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FIRST RESULTS OF SEDIMENTOLOGICAL AND GEOTECHNICAL DETERMINATIONS ON JOIDES BASIN CORES IN RELATION TO THE PLEISTOCENE GROUNDING LINE

ABSTRACT: CORRADI N., FERRARI M. & IVALDI R., *First results of sedimentological and geotechnical determinations on Joides Basin cores in relation to the Pleistocene Grounding Line.* (IT ISSN 0391-9838, 1997).

Studies carried out on gravity cores collected in the Joides Basin during the Xth and XIth Antarctic expeditions of «Programma Nazionale di Ricerche in Antartide», in the framework of the «Glaciologia e Paleoclima» Project were addressed to identifying the effects of by West Antarctic Ice Sheet advance in the Last Glacial Maximum (Lgm). The Western Ross Sea continental shelf is characterized by a series of northeast-southwest trending banks and basins. The Joides Basin is one of these depressions. It is characterized by a rim near the continental shelf break that is higher than the centre of the basin. High resolution geophysical surveys were conducted in the study area to show the geometry and seismostratigraphy of the upper metres of superficial sediments. These studies allowed us to locate the sampling sites. 13 gravity cores were collected during the two Antarctic Expeditions for sedimentological and geotechnical studies.

The sedimentation patterns of the Ross Sea continental shelf, as described in literature and obtained by laboratory testing and campaign results, show many glacial erosion surfaces and relative overlying sediments.

The sedimentary sequence following the last glacial event consists of two facies overlying the basal till: marine sedimentation, composed of fine, mostly clayey sediments with limited internal unconformities; glaciomarine deposits characterized by glaciomarine sediments (diamicton) of variable thickness; below this deposit, the sediments are represented by a basal till of variable and not easily quantifiable thickness. The basal till is characterized by unstratified sediments, with mixed texture, low water content and overconsolidation.

The first results from the cores collected show that the characteristics of the sediments vary according to the location of the sampling site. Geotechnical characterisation of the sediments also highlights the peculiar sedimentation environment and the presence of overconsolidation phenomena that may be due to the presence of a grounding ice sheet during the Lgm, in a site very close to the shelf break.

KEY WORDS: Seismic stratigraphy, Glaciomarine sediments, Antarctica, Ross Sea.

RIASSUNTO: CORRADI N., FERRARI M. & IVALDI R., *Prime risultanze delle determinazioni sedimentologiche e geotecniche su carote del Joides Basin in relazione alla Grounding Line Pleistocenica.* (IT ISSN 0391-9838, 1997).

Le indagini condotte sulle carote a gravità raccolte nel Joides Basin durante la X e XI Campagna Antartica, nell'ambito del Progetto del Pnra «Glaciologia e Paleoclima», sono state volte alla individuazione degli effetti sui sedimenti che l'avanzata della *West Antarctic Ice Sheet* ha prodotto durante l'ultima massima espansione glaciale pleistocenica - Lgm. L'azione erosiva delle lingue glaciali, nella porzione occidentale del Mare di Ross, ha conferito alla piattaforma continentale una morfologia a banchi e bacini orientati NE-SW.

Il Joides Basin rappresenta una di queste depressioni ed è caratterizzato dalla presenza di una soglia in prossimità del ciglio della piattaforma continentale, più rilevata rispetto al centro del bacino. Le campagne di prospezione geofisica ad alta risoluzione hanno consentito da un lato di mettere in evidenza la geometria dei corpi sedimentari e la sismostratigrafia dei primi metri di sedimento, dall'altro hanno consentito di ubicare i siti di campionamento. Sono state pertanto raccolte 13 carote a gravità, durante le due Campagne Antartiche, dedicate allo studio sedimentologico e geotecnico.

I modelli di sedimentazione della piattaforma continentale del Mare di Ross, noti in letteratura e desunti dalle risultanze di laboratorio e di campagna, mettono in evidenza le numerose superfici d'erosione glaciale con le relative coperture sedimentarie. La serie sedimentaria successiva all'ultimo evento glaciale consiste di due facies sovrastanti il till basale: sedimentazione marina, caratterizzata da un drappeggio di fanghi per lo più biosilicei, con limitate discordanze interne, e serie glaciomarina, a tessitura eterogenea (diamicton) e potenza variabile, al di sotto della quale i sedimenti sono rappresentati da «basal till», caratterizzati da assenza di stratificazione, basso contenuto in acqua ed alti valori di consolidazione.

I primi risultati hanno messo in evidenza come le carote prelevate rispecchino le caratteristiche sedimentologiche già note, ma con caratteristiche peculiari dei siti di campionamento; in particolare, alti valori di consolidamento segnalano in posizione prossima al ciglio della piattaforma la possibilità di ghiaccio ancorato durante il Lgm.

TERMINI CHIAVE: Sismostratigrafia, Sedimenti glaciomarini, Antartide, Mare di Ross.

INTRODUCTION

The study of marine sediments paleoclimate records in the Antarctica is one of the aims of the «Glaciologia e Pa-

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leoclima» Project in the framework of the «Programma Nazionale di Ricerca in Antartide» (Pnra). Marine geology activities formed part of two Oceanographic Cruises (X, 1994/95 and XI, 1995/96). These activities included high resolution geophysical surveys (Sub Bottom Profiler-S.B.P.) and the collection of gravity cores from the Ross Sea continental shelf. During the two expeditions a total of 13 gravity cores were collected, with the aim of investigating how the action of the grounded ice had affected continental shelf sediments in the Ross Sea and starting a mapping to recognise the possible extension and thickness of the Western Antarctic Ice Sheet, during a period presumably corresponding to the last Pleistocene glacial cycle.

The aim of the research project was to identify the limit (on the basis of sedimentological and geotechnical characteristics) between normal deposits (Ncd) and overconsolidated deposits (Ocd) as indicator of the position of the grounding line. The overconsolidation ratio is a good indicator of the overloading of deposits under the ice sheet, and collating results from different sites, allows us to hypothesise the extension of the ice sheet that shaped the continental shelf.

There is a great deal of evidence of variations in the extension of «glaciers» causing the western ice sheet to move over the Antarctic seabottom. This evidence has been collected by means of geophysical surveys, drilling surveys and surface sampling. Dsdp drilling sites 270, 271, 272, 273, Ciros-1, Mssts-1 and subsequent surveys on the Ross Sea continental shelf have indicated the main sedimentation characteristics and unconformities due to erosion linked to ice sheet oscillations starting in the mid Miocene period (Anderson & *alii*, 1984, 1980; Edwards & *alii*, 1987; Hall & *alii*, 1989). The results of studies performed on samples taken during the Xth Expedition and preliminary studies on board during the XIth Expedition indicate deposits subjected to overloading due to the presence of ice sheets grounded on the seabottom.

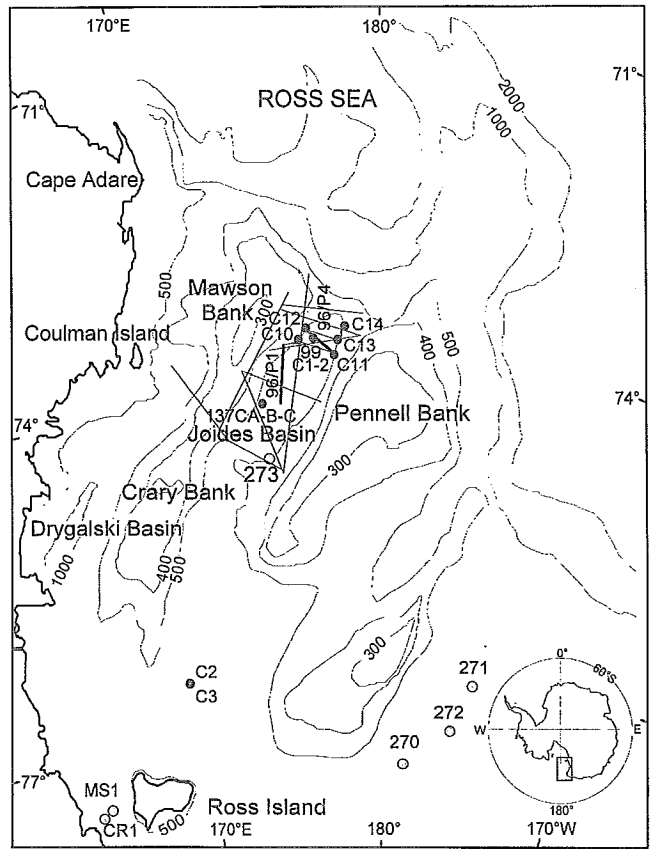

FIG. 1 - Index map showing the batimetry (depth in metres), the coring sites, the drill sites (270-273: Dsdp leg 28 sites; Cr1: Ciros-1; Ms1: Mssts-1) and the gridwork of the seismic-reflection lines in the Joides Basin used in this study. Highlighted lines are shown in figure 2 and 3.

MORPHOLOGY OF THE CONTINENTAL SHELF

The continental shelf in the Western Ross Sea has the peculiar characteristics of circumpolar sea bottoms. The shelf break is located at a variable depth of between 400 and 800 metres, while the greatest depths (sometimes exceeding 1,000 metres) are located in the proximity of the coast (Drygalski Basin). This morphology is a result of exaration by the ice sheets on the sea bottom since the middle Miocene.

The ice sheets have repeatedly passed over the continental shelf, eroding hundreds of metres of sediment, and giving the sea bottom a morphology characterized by banks and basins, arranged along tectonic lines (Vanney & *alii*, 1981).

The Joides Basin is a NE-SW elongated depression, situated in the western sector of the Ross Sea between Crary Bank and Mawson Bank to the west, and Pennel Bank to the east. The morphology of Joides Basin is illustrated by the bathymetric contours in fig. 1. The rim near the continental shelf break is higher than the center of the basin. This is in accordance with models of evolution regarding circumpolar shelves, and is the result of glacial exaration. We therefore hypothesise that during the Last Glacial Maximum, the grounding line was much closer to the rim of the continental shelf break, in accordance with the model proposed by numerous researchers (Anderson & *alii*, 1992; Drewery, 1979; Denton & *alii*, 1991; Licht & *alii*, 1996).

SEISMOSTRATIGRAPHY OF PLIO-PLEISTOCENE DEPOSITS

Studies conducted on seismic profiles (Anderson, 1984; Anderson & *alii*, 1992; Cooper & *alii*, 1987) and Dsdp drillings have provided the means to develop models of sedimentation along the Ross Sea continental shelf and indicate the numerous glacial erosion surfaces and relative overlying sediment. On the basis of these studies and an examination of Sparker and S.B.P. profiles (collected in the Joides Basin area during the 1990/91, 1994/95 and 1995/96 Pnra Expeditions), it has been possible to identify

the particular seismostratigraphy of sedimentary bodies, due for the most part to erosion and deposition phenomena caused by the action of the ice sheet (Cooper & *alii*, 1987; Anderson, 1991). The sedimentary series are therefore characterized by numerous unconformities linked to the extensions and retreats of the ice sheet. The sedimentary series relative to the LGM in the Pleistocene period has similar characteristics.

The Sparker (1990/91) and high resolution S.B.P. (1994/95 and 1995/96) seismic profiles conducted in the Joides Basin during Pnra Expeditions (fig. 1), highlight the geometry of deposits derived from sedimentary processes linked to the action of the ice (Anderson & *alii*, 1992; Cooper & *alii*, 1987). The profiles show numerous layers relative to the evolutionary phases of the shelf. In some cases these surfaces outcrop and are characterized by a particularly condensed sedimentary series.

Three basic sedimentary facies can be identified as characterizing depositional sites: central basin sedimentation, characterized by fine, mostly clayey sediments and limited internal unconformities; basin flanks, in which larger deposits of moraine sediment can be observed with characteristic morphology and coarser texture (Alonso & *alii*, 1992; Anderson & *alii*, 1992; Buonocore, 1994); finally, the banks represent coarse texture sedimentary deposits with numerous internal unconformities which occasionally outcrop.

The network of S.B.P. surveys was used to locate the core collecting sites most appropriate foro sampling the exaration surface relative to the Lgm (or in any case to the basal till regarding that event) and allowed a better resolution of the superficial sediments. The erosion surface is not always so easy to identify. Glaciomarine deposits are much better defined and are comprised predominantly of diatomaceous mud/ooze. They range between few metres to tens of metres thick, with irregular morphology and no internal stratification (Kellogg & *alii*, 1979; Anderson & *alii*, 1992). The peculiar tortuous morphology of the deposits (Marchetti & *alii*, 1993) may in part be related to methods of sedimentation from the ice sheet and the abundant sedimentation of dropstones deriving from melting icebergs and the breaking up of the ice sheet during retreat. A further complication of the morphology could be due to the ploughing action on the sea bed by the still partially grounded ice sheet or by icebergs. Pelagic sediments on the other hand, are mainly composed of silt and clay with a high diatomas content and frequent dropstones. It is present for the most part as transparent sediment drapings without internal unconformities.

The profile in fig. 2 illustrates a S-N section from the center of the southern Joides Basin to the flank of the Mawson Bank. In the profile it is not possible to identify the Lgm exaration surface and the separation limit between the basal till and the glaciomarine sediments above, formed of accumulations caused by the extensions and retreats of the grounded ice sheet orsubsequent removal on decoupling. Above this the pelagic sediments are clearly visible, characterized by a regular transparent draping and no internal unconformities. At the flanks of the basin the pelagic sediment is reduced, the sediments have a coarser texture and the morphology more closely resembles the characteristic morphology of glaciomarine deposits. The sedimentary elements are characterized here by numerous internal reflections, related to the direct action of the glaciers that affected this sea bottom for a longer period of ti-

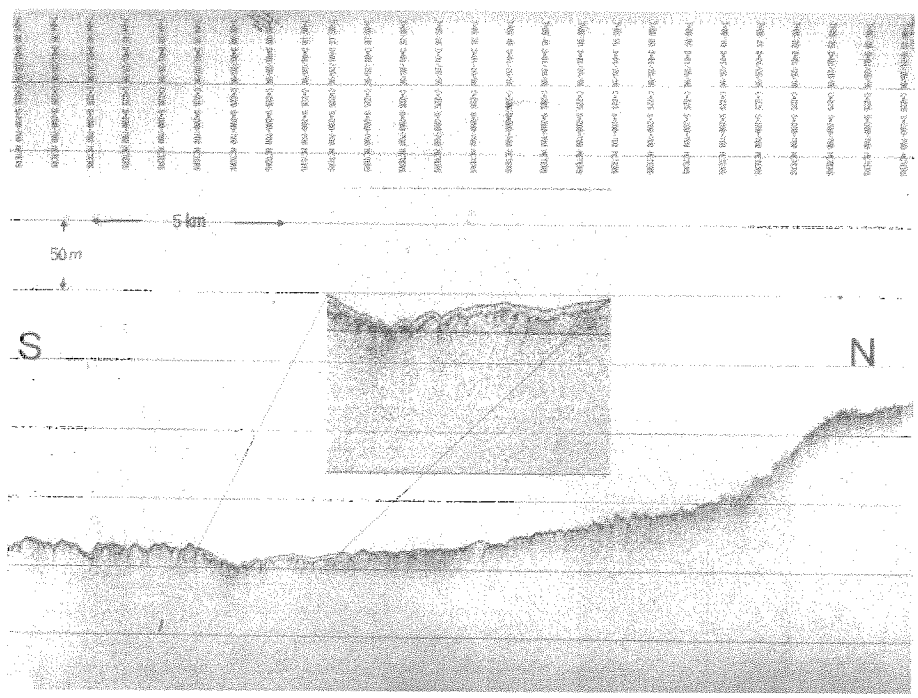

FIG. 2 - Sub Bottom Profiler (96/P1) section from the center of the southern Joides basin to the flank of the Mawson Bank. See figure 1 for location of this profile.

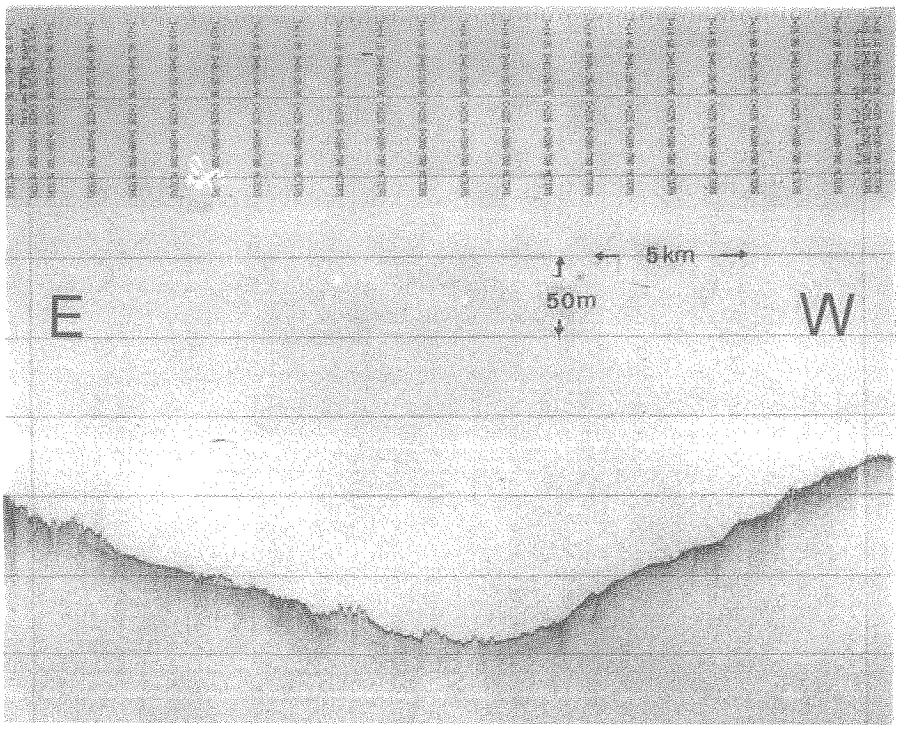

FIG. 3 - Sub Bottom Profiler (96P4) section transverse to the axis of the northern Joides basin. See figure 1 for location of this profile.

me than the more depressed portions. A transverse profile of the basin (fig. 3) shows a typical example of a submarine glacial valley. The section was performed in the southernmost sector of the basin, and shows the basal erosion surface related to the Lgm (which often outcrops) with fine detail and in a number of points. The glaciomarine deposits are always very well defined. The marine sediments are also present, but with limited thicknesses that are hard to distinguish in the profile.

SEDIMENTOLOGICAL AND GEOTECHNICAL METHODS AND RESULTS

The cores were subjected to a series of preliminary analyses on board immediately after collection. The results of sedimentological tests performed at the points the core was cut into sections enabled us to assess a number of significant parameters in addition to the visual classification, including undrained shear strength, water content value, grain size analysis, bulk density and Atterberg's limits.

In the laboratory the cores were subjected to X-ray lab analyses, and then cut longitudinally, opened, photographed and subsampled, and analysed on average every 10 cm according to the sedimentological procedures used by various researchers (Anderson & *alii*, 1980; Anderson & *alii*, 1984; Edwards & *alii*, 1987). The X-ray lab analyses revealed the internal structures and pebbles content. When considered in conjunction with the preliminary analyses, this information enabled us to select the most representative cores from the central part of the basin (137CC) and the northern part (99C2), where glaciological models hypothesise the presence of the Lgm grounding line.

Work performed included textural analyses (Folk, 1966; Shepard, 1954), undrained vane shear strength test, water content, bulk density, Atterberg's limits, biogenic silica (opal), organic carbon and calcium carbonate content. The undisturbed samples, prepared on board, were subjected to consolidation and triaxial strength testing to evaluate loading.

Core 137CC can be divided into three portions on the basis of analysis results (fig. 4). The upper (0-73 cm) part is texturally characterized by silt and sandy-silt, and water content values are greater than 100%. The subsequent section (73-300 cm) is distinguished by the increase of the sandy fraction (sandy silt and silt), with the occasional presence of slightly gravelly levels. In the portion between centimeters 212 and 216 there is a layer of gravely mud, the water content values between 88% and 40%, and a downward water content trend as depth increases. The third layer (300-406 cm) is characterized by sediments similar in texture to the previous section. The water content values decrease with depth and are always less than 40%. Large pebbles are also dispersed in the sediment, particularly in the sections between centimeters 125-223 cm and 286-374 cm.

In the core 137CC the content in organic matter is always <10%. The trend is very similar to that of the biogenic silica (8.68% maximum value at 35 cm, 2.40% mini-

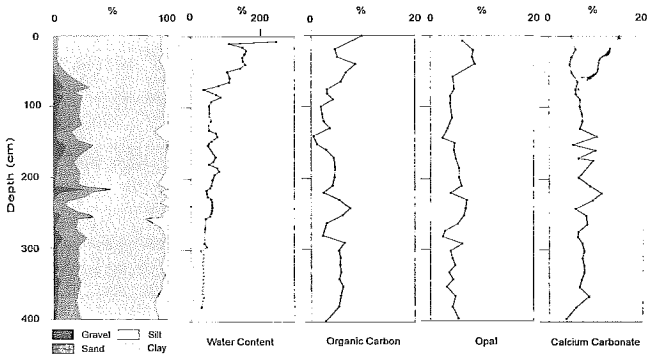

FIG. 4 - Textural and compositional log of the 137CC core.

mum value at 135 cm) and related to the textural variability, generally recording the lower values in the silty levels while higher values are recorded in the more clayey levels, with the exception of the very superficial level.

For this reason, also for the organic matter and biogenic silica, the core 137CC can be divided into three parts:
– from 0-73 cm there is a decreasing trend probably due to a higher productivity in the upper part;
– from 73-300 cm the trend is less regular with alternance of coarser and finer levels;
– from 300-406 cm the values are more constant around 5%.

The carbonate content varies from 3.14% to 10.21% and the trend is different to that of organic matter and biogenic silica content, except for the basal level, where the the values are decreasing. The relative maximum values are recorded where the gravel content is higher.

Core 99C2 can be divided into two sections (0-28 and 42-103 cm), separated by two coarse layers at 28-32 centimeters (muddy-sandy gravel) and 32-34 (gravelly-muddy sand) (fig. 5). The upper layer is silty sand and the second layer is silt and sandy silt.

Water content decreases with depth, with values less than 50% even in the surface portion, with the exception of the top of the core (98%). In the core 99C2 the content of organic matter, biogenic silica and carbonate is always lower than 7%. The trends of organic matter and biogenic silica are very similar and show variations related to the textural setting, as in the 137CC core. Due to the textural uniformity of the sediment, in the fine fraction is not possible to identify significant variations in these two parameters. The considerable decrease in the values recorded in the basal levels is probably related to the sterility of the sediment.

Geotechnical analyses conducted on cores 99C2 and 137CC (Corradi & *alii*, 1995) were integrated with data from cores C2, C3, C10, C11 C12 and C14. The first results of sedimentological and geotechnical analyses on these last two cores, collected during the XIth Expedition, indicated extremely variable textural characteristics. C2 and C3 were collected in the Southern Joides Basin, and are basically composed of sandy mud and mud, with the fine component predominating, while C10 and C14 (Northern Joides Basin) are predominantly sand in the top layers, followed by an increase of the fine fraction toward the bottom.

The Undrained Shear Strength values were directly measured on board with a pocket scissometer on all the cores. They are very low in the superficial levels (0-1.5 kPa) while in the basal levels they seemed tobe around the normal-over consolidated limit. Only the 137CC and the 99C2 cores were measured in laboratory with a Vane test and they show values of up to 30 kPa (99C2 bottom). The unit weight values show an increasing trend with depth up to values of 1.23 g/cmc (C3) and 1.70 g/cmc (99C2) for the wet unit weight and of 0.5 g/cmc (C3) and 1.36 g/cmc (99C2) for the dry unit weight.

The plasticity chart shows that the cores collected in 1996 are characterized by a sediment that can be classified (Casagrande 1948) as low to medium plasticity clay and inorganic silt. When considered in relation to the values measured in core 99C2, the hypothesis is overloaded sediments (fig. 6).

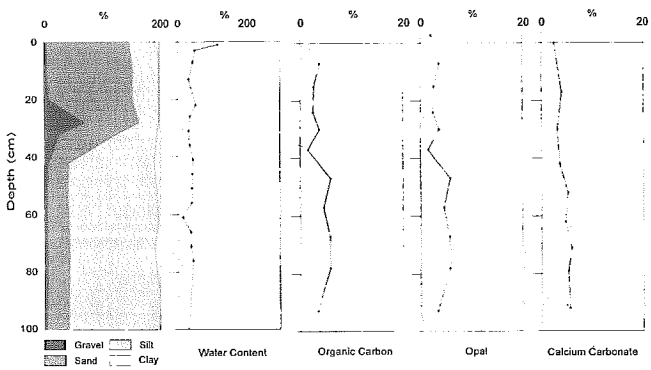

FIG. 5 - Textural and compositional log of the 99C2 core.

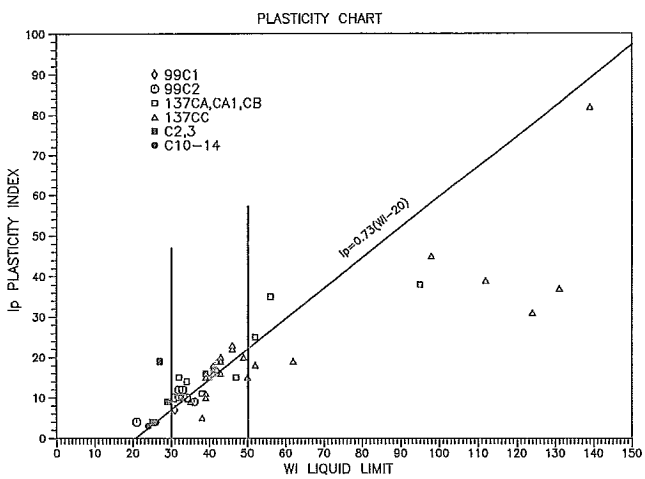

FIG. 6 - Plasticity chart relative to the geotechnical analyses.

CONCLUSIONS

The seismic surveys conducted during Pnra expeditions, considered alongside published material, have revealed the superficial seismostratigraphy and made it possible to identify sites characterized by expanded or condensed sedimentary series to correlate with the action of ice sheets on the Ross Sea continental shelf. High resolution seismic profiles (Sbp) have also indicated the characteristics of the sedimentation, differentiating pelagic sediments from glaciomarine sediments and basal till. This made it possible to identify the sampling sites, where the erosion surface of the Lgm is close to the sea bottom.

Sedimentological analyses enabledus to identify two sites with different depositional characteristics. In particular core 137CC, collected in the central Joides Basin where the surface layer of pelagic sediment (diatomaceous mud/ooze) and the underlying glaciomarine layer (diamicton) are best represented, revealed in good detail the sedimentation characteristics already indicated by seismostratigraphic analysis. Core 99C2 is composed of a condensed sedimentary series, almost entirely from glaciomarine sediment. In the basal portion, the sediments present low water content (<25%), high undrained shear strength (>10%), overconsolidation characteristics and mainly sterile reworked sediments so that we can refer them to a basal till that, in relation to the considerations of Lee & *alii* (1981) and Edwards & *alii* (1987), has been subject to a load of 76 metres of excess ice thickness or 32 metres sediment thickness, assuming that the sea level had gone down by 120 metres.

It is not yet clear how much the Ice Sheet on the western Ross sea continental shelf has advanced, and the many existing hypotheses confirm the complexity of the question. Marine sediments, for example, provided bad information because of the scarcity of good material on which it is possible to carry out radiometric datings and of the difficulty in distinguishing subglacial deposits from that proximal to the glacier line. In fact they have very similar characteristics.

As a consequence, their interpretation gave rise to different hypotheses, showing the ice sheet at very different positions: very similar to the present (Drewry, 1979), immediately south to Coulman Island (Licht & *alii*, 1996) or close to the continental shelf break (Thomas & Bentley, 1978; Stuiver & *alii*, 1981; Shipp & anderson, 1994). Probably, analogously to the situation present in similar environments nowadays, the extreme complexity of ice shelf geometry and the irregular position of the ice grounding line justify these apparently discordant results. In fact, these data were obtained from samples that represent only a single reality.

The preliminary results of the gravity cores collected during the XIth Italian Antarctic Expedition concur with the hypothesis of sediments overconsolidated by the action of the ice sheets. They also allow us to confirm additional sites in the Northern Joides Basin where the ice sheets were grounded during the Lgm.

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