Past global changes investigated by drilling Mediterranean continental margins

Between June, 24th and July, 22nd, 2004, a team of European scientists embarked from Brindisi (Italy) to Barcelona (Spain) onboard the Russian vessel "Bavenit", operated by the Dutch geotechnical company FUGRO, for a drilling expedition in the Adriatic Sea and the NW Mediterranean Sea.

The purpose of this cruise was to collect, for the first time, long (up to 300 m) sediment sections and in situ measurements from two deltaic margins where the history of global changes during the last ca. 500,000 years is particularly well preserved. The project, named PROMESS 1 (PROfiles across MEditerranean Sedimentary Systems), is supported by the European Community within its 5th Framework Programme (FPV). Through FPV, European scientists may have access to Large Research Infrastructures such as drilling vessels, not accessible to any single country or institute.

PROMESS 1 general objectives

So far, very few projects explored the record of global changes on continental shelves and upper slopes, because vessels available to the scientific community were mainly designed for deep sea drilling. PROMESS 1 has three major complementary objectives:

- The reconstruction of sea-level and climate changes during the last 500,000 years. Such reconstructions have been based, mainly, on coral reef studies and the analysis of isotope ratios in foraminifers from deep-sea sediments. Because of the very high sedimentation rates (> 1m/1000 yr on average) of the studied areas, PROMESS 1 scientists will have access to very high resolution record of global changes. It is expected, in particular, to identify rapid climate changes and their impact on sedimentary environments. Dating buried shorelines will permit to determine the position of sea-level during glacial periods.

- The analysis of the impact of global changes on slope stability, and the quantification of slope processes by in situ measurements of physical parameters in zones prone to failure, or where slides already occurred. This approach is applied to zones situated at the edge of the continental shelf where canyons form, and where avalanches are triggered during glacial periods. It also applies to the

inner continental shelf in the Adriatic, where a thick (35 m) wedge of unconsolidated sediments accumulated during the last ca 12,000 years.

- The understanding of the processes that form strata on continental margins, in relation with sea-level and climate changes, instabilities and oceanic processes, and the recent tectonic activity of the Earth. This will provide clues to “sequence stratigraphy”, a method of interpretation of geophysical and sedimentological data utilized by exploration geologists from the oil industry. The impact on strata of major past events (tsunamis, volcanic eruptions, earthquakes, major storms) will be evaluated.

These objectives are not only interesting for the sake of knowledge, but help understanding the Earth state and envisaging future scenarios to be taken into account by policy- and decision-makers. Sediment stability in continental shelf areas offshore densely inhabited coastlines is also an issue that deserves better constrained studies. An additional purpose is to help understanding how sandy deposits formed during the Quaternary (a period which is very well known compared to older geological time intervals), in order to better predict their occurrence in the deep offshore, where they represent important oil and gas reservoirs.

The Quaternary is the most recent period of Earth history and accounts for the last ca. 1.5 million years. During the second half of this period, the Earth experienced dramatic climate changes, likely linked to variations of the solar radiation. One of the most striking climatic changes at a relatively long time scale is that of glaciations, which occurred every ca 100,000 years. During the last glaciation, ca. 21,000-18,000 years ago, a large percentage of the Earth’s surface water was trapped in ice caps, and consequently the world ocean level was globally about 120 m lower than today. Then, as the Earth was entering a warm interglacial period, the sea level rose to the present sea level between ca. 17,000 and 6,000 years ago (the deglacial period), and reached the present position about 6,000 years ago.

The cycle of glaciations has been repeated several times, with long phases (several tens of thousands of years) of cooling temperatures and growing of ice caps, followed by short (few thousands of years) full glacial conditions, rapid (few thousands of years) warming conditions with fast ice cap melting and short (few thousands of years) interglacial periods

with temperatures and sea levels at maximum values, similar to today. During each glacial maxima, the shorelines were situated at 10s to 100s of km from the present coastline and rivers such as the Rhone and the Po, fed by sediments eroded by Alpine glaciers, formed large subaqueous deltas at the edge of continental shelves. Similar to fresh snow in the mountains, these accumulations were unstable, and submarine avalanches periodically swept continental slopes, carving canyons and accumulating sediments in the abyssal plain, such as the Rhône deep-sea fan.

During the last deglaciation, melting glaciers also provided a lot of sediment to the sea, mainly accumulated close to the present coastal area.

A huge database of seismic profiles was accumulated in the Adriatic and the Gulf of Lions during the recent years, allowing to map in three dimensions the sedimentary units formed during each of these climatic cycles. However, the longest core for ground-truthing the interpretation of these seismic images was 22 m in length. PROMESS 1 is one of the few opportunities for having access to expanded records of past global changes on continental margins, and to understand processes that trigger slope instabilities.

European scientists on the drilling vessel Bavenit

PROMESS 1 required more than one year of preparation. First, detailed specifications, including the scientific and technological needs of the project, as well as safety and environmental issues, were included into an European call-for-tender. After proposal evaluation, FUGRO BEV was selected in December, 2003 as PROMESS 1 contractor for sea-going operations. FUGRO owns or contract drilling vessels specialized in soil foundation studies for the offshore oil industry. The vessel utilized for PROMESS 1, SRV “Bavenit” belongs to the Russian company AMIGE. “Bavenit” is equipped with a 35 m-high derrick, a Dynamic Positioning system for maintaining the vessel vertically above the borehole, and a system for compensating the effect of heave on the drill pipe.

Several meetings between the partners of PROMESS 1 and the engineers of FUGRO were necessary to prepare this relatively unusual operation. During surveys for the industry, only one representative of the client generally embarks, whereas it was necessary for PROMESS to embark a party of 14 scientists. This group had to go through special training required by the offshore industry including Basic Offshore Safety Induction and Emergency Training. They carried out several tasks onboard (Table 1).

Task	Description
Geotechnical tests	pre-processing of in situ geotechnical tests carried out by FUGRO engineers
Downhole logging	Several sensors, measuring various physical and chemical parameters of the strata, are successively lowered in the open hole, after pulling up the steel drilling pipe. The data are pre-processed onboard after acquisition.
Sediment coring	Recovery of a continuous section of sediment contained into a plastic liner (called a core) that has been pushed into the strata
Physical properties	Measurement of physical properties of cores (density, magnetic susceptibility, sonic velocity), using a multi-sensor core logging equipment. This equipment was installed in a dedicated container that was set on the ship for the purpose of the cruise.
Bio-stratigraphy	Preliminary analysis of micro-fauna in samples taken every 80 cm in order to obtain a first estimate of ages of strata and environmental changes.
Storing	Storing of sediment cores in a refrigerated container, allowing further geochemical analyses at a later date. Organic components, in particular, are sensitive to temperature changes. Therefore, the cores are stored at a constant temperature of 4°C on the ship, and during transportation to Ifremer in Brest. After core analysis and sampling, the remaining fractions will be archived at University of Bremen.
Data management	All data and information have to be stored into a data base, with proper geographical position, corrected position with respect of the sea-floor and sea-surface. After the cruise, these data will be integrated into the PANGAEA data base at University of Bremen.

Table 1: Main tasks carried out during PROMESS 1.

In the Adriatic, two boreholes were drilled at the first site PRAD1 (water depth 184 m), where the objective was to study the record of the last four glacial cycles (about 400 kyr). A

pilot hole (without core recovery) was first drilled for assessing the risk of shallow gases, a downhole logging was carried out in this borehole. A second site allowed continuous coring to the targeted depth (71m below sea-floor) with excellent recovery (better than 95%). Very preliminary interpretation indicates that seismic sequences previously identified correspond to 100,00 years glacial cycles. Downhole logging and physical properties of cores allow to identify magnetic events, and layers formed by volcanic eruptions. The second site (PRAD2) was devoted to the study of the recent most sediments (last 12,000 yrs) near the coastline, at a water depth of 56m. The targeted depth was 32 m below sea floor, sufficient to obtain a good record for the last ca 12,000 years. All together, six boreholes were drilled at PRAD2, including a pilot hole, a hole for continuous sediment recovery, and additional holes for in situ geotechnical tests and sampling. One of the objectives of these tests is to determine whether the wavy features shaping the sedimentary sequences are caused by near-bottom currents or result from liquefaction of unstable sediments triggered by earthquakes or storms.

After 5 days of sailing, the first site in the Gulf of Lions was reached on July, 7th. The water depth at this site was 298 m, and the targeted depth below sea floor was also 300 m, allowing to reach an expected age of about 430,000 years before present. A pilot hole was drilled down to 310 mbsf, and logged. Two geotechnical boreholes were drilled, allowing tests and measurements to a depth of 150mbsf. Another borehole was drilled for continuous coring to the depth of 300 mbsf, which represents the deepest depth below sea floor ever reached by the "Bavenit". The recovery was excellent (>95%). Preliminary estimations of coccolithophore assemblages provides a general time-frame for this site. Marine isotope stage (MIS) 12 was reached at the bottom of the hole. We have also good estimates of the position of the intervals corresponding to MIS 2-3, MIS 4, MIS 5a-d, and the transition between MIS 8 and 7. This shows that, as in the Adriatic Sea, seismic bounding surfaces are linked to 100 kyr-glacial-interglacial cycles, that modify lithology and sedimentation rates on the upper slope. The presence of coarser sediment at the end of each "forced regression" (sedimentary sequence formed during sea-level fall), and the occurrence of some biogenic gas, trapped by the overlying clayey sediments deposited during the ensuing warm period, is likely at the origin of seismic anomalies. On July, 18th, operations started at site PRGL2. This site is at 103 m water depth, in area where the shorelines that deposited during the glacial periods are the best preserved, and can be used as a "dipstick" of past sea-levels. The objective was to sample shoreline/shoreface deposits that formed during the last ca 500 kyr, down to 100 m below sea-floor. A CPTU borehole was first drilled (PRGL2-1), followed by a sampling borehole (PRGL2-2). As expected, many sandy intervals were encountered, but the overall

recovery was however quite good, in the order of 82%. Gamma ray downhole logging was performed in the drill pipe afterward. On July 21st, operations were finished and the SRV "Bavenit" sailed toward Barcelona, the port of demobilisation of PROMESS 1.

Europe within the Integrated Ocean Drilling Programme

Offshore drilling is an expensive operation that is mainly undertaken by the offshore industry for exploration and recovery of oil and gas. One remarkable exception was, since the 60s, the scientific Deep Sea Drilling Programme (DSDP), followed by the Ocean Drilling Programme (ODP), which became the Integrated Ocean Drilling Programme (IODP) in 2004. IODP aims at providing to the international scientific community drilling platforms that have the capability to drill in different settings, in terms of water depth and penetration below sea floor, in order to address questions related for example to global changes, generation of earthquakes in seismogenic zones, and deep biosphere. The European Community decided to join this international effort by providing "mission specific platforms", that is to say drilling vessels or other platforms to objectives that cannot be attempted by the Joides Resolution (an American vessel utilized by the ODP) and the new Japanese vessel "Chikyu", that will start deep drilling operations in 2006. Such "mission specific platforms" may include jack up rigs for deep penetration in shallow waters, barges for drilling coral reefs, and geotechnical vessels. PROMESS 1 was considered by the EC as a test for organizing such an operation with the industry in preparation to its participation to IODP.

During the preparation phase of PROMESS 1, IODP provided support through its "Pollution Prevention and Safety Panel" by giving advice about the risks for shallow gases (that accumulate in sediments rich in organic matter and may represent a risk when they are drilled through).

Conclusion

PROMESS 1 demonstrates the feasibility of conducting a research project, involving a relatively large scientific group, on a vessel from the offshore industry. Despite limited space available onboard "SRV Bavenit", all tasks that cannot be delayed for onshore processing were carried out without major problem. It is the first time that such a large data set of sediment archives is collected from shelf and upper slope sequences. Preliminary analysis onboard indicates that the objectives will be reached. The collected data will allow calibration of geophysical data already available, paleoclimatic reconstructions, and future experiments

for testing new equipments. The cruise was, for most scientists, especially the young PhDs and post-docs, an unique opportunity to share the experience and life of engineers and technicians from FUGRO, who are working at sea with the industry. The cruise will certainly also strengthen the links between the laboratories and individuals (from 7 European countries) involved in the project. The very experienced Russian crew and drillers made the project a success, their hospitality and friendship will leave only life long memories.

The PROMESS 1 shipboard party: Serge Berné (Ifremer Brest, chief scientist), **Miquel Canals** (Univ. Barcelona, drilling supervision), **Antonio Cattaneo** (CNR-ISMAR Bologna, Adriatic sites and sedimentology), **Elena Colmenero** (Univ. Salamanca, biostratigraphy), **Gilbert Floch** (Ifremer Brest, physical properties), **Bernard Dennielou** (Ifremer Brest, physical properties), **Jaume Frigola**, (U. Barcelona, geotechnics), **Ralf Gelfort** (GGA Hannover, downhole logging), **José Gravalosa** (Un. Salamanca, Biostratigraphy), **Domenico Ridente** (CNR-ISMAR Bologna, Adriatic sites and sedimentology), **Tina Schoolmeester** (GGA Hannover, downhole logging), **Nabil Sultan** (Ifremer Brest, geotechnics), Graham Tulloch (BGS Edinburgh, drilling supervision), **Hans-Joachim Wallrabe-Adams** (Univ. Bremen, data management)

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