HIGH-RESOLUTION THREE-DIMENSIONAL SEISMIC SURVEYING OF SUBMARINE LANDSLIDES: RATIONALE AND CHALLENGES

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ABSTRACT

The use of three-dimensional (3-D) seismic data has had a dramatic impact on the petroleum industry because they allow geoscientists to make accurate interpretations of subsurface structure, stratigraphy and rock properties. We contend that similar benefits will be had from application and adaptation of 3-D seismic techniques to geotechnical studies. As part of COSTA-Canada, we will be collecting and analysing high-resolution 3-D seismic data from known submarine failures in the Saguenay Fjord. Our objectives include both better definition of the internal geometries of the failures, but also (through integration of geotechnical information obtained through coring) prediction of the 3-D distribution of geotechnical properties.

RÉSUMÉ

L'utilisation de données sismiques trois dimensions (3-D) a eu un impact dramatique dans l'industrie pétrolière, en permettant aux géoscientifiques de faire des interpretations de plus en plus précises des structures géologiques, de la stratigraphie et des propriétés des roches. Nous croyons obtenir des resultants similaires en appliquant et adaptant les techniques sismiques 3-D à des etudes géotechniques. Dans le cadre du projet COSTA-Canada, nous viseront à collectionner et interpreter des données sismiques 3-D de haute-resolution provenant des divers sites connues de glissements sous-marins dans le Fjord du Saguenay. Nos objectifs sont non seulement d'obtenir une meilleure definition de la géométrie interne et externe de ces glissements, mais de prédire la distribution spatiale (3-D) des propriétés géotechniques suite à l'intégration des informations géotechniques obtenues par carottages.

1. INTRODUCTION

Three-dimensional (3-D) seismic technology has become a mainstay of the petroleum industry. 3-D seismic data provide the most accurate, high-resolution data available for analysing subsurface structure and stratigraphy. Routinely, subsurface geologic features of interest are found to be more complex than previously thought, to varying degrees (Fig. 1). Furthermore, through integration of 3-D seismic data with information from borehole logs, it may be possible to make predictions of reservoir properties of interest throughout the 3-D seismic area. These and other aspects of 3-D seismic technology have been described by Brown (1996) and Hart (1999, 2000) amongst others.

We seek to adapt and apply 3-D seismic surveying techniques utilized in the petroleum industry to the study of submarine failures. Through this work, we intend to image the internal structure of failed masses, which (by

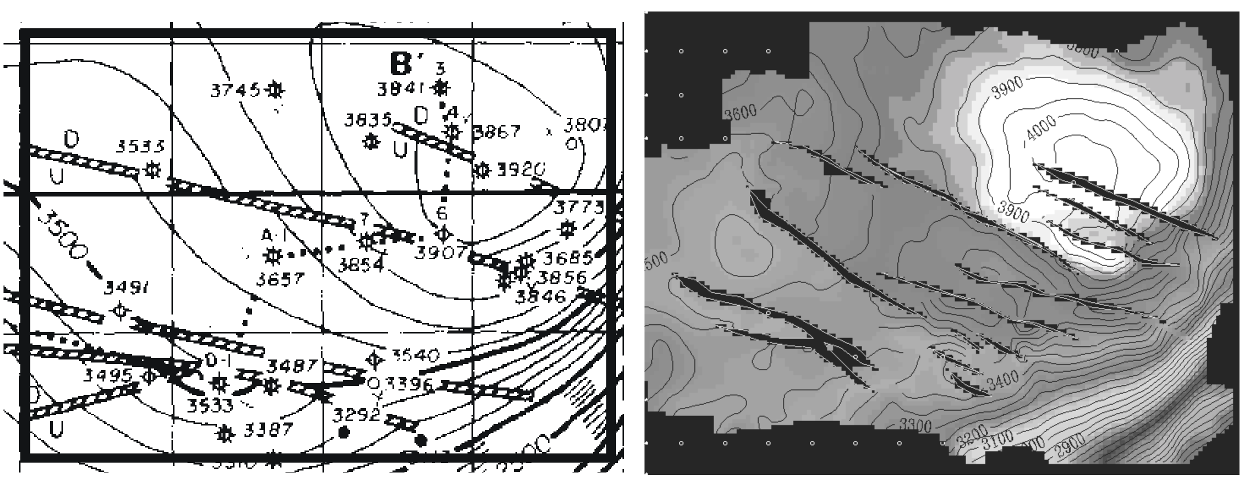

Figure 1. Structural interpretations of a hydrocarbon pool pre- (left) and post- (right) 3-D seismic acquisition. Contours in feet above sea level in both cases. Image on right approximately corresponds to area of dark black rectangle on left image. Without 3-D seismic data, geoscientists were able to image five faults. With 3-D seismic data, geoscientists were able to image 14 faults in the same area. Adapted from Hart et al. (2001).

analogy with petroleum applications) may be more complex than can otherwise be imaged. Furthermore, by integrating seismic attributes with sediment physical properties derived from long cores, we will attempt to predict the 3-D distribution of those properties throughout the seismic survey area. The combination of detailed investigations of the internal structure, surface morphology and 3-D distribution of physical properties we develop should serve as a prototype for similar future investigations. Benefits will include better hindcasting and forecasting of conditions necessary for the development of submarine landslides, as well as better definition of the mechanics of submarine failures.

2. MARINE GEOPHYSICAL SURVEYING – COMPARISON TO PETROLEUM INDUSTRY SEISMIC DATA

High-resolution seismic profiling is used routinely to study submarine failures and other aspects of hazard assessment (e.g., Hart and Barrie, 1996). Like seismic data that are collected for the petroleum industry, high-resolution methods use acoustic energy to image subsurface structure and stratigraphy. The two techniques differ in that petroleum industry seismic data typically penetrate several km and have resolution on the order of several to 10s of m, whereas marine high-resolution seismic data might penetrate several 10s of m but resolve features that are 10s of cm thick. Other differences (including acquisition and processing parameters), and a discussion of the current state-of-the-art in high-resolution work, are presented by Mosher and Simpkin (1999). Generally, high-resolution seismic surveying involves the collection of a grid of 2-D profiles. In the petroleum industry, although 2-D data are still collected, 3-D seismic data are becoming the norm in most onshore and offshore areas.

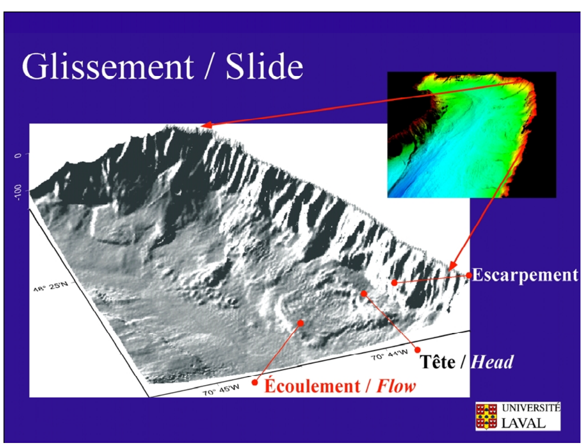

Figure 2. Multibeam bathymetric image of a portion of the Saguenay Fjord showing submarine failures.

One of the problems facing seismic interpreters in both the petroleum and marine hazards fields is that grids of 2-D seismic profiles may not be adequate to define the distribution of complex 3-D structures. Accordingly, multibeam bathymetric surveys have become widely used in the marine geotechnical sector because they provide continuous coverage of the seafloor (e.g., Fig. 2). This detailed surficial morphology information may then be used to make inferences about submarine failure or other processes. One of the problems working with multibeam data is that similar surface morphologies may be produced by different mechanisms. Because multibeam data provide no information about the internal structure of the features they image, process interpretations may still be ambiguous.

Petroleum industry 3-D seismic data collected offshore illustrate one of the major advantages of working with this technology (Fig. 3). Not only can these data provide interpreters with high-resolution images of the seafloor (comparable in quality to multibeam data), but they also provide information about the internal structure of the features being imaged: vertical transects may be “cut” through the seismic data anywhere and in any direction. This combination, along with other visualization techniques (e.g., Brown, 1996; Hart, 1999, 2000) can significantly help to reduce the ambiguity inherent in structural interpretations of geophysical data.

3. SEISMIC ATTRIBUTE-BASED PREDICTION OF SUBSURFACE PROPERTIES

A current trend in the petroleum industry is to integrate attributes (e.g., instantaneous frequency, reflection strength, coherency) derived from 3-D seismic and borehole log data to make predictions of subsurface physical properties of interest such as porosity, lithology, etc. (e.g., Schultz et al., 1994; Hart, 1999, 2000; Hampson et al., 2001). Products might include maps of the distribution of these properties, or physical property volumes (Fig. 4).

Interpreters seek statistically significant empirical correlations between borehole log-derived physical properties and seismic attributes extracted at the well location. Multivariate linear regression, geostatistics and artificial intelligence might be employed during the correlation exercise. As discussed by Hart (2000) and others, statistical significance by itself is not enough to ensure the validity of the results. The results must also be assessed from a geological and geophysical perspective.

We seek to adapt this technique to the study of geotechnical properties. We propose the integration of seismic attributes with profiles of geotechnical measurements from cores (Fig. 5), instead of data from borehole geophysical logs (as used in the petroleum industry), to generate physical property volumes. These

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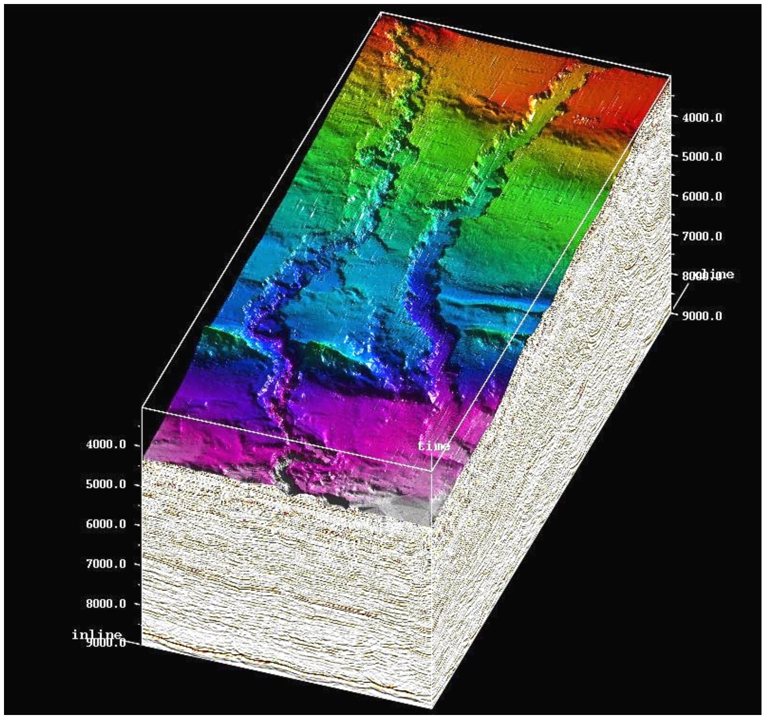

Figure 3. 3-D seismic volume from offshore West Africa showing colour-coded shaded relief bathymetry. Note the location of two submarine channel/canyon systems. Vertical faces of the cube may be zoomed in on and viewed to examine details of the internal structure of surface features. Area of cube is approximately 20 km x 40 km. Image courtesy of Henry Posamentier.

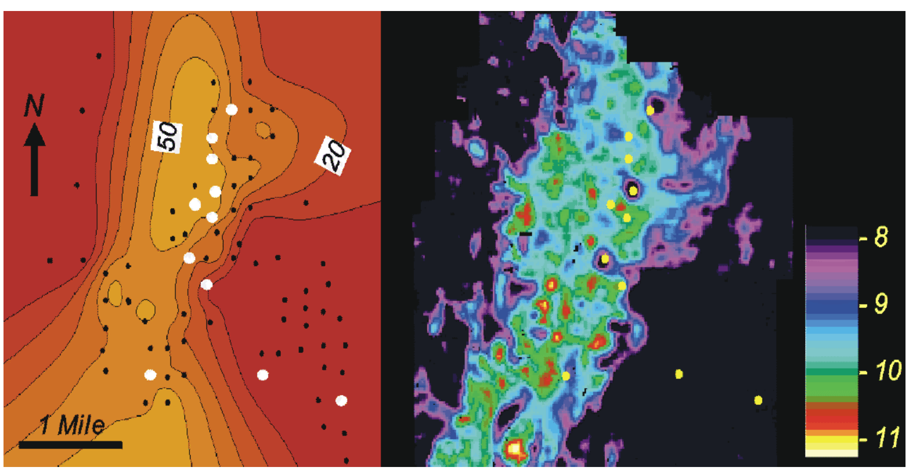

Figure 4. Comparison of a buried submarine channel sandstone as mapped using 77 borehole logs (left) and as imaged by a porosity volume that was generated by integrating seismic attributes with 11 borehole logs (right). The image on the left shows the thickness in feet of the unit. The image on the right shows a stratigraphically equivalent level through a porosity volume, scale in percent. The attribute-based approach identified the location of the channel sandstone, and it provides quantitative physical property data (porosity) that are needed for exploration and petroleum engineering studies. From Leiphart and Hart (2001).

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volumes might predict the 3-D distribution of properties such as liquidity index, shear strength or grain size, and may be used for further geotechnical investigations. The ability to generate and analyse digital physical property volumes could provide fundamental and exciting new insights into the field of submarine slope stability.

4. THE ROAD AHEAD

Implementation of 3-D seismic technology for high-resolution marine surveying will be somewhat different to approaches used in the petroleum industry. First, we will be working with single-channel seismic data as opposed to the multi-channel data employed in industry. Although, as described by Mosher and Simpkin (1999) this will allow us to preserve higher frequencies (and thereby improve resolution) than if we were working with stacked multichannel data, we will be missing subsurface velocity information that may be obtained during processing. Additionally, recording geometries will be different than in the petroleum industry. Our single-channel data will consist of a series of tightly spaced 2-D transects that will be merged into a 3-D volume. Lacking velocity information that is usually obtained through stacking, and wishing to preserve high frequencies, we will not be able to migrate the data. As such, there may be some ambiguity about the true subsurface location of some features. Our processing efforts will need to focus on factors such as accounting for transmission losses (through gain control), sharpening the pulse (deconvolution) and noise reduction (filtering).

Data collection is planned for July 2001, with processing and analyses to begin shortly thereafter. We have chosen the Saguenay Fjord for a pilot program, because: a) several candidate slides have already been identified

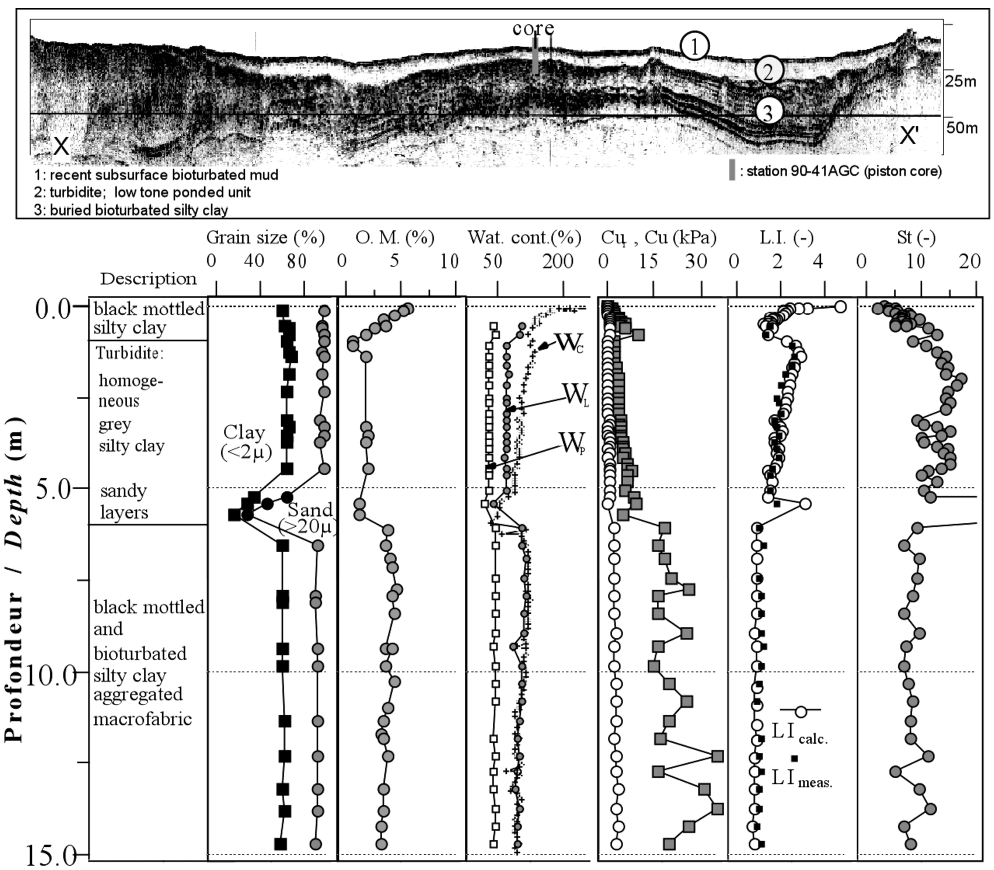

Figure 5. Comparison of high-resolution seismic image (above) with geotechnical profiles from core analyses. Our seismic attribute studies will work with similar profiles, rather than with borehole geophysical logs as employed in the petroleum industry. From Locat and Lee (2000).

(Locat et al., this volume), b) conditions (waves, currents, marine traffic, etc.) for surveying in the Fjord are likely to be better than in more exposed areas (e.g., open ocean sites), and c) there is abundant previous work that will help us to evaluate the geologic context of our study area (e.g., Locat et al., 1998, Perret et al., 1995). Although high-resolution 3-D marine seismic surveying has been undertaken before (e.g., Davies and Austin, 1997), we are unaware of any such study that has specifically focused on submarine landslides or prediction of subsurface physical properties using seismic attributes.

5. SUMMARY

Application of 3-D seismic technology to the study of submarine landslides is still in its infancy. However, and by analogy with the petroleum industry, we are confident that the results will provide important new insights into the processes and products of submarine landslides, and provide an important new tool that may be used is submarine slope stability analyses. Although there are hurdles to cross, the program undertaken by researchers of the Costa-Canada program will help to significantly advance this field.

6. ACKNOWLEDGEMENTS

We thank the National Science and Engineering Research Council for Costa-Canada funding. Software for seismic analyses has been provided by GeoGraphix and Hampson-Russell Software Services.

7. REFERENCES

Brown, A.R., 1996, Interpretation of three-dimensional seismic data, fourth edition: AAPG Memoir 42.

Hampson, D., Schuelke, J., and Quirein, J.A., 2001, Using multiattribute transforms to predict log properties from seismic data: Geophysics.

Hart, B.S., 1999, Definition of subsurface stratigraphy, structure and rock properties from 3-D seismic data. Earth-Science Reviews, **47:** 189-218.

Hart, B.S., 2000, 3-D seismic interpretation: a primer for geologists. SEPM Short Course Notes #48, Tulsa, OK, 124p.

Hart, B.S. and Barrie, J.V., 1996, Environmental geology of the Fraser Delta, Vancouver. Geoscience Canada, **22:** 172-183.

Hart, B.S., Cooper, S. P., Ralser, S., Nickolaissen, K., Herrin, M., and Balch, R.S, 2001. Ute Dome I: Multidisciplinary integration defines Dakota reservoir compartments. In: D. Anderson, E. Coalson, J. Robinson and J. Estes-Jackson (eds.). Gas in the Rockies: Rocky Mountain Association of Geologists Guidebook, 309-322.

Leiphart, D.J., and Hart, B.S., 2001. Comparison of linear regression and a probabilistic neural network to predict porosity from 3-D seismic attributes in Lower Brushy Canyon channeled sandstones, southeast New Mexico. Geophysics, *in press*.

Locat, J. et Bergeron, M., 1988. Étude à rebours de glissements sou-marins, Fjord du Saguenay, Québec, Canada. Compte rendu de la 41 ème conference canadienne de géotechnique, Waterloo, 338-346.

Locat, J., and Lee, H. J., 2000. Submarine Landslides: Advances and Challenges. Proceedings, 8th International Symposium on Landslides, Cardiff, U.K., June 2000

Mosher, D.C. and Simpkin, P.G. 1999. Environmental marine geoscience; 1, Status and trends of marine high-resolution seismic reflection profiling; data acquisition. Geoscience Canada, **26**: 174-188.

Perret, D., Locat, J. et Leroueil, S. 1995. Strength development with burial in fine-grained sediments from the Saguenay Fjord, Quebec. Revue canadienne de géotechnique, **32** : 247-262.