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Geotechnical characteristics of deep-sea sediments from the North Atlantic and North Pacific oceans

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ABSTRACT

Geotechnical properties from a series of deep-sea sites in the North Atlantic and North Pacific oceans are examined to evaluate overall trends and to compare with similar fine-grained soils found on land. The study areas encompass a range of sedimentary environments dominated by combinations of turbidite and pelagic deposits. Carbonate content in excess of 20% is seen to result in a decrease in liquid limit and compressibility. Vertical profiles of geotechnical properties in the North Pacific show broader changes in down-core geotechnical properties compared to the North Atlantic and reflect the effects of long-term climatic changes and seafloor spreading. Sediments in the North Atlantic indicate significant differences depending on location, which is attributed to variability in turbidite deposition, water depth, distance from sediment sources, and the effects of bottom currents. Compared to equivalent fine-grained soils on land, deep-sea sediments are generally softer, more compressible and have higher friction angles at comparable Atterberg limits. Deeper and older sediments in the North Pacific are characterized by unusually large plastic limits, which are attributed to the presence of volcanic fractions. Empirical relationships for compression index and friction angle are discussed for sediments from both oceans.

1. Introduction

Geotechnical characterization of the seafloor has focused largely on continental margins. This is driven by economic interest and scientific curiosity. The deeper ocean basins have received comparatively less attention, despite the fact that they underlie about 80% of the total area of the oceans. Nearly 60% of the seafloor is located at depths of 4000 m or deeper (Anikouchine and Sternberg, 1973). A few notable efforts to investigate the geotechnical properties of these vast deep-sea deposits have taken place over the years, primarily in connection with the Integrated Ocean Drilling Program and its predecessors. In addition, there have been many scientific expeditions to recover deep-sea sediments for scientific study, including geotechnical characterization. Most of these have relied not on drilling methods for sampling, but on gravity cores, box corers, grab samplers, and similar devices (Schütenhelm et al., 1989; Silva and Hollister, 1979). While many of these techniques provide relatively undisturbed specimens, often of much better quality than those obtained using drilling methods, they are limited in terms of penetration.

In order to increase penetration, large free-falling gravity corers have been developed that can recover up to about 40 m of fine-grained seafloor sediments (Driscoll and Hollister, 1974; Montarges et al., 1983; Young et al., 2000). These corers are cumbersome and expensive, but they can provide samples of exceptional quality and this is of obvious interest for geotechnical purposes. This article includes the results from a number of such cores that were collected over a period of about 20 years from locations in the North Atlantic and North Pacific oceans. These cores were obtained from several expeditions, some of which were connected with US and international efforts to identify and characterize deep-water sites for the disposal of high-level nuclear waste (Hollister et al., 1981; Shephard et al., 1988). The purpose here is to analyze vertical trends to substantial depths below the seabed and to seek correlations among index properties, compressibility, strength, and also to compare results across individual study sites and across oceans in order to provide a deeper insight into the range and character of deep-sea sediments. A number of empirical correlations are also presented that should prove useful for engineering design.

The North Atlantic Ocean basin includes three major provinces. Abyssal plains are found along the eastern and western edges, adjacent to the continental margins. They are among the flattest areas on earth, occurring between 3000 and 6000 m of water, and contain sediment deposits of great thickness, typically in excess of 1000 m. The thickest deposits are found off the east coast of the

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US, where they can amount to several thousand meters (Ewing et al., 1973). These thick deposits are derived to a large extent from adjacent continents and overlay a topographically irregular oceanic crust. A major mode of sediment transport to these areas is in the form of turbidite currents that originate on the continental margins. The geotechnical characteristics of these deposits are discussed in this article. Extending between the abyssal plains and the Mid-Atlantic Ridge province is the abyssal hills region, which is defined by numerous sharp hills rising up to 1000 m above the surrounding seafloor. These hills usually take their form from highs on the basement crust, although some are of strictly sedimentary origin (Kennett, 1982). Water depth and sediment thickness generally decrease toward the Mid-Atlantic Ridge. The flanks of the ridge rise to less than 3000 m water depth, although the central valley may be 1000–3000 m below these highs.

The morphology of the North Pacific basin is quite different from that of the North Atlantic. The central portions, which are the focus of this study, are far removed from continental margins and sediment accumulates there at very slow rates from wind-blown, volcanic, authigenic, and biogenic sources. Because of the size of the Pacific Ocean, these pelagic deposits are quite widespread. They serve as a useful contrast to the sediments found in the North Atlantic.

Water depth is an important factor in determining the nature of pelagic sediments. Major differences occur in the abundance of biogenic components, chiefly carbonate, depending on the level of saturation of calcium carbonate in the water column. Although

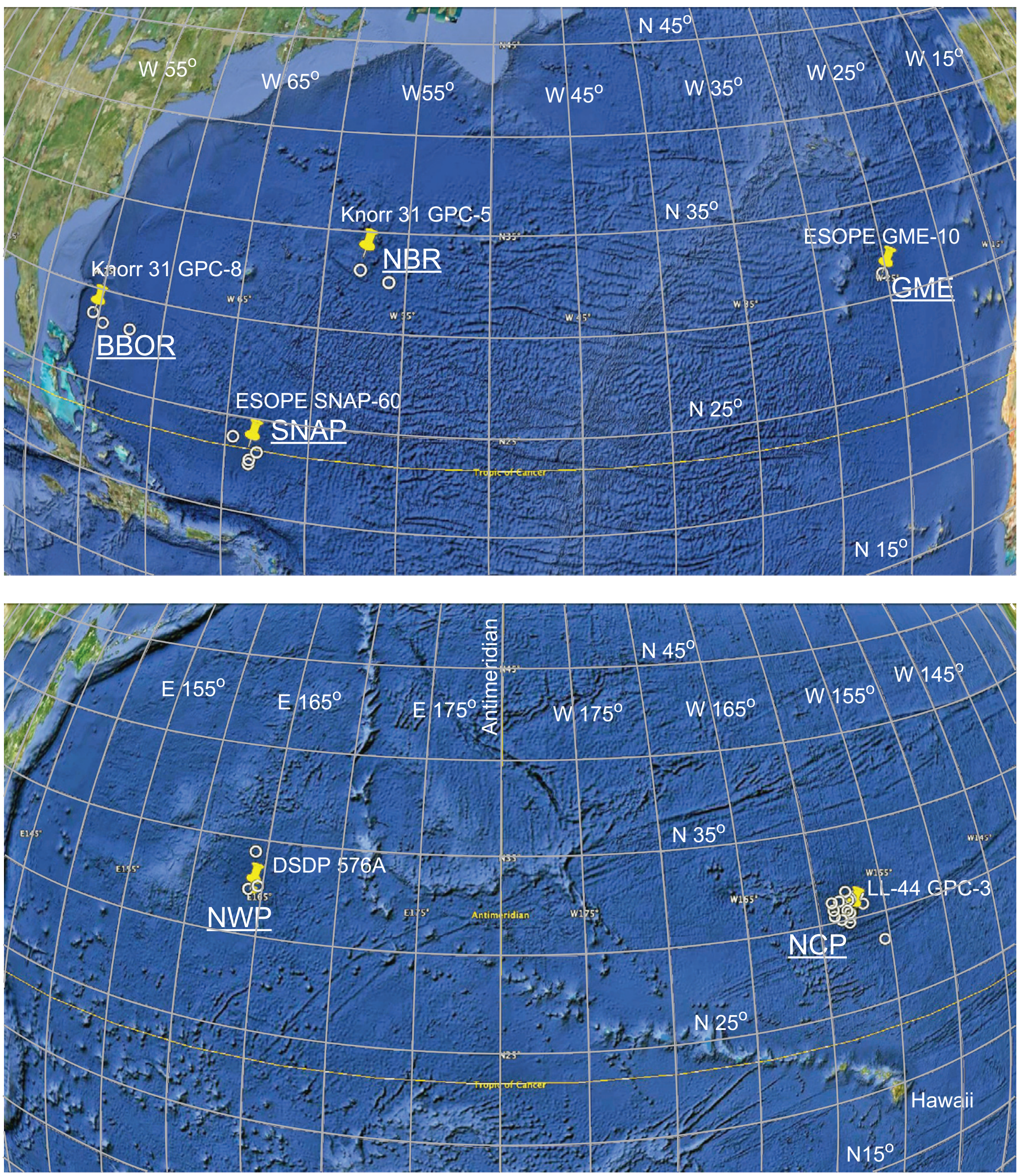

Fig. 1. Study sites with locations of cores used in this study. Thumbtacks identify the main cores at each site. (Data©2010 MIRC/JHA, Image©2010 DigitalGlobe & TerraMetrics.)