Sediment Formation in Nearshore Environments: Strength, Rheology, Microstructure, and Stability

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LONG-TERM GOALS

Our goals are to understand how geotechnical and physical properties develop in marine sedimentary deposits on continental margins and how these properties influence sediment transport processes and the development of geomorphology. Our studies include predicting stability of sediment on the continental shelf and slope, providing input parameters for models of sediment transport and deformation, and distinguishing morphologic features caused by slope failure from those caused by other gravity-driven processes. Our studies also include improving our understanding of the transition between initial slope failure and the development of debris flows and turbidity currents and predicting the rheological properties that determine the dynamics of such flows. We plan to apply our studies to the EuroSTRATAFORM project, within which we collaborate with scientists seeking to model the formation and alteration of nearshore sedimentary bodies.

OBJECTIVES

Our main objectives for FY04 focused on: (1) understanding the ways in which sediment bodies develop shear strength, rheological properties and structure; (2) test shear strength development models in controlled environments, (3) further the development of the concept of seismic and biologic strengthening; (4) relate regionally distributed geotechnical properties to index properties that can be determined easily or, potentially, mapped remotely; (5) assess the signatures of catastrophic events to determine whether they are produced by deformational (landsliding) or depositional (turbidity current sediment waves) processes; (6) provide the scientific community the rheological properties of fully deformed sediment mass to be use by turbidity current and debris flow modelers.

APPROACH

Our research focuses on the geotechnical changes that occur to sediment as it is buried under the seafloor. These changes include the direct influence of burial, the impact of repeated seismic shaking (seismic strengthening), and the effects of biological activity (biological strengthening). Part of this analysis also relies on obtaining information on non-bioturbated, normally consolidated sediments via SEDCON (SEDimentation-CONsolidation) tests which can be integrated into geotechnical profile as a reference curve enabling us to extract the relative influence of either bioturbation and/or seismic strengthening. We use samples taken in connection with the EuroSTRATAFORM project in the Adriatic Sea as well as synthetic sediment produced in the laboratory (SEDCON). We also determine the sediment microstructure using SEM techniques and mercury microporosimetry. We compare field geotechnical and microstructure profiles with those developed in the laboratory following the

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application of compressive loads. This will help ascertain the significance of seismic and biological strengthening in altering geotechnical profiles. The bioturbation contribution to the sediment characteristics is evaluated by considering the bio-pores as bio-porosity which is evaluated using CATSCAN imaging. These results are then used to evaluate the potential bias of bio-porosity on sediments physical properties.

Key individuals, at Laval: Jacques Locat, Marie-Claude Lévesque, Serge Leroueil, and Pierre Therrien: strength and compressibility measurements, SEM studies, rheology measurements, and simulation of sediment accumulation; at the USGS: Homa Lee, Dianne Minasian, Pete Dartnell, and Kevin Orzech: physical property logs of sediment cores and relations between geotechnical and classification properties, algorithms relating sediment properties, environmental factors, and slope stability within the framework of a GIS, and strength development from seismic shaking. Partners in Italy are N. Sultan (France), M. Canals and R. Urgeles (Spain), and F. Trincardi (Italy). NA-EuroSTRATAFORM partners who have also been involved in FY04 research are R. Wheatcroft and T. Milligan.

WORK COMPLETED

During FY 04, we completed the work related to EuroSTRATAFORM project in the Adriatic Sea. The work included detailed physico-chemical, mineralogical and geotechnical analyses of 11 cores from the shallow shelf off the Po delta. It included water content, strength (intact and remoulded), grain size (mostly done by T. Milligan's team), Atterberg's limits, organic content, cation exchange capacity, specific surface area and X-ray diffraction. Three cores were selected for a detailed analysis of the bio-porosity, including one from the Saguenay Fjord for comparison on which detailed CATSCAN analyses and Multi Sensor Core Logging (MSCL) was carried out along with SEM and mercury microposimetry. SEDCON and rheological tests were carried out on a mixture of sediment taken from the various cores. Detailed 3D CATSCAN was also carried out on the two SEDCON samples. In addition to contribution of papers to various workshops (ComDelta) and special session (Lévesque et al. 2003, Locat et al. 2003), the work completed in FY04 also included the completion of major contribution to two books: the Master Volume of STRATAFORM (Lee and Locat, 2004, ch. 6) and another volume on debris flows (Locat and Lee, 2004, ch. 9).

RESULTS

The detailed analysis of cores from the Po Delta has shown that the consolidation process has been largely influenced by bioturbation which has resulted in a significant decrease in the in situ water content to a point well below the SEDCON reference curve (Figure 1). This is shown by comparing the SEDCON liquidity index (I_L) profile, in Figure 1,with the core values. Until a depth of about 40 cm, the in situ (core) liquidity index is still lower that it equivalent value obtained from the SEDCON tests except at a depth of about 20cm. The 20 cm level correspond to a portion of the 2000 flood layer which has not been significantly bioturbated. Much efforts in FY04 were devoted to develop a technique to estimate the contribution of bioturbation to the actual porosity of the sediment. We opted for the use of the CATSCAN to evaluate the bioporosity in a way similar to that propose by Michaud et al (2003). In this way we defined for each layer (less than 2 mm thick) the threshold value below which the tomographic intensity could be linked to a pore and then the volume occupied by this component of the signal was computed over the total signal (or volume) thus giving a measurement of the bio-porosity. Results are shown in Figure 2 which present the detailed distribution of the bioporosity in core O19 (same core as in Figure 1). Results indicate that for this core, the bioporosity can be as high as 40% while the bulk porosity is at about 80%. This is a very significant contribution and has also impact on the measurement of water content in samples.

These results have been discussed in greater details in Lévesque et al. (2004). Here also, we can see that very little bioturbation has taken place at a depth of about 20cm. In conclusion we have clearly shown that bioturbation can have a significant impact on the physico-chemical characteristics of a sediment and thus on in geotechnical behavior.

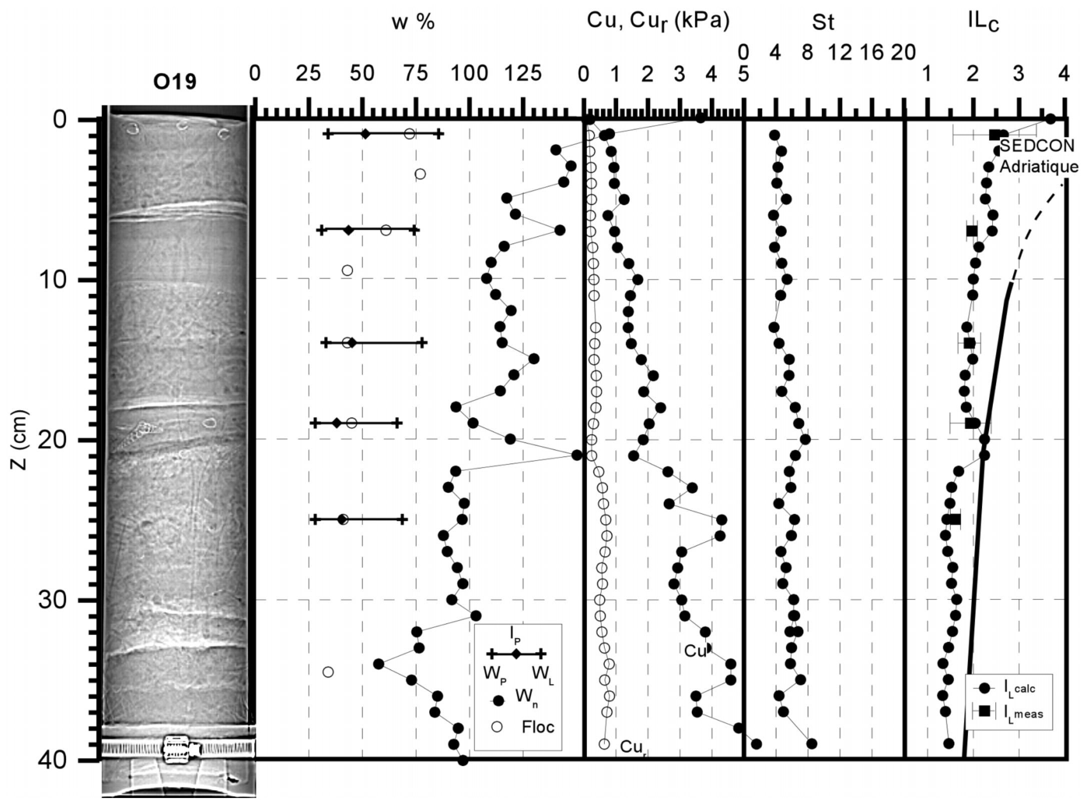

Figure 1. Detailed geotechnical analysis of core O19 including the reference to the SEDCON curve.

IMPACT/APPLICATION

Results obtained in FY04 have provide a unique opportunity to clearly demonstrate the potential role of bioturbation and its impact on the properties of recent sediments. This information will be added to what we have done in the past to provide, during FY05, a conceptual model illustrating biological strengthening. The methodology developed to evaluate the bioporosity of a recent sediment may be of great help in environmental studies where the physico-chemical properties of the sediment are of concern. Our results can also be used to improve on strength development models used for modeling sediment accumulation and stability.

TRANSITIONS

Rheological properties are being used by modelers to represent debris flows (Imran et al. 2001). Landslide generation models are being used by landscape evolution modelers. Offshore research groups interested in margin and in oil and energy development were used as a platform to present our knowledge on submarine slope stability and hazard acquired as part of STRATAFORM and EuroSTRATAFORM. We have also contributed to a major effort in assembling all the existing knowledge on submarine mass movements and their consequences by publishing a book containing refereed papers on the topic (Locat and Mienert 2003) including papers by Lee et al. (2003) and Locat et al.2003a) related to STRATAFORM. We also transfered our knowledge developed as part of STRATAFORM to those interested in tsunami modeling (Locat et al.2004) and more recently in two volumes (Lee et al. 2004, and Locat and Lee 2004).

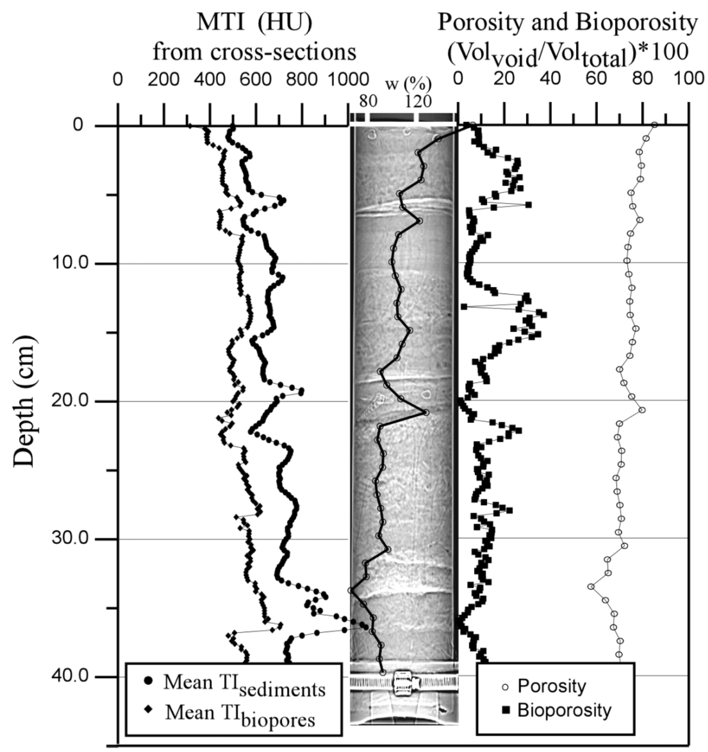

Figure 2. Evaluation of the bioporosity of core O19 using Mean Tomographic Intensity (MTI).

RELATED PROJECTS

Lee has developed a USGS project to investigate sediment and pollutant transport on the Los Angeles margin that uses techniques produced by STRATAFORM. The development of this project benefited from approaches developed within STRATAFORM. A group of Canadians led by J. Locat, and H. Lee developed a new project with project COSTA (COntinental Slope STAbility) in Europe that will last until 2005.

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