The Impact of Quaternary Global Changes on Strata Formation

Exploration of the Shelf Edge in the Northwest Mediterranean Sea

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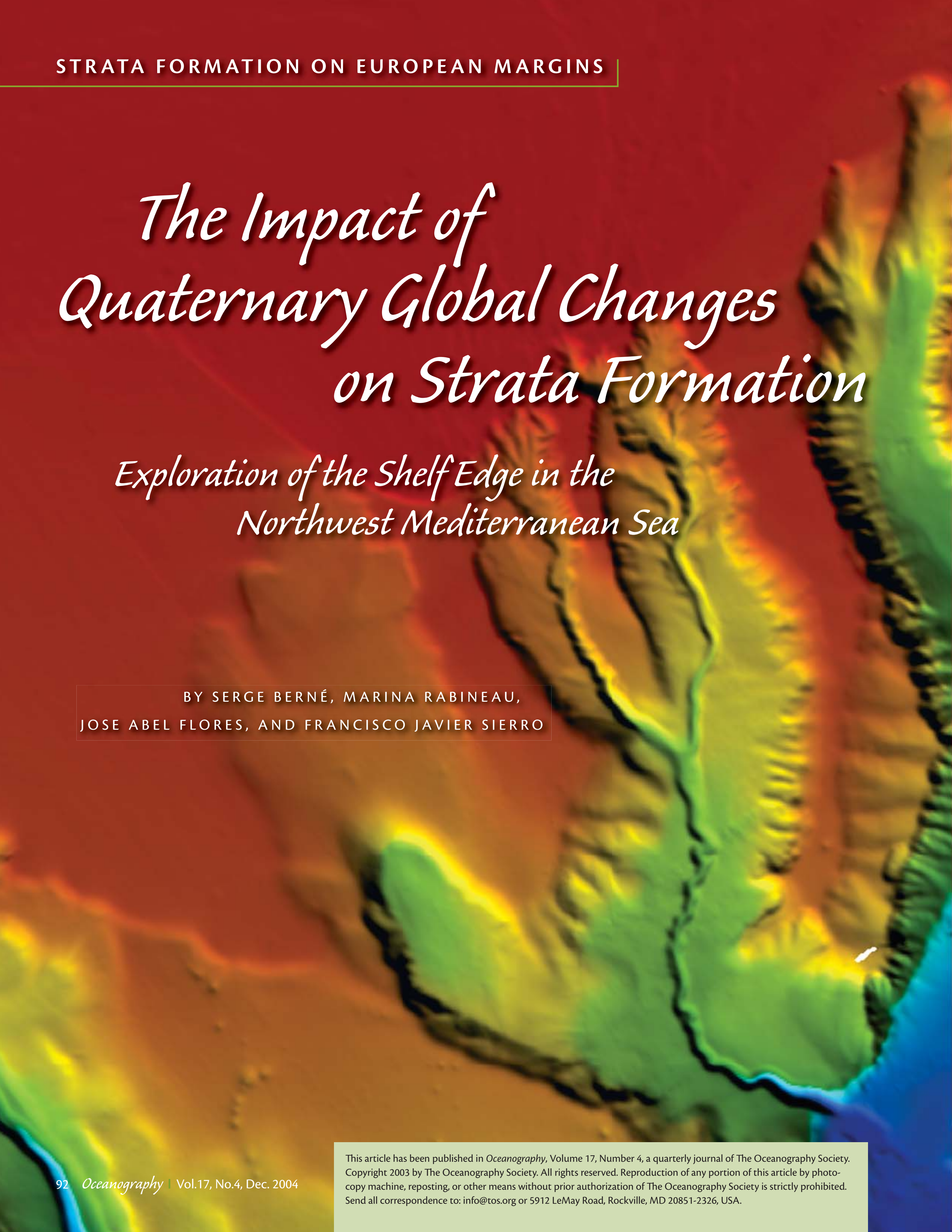

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INTRODUCTION

Paleoceanographic and marine paleoclimatic investigations commonly use deep, open-ocean sediments or coral reefs to establish a continuous record of past global environmental changes because they both contain living organisms that are very sensitive to climate variations. Foraminifera (microorganisms with calcium carbonate shells) in particular are very sensitive to changes in temperature and chemical composition of the ocean. When conditions change, the organisms die, fall to the bottom of the sea, and become encased in sediments, therefore fossilizing information on past conditions. Continental margin records are more difficult to study than open-ocean records because continental margins are the receptacles of large amounts of sand, silt, and clay that dilute the microfossil concentration in the sediment. In addition, sea-level oscillations during the Quaternary exposed a large portion of shelves to continental erosion. Continental margins are therefore the subject of intense reworking by subaerial and submarine erosion. Thus, unlike deep, open-ocean records, sedimentary records from continental margins are often discontinuous, and deposits can be subject to post-depositional reworking by sedimentary processes.

Sedimentary successions from deltaic margins with sedimentation rates in excess of 1 m/kyr (with "instantaneous" sedimentation rates in prodeltaic systems reaching values of ca. 1 m/yr), however, offer unequalled records of rapid changes that affected Earth. The architecture of these sedimentary bodies responds to (1) glacio-eustatic sea-level changes, (2) changes in sediment and water fluxes from the continental domains, and (3) vertical movement of the margins that controls the space available for deposition and therefore the distribution and preservation of sediments. If we can disentangle local from global factors, we could have access to ultra-high-resolution sedimentary records of specific time frames as they were recorded across continental margins fed by continental erosion. This requires the combined use of (1) geological, geophysical, and sedimentological investigations in order to reconstruct a regional framework of the margin, and (2) detailed multidisciplinary analysis of long sediment cores that provide archives of past environmental changes.

This novel approach is being employed in the shelf-edge area of the Gulf of Lions (Northwest Mediterranean Sea), which is a favorable environment for preservation of rapid sea-level and climatic changes.

SEQUENCE STRATIGRAPHY AND HIGH-RESOLUTION SEQUENCE STRATIGRAPHY

Sequence stratigraphy is the subdivision of sedimentary-basin fills into small-scale packages bounded by discontinuities (surfaces that represent a change in the sedimentation regime, and/or erosion). In its most commonly accepted version, sequence stratigraphy is based on the concept that the formation of those sedimentary sequences is related to relative sea-level changes (Posamentier et al., 1988). It has its roots in the principles of seismic stratigraphy based on the analysis of strata geometries as seen on seismic profiles, which provide a vertical image of Earth's sediments and surfaces. This tool was developed in the 1970s by Peter Vail and his colleagues at Exxon Production Research Company (Vail et al., 1977). The question of whether these relative sea-level changes are induced by global eustasy (a uniform worldwide change in sea level), tectonism, or a combination of several factors remains a matter of controversy (Miall and Miall, 2001).

Initially, seismic and sequence stratigraphy were designed to interpret sequences with a resolution of several tens of meters that broadly correspond to 0.5 to 3 million year sequences. Later, similar concepts were adapted to the recognition of higher-frequency cycles (0.1-0.5 and <0.1 million year cycles) on outcrops, in well data, or on high-resolution seismic profiles from Quaternary continental margins. However, the application of sequence stratigraphic concepts to such deposits is questionable because these concepts are very sensitive to processes other than relative sea-level changes. For instance, the abrupt shift of deltaic lobes may create depositional architectures that mimic that of sequences formed by abrupt sea-level rise.

SEA-LEVEL CHANGES DURING THE QUATERNARY

In terms of unraveling the relative influence of "global" (sea-level) effects from that of local (sometimes called autogenic) processes, the Quaternary (about 2 million years ago [Ma] to present) has several advantages. First, relatively precise sea-level curves have been established, based on analysis of deep foraminifera oxygen isotope records or coral reef studies (see below). Second, precise dating methods exist, allowing correlation of sedimentary units with these events. In addition, detailed mapping techniques (swath bathymetry, high-resolution seismics) provide a three-dimensional view of continental margins that is much more accurate than that of conventional seismic exploration. They allow imaging of sedimentary bodies and sequences only few meters thick and mapping at regional scales in order to determine their overall significance.

The oxygen isotope data from deep-sea foraminifera provide a time-averaged record of deep-sea temperature and continental ice volume (the oxygen isotope ratio increases with the amount of ice on the poles). These data show that the transition to the "icehouse world" started with an overall cooling during the early Oligocene (around 32 Ma) with the initiation of Antarctic ice sheets, followed by a more pronounced cooling starting during the Pliocene around 3.2 Ma, related to northern hemisphere glaciation (Zachos et al., 2001). During the Quaternary, climate is characterized by important cyclic variations that are linked to modifications of Earth's orbit and axis tilting. These "Milankovitch cycles" are about 400, 100, 40, and 20 kyr (thousands of years) duration. To a first approximation, the oxygen isotope record gives a history of global continental ice volume, which allows calculation of the glacio-eustatic component of sea-level change. However, because the mean oxygen isotope ratio of the ocean is also affected by changes in deep-water temperature, the curves should be calibrated by independent measurements of sea-level position, as was done for the last sea-level rise by combining isotopic sea-level records and dated coral reefs (Figure 1). Despite the fact that the absolute value of sea level during glacial maxima (Clark and Mix, 2002) and some other time intervals is still debated, these curves are much more precise than those established from sequence stratigraphic interpretation (Haq et al., 1988) or composite oxygen isotope records (Abreu and Anderson, 1998) for older periods of the stratigraphic record. Therefore, the Quaternary can be used for testing some of the concepts of sequence stratigraphy, especially for high-resolution sequences that correspond to durations on the order of Milankovitch cycles.

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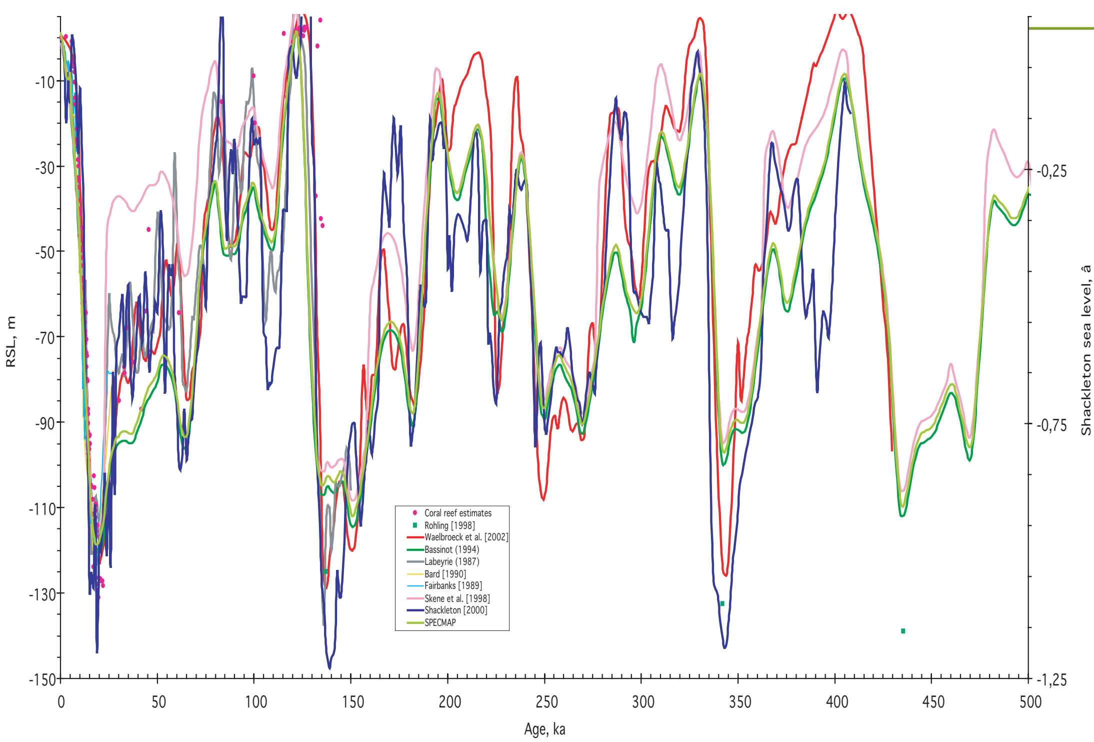

Figure 1. Compilation of relative sea-level curves for the last 500 kyr, based on isotopic studies, coral reef studies, or interpretation of paleo-delta fronts. The right axis represents the mean ocean $\delta^{18}O$ (oxygen isotope ratio) derived by Shackleton (2000) from atmospheric $\delta^{18}O$. This figure shows 100 kyr cycles (eccentricity) are dominant, inducing global sea-level changes on the order of 100 m. However, obliquity (40 kyr) and precession (20 kyr) cycles also induce sea-level changes of several tenths of a meter. Note the important difference between various curves during Marine Isotope Stage 3 (30 to 60 kyr brink point [BP]) (Jouet, 2003).

SEA-LEVEL CHANGES RECORDED IN CONTINENTAL MARGIN SUCCESSIONS: THE NORTHWEST MEDITERRANEAN SEA AS AN EXAMPLE

During the last ca (circa) 500 kyr, sea level has been oscillating between its present position and about 100 m below present sea level. Because the shelf edge is generally located between 100 and 200 m water depth, a large portion of continental shelves were exposed during glacial periods. As a result, the stratigraphic record displays major erosional surfaces that are the result of both continental erosion and shallow marine erosion during sea-level fall, lowstand, and sea-level rise. But margins are also the objects of vertical motion (i.e., subsidence). After deposition, the substratum of passive margins is moving down so that space is created above it, which enables new sequences to be deposited. If the rate of subsidence is low, shelf sediments will be reworked during each glacial/interglacial cycle, with only the ultimate glacial/interglacial sequence being preserved. On subsiding margins, shelf sequences can be preserved, providing that wave energy is not too high and/or that the rate of sea-level rise is fast enough to leave sediments in place. These conditions are encountered in the Gulf of Lions in the Northwest Mediterranean Sea (Figure 2). In addition, the Gulf of Lions is a passive margin where tectonic effects are minimal (no faults and no rapid movement occur; the margin evolves quietly in relation to the progressive cooling of the substratum) during the last five million years, and it is also situated sufficiently far from the former margins of the major ice sheets for sea level to follow global eustatic changes to a first approximation (Lambeck and Bard, 2000). The shelf, which reaches 70 km in width (a rather large dimension compared to other Mediterranean margins), is fed by the

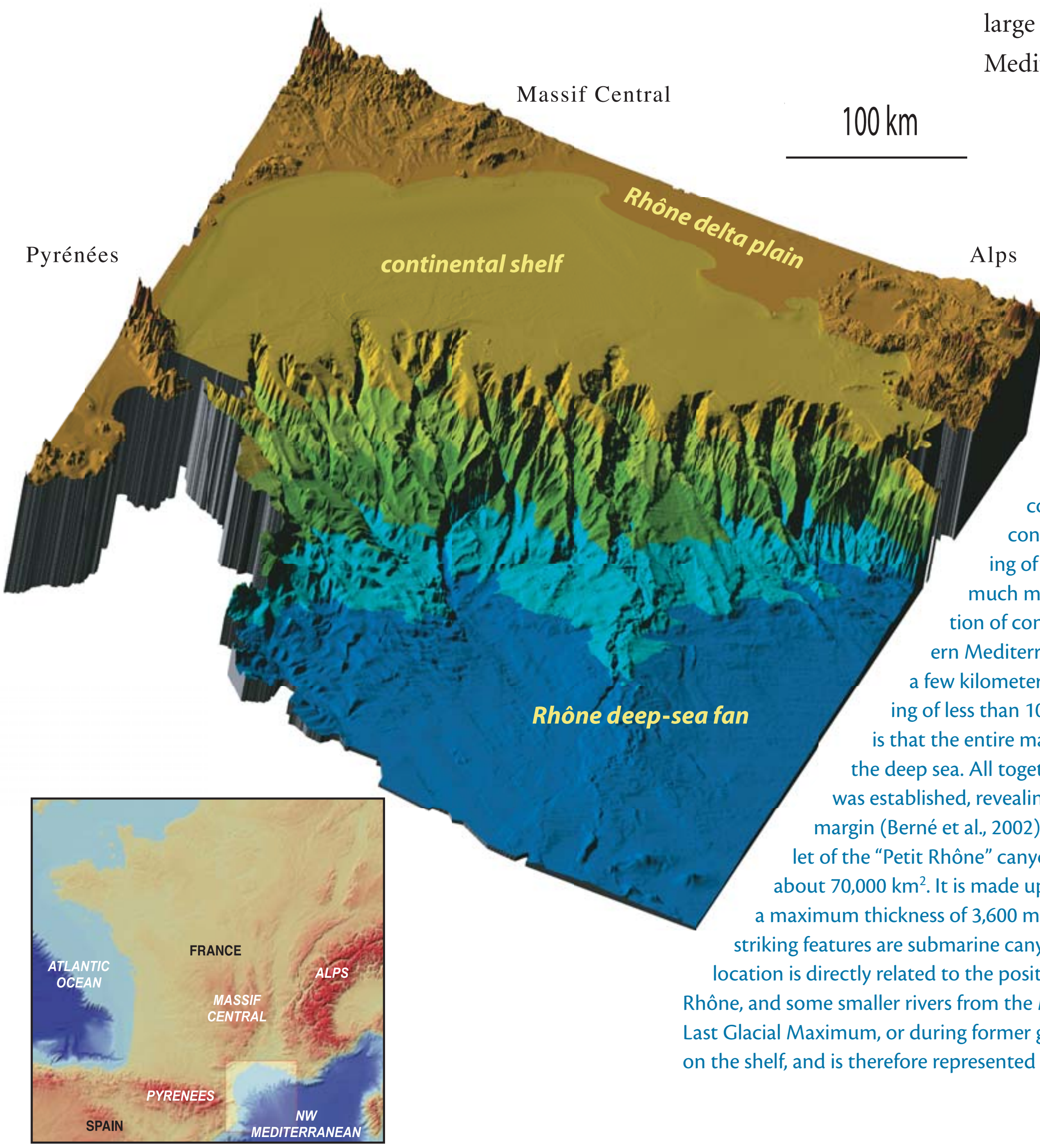

Figure 2. Three-dimensional view of the Gulf of Lions continental margin. Depths range from 0 to 2500 m. A paradox of marine sciences is that, nowadays, the morphology of the deepest part of most continental margins is better known than the continental shelves. This is due to the functioning of swath bathymetric systems, which produce much more data in deeper water depths. Investigation of continental rises at 2000 m depth (in the western Mediterranean Sea) only requires track lines spaced a few kilometers apart, whereas the inner shelf needs spacing of less than 100 m. A great advantage of the Gulf of Lions is that the entire margin is well mapped, from the coastline to the deep sea. All together, a detailed digital terrain model (DTM) was established, revealing the key morphological elements of the margin (Berné et al., 2002). The Rhône deep-sea fan forms at the outlet of the "Petit Rhône" canyon. This major sedimentary body covers about 70,000 km^2. It is made up of Plio-Quaternary sediments that reach a maximum thickness of 3,600 m in the central fan (Droz, 1983). The most striking features are submarine canyons, some of them as deep as 800 m. Their location is directly related to the position of rivers (different distributaries of the Rhône, and some smaller rivers from the Massif Central and the Pyrénées) during the Last Glacial Maximum, or during former glacial periods. The relief is much smoother on the shelf, and is therefore represented on a close-up view in Figure 3.

Rhône, a major river that mainly originates from the western Alps. All together, these conditions make this area an ideal target for exploring the impact of sea-level changes on depositional architecture, from the shoreline to the abyss.

Morphology as a Key to Understanding the Last Glacial/Interglacial Cycle

A first approach to the record of recent sea-level changes is to look at the morphology of zones that were affected by sea-level oscillations during the last glacial cycle, namely the continental shelf between 0 and 150 m. From this point of view, the Gulf of Lions displays a particularly interesting landscape, because of the large amount of sediment delivered by the Rhône River and because of the relatively moderate energy conditions, allowing preservation of morphologies during shelf flooding. A striking feature is the step that can be tracked along the entire outer continental shelf between 98 and 120 m below sea level. It forms a 10 to 20 m high relief where the slope is on the order of 4 degrees, instead of about 0.15 degrees for the general slope of the outer continental shelf (Figures 3 and 4). This relief corresponds either to the seaward limit of the shoreline, with sands deposited during the last sea-level fall between Marine Isotope Stage 3 and the Last Glacial Maximum (LGM, around 20 ka [thousands of years ago]), or to an erosional wave-cut notch formed during an early phase of sea-level stabilization at the onset of deglaciation and sea-level rise. The morphology of these offshore sands is rough because they were exposed to subaerial erosion, sometimes cemented, and subsequently reworked by marine processes into dunes and sand ridges (Berné et al., 1998). Further offshore, sedimentation and morphology were influenced by the relative position between streams and the shelf edge, and by dispersion of sediment plumes by oceanic currents.

In the Gulf of Lions, the slope is cut by numerous submarine canyons. Small-scale meandering axial incisions are observed within the major valley of the canyons at places where there was a direct connection between glacial rivers and canyon heads (Figure 5). These axial incisions are probably generated by very-high-density flows (hyperpycnal flows) that form during floods. They affect most of the canyon course, and trigger lateral slope failures. These very-high-density flows are likely the mechanism by which canyons in the Gulf of Lions form and evolve (Baztan et al., in press). The canyons that are not connected to streams, but instead are situated to the lee of sediment plumes formed at river outlets, are rapidly buried by decantation of fine-grained sediments. Some canyon interfluves, such as the Bourcart/Hérault

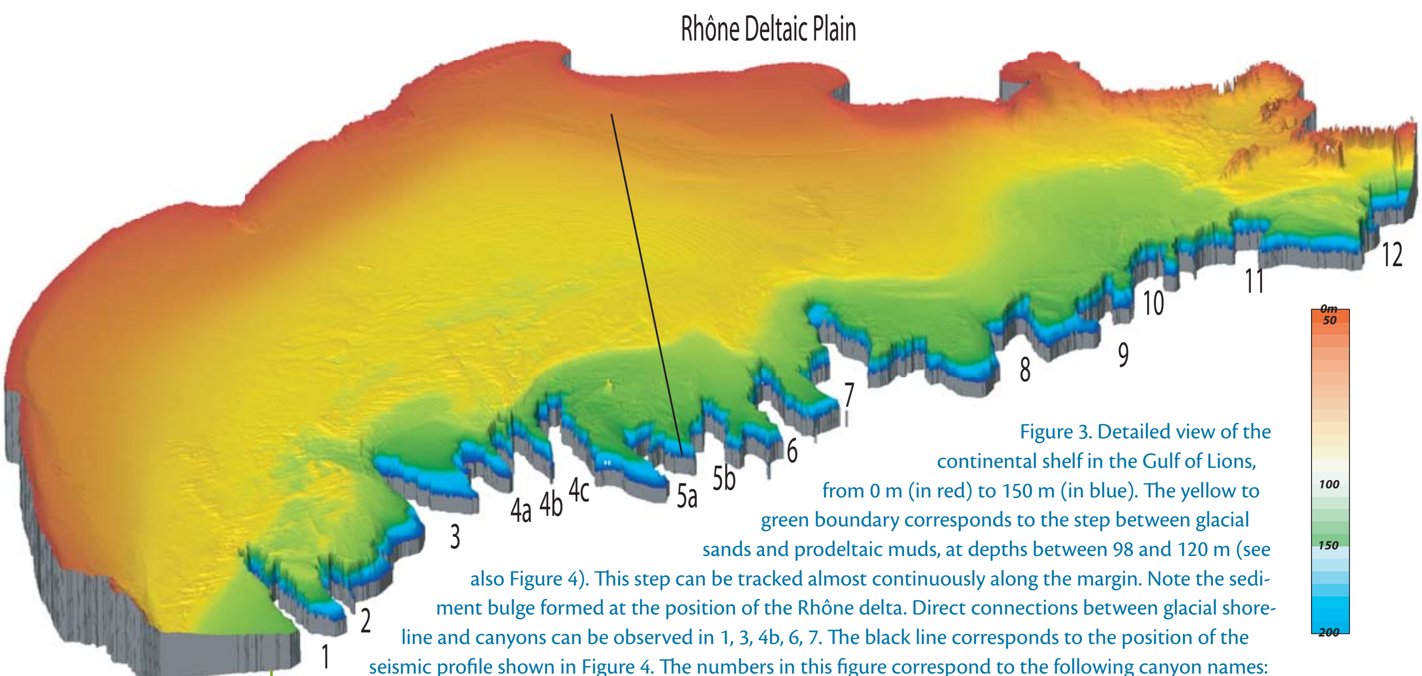

Figure 3. Detailed view of the continental shelf in the Gulf of Lions, from 0 m (in red) to 150 m (in blue). The yellow to green boundary corresponds to the step between glacial sands and prodeltaic muds, at depths between 98 and 120 m (see also Figure 4). This step can be tracked almost continuously along the margin. Note the sediment bulge formed at the position of the Rhône delta. Direct connections between glacial shoreline and canyons can be observed in 1, 3, 4b, 6, 7. The black line corresponds to the position of the seismic profile shown in Figure 4. The numbers in this figure correspond to the following canyon names: 1) Lacaze-Duthiers, 2) Pruvot, 3) Bourcart or Aude; 4a to 4c) Hérault, 5a-b) Sète; 6) Marti; 7) Petit Rhône, 8) Grand Rhône, 9) Estaque, 10) Marseille, 11) Planier, and 12) Cassidaigne.

interfluve (Figure 5), are situated under the mixed influence of sediments coming from the continent (fluvial plume) and from the decantation of marine microorganisms. Because of the very high sedimentation rate and organic-matter content, pockmarks (i.e., circular structures on the seafloor related to gas or fluid escapes) form at the seafloor and are associated with dewatering and/or gas expulsion.

On the inner and middle shelf, the morphology is smoothed by the deposition of fine-grained muds that form a wedge all around the continental shelf at water depths between 0 to about 80 m. This wedge, first described by Aloïsi et al. (1977) as an "epicontinental prism," reaches a thickness of about 50 m and pinches out seaward. It includes sediments formed during the sea-level rise at the end of the last glaciation and ensuing high sea-level stand. Recent studies show that the sea-level rise was not continuous but pulsed, with periods when the rate of rise reached 4 cm/yr (the melt-water pulse 1A described by Fairbanks [1989]), whereas it was less than 3 mm/yr during intervals such as the relatively short, cold Younger Dryas. In response to this slowdown of marine flooding, the Rhône delta resumed progradation and built deltaic sand ridges/prodeltaic mud systems

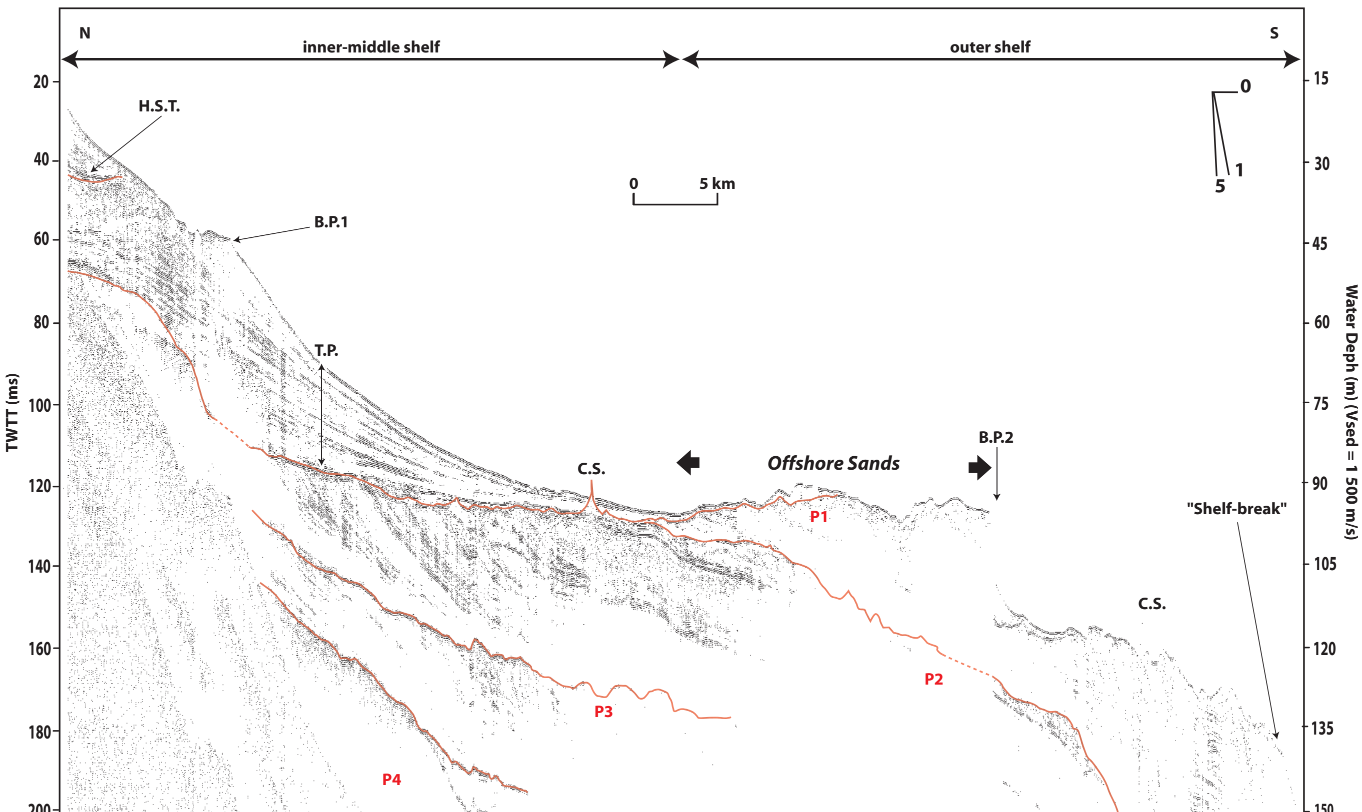

Figure 4. Ultra-high resolution seismic (Chirp) profile across the Gulf of Lions continental shelf. The H.S.T. (Highstand systems tract) corresponds to one of the Rhône deltaic lobes that formed when sea level stabilized at its present position. The T.P. (transgressive parasequence) are deposits formed during a still-stand of sea level. The most landward B.P.1 (brink point 1) corresponds to the position of a former shoreline when sea-level rise slowed down during the overall deglacial sea-level rise. P1, P2, and so on, are forced regressive systems tracts formed during the last Quaternary falling stages of sea level. Early diagenesis of C.S. (cemented sands) in subaerial, intertidal, or submarine settings may result in rocks that will better resist erosion than surrounding loose sediments. Such pinnacles are colonized afterward by calcareous algae and corals. The offshore sands formed during the falling stage of sea level. Their seaward limit is an abrupt step (B.P.2) that reaches 20 m in height. Note that this limit, which roughly corresponds to the position of the sea during the last stabilization of sea level during the glacial period, is about 15 km from the shelf break. On conventional seismic data from the oil industry, the shelf break, identified as the "offlap break," is generally considered as equivalent to the position of sea level. Note the erosional nature of the seafloor beyond the position of sea level during LGM, down to the shelf break (i.e., about 135 m below sea level). This is an illustration of the importance of submarine erosion, an aspect that was generally overlooked by sequence stratigraphers.

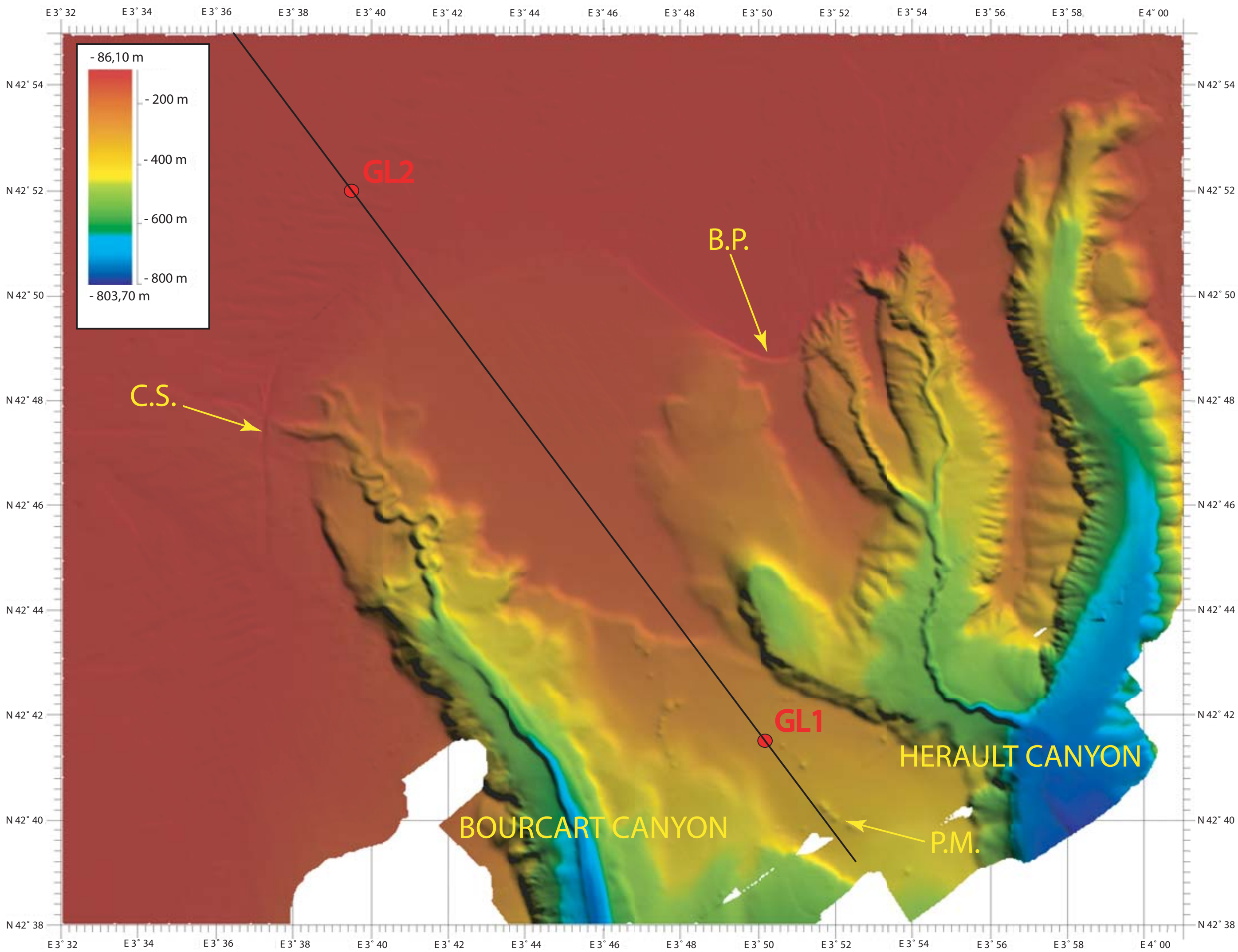

Figure 5. Detailed view of the Bourcart/Herault canyon interfluve. The map is based on swath bathymetric data acquired with Simrad EM 1000 and EM 300 systems onboard the R/V *L'Europe* and *Le Suroît*. A synthetic Digital Terrain Model (DTM) with a grid spacing of 50 m was created from various surveys. The dark line represents the position of seismic profile in Figure 6. Cemented sands (C.S.), pockmarks (P.M.), and brink point (B.P.) represent the seaward limit of the glacial shoreface sands. Note that these shoreface sands and probable glacial rivers reached the canyon head in the Bourcart and Herault 2 canyons. GL1 and GL2 correspond to the position of the PROMESS 1-targeted drill sites. GL1 also corresponds to the position of core MD992348 shown in Figure 9.

that were partly preserved by the ensuing acceleration of sea-level rise (Figure 4).

Buried Shorelines From Former Glacial Periods

The processes that formed isolated sands at the shelf edge during the last glacial cycle acted repeatedly during the last 500 kyr. This was possible because the subsidence rate at the shelf edge approximates the sediment accumulation rate (about 25 m/100 kyr, [Rabineau, 2001]) in the Gulf of Lions. Seismic profiles acquired across the margin show the same motif with two prisms of sediment PI/PII laterally juxtaposed and capped by erosional surfaces (D30, D40, ... shown in Figure 6). These seismic units and surfaces were mapped at the regional scale, and form elongated sediment bodies roughly parallel to the bathymetric contour lines with more than 100 km of lateral extent. Therefore, they are interpreted as sequences formed in response to global sea-level changes, rather than deltaic lobes, whose shape is lobate and whose lateral extent is limited (in the range of a few tens of kilometers for the Holocene Rhône). To estimate the time scales and processes involved in the formation of these sequences, we numerically modeled the observed geometries. The subsidence rates (or the

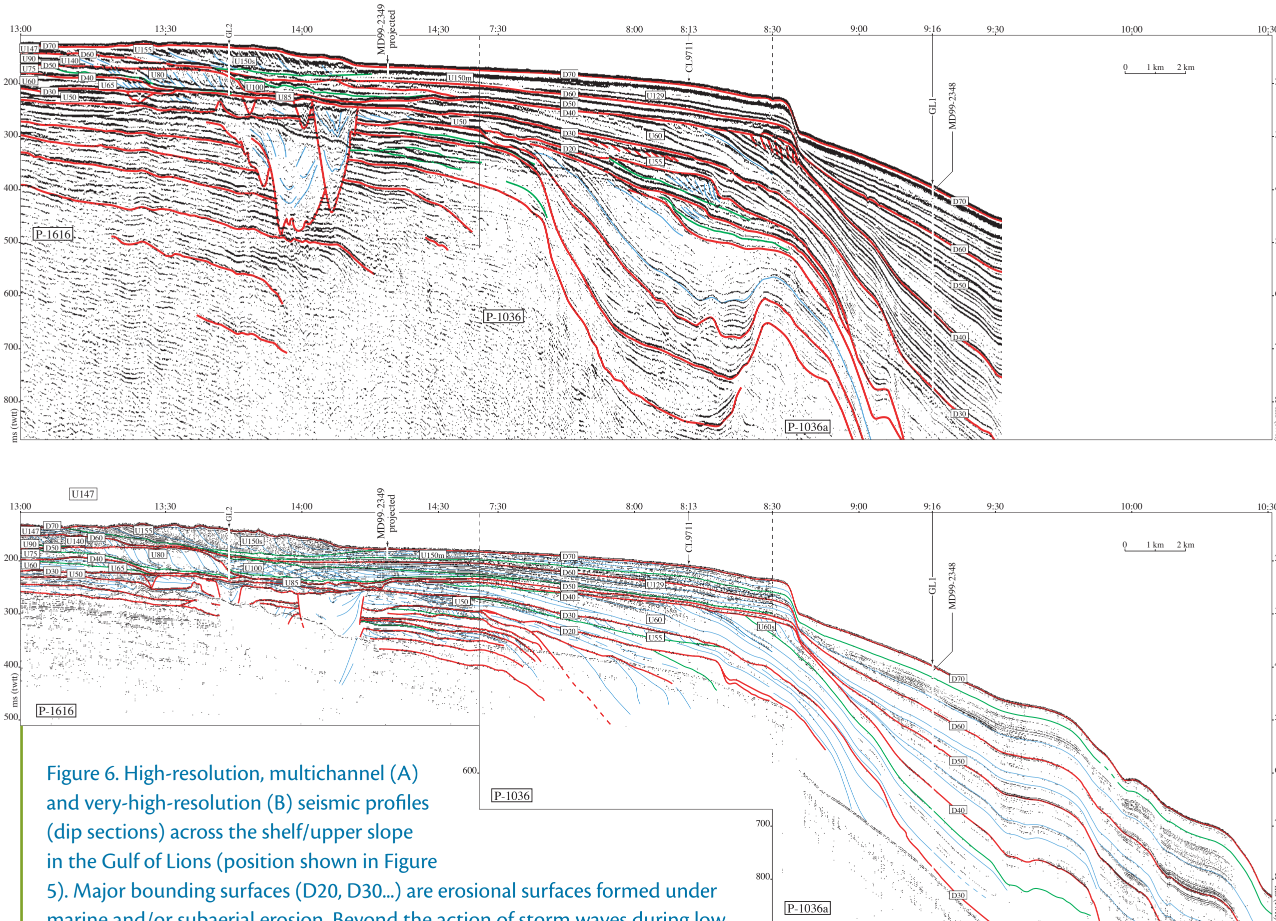

Figure 6. High-resolution, multichannel (A) and very-high-resolution (B) seismic profiles (dip sections) across the shelf/upper slope in the Gulf of Lions (position shown in Figure 5). Major bounding surfaces (D20, D30...) are erosional surfaces formed under marine and/or subaerial erosion. Beyond the action of storm waves during low sea-level periods (about 200 m below present sea level), these major bounding surfaces progressively pass to conformable surfaces (named correlative conformities). Along the upper slope, some of these surfaces are underlined by buried pockmarks, similar to those observed on the seafloor. In-filled canyons, now situated several kilometers landward of the shelf break, demonstrate the overall progradational nature of this shelf. Chronostratigraphic data (for the recent-most 35 ka to 10 ka interval) and stratigraphic modeling (see Figure 8) suggest that discontinuities D30, D40, D50, and D60 correspond to low sea levels of Marine Isotope Stages 12, 10, 8, and 6, respectively (Rabineau, 2001; Rabineau et al., in press). Units with steep internal reflections (named clinoforms) (U150s, U140, U80, U60s) correspond to buried shoreface sands formed during the falling of sea level prior to MIS 2, 6, 8, and 10, respectively. GL1 and GL2 are proposed targets for PROMESS 1 drilling sites.

angle of rotation with respect to a hinge point situated landward) were calculated through the last 5.3 million years (Rabineau, 2001). For this calculation, an erosion surface (5.3 million years old) was used as a well-constrained time line. This erosion surface, clearly identified on seismic profiles, formed as a result of a major drawdown of sea level in the Mediterranean Sea, related to the closing of the Gibraltar Strait at this time. Several sea-level curves, such as those shown in Figure 1, were used for different runs of the model. The main unknown parameter was the sediment flux during the considered interval. By trial and error, it was possible to simulate geometries similar to those observed on seismic profiles (Figure 8).

The simulations demonstrate that the 20 to 30 m thick sequences observed at the shelf edge can in no way be attributed to 40/20 kyr eustatic changes, whatever the sediment flux would be, except by using unrealistic subsidence rates. The stratigraphic modeling also predicts that very few transgressive deposits (those formed during sea-level rise) are preserved on the outer shelf and slope. This is confirmed by piston cores from the slope between two canyons (see below), showing that below about >1 m of recent mud, sediments date back to the LGM—a time when depocenters were in the vicinity of the shelf edge. The imprint of sea-level rise on the outer shelf is mainly represented by elongated sand bodies (transverse dunes or longitudinal sand ridges), with crests roughly orient-

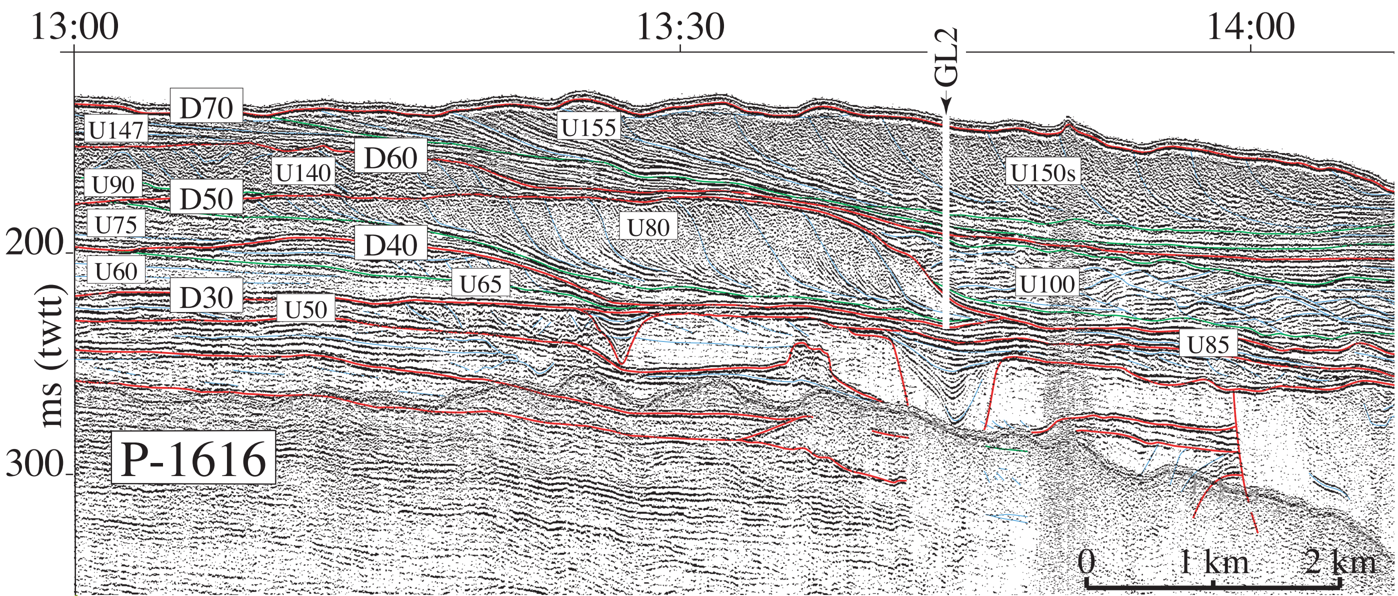

Figure 7. Close-up view of the buried shorefaces (U150s, U140, U80) at the position of the proposed GL2 drillsite. Also note the wavy structure of U100, interpreted as sediment waves created by oceanographic circulation during the time of reduced sea level.

ed East-West, as seen in Figure 5. These bedforms cannibalized the former glacial sandy shorelines. They are also observed along the retreat path of the streams, up to the –80 m isobath, where they are buried under the modern muds.

In summary, the continental shelf in the Gulf of Lions exhibits strong sediment partitioning through time. When sea level is low, sediments are deposited on the outer shelf and upper slope, especially during the falling stage of the sea level; slope failure and direct connection between rivers and canyons allow a large fraction of the sediment to be delivered to the deep basin. When sea level rises, sediments mainly get deposited on the middle/inner shelf. A thick littoral prism of sediment accumulates along the coastline, most of it being eroded during the ensuing sea-level fall. Between the Bourcart-Herault canyons in particular, a thick wedge of fine-grained sediments mixed with hemipelagic sediments accumulated during each glacial period, which were fed by plumes from the Rhône tributaries. In this area, the shelf unconformities can be traced on seismic profiles (Figure 6), probably because of changes in sedimentation rates and/or grain size. They represent time lines, allowing correlation at the margin scale. The zone between 250 and 350 m below present sea level is very favorable for investigating environmental changes at very high-resolution because it is situated beyond the action of storm waves during the low stands of the sea, but above the landslide scars that affect most of the continental slope. It has been the target for giant piston coring, and has been selected for a drilling operation within the European PROfiles across MEditerranean Sedimentary Systems Part 1 (PROMESS 1) project.

The Record of Rapid Climate Changes at the Shelf Edge: Coring the Bourcart-Herault Canyon Interfluve

From the oceanographic point of view, the Gulf of Lions is one of the regions in the Mediterranean where seasonal variations (mainly linked to temperature and wind regime changes) produce important variations in the water column, affecting the western basin. During winter, surface waters become colder and sink with the consequent generation of intermediate (cold and salty) water masses flowing southwards. This situation is reversed during the summer: differences in the gradient provoke a stratification and reduction in the generation of intermediate water masses.

During the latest Pleistocene, particularly during the last glacial/interglacial cycle, studies carried out in the western Mediterranean show important and abrupt changes in oceanic parameters such as sea-surface temperature, oxygenation, and organic nutrients (Cacho et al., 2000), reproducing the alternating seasonal situation observed today. These changes in temperature affected the gradient between water masses, generating drastic environmental changes with a millennial periodicity. The so-called

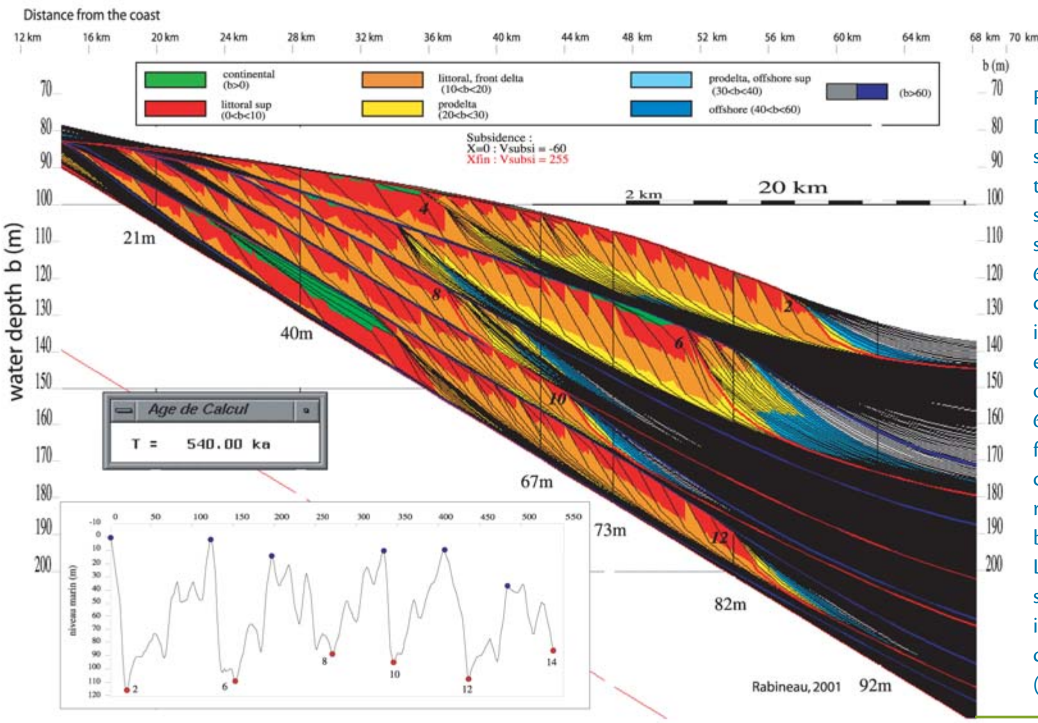

Figure 8. Stratigraphic modeling using DIONISOS software. This image shows shoreface/shelf sequences modeled for the last 540 kyr period, using a constant subsidence rate of 25.5 m/100 kyr at the shelf edge, a constant sediment flux of 6 km3/Myr, and the SPECMAP sea-level curve (Rabineau, 2001; Rabineau et al., in press). The model simulates geometries similar to the actual architecture observed on seismic profiles (see Figures 6 and 7), especially for high-angle clinoform units. A difference is that Holocene offshore muds are much thinner in reality than in the model, and they are bypassed seaward, instead of on-lapping LGM shoreface sands. Numbers within shoreface units correspond to marine isotope stages. DIONISOS software was developed by Institut Francais du Pétrole (Granjeon and Joseph, 1999).

Heinrich Events (HE) are examples of these millennial changes. Although originally observed in the North Atlantic in relation to peaks of IRD (Ice-Rafted Debris, linked to iceberg melting and discharge), these changes can also be identified in Mediterranean sediment cores because of strong variations in (paleo)temperature proxies (Cacho et al., 2002). In addition, between HE, other periodic changes in several paleoceanographic proxies can be observed in both ice cores and marine sediment cores, such as the Dansgaard-Oesschger (DO) cycles (Bond et al., 1993; Dansgaard et al., 1993). These as yet poorly understood events also represent abrupt and relatively rapid changes in temperature and oceanographic parameters and have been differentiated into stadials (cold pulses) and interstadials (warm pulses).

Core MD992348 is 21.5 m long. It was sampled during the IMAGES 5 cruise on the *Marion Dufresne*, at 296 m water depth on the Bourcart-Herault canyon interfluve, using the giant piston corer "Calypso." Based on seismic stratigraphic interpretation (see above), it corresponds to the uppermost part of a sequence that formed during the sea-level fall between Marine Isotope Stages 3 and 2. During that period, the shelf margin was under the direct influence of the Rhône system, either through decantation of sediment plumes, or by direct connection of the river system to the Herault canyon head when sea level reached its lowest position around LGM. Therefore, marine fauna are mixed with abundant detrital material.

The core consists of homogeneous silty clay. A preliminary micropaleontological and biogeochemical study allowed us to identify two important and abrupt changes in the sea-surface conditions during the last 25 kyr; these episodes are characterized by peaks in cold-water microfossils (Figure 9). Radiocarbon dates indicate that these two peaks are HE 1 and 2, respectively. It is also important to note that other rapid changes are observed in the micropaleontological assemblages between HE, probably related with DO cycles. Analysis with a narrower sampling interval and additional ^{14}C dating will permit us to solve this question.

PERSPECTIVES AND CONCLUSIONS

In areas where dense seismic coverage of Quaternary shelf sequences exists, such as the Gulf of Mexico or the Mediterranean Sea, the impact of global sea-level changes and the importance of climate control on strata formation have been broadly recognized. Published results from shallow cores taken in the Adriatic Sea (Asioli et al., 2001) and our results from the Gulf of Lions indicate that shelf/upper slope sequences can give access to a very-high-resolution record of rapid climate changes, despite the dilution of marine fauna by detrital material. Conversely, access to a precise chrono-

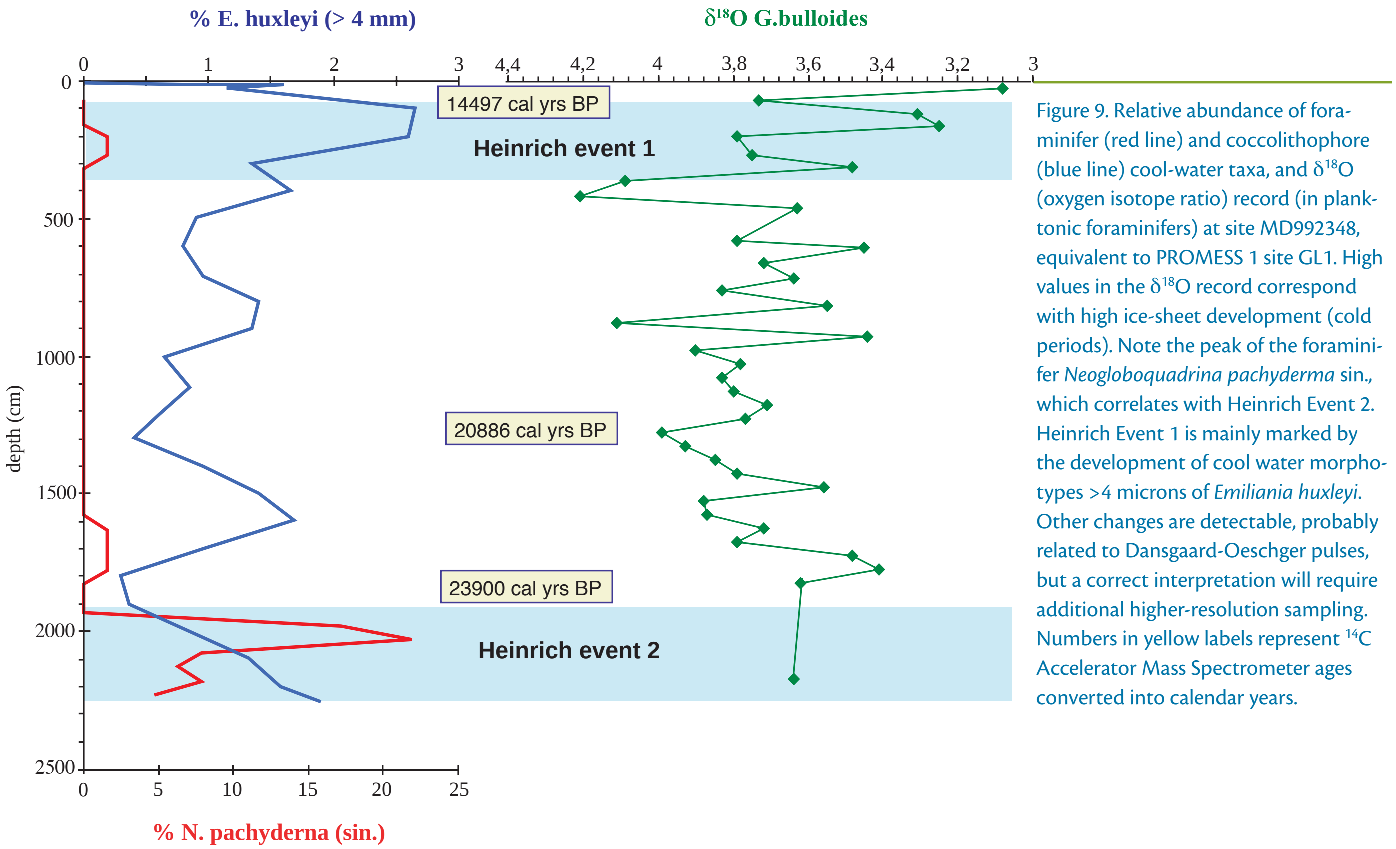

Figure 9. Relative abundance of foraminifer (red line) and coccolithophore (blue line) cool-water taxa, and $\delta^{18}O$ (oxygen isotope ratio) record (in planktonic foraminifers) at site MD992348, equivalent to PROMESS 1 site GL1. High values in the $\delta^{18}O$ record correspond with high ice-sheet development (cold periods). Note the peak of the foraminifer *Neogloboquadrina pachyderma* sin., which correlates with Heinrich Event 2. Heinrich Event 1 is mainly marked by the development of cool water morphotypes >4 microns of *Emiliania huxleyi*. Other changes are detectable, probably related to Dansgaard-Oeschger pulses, but a correct interpretation will require additional higher-resolution sampling. Numbers in yellow labels represent ^{14}C Accelerator Mass Spectrometer ages converted into calendar years.

stratigraphic framework may allow the sequence stratigrapher to better understand the real impact of rapid events on strata formation. For instance, periods of increased precipitation may trigger deltaic channel switching, rapid sea-level rise during melt water pulses may favor destabilization of the shelf edge, and cold water cascading during DO pulses will increase the transfer of sediments through canyons to the deep sea.

Piston coring is insufficient to investigate the impact of such events on strata formation (and preservation) at the scale of one or several glacial cycles on continental shelves, slopes, and rises. One important scientific effort attempting to reconstruct the history of sedimentary processes and sequences across a siliciclastic continental margin is currently being carried out on the New Jersey margin. This project aims to reconstruct the sea-level, tectonic, and climatic history of that particular area through nested (at different resolution scales) seismic exploration, and with a package of scientific drilling schemes from the coastal plain to the deep sea (Miller et al., 1998). The PROMESS group of projects has a similar objective for the Rhône margin, and will use different "Mission-Specific Platforms" for scientific drilling across the margin, from the deltaic plain to the deep-sea fan. PROMESS 1 is the first step of this integrated program. It is designed to obtain cores and in situ physical measurements from two contrasting Mediterranean sites that have been extensively studied by various geophysical techniques: the Gulf of Lions, presented in this article, and the central Adriatic Sea, where tectonism has a much more important impact on strata formation. PROMESS 1 will focus on the last ca. 450 ka, through geotechnical boreholes of a length of 100 m (shelf shorefaces) and 300 m (upper slope prodelta muds, Figure 7). PROMESS 1 was initiated and funded by the European Community as a test for the use of a "Mission-Specific Platform" in the perspective of the European contribution to the Integrated Ocean Drilling Program. It will bring together a large and complementary group of European and North American partners that will create a virtual laboratory to fully exploit the results of the project. The collected material and data will be analyzed in conjunction with the development of numerical tools and models to better understand and predict the processes and time scales responsible for sedimentary events and deposits on continental margins. Work is carried out in close co-operation with the EU-US EUROSTRATAFORM project.

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