Nevada, Nov. 9-18, 2000, Abstracts with Programs 2000 Annual Meeting of the Geological Society of America, v. 32, A-513.

Bartek, L.R., Warren, J.D. and Miller, K., 2001, Perched Lowstand Stratigraphy on the East China Sea Continental Margin, Chapman Conference on the Formation of Sedimentary Strata on Continental Margins, June 17-19, 2001, Ponce, Puerto Rico, p. 26.

Flaum, J.A., **Bartek, L.R.** and Keen, T.R., 2000, Stratigraphy of the Transgressive Systems Tract of a Continental Margin with High Sediment Input and Frequent and Intense Storms: A Comparison of Model Output and Groundtruth, American Geophysical Union Fall Meeting, San Francisco, CA., Dec. 15-19, 2000, EOS, v. 81, p. F652.