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Onshore and offshore view of the Mellila and Boudinar Basins (Morocco)

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New field investigations in the Melilla and Boudinar Messinian basins (northern Morocco) located at the foothill of the Rif Chain, together with seismic lines interpretation in the south Alboran basin allow us to bring new insights on the late Messinian erosion and the overlying marine deposits. By combining field investigations and seismic lines interpretations, it is possible there to reconstruct the whole erosional system from emergent areas to deep sea basin.

Onshore, in littoral areas, our results show that the late Messinian erosional surface is governed by large scale ($\sim$10 km) landslides. In the Melilla basin, the erosional surface is sharp, crosscuts the Messinian reefal complex and is incised by deep (up to 70 m) paleovalleys. The minimum relative sea-level drop is estimated at 70 m in the emergent Melilla basin, but it is probably much more with regard to the indication that a large-scale landsliding has occurred (Cornée et al., 2005). The post-erosional deposits comprise one major depositional sequence composed of two high-order sedimentary subcycles. Deposits of the first subcycle are transgressive sandy marls and filled in the erosional basin and the paleovalleys; deposits of the second subcycle are sandy and overflowed the paleovalleys and the erosional plateau. In the boudinar basin, the low angle erosional surface is located in lower messinian marls and diatomites which can be totally eroded. It is underlined by dismembered messinian reefal blocks up to tens of meters in size. The erosional scars are infilled first with conglomeratic proximal deltaic deposits, then by distal sandy deltaic formations up to 200 m thick. As the erosional surace is affected by late normal faulting, the minimum estimated sea-level drop can only be roughly estimated around 100 m in the emergent Boudinar basin. In both basins, the oldest deposits above the late messinian erosional surface constitute a thin transgressive systems tract, latest messinian or pliocene in age, and are overlain by very thick highstand systems tract.

Offshore from the Melilla basin the Messinian erosional surface is prominent and a deep canyon can be identified on the slope. The Offshore extension of the Boudinar Basin is bounded towards the east by a N-S ridge that is the submerged extension of the Ras Tarf volcanic massif. The canyon ends in the South Alboran Basin that is not connected to the deep Algerian Basin. The rifian margin of the south Alboran basin consequently provides one of the most complete erosional system of the late Messinian dessication event.

J.-J. Cornée, M. Ferrandini, J.-P. Saint-Martin, Ph. Münch, M. Moullade, A. Ribaud-Laurenti, S. Roger, S. Saint-Martin, J. Ferrandini. The late Messinian erosional surface and the subsequent reflooding in the Mediterranean: New insights from the Melilla–Nador basin (Morocco), Palaeogeography, Palaeoclimatology, Palaeoecology 230 (2006) 129– 154

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Evidences of the Messinian erosional surface in the Black Sea

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In 1975, sediment cores from leg DSDP 42b (sites 380A and 381) revealed a thin sediment layer in the Black Sea basin indicating a shallow water environment at the Miocene-Pliocene boundary. From this evidence and in the wake of the hypothesis of the Messinian Salinity Crisis (MSC), it was proposed that the Black Sea, like the Mediterranean Sea, suffered a desiccation period at the end of the Messinian (Hsü and Giovanoli, 1979). Whereas the main topics of the MSC in the Mediterranean Sea is now widely accepted, the lack of evidence for a Messinian erosional surface in the Black Sea left the debate about the Messinian desiccation of this basin open until today. The analysis of high resolution multi-channel seismic data acquired during the BlaSON surveys brings important new elements for this scientific debate: (1) Down the slope off the Bosporus, a clear erosional surface linked to the top of the Late Miocene shallow water environment unit of site DSDP 381 was found. The Lower Zanclean overlying unit inevitably dates this erosional surface of the Messinian event. (2) A wide intra-Pontian erosional surface (IPU) is evidenced on the Romanian shelf. This IPU is characterized by a sharp decrease in the incision rate from outer (deep canyons) to inner shelf (superficial incisions network). According to the most recent Paratethyan and Mediterranean stratigraphic scale correlations, the IPU erosional surface is considered as the analogue to the Messinian Erosional Surface described down slope off the Bosporus. In addition to recently evidenced inland erosional signature (Clauzon et al, 2005), the wide regional Messinian erosional surface we underline on the Western Black Sea margins validates the Black Sea Messinian desiccation hypothesis.

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What are we expecting from a deep drilling in the Gulf of Lion ?

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Thanks to an exceptionally huge quantity of data (seismic profiles of different resolution, cores, drillings) coming from both industry and academia, the Gulf of Lion has appeared in the last 5 years as a real natural laboratory. This development has been possible thanks to the creation of the " Golfe of Lion " group of active researchers from the French national GDR Marges working on continental margins with the Gulf of Lion as one case study, (http://gdrmarges.lgs.jussieu.fr). Here, we present, in the name of this group, the main objectives for a deep drilling at the toe of the continental slope in the Gulf of Lion. This drilling WMED-1A is part of a larger Complex Drilling project held by L. Jolivet with other drilling sites in the Mediterranean. Seeing the Gulf of Lion as a natural laboratory or observatory is due to a number a peculiar characteristics. Ţ First, it represent a segment of a continental margin which is both young (less than 35 Ma) and which slope gradient is very low (less than 1°). This allows the precise observation of its structuration and the detailed analysis of its sedimentary cover; its homologous margin, in Sardinia, is equally accessible. Such an entire system is a very rare object that needs to be used to validate models of continental break-up. Ţ Similarly, its large shelf and its low continental gradient, also enable the best possible observations for understanding the Messinian Mediterranean event as a whole. Here we can measure subaerial erosion on the shelf, observe markers of marine transgression on the slope and at the toe of the slope map the succession of detritic units and their lateral variation to evaporites. Ţ Finally, the shelf and slope of the Gulf of Lion have register with a great detail the successive glacioeustatic fluctuations of the last

500,000 years, giving precise paleobathymetric markers (shoreline position for example). This interpretation has been recently confirmed by the PROMESS European drilling project.

Interpretation of sediment strata gives therefore two kinds of information: information on paleoclimatic history and information on tectonic history of the margin. From the climatic point of view, we now try to identify the first glacioeustatic cycles (around 2,5 Ma ?), the signature and dating of changing cyclicities (around 0,8 Ma ?) and to correlate those climatic events and their effects from the coast down to the abyssal plain. From the tectonic point of view, detailed paleobathymetric markers, as those of the messinian surface and observations on all the sedimentary cover, should give markers with a precision never reached before to reconstruct the history of margin formation and evolution.

As a summary, the objectives of the drilling are from top to bottom of the record: 1) Date the initiation and the change in glacioeustatic cyclicities and evaluate the effect of alpine glacier on sedimentation. As the Gulf of Lion receives most of the sediments eroded from the Alps and transported through the Rhône River, we infer that the amount of sediment will vary significantly according to the existence or not of ice sheet and glaciers. 2) For the messinian: the end of the messinian episode is well known and dated, as drillings have reached the upper part of the evaporites. The beginning of the crisis is still a matter of conjectures. Our observations suggest a thick serie of "lower evaporites", i.e. under the halite. The drilling will enable, according to its exact position, either to drill through the complete serie of evaporites (around 2 km thick) or to drill through its upper part, on the edge of the evaporitic basin and sample the first detritic deposits related to the lowering of sea-level. 3) For the Miocene and older sediments (Oligocene ?), the drilling combined to seismic reflexion data, will give the nature and dating of deposits of this badly known period in the Gulf of Lion. 4) For the substratum, seismic reflexion data (ECORS) image quite clearly, at the toe of the slope, the limit between continental crust and oceanic substratum. The highly reflective lower crust is clearly visible below the shelf but disappear below the continental slope. Refraction data confirm those observations: the upper continental crust thins to less than 5 km, and changes laterally to a relatively thin crust with high velocities which precise nature is still a problem. Magnetic maps also indicate a large smooth domain as sometimes observed at the toe of margins in the world. The aim of the drilling is to bring crucial information on the nature of this puzzling crust. Two cruises, one programmed at the end of the year (SARDINIA : multichannel deep penetrating seismic reflexion and refraction) the other one submitted for 2007 (ECLECTIQUE : multichannel high resolution and surficial cores) are companion and complementary projects to this drilling project that also coincide with a renewed industrial interest in the deep domain of the Gulf of Lion.

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Solid earth response to complete dessication of the Mediterranean as predicted from a 3D regional isostasy model

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The reconstruction of Mediterranean canyon and margin profiles in the during the Messinian sea level drop has been the topic of many studies. Isostasy is an important component in these reconstructions. We use flexure models to quantitatively predict possible signatures of the Late Messinian removal of the Mediterranean water load. The typical time scale of dessication events is probably on the order of 3000-8000 years, which is similar to the time scale for lithospheric flexure to develop fully. We focus on the resulting uplift/subsidence, basement tilting and stresses. Near basin margins, plate bending effects are most pronounced which is why flexure is particularly important for a relatively narrow basin like the Mediterranean. The highly irregular shape of the Mediterranean basin calls for a three-dimensional model. The results can be understood best if we simplify the unloading history. We show that marginal uplift of 100s of meters and subsidence up to 50 m of the continent may be expected, as well as stress changes on the order of a few kPa and basement tilting up to 1 degrees. However, even if we ignore the existing variability of lithospheric properties, uplift patterns are highly variable. Prominent signatures of Late Messinian dessication in onshore geology are predicted in northern Algeria, western Corsica and Sardinia, the Nile Delta and Northern Syria. Uplift of the Gulf of Lions margin is substantially less than previously predicted on the basis of 2D models. The famous Messinian localities on Sicily are probably difficult to interpret because of the complexity of the flexural pattern and due to the nearby presence of an active plate boundary. We illustrate that two-dimensional models do not correctly predict regional isostatic features.

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Structural evolution of messinian evaporites in the levantine basin

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The Levantine Basin in the South-eastern Mediterranean Sea is a world class site for studying the initial stages of salt tectonics driven by differential sediment load, because the Messinian evaporites are comparatively young, the sediment load varies along the basin margin, they are little tectonically overprinted, and the geometry of the basin and the overburden is well-defined. In this study we analyse depositional phases of the evaporites and their structural evolution by means of high-resolution multichannel seismic data. The basinal evaporites have a maximum thickness of about 2 km, precipitated during the Messinian Salinity Crisis, 5.3 - 5.9 Ma ago. The evaporite body is characterized by 5 transparent layers sequenced by four internal reflections. We suggest that each of the internal reflections correspond to brittle evaporites, possibly interbedded clastic sediments, which were deposited during temporal sea-level rises. All of these internal reflections are differently folded and distorted, proving that the deformation was syn-depositional. Thrust angles up to 14 degrees are observed. Backstripping of the Plio-Quaternary reveals that salt tectonic is mainly driven by the sediment load of the Nile Cone. The direction of lateral salt displacement is mainly SSW - NNE and parallel to the bathymetric trend. Apparent rollback anticlines off Israel result rather from differential subsidence than from lateral salt displacement. Slumps are observed in the south-eastern basin margin, which are coeval to a number of contractional faults, providing a link between slumping processes and salt tectonics. The superposition of 'thin-skinned' tectonics and 'thick-skinned' tectonics becomes apparent in several locations: The fold belt off the Israeli Mediterranean slope mainly results from active strike-slip tectonics, which becomes evident in faults which reach from the seafloor well below the base of the evaporites. Owing to the wrenching of the crustal segments, which are bounded by deep-rooted fault lines like the Damietta-Latakia-, Pelusium- and Hinge line, the setting is transpressional

south of 32°N where the fault lines bend further towards the west. This adds a component of 'thick-skinned' transpression to the generally 'thin-skinned' compressional regime in the basin. , above 1.5 km of evaporites, a mud volcano is observed with the mud source seemingly within the evaporite succession. At the eastern Cyprus Arc, the convergence zone of the African and the Anatolian plates, deep-rooted compression heavily deformed the base of the evaporites, whereas at the Eratosthenes Seamount mainly superficial compression affecting the Post-Messinian sediments and the top of the evaporites is observed.

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Modeling the climate impacts of the messinian desiccation

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The Messinian desiccation is the only known event when a substantial region of dry ground existed at such great depths below sea level. Since there is no good present analog, geologists cannot expect to estimate its climate implications by comparison with or extrapolation from current features. Thus the desiccation presents a good opportunity for progress using sophisticated modeling tools. Climate questions amenable to modeling can be placed in two groups. The first group concerns the climate of the exposed basin itself, and how climate change forced by reduction in sea level may have interacted with the desiccation process. How did the desiccation proceed, against the increasing difficulty of removing water from an ever deeper basin? The second group concerns the impact of a large sub-sea level depression on the flow of the atmosphere, and resulting changes in cloudiness, precipitation and dustiness.

To investigate these questions we are using a range of models, from single column models through dry stationary wave response models and regional climate models to general circulation models. Here we present results from single column experiments, and from a simple GCM.

Preliminary work with a single column model using the Emanuel (1991) convection scheme and Chou (1994) radiation scheme demonstrate that the temperature at a lowered sea level depends strongly on the strength and nature of the coupling between the atmosphere over the basin and the surrounding atmosphere. Increased sea level pressure alone has very little impact on surface temperature for spring conditions, yielding instead a reduction in tropopause height. However, an assumption that temperatures in the free troposphere above the deep basin would be dynamically linked to temperatures outside the basin produces a much warmer surface temperatureÑan increase well

approximated by extrapolation by a moist adiabat from the 1000 mb to the 1200 mb level.

Two experimental model simulations, using the Planet Simulator GCM, demonstrate the effects of the Mediterranean drawdown. In the first simulation, the surface of the Mediterranean is lowered, leaving standing water in the bottom of the basin. In the second simulation, basin is emptied, representing the completely desiccated basin. Both experiments are compared to a control simulation, where the Mediterranean remains unchanged.

Results from these simulations show the strongest changes during the summer months of June, July, and August. Surface temperatures show a decrease of up to 10 K in the Mediterranean region for the lowered water level simulation, while the desiccated basin shows an increase of up to 15 K. Shifts in upper and lower wind patterns, surface pressure, and precipitation patterns were also observed. The findings indicate that the Messinian Salinity Crisis had a considerable effect on the regional climate.

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Quantitative studies of the Messinian Salinity Crisis

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We aim to achieve quantitative, physics-based, insight into the processes that played a role during the Messinian Salinity Crisis of the Mediterranean basin. To this extent we study in isolation two configurations that are part of many of the proposed evolutionary scenarios: (1) that of sea-level drawdown or desiccation (and subsequent re-filling), and (2) that of continuous inflow of Atlantic water in combination with blocked outflow. While the blocked-outflow configuration probably dominated during deposition of the lower part of the evaporite sequence, desiccation most likely controlled the upper part. Calculations are performed on the basis of both the present-day geometry and a paleogeographic reconstruction and the sensitivity to variations in the freshwater budget is assessed.

Our results support previous inferences that desiccation and re-filling are fast; desiccation occurs on a time scale of 3-8 kyr, re-filling probably even faster. Equilibrium sea levels imply most water has gone from the western basin while a significant water column remains in the eastern basin. Whether or not the eastern basin reaches the level of halite saturation depends critically on the freshwater budget in particular. The fast rate of desiccation and re-filling imply that temporal differences in the onset of salt precipitation between western and eastern basin and between marginal basins and basin centres are below the resolution of (astronomical) dating. Also, when Atlantic sea level periodically varied from below to above the level of the intervening sill, the Mediterranean basin will have responded with repeated desiccation and re-filling. Fast re-filling is found to require only a small connection to the Atlantic ocean. This, in combination with the previous, suggests the Mediterranean is unlikely to attain stable intermediate water levels.

The configuration of blocked-outflow is examined using a simple box model with parametrised exchange between sub-basins. Main results are (1) the rate of salinity

increase is fast, (2) the western and eastern sub-basin evolve in concert except when exchange at the connecting strait is greatly reduced and then only when the basins are poorly stratified, and (3) near complete separation from the Atlantic is required to reach saturation.

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On the origin of the strait of Gibraltar

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Most interpretations of the Early Pliocene opening of the Strait of Gibraltar, which ended the Messinian Salinity Crisis, involve a tectonic process. All previous studies did not provide really convincing proof for the crucial role of tectonics in the opening of the Strait of Gibraltar during the Early Pliocene. Whereas the Gibraltar area is a topographic low, that this one corresponds to some structural feature (i. e., graben, pull-apart basin or syncline) was never proved. Indeed, numerous, contradictory fault mappings have been proposed that rely on regional tectonic interpretations but apparently not on field observations in the Gibraltar area itself. Deformation on a lithospheric scale such as roll-back subduction, producing surface uplift and subsequent gravity-induced slumping, has been also put forward as a possible cause of the opening of the strait (e.g. Duggen et al., 2003), but whatever the reality of such a process, it requires the occurrence of a topographic low in the Gibraltar area that this process does not explain. Considering that the reflooding of the desiccated Mediterranean basin cannot be ascribed to the Atlantic sea-level rise alone, especially not during the Early Pliocene (e.g. Hodell et al., 2001), this suggests an alternative process. On the other hand, it has been recognized long before that the desiccation of the Mediterranean during the Messinian has produced a vigorous incision of the drainage networks that were flowing into the Mediterranean. Messinian incision rates (up to 10 mmy-1), as the rates of inland migration of associated knickpoints (up to 10 my-1), are among the fastest of geological archives. It would be very unlikely that such rejuvenation power did not also develop, and influence the morphology of the future strait. This is all the more so as, in the surrounding areas, even small catchments display a significant incision. We present a numerical modelling of erosion dynamics showing that a drainage network may develop in the Gibraltar area. Using pertinent parameters, it shows that fluvial regressive erosion is able to penetrate within a proto Gibraltar area (as we considered

as a flat bottom of a saddle) to eventually capture the Atlantics waters (Blanc, 20002). We therefore propose that the deep cut into the threshold of Gibraltar was due to the regressive erosion of a stream that was flowing toward the desiccated Mediterranean basin, resulting in the opening of the "Strait of Gibraltar".

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Identical seismic markers of the Messinian Salinity Crisis within the intermediate depth type basins (Valencia Basin and East-Corsica Basin)?

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The MSC affected the whole Mediterranean that was configured as an assemblage of deep oceanic and shallower margin basins. An integrated scenario of the crisis is difficult to provide because of the diachronic evaporite deposition between deep and marginal basins. Between these two types of basins, we define the intermediate depth basins, actually located offshore between 500 and 1500m depth. Because of their location in the transitional domain with relatively shallow water depths, the intermediate basins could register small sea-level variations and recorded MSC markers that are not present or poorly present in the deep basins. The comparison between to of them, located in each border of the western Mediterranean, allowed to identify common Messinian markers and to propose a coherent chronology of the Messinian events in these basins. The Valencia Basin is an elongate NE-SW-trending basin with a 1300 - 2000 m depth, that widens to the east into the abyssal plain of the Ligurian-Provençal Basin. The East Corsica basin is a narrow NNE-SSW oriented basin of 800m maximal depth. This basin is a perched basin with no connection to the Tyrrhenian deep basin and the Ligurian-Provençal Basin. Though their structural contexts are quite different (the Valencia basin is an aborted rift and the east-Corsica basin is a fore-arc basin below the appenninic prism), both basins show evidences of two major Messinian erosion surfaces located between the Pliocene-Quaternary sequence and the pre-Messinian Miocene sequence -a Basal Erosion Surface and -a Top Erosion Surface. The Basal Erosion Surface extends into the basins the polygenic erosion of

the margins and displays a gullied morphology: it records an important sea-level fall at the beginning of the Messinian Salinity Crisis. The Top Erosion Surface, exactly similar in both basins, consists of an almost flat-lying surface cut by a network of incisions, and records the end of the Messinian Salinity Crisis. Between the two erosion surfaces, syn-Messinian deposits show a variability of seismic facies, probably linked to the regional context, and can be locally interpreted as detritals, or as equivalent to the Upper evaporites of the deep basins, but in all cases are different from the complete deep offshore evaporite type sequence.

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Flow and dissolution of Messinian salt along the eastern margin of the Levant Basin: deciphering enigmatic structures

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Extensive slumps and landslides overlie enigmatic structural features of Messinian evaporites and the overlying Plio-Quaternary sequence at the base of the continental slope of the Levant. These composite structural features were traced along a strip ∼20 km wide that stretches some 200 km off Israel and Lebanon. The deformation of the Plio-Quaternary strata comprises tilted blocks and detachment faults, that were encountered where the Plio-Quaternary deposits are the thickest. These slumps overlie a deformed section of the Messinian evaporitic series that occurs in the pinching-out zone of these strata. These structures have been known for more than 30 years and their origin was considered unresolved, however, recent discovery of numerous reverse faults that offset only the Messinian evaporites and the overlying strata some 30-50 km west of the deformation zone, seems to illuminate the process that formed these enigmatic structures. We suggest that the enigmatic structures are associated with the wedging out of the Messinian evaporites. The initial deposition of the Messinian evaporitic sequence took place in a hypersaline lake that covered the deeper parts of the Mediterranean Sea, where the configuration of the bottom of the lake is represented by seismic reflector N, whereas the top of the evaporitic sequence, reflector M, was deposited in the proximity of the lake level. The shaoling of that lake are represented by the wedging out of the evaporites and the merging of reflectors M and N, which can be discerned at reflection time of 2.4 seconds, or approximately 2 km. Slight basinal subsidence of the Levant Basin during the late Pliocene due to sedimentary loading probably initiated westwards flow of the Messinian salt, as indicated by numerous eastwards-dipping reverse faults. This flow tapered off at the eastern edge of the salt

deposit, where the flow of the salt was compensated by subsidence of the overlying strata. This subsidence generated geotechnical faulting that enabled the penetration of water into the evaporitic layer and dissolved it gradually. The dissolution removed portions of the evaporites, and left behind irregular relicts of the evaporitic layer, further enhancing the subsidence of the overlying strata. Consequently, attributing the structures at the base of the continental slope of the Levant either to some questionable megashear or to enigmatic subduction, as had been previously presumed, is poorly founded.

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Paleoenvironmental changes at the Miocene-Pliocene Boundary in the Mediterranean from high resolution studies along a West-East transect

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The deposition of the Messinian evaporites ended in the whole Mediterranean area by an episode of brackish environment (the so-called Lago-Mare), before the rapid restoration of open marine conditions in the earliest Zanclean. A multidisciplinary study of the upper Messinian-lower Zanclean (biozone MPl1) sedimentary interval has been carried out using a high sampling resolution along a W-E Mediterranean transect from southern Spain, Balearic basin (ODP Site 975b), Tyrrhenian basin (ODP Site 974), Sicily, Zakynthos, Corfu, Crete, including previous data obtained in Morocco and the Levantine Basin (Cyprus and ODP Sites 968 and 969). All the studied sections have been correlated using planktonic foraminiferal assemblages, sedimentological and stable isotope variations. In addition, the Messinian/Zanclean transition in the Eraclea Minoa section from Sicily has been re-examined with a continuous sampling each centimetre across the boundary.

Strong variations of $CaCO_3$ content, oxygen and carbon stable isotopes of carbonates and foraminiferal assemblages can be correlated between the different studied sections. The uppermost Messinian deposits are barren of fossils or characterized by only reworked planktonic foraminifera, except for the sporadic presence of *Ammonia beccarii tepida*, ostracods and brackish mollusks. The bulk carbonate oxygen and carbon isotopic compositions usually exhibit large variations with dominant negative values indicating huge freshwater dilution. The basal Pliocene deposits (MPl1) biozone dis-

play a rapid and progressive increase of the isotopic values and the progressive re-colonisation by marine fauna. Thus, the restoration of open marine conditions was a sharp but progressive event recorded throughout the whole Mediterranean. During a very short transitional period, the inflowing sea water was mixed with the Lago-Mare brackish or fresh waters and the planktonic foraminifers carried by sea water hardly survived in such still unstable marine conditions. Deep water conditions were restored rapidly without erosional boundary except in some marginal basins where the marine waters flowed on an erosional surface (Crete, Morocco) and the earliest Pliocene deposits are represented by molluscs-rich shallow benthic macroorganisms associated to *Lithophaga* boring activity (Morocco). Normal and stable marine conditions were established definitely one precession cycle after the re-opening of Atlantic connections.

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Impact of the Messinian subsalt morphology on the structural evolution of salt tectonics off the Gulf of Lions, Western Mediterranean

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The young Messinian salt offshore the Gulf of Lions is a shallow décollement layer sandwiched between deep-water marine sequences. In such a context, the interpretation of about 30.000 km of closely-spaced multichannel seismic reflection profiles clearly depicted the subsalt relief, showing that salt tectonics off the Gulf of Lions was driven by an essentially autochthonous salt mass. Seismic interpretation shows as well, that the gravitational kinematics was affected by the Messinian paleogeography. At regional scale, the Messinian subsalt relief reveals a complex morphology marked by either conical (divergent) or concave (convergent) shapes of subsalt morphology. This basin shape triggered a mechanism of radial gravitational gliding. Radial gliding is illustrated by the Messinian salt isopach map and is also reflected by both secondary normal fault families related to strike-parallel extension, and by salt-cored compressional folds related to layer-parallel shortening. At smaller local, subsalt morphology is particularly affected by residual relief formed by both tectonic and sedimentary processes related to the Messinian event. Basement transfer zones (e.g. the Catalan and the Rascasse basement transfer zones) form basement steps that impacted subsalt relief. Scarps along transfer faults represent a category of residual relief that conditioned the emplacement of Plio-Quaternary strike-slip faults offshore the Gulf of Lions. Disposition and geometry of their fault planes favour their interpretation as thin-skinned transfer zones (detached transfer faults) that define salt subsystems limits. Still associated with the Messinian event, detritic deposits form sedimentary wedges with high frontal slope. These step-like features also favoured rooting of basinward-dipping

faults, with local consequences for the Plio-Quaternary tectono-stratigraphic evolution of fault styles. In such a situation, deformation was dominated by overburden subsidence into the evacuated salt horizon, forming local minibasins. Linking of subsalt relief and structural styles illustrated in this work stress that, other than the evaporitic deposition, processes that occurred during the Messinian Salinity Crisis influenced the Plio-Quaternary evolution of salt tectonics offshore the Gulf of Lions.

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Physiographic constraints on evaporite deposition: A key-point for the interpretation of the Messinian Salinity Crisis

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After a period of relative agreement about the model of deep basin-shallow water evaporite deposition, the debate about the interpretation of the Messinian salinity crisis (MSC) was reactivated, by the middle of the 1990's, by the proposition of several scenarios. New controversial interpretations raised which concern mostly the chronology and distribution of the major evaporite steps according to basin physiography, the importance and timing of the drawdown phases and related erosional events, and the depositional conditions of evaporites and post-evaporitic sediments. Did the main evaporite phases occur quite synchronously at the Mediterranean scale or with a complete diachronism according to the position in deep versus marginal basins? What is the real significance of the peripheral basins and the status of the central Sicilian basin: an exhumed deep basin displaying a complete sedimentary record of the MSC comparable to that of the deepest basins, or a perched shallow basin? Did the evaporites precipitate in shallow water settings related to sea level falls or in deep water conditions? Such are some of the most crucial questions that raised during the last decade.

The re-examination of the main evidences of depositional depth during the MSC along with consideration of general requirements for evaporite deposition, indicate the Mediterranean physiography was much more complex than a simple two-fold subdivision into deep and shallow perched marginal basins. The Mediterranean was segmented into a mosaic of interconnected sub-basins of various sizes inherited from a complex structural history and displaying gradual depth boundaries from deep to shallow basins. The central Sicilian basin was deep although not as deep as the deepest ones and, like other basins located in active orogenic belts, submitted to tectonically-

driven changes of the sedimentary settings. Deep water conditions are also reported before and after the evaporites in many peripheral basins. These different paleobathymetric settings governed the distribution of the evaporite deposits as well as their temporal evolution while the role of the inter-basins thresholds was crucial for hydrological evolution. In our scenario, the MSC involved two major steps which affected the whole Mediterranean even though the morphological differentiation of the domain introduced a slight diachronism of the onset of evaporite deposition. The first step started when the huge drop of base level caused the beginning of the lower evaporites deposition in shallow brine bodies and the widespread erosion of the margins. The erosion remained active throughout the crisis, but was enhanced during the second step of salt deposition and at the end of the lower evaporites, and finally during the latest Messinian dilution (lago-mare event). This last event affected the whole Mediterranean just before the abrupt restoration of the marine conditions in the earliest Zanclean.