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R.C.M.N.S. Interim Colloquium
“The Messinian salinity crisis revisited-II”
Parma (Italy), 7th-9th September 2006

ABSTRACT BOOK

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front cover:
The Baptistery of Parma (up left); Panoramic view of the Vena del Gesso (Lower Evaporites) along the east side of the Santerno River valley at Borgo Tossignano, Northern Apennines (up right); Panoramic view of the Upper Evaporites at Montagna Grande, east side of the Salso River Valley, Sicily (down).

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The upper Messinian post-evaporitic phase in Tuscany: high resolution stratigraphy and cyclostratigraphy of the Serredi Quarry succession

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The Serredi Quarry succession, one of the most studied Neogene successions of Northern Apennines (Fine Basin, Tuscany), has been measured and studied through a multidisciplinary approach, in order to define a high-resolution stratigraphic framework for the exposed post-evaporitic deposits and assess evidence of sedimentary cyclicity.

The Serredi Quarry succession consists of about 150 m thick, upper Messinian lacustrine deposits, which are overlain conformably by Pliocene marine marls (22 m thick in the measured section). More than 700 samples have been collected in the Messinian deposits and characterised in terms of quantitative and qualitative micropaleontological content (foraminifers, nannofossils, ostracods, pollen and dinocysts), and chemical (calcimetric analysis) and geophysical (magnetic susceptibility analysis) properties. Particularly, the Messinian succession has been divided into three intervals (Aldinucci et al., 2005). The lower interval (at least 18 m thick) consists of relatively deep, anoxic, thinly-laminated mudstones with subordinate sandy and silty beds. An ash layer, about 1 cm thick (referred to 5.35 ± 0.32 Ma by fission track dating: Aldinucci et al., 2005), has been found about 3 m above the base of the measured section. The macro- and microfossil content is scarce (with the exception of pollen grains), being represented only by plants debris, leaves and occasional fish remains, insects, and by scattered benthic foraminifers and ostracod valves (*Loxoconca mülleri* sp.), respectively.

The middle interval (about 64 m thick) includes mudstones with interbedded sands and subordinate limestones. It is separated from the lower interval by an erosional surface thought to be an unconformity. Macrofossil content is represented by oligotypic assemblages of molluscs *(Dreissena, Limnocardium, Melanopsis, Teodoxus* and others small taxa). The microfossil associations are dominated by ostracods of Paratethyan domain (*Candona*, *Amnicythere, Euxinocythere, Loxoconcha, Cyprideis*) and include rare benthic foraminifers, such as *Ammonia tepida* and *Bolivina paralica.*

The upper interval (about 68 m thick) is mainly made up of mudstones (occasionally with pedogenic features), diagenetic gypsum-rich mudstones, limestones, gravels and selenite gypsum. Macro- and microfossils are represented by the same taxa found in the middle interval.

Palynological analyses from the three intervals pointed out rich pollen assemblages typical of prevalent humid-subtropical/warm-temperate conditions. However temperature and humidity fluctuations are testified by the increase of altitudinal arboreal taxa (e.g. *Abies*, *Picea* and *Cedrus*) and herbs (e.g. Asteraceae, Chenopodiaceae and Poaceae) respectively. Dinocysts are abundant only in the upper interval where the arrival and the dominance of taxa with Paratethyan affinity (e.g. *Impagidinium* (?) sp. 1, *I.* (?) sp. 2 and *Galeacysta etrusca*) have been recorded.

The Pliocene succession, characterised by a sulphides-rich horizon at the base, consists of bioturbated, massive grey-blue marls ("Argille azzurre" Auct.). The surface separating the uppermost post-evaporitic deposits from the overlying Pliocene fines corresponds to the M/P boundary of its type-section (Riforgiato et al., this volume).

The integration of a detailed facies analysis with the above mentioned micropaleontological, chemical and geophysical data reveals cyclical patterns of sedimentation, which have been related to a Milankovic cyclicity

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The Messinian in Tuscany: an integrated high resolution stratigraphic framework from selected sections

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This work represents a synthesis of a research program (COFIN 2003) developed on the Messinian succession of Tuscany. The Messinian was characterized by dramatic palaeoenvironmental changes; sedimentation patterns, tectonic regimes and palaeogeography rapidly changed depending on regional and global factors. Upper Miocene deposits of Tuscany accumulated in a variety of depositional settings highly sensitive to these factors. As a consequence they have been intensively studied during the last two century. This resulted in the definition of a reliable stratigraphic and paleontologic framework (Bossio et al., 1996 and references therein) which represented the starting-point for new studies. Accordingly, four well-known stratigraphic sections were selected and studied using a multidisciplinary approach, aimed at defining a high-resolution stratigraphic framework. Sedimentological, chemical, geophysical, palaeomagnetic and micropalaeontological analyses have been carried out and integrated in order both to recognize a milankovich periodicity and to calibrate tentatively the selected sections with the astronomical time scale.

The studied sections are representative of the middle-upper Messinian interval. They are: 1) Gello Section (Aldinucci et al., this volume), 2) Migliarino Section (located to the S of Livorno), 3) Faltona Section (located to the SW of Volterra), and 4) Cava Serredi Section (Aldinucci et al., this volume). Gello and Faltona sections pertain to the Volterra Basin, whereas Migliarino and Cava Serredi sections belong to the Fine River Basin.

Preliminary results can be enumerated as follows: 1) the Messinian salinity crisis and the Pliocene transgression recorded in the Tuscan succession are coeval with the same events of other Mediterranean sections.) Similarly to other well-known areas (e.g. Vena del Gesso type-area), it can be assumed that evaporitic sedimentation in Tuscany was controlled by astronomical (precessional) periodicity; at least 11 pelite-gypsum couples are exposed in Rosignano area; 3) a regional unconformity encompass the evaporitic – lacustrine transition; 4) lacustrine sedimentation was characterized from the base by microfauna of the Parathetyan realm; 5) a volcanic activity is recorded both in the evaporitic and post-evaporitic Tuscan deposits.

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The pre-evaporitic Messinian in Tuscany (Italy) as recorded in the Gello section (Volterra Basin, Tuscany – Italy)

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The pre-evaporitic Gello section (about 50 m thick) consists dominantly of grey bioturbated marls, bearing in its lower part decimeters- to meters-thick, thinly-laminated marls. The uppermost part of the section is represented by few meters of dark-grey fetid marls, which in the surrounding area underlie gypsum beds. More than 350 samples have been collected and characterized in terms of micropaleontological, sedimentological, geochemical (calcimetric analysis) and geophysical (magnetic susceptibility and paleomagnetic analyses) features.

Preliminary paleomagnetic analyses have been performed in the lower-middle part of the section and allow to recognize the C3An.1r/C3An.1n boundary at 15 m from the base.

The fossiliferous assemblage characterizing the lowermost Gello section (0 – 5 m) is represented only by Characeae oogonia and ostracods (*Cyprideis*, *Loxoconcha*, *Candona*), whereas, from 5 to 12 m, ostracods and rare benthic foraminifera (small *Ammonia beccarii*, *Cassidulinita prima*, *Bolivina* spp.) occur. Moreover, poorly diversified and, occasionally, oligotypical (mainly *Bolivina dentellata, Bolivina spathulata* e *Bulimina echinata*) benthic foraminifers assemblages characterize the rest of the section. Calcareous plankton is firstly recorded at 12 m in concomitance of echinoids remains. Calcareous plankton is typically represented by few species and specimens, although some taxa (e.g. *Turborotalita quinqueloba* among the foraminifera and "small" *Reticulofenestra*, *Dictyococcites* spp. and *Sphenolithus* spp. among the nannofossils) are occasionally abundant and the planktonic assemblages assume an oligotypical character.

Based on micropaleontological analyses, brackish and marine (with anomalous conditions both at the bottom and in the water mass) paleoenvironments can be recognized in the lower and middle-upper part of the section, respectively. The uppermost part of the section contains a peculiar planktonic assemblage (orbulinids, neogloboquadrinids and sphenolithids) which points to anomalous chemical-physical conditions of the sea heralding the "salinity crisis" and precipitation of evaporites.

From a biostratigraphycal point of view, the marine part of the Gello section, which belongs to the *Turborotalita quinqueloba* Zone and to the *Amaurolithus delicatus*-*A. amplificus* Zone (*A. amplificus* Subzone of the zonal scheme of Foresi et al., 2001), records the same key bioevents previously recognized within some of the most studied pre-evaporitic Messinian sections, such as Abad composite section (Sierro et al., 2001) and Falconara composite section (Sprovieri et al., 1996; Hilgen et al., 1999; Blanc-Valleron et al., 2002). Specifically, the main calcareous plankton events are the following: 1) the first *N. acostaensis* sinistral influx, 2) the second *G. scitula* dextral influx, 3) the second *N. acostaensis* sinistral influx, 4) the LO of *T. multiloba*, 5) a peak of abundance of *Orbulina* spp., 6) a peak of abundance of *Sphenolithus* spp. These, together with paleomagnetic data, strongly support that the onset of evaporitic deposition in Tuscany is isochronous with that recorded within circum-Mediterranean type-successions.

Finally, calcimetric and magnetic susceptibility data suggest that a Milankovic cyclicity is recorded in the Gello section. Accordingly, key-beds have been astrochronologically calibrated.

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Anatomy and development of Messinian mass-wasting deposits in submarine confined basins: examples from Northwestern Apennine of Italy

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Among the many examples of submarine "chaotic bodies" from both passive and convergent continental margins, very few are from collisional margins. Though the different margin types have clearly contrasting morphologies, topographic control on the architecture and emplacement of submarine wasting deposits has not been adequately remarked. In Northwestern Apennine collisional orogen, two composite Messinian mass-wasting bodies have been analyzed throughout extensive stratigraphic and structural studies, integrating surface and subsurface data (Artoni et al., 2004; Rizzini et al., 2004); they reveal geometry and a progressive development strictly controlled by actively forming basin topography.

In early Messinian, Cretaceous to late Miocene allochthonous units reached the southern and tectonically-controlled margin of the foredeep/wedge-top basins. During the intra-Messinian tectonic pulse, these allochthonous units further advanced by means of mass-wasting processes. Two major lens-shaped bodies, elongated parallel to the foothills' structures, were laid down. Few kilometres wide, tens of kilometres in length and with estimated volumes of about $100km^3$ each, they are made by coalescing chaotic masses that show similar internal organization. At the base, monogenic gypsum arenite or breccia, containing decametric blocks with primary evaporitic precipitates, are debris flow derived from nearby intra-basinal highs. In the external zone of the chaotic bodies, the clastic gypsum units lay directly above early Messinian turbiditic to shelfal deposits; whereas, in the internal zones, they are either on top or encased inside the allochthonous units. Going upward, the largest volume of the mass-wasted deposits is made by pieces of dismembered allochthonous units; kilometres-wide klippens of well-bedded, limestone-marly Cretaceous-Paleogene turbidites are floating on top of the chaotic bodies. The isolated masses slided away from zones that preserve headwall scarps and scars. In the external zones, the chaotic bodies show embricate thrust-stacks formed by allochthonous units accreting and scraping off the gypsum debris flows. The overall architecture of the mass-wasting bodies show a denudational area, located inside the allochthonous units, and an accumulative area that coincides with the embricate thrust-stack. The run-out distances of the wasted masses, few kilometres, is very similar to the width of wedge-top basins; while, their lengths are comparable to the wedge-top depocenter. Based on the available regional Messinian chronostratigraphic scheme and dating, the two chaotic bodies are emplaced contemporaneously in less than 100 ka. The gypsum resedimentation, producing debris flows and turbidites, generally precede the gliding of allochthonous units.

In contrast to coeval mass-wasting deposits (Dela Pierre et al., 2001), mud-diapirism and carbonate related to clathrate-dissociation are lacking; thus, the studied Messinian gravity-driven mass movements are believed to be triggered by a progressive increase of relief steepness in the Northwestern Apennine accretionary wedge and they mark major uplift pulses of the orogenic wedge. The gypsum-bearing debris flows form when the wedge relief started to increase; whilst, larger masses of allochthonous units slided with relative steeper angle of wedge relief. Then, the gliding masses stopped and accreted against the outer margin of the wedge-top basins, indicating confinement in submarine basins morphology.

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Tectonic-climatic controls and cyclicities in Late Miocene sedimentary record of Cortemaggiore wedge-top basin (Nortwestern Apennines, Italy)

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Tectonic and climate are regarded as major controlling factors on sedimentary successions, also in foreland basin system. In between emerged orogen, mainly under erosion, and foredeep basin, with high sedimentation and subsidence rates, the wedge-top basins are the most suitable to investigate the tectonic and climate interplay on sedimentary record of foreland basins. In the Mediterranean area, the refined and high-resolution late Miocene chronostratigraphy (Hilgen et al., 2000; Van Couvering et al., 2000) makes it possible to time constrain the tectonic and climatic events and their ciclicity.

At the foothills of Northwestern Apennine, the Cortemaggiore Wedge-Top Basin (CWTB) is bounded by the buried and arcuate Cortemaggiore anticline, to the north, and by the poliphased and complex Salsomaggiore structure, to the south. The CWTB started to form in response to the late Tortonian tectonic pulse that uplifted the Cortemaggiore anticline and established euxinic conditions. The major intra-Messinian tectonic pulse further shortened the CWTB and triggered the emplacement of gravity-driven mass-wasting deposits above which turbiditic, shelfal deposits evolve upward to fluvio-deltaic deposits. The former, Late Messinian hypohaline succession, are characterized by a well-developed cyclical pattern which falls in the range of astronomically-controlled climate changes with precessional periodicity modulated by obliquity and eccentricity periodicity as in most Apenninic foredeep and Mediterranean coeval deposits (Roveri et al., 2005).

Tectonic and climate controls on sedimentary succession of CWTB act at different frequencies. Tectonics control acts at low frequency (order of 2 Myr) and produces major and fast morphologic changes of the basin. Climate acts at variable higher frequency (order of 20-100 kyr); it both distributes laterally and cyclically stacks vertically the sediment supplied to erosion by tectonic uplift. The tectonic and climatic controls should have acted homogeneously and synchronously over the entire Northern Apennine foreland basin system and Mediterranean area, because cyclicity and depositional characters of late Miocene succession present common features. In the CWTB, two dryer climate events, corresponding to lower and upper evaporites of Mediterranean region, are closely preceded by tectonic pulses. This is explained by tectonic uplift which causes basin-wide hydrologic and hydrogeologic changes that induce increased evaporation. However, considering that earth's tides control earthquakes cycles at plate boundaries during the last two decades (Tanaka et al., 2006), it is speculated that the 2 Myr periodicity might be a low-frequency, global-scale and astronomic-related cycle that is able to drive simultaneously tectonic pulses and climate changes.

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Syntectonic deposition during the Messinian in selected basins of Tuscany (Central Italy): preliminary synthesis of data

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The stratigraphic-depositional architecture of the Messinian successions exposed in some basins of central-southern Tuscany is discussed in a framework of a dominant tectonic control. The primary aim of this study is to illustrate a Messinian tectono-sedimentary dynamics of the western side of the Northern Apennines particularly active and somewhat more complex than that derived from the current structural pictures of this orogen for the late Neogene interval. A dominant extensional mode of basin formation and development in central-southern Tuscany, in fact, is widely accepted and adopted for regional correlations across the Late Miocene Northern Apennines. The south-western portion of the Volterra basin (SWV), the Tora-Fine basin (TF), the Baccinello-Cinigiano basin (BC) and the Casino basin (C) apparently did not behave during the Messinian as grabens or half-grabens. Starting from the distribution of these selected tuscan basins it appears that the regional physiography was quite articulated and affected by active tectonism during the late Miocene creating peculiar conditions for the sedimentary record of Messinian events. The Mid Tuscan Ridge, an arc-shaped regional divide, prevented during the Messinian any marine influence in the fully terrestrial (i.e fluvio-lacustrine) eastern basins (BC and C). On the contrary marine incursions into the western basins (SWV and TF) prepared since the early Messinian favourable conditions for evaporite deposition during the Salinity Crisis.

At the specific basin scale we will discuss the following lines of evidence supporting a dominant tectonic control on the Messinian depositional evolution:

1) the complex response of fluvial systems draining actively growing margins, due to the activation or re-activation of compressive structures, and supplying huge amount of terrigenous sediments to the basin depocentres;

2) the cyclothemic facies architecture as the result of combined tectonic and climatic forcings;

3) the development of local sub-basins controlled by growing blind compressive structures.

Available chronologic constraint of the studied successions suggests that the syntectonic control on the depositional patterns acted at time frequencies comparable with those of astronomically-forced climatic cycles whose sedimentary imprinting has been widely recognized in the Messinian successions of the Mediterranean basin. This aspect may have serious consequences in attempting correlations of events, such as the development of the late Messinian *Lago-mare* and the marine flooding at the Messinian-Zanclean transition, between relatively shallow and deep basins developed respectively west and east the Northern Apennines divide.

The ecological significance of dinocysts from the Italian Lago-Mare to understand the Mediterranean and Paratethyan connections

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Palynological analyses from several late Messinian sites of Central (Fonte ai Pulcini and Le Vicenne) and Northern (Cava Serredi, Trave, Maccarone) Apennines (Italy) allow the detection of rich organic-walled dinocyst assemblages. They illustrate two main changes in the hydrological settings:

- The first change is documented by the arrival of a non-marine flora linked to the Lago-Mare event, after 5.5 Ma. The non-marine flora includes a dominant component showing Paratethyan affinities (e.g. *Galeacysta etrusca*, *Caspidinium rugosum*, *Pyxidinopsis psilata*, *Spiniferites cruciformis, Impagidinium* (?) sp. 2, *I.* (?) sp. 3, …) as well as other aquatic palynomorphs, notably the freshwater to brackish algae *Pediastrum*. Dinocysts showing Paratethyan affinities are characterized by large morphological variations which we relate to environmental changes.
- The second change, temporally very close to the previous one, is characterized by the sudden disappearance of non-marine taxa as well as by the arrival and rise to dominance of taxa of marine affinities (e.g. *Impagidinium patulum*, *Spiniferites* spp., …) at the Messinian-Zanclean transition; the modality of such transition is rather diverse in the different analysed sites.

The recent studies on dinocysts of both Late Quaternary sediments from eastern Mediterranean regions and recent to sub recent sediments from the Central Asian seas (southwestern Black, central Marmara, Caspian and Aral Seas) as well as those from Neogene Paratethyan deposits provide an exceptional record in order to solve the systematic, ecological and palaeogeographic controversies involving the Lago-Mare taxa. In this connection, two main questions are discussed in the frame of this contribution, (1) Morphological variability of the organic-walled dinocysts, with the analysis of the different ecophenotypes and their comparison with the recent species (e.g. *Impagidinium* (?) sp. 1. with *Caspidinium rugosum*); (2) Ecological affinity, by the evaluation of sea-surface requirements (e.g. salinity, temperature, and nutrient level conditions) of the recent taxa correlative with the fossil ones.

This new evidence from dinocysts provides information about the hydrographic changes of the Mediterranean sea during the late Messinian and contributes also to the understanding of the Lago-Mare in term of causes and mechanisms involved.

The Trave section (Ancona, Italy): palynological evidence from the Messinian post-evaporitic deposits

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In the last years, several physical and stratigraphical researches have been carried out in the Adriatic foreland with the aim to delineate the history of the Northern Apennines during the Messinian (see Roveri et al. 2004 and references therein). In the Conero Riviera (Adriatic sea coast) near Ancona, the Trave succession was measured, sampled and submitted to several micropaleontological analyses (e.g. Roveri et al., 2005). Here we present palynological data as a contribution for the palaeonvironmental characterization of the lower (pe-v_1) and upper post-evaporitic (pe-v_2) Messinian sequences.

Pollen assemblages delineate the vegetational and climatic conditions in the terrestrial environments attesting to prevailing subtropical to warm temperate climate. Humid conditions, indicated by high frequencies of *Engelhardia*, are common throughout the pe-v_1 portion. Cyclical humidity fluctuations, marked by the successive peaks in herbs, especially Asteraceae accompanied by Chenopodiaceae and Poaceae, characterized the pe-v_2 deposits.

Dinocysts contribute significantly to the reconstruction of the aquatic environments though their concentrations are considerably lower than those of pollen. In pe-v_1, dinocyst assemblages consist principally of marine taxa. Close to the transition between pe-v_1 and pe-v_2 such assemblages suffer a phase of decline which follows a short peak (ca 10 meter below) and precedes a major change in their composition. The latter is marked by the progressive arrival and/or the dominance of taxa showing affinities with those of the Paratethys (e.g. *Impagidinium* ?sp. 1, I. ? sp. 2 and *Galeacysta etrusca*).

For a better understanding of the main crucial questions concerning the development of the Messinian salinity crisis, the palynological evidence from the Trave section is discussed within the stratigraphic context of vegetational and climatic changes in some key Messinian localities of the Italian area such as the Po plain, the Vena del Gesso (Brisighella), the Maccarone section (Marche region) and the Caltanisetta basin (Sicily) (e.g. Bertini, 2006; Fauquette et al. 2006).

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Calcareous dinoflagellates turnover related to the Messinian salinity crisis in the Eastern Mediterranean Pissouri basin, Cyprus

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The extent to which the Messinian Salinity Crisis modified the initially Tethyan, oceanic to neritic Eastern Mediterranean phytoplankton communities has been investigated by monitoring the fate of calcareous dinoflagellate cyst assemblages prior, during and after the Salinity Crisis in the Pissouri Section (Cyprus). A rich, but low diversity open oceanic assemblage, dominated by *Calciodinellum albatrosianum,* occurs during the Tortonian and lower Messinian. The upper Messinian sediments yield only few cysts but the assemblage is much more diverse and reflects more neritic and euryhaline conditions. The lower Pliocene sediments reflect the return to open oceanic conditions; the assemblages are again rich in cysts and have a low diversity. However, in contrast to the *C. albatrosianum*-dominated pre-Messinian sediments, *Leonella granifera* dominates the Pliocene associations. Apart from this shift in dominance, the transition to the Pliocene is furthermore marked by the first appearance of *C. levantinum* and *C. elongatum*, which must have immigrated from the Atlantic. Probably *Lebessphaera urania*, a postulated remnant of the Tethyan Ocean, survived the Salinity Crisis in as yet unidentified marine refuges in the Mediterranean itself.

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The redeposition of halite in the Middle Miocene basins of Central Paratethys (Poland and Slovakia)

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The redeposition processes generally have played a very important role during the deposition of evaporites and while the profiles of resedimented gypsum and anhydrite are well known (e.g. Manzi et al. 2005) the resedimented halite deposits are less commonly noted (e.g. Ślączka & Kolasa 1997).

The Middle Miocene evaporites were deposited in the subbasins of Paratethys at the Langhian/Serravallian boundary (Badenian stage) and they were studied in the Polish Carpathian Foredeep (Wieliczka Formation) and in the East-Slovakian Basin (Zbudza Formation). Part of them evidenced distinct features of salt redeposition.

We found that the mixed clastic-evaporitic deposition in these basins was controlled by frequent tectonic and seismic phenomena and high continental clastic supply that produced repeated slump sediments with dominant proximal mass flows and distal flows. These processes produced the diverse salt types (e.g. salt/clay rhythmites, finer halite-arenites, coarse halite-rudites). In-between occur the primary halite units (fine from suspension and bottom grown halite, clay laminated) precipitated in situ from bottom brines during calm periods.

Most of the clastic material composing the evaporitic deposits (redeposited halite-rudites and halite-arenites) and siliciclastics were probably transported from the intensively eroded coastal mud-salt flats framing the basin but these facies had not preserved in the sections due to postdepositional tectonics and erosion.

Both the clastic-evaporitic deposition in the Polish Carpathian Foredeep (Wieliczka Formation) and in the Zbudza area (East Slovakian Basin, Zbudza Formation) recording the cyclicity of evaporites deposition. The observed cyclicity reflects varied tectonic activity of the basin margins that mechanically remobilised the sediments from marginal salt pans, flats and adjacent uplifts.

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Fossil marine fishes and the paleoenvironmental significance of the Messinian "Lago-mare" event in the Mediterranean

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In the course of a revision of the macropaleontological record of the Messinian 'Lago-mare' deposits of Italy, fish remains (articulated skeletons, otoliths, teeth) have been found from five localities, Le Vicenne in the Abruzzo Apennines, Cava Serredi (Carnevale et al. 2006b) and Podere Torricella respectively in the Fine and Volterra Basins in Tuscany, Capanne di Bronzo (Carnevale et al. 2006a) in the Montecalvo in Foglia Syncline (Marchean Apennines) and Ciabòt Cagna in the Tertiary Piedmont Basin.

The fish bearing deposits mostly originated in paralic settings and are typically characterized by brackish ostracods and molluscs and by marine stenohaline and estuarine fishes. Although estuarine fishes quantitatively dominate the assemblages, marine stenohaline fishes are represented by a moderately high number of taxa belonging to the families Myctophidae, Bythitidae, Blenniidae, etc. Estuarine fishes consist of an ecologically heterogeneous assemblage of taxa that include marine migrants, marine occasional, estuarine residents, and estuarine migrants. Therefore, fish remains are clearly indicative of the presence of normal marine conditions in the areas surrounding the paralic depositional environments. The paleoenvironmental information derived from the analysis of fish remains evidently contrasts with those provided by the interpretative study of the benthic resident biota. This is mostly due to the mobility and frequent migratory behaviour that characterize fishes during their lifecycle.

A comprehensive paleoecological analysis of the 'Lago-mare' marine and estuarine paleoichthyoceonoses reveals the presence of several different ecological and trophic categories, thereby suggesting that a complex ecological structure characterized the Mediterranean Basin in the late Messinian.

Our results clearly indicate that a new paleoenvironmental interpretation of the Messinian 'Lago-mare' event is necessary, and provide unquestionable demonstration that the marine reflooding preceded the Messinian-Zanclean boundary. Fossil fishes suggest that the catastrophic basal Pliocene inundation was anticipated by a progressive transgression that re-established the marine biotic communities in the Mediterranean.

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High-resolution stratigraphy and stable isotopes at the Messinian/Zanclean boundary in the Mediterranean basins. Paleoceanographic reconstruction

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A multidisciplinary study using planktic foraminifera fluctuations, mineralogical contents and stable isotopes ($\delta^{18}O$, $\delta^{13}C$) was carried out across the Messinian/Zanclean boundary on several sections along a West-East Mediterranean transect. The study, with a high resolution sampling, was performed on the: Vera/Almanzora section (southern Spain), Eraclea Minoa (Sicily), Kalamaki (Zakynthos), Aghios Stefanos (Corfu), Aghios Vlasis (Crete) and Algerian sections. The data were compared with those of ODP Site 975 (Balearic Basin), ODP Site 974 (Tyrrhenian Basin) obtained by other authors.

In particular $\delta^{18}O$ and $\delta^{13}C$ values were measured on *Globigerinoides obliquus*, *Globigerina bulloides* and *Sphaeroidinellopsis* spp. tests. The studied sediments span the interval from the last cycle of "Lago-Mare" (uppermost part of Messinian) to the lowermost part of Zanclean, biozone MPl1.

The latest Messinian sediments are essentially barren of fossils or characterized by only reworked foraminifers from lower Messinian and sometimes from Cretaceous-Eocene, except for the sporadic presence of *Ammonia tepida, Haynesina germanica* and *miliolids* characteristic of hypohaline conditions, by brackish to lacustrine ostracods and by brackish mollusks typical of the "Lago-Mare" facies. The return to marine conditions is testified by the synchronous occurrence of plantkic foraminifera that have recolonized the Mediterranean Basin at the base of Zanclean (MPl 1, cycle 1). All the sections were correlated using benthic and planktic foraminifera bioevents, using especially the acme interval of *Sphaeroidinellopsis* that occurs between cycles 2 and 6 of the MPl1 biozone. In this interval two peaks of *Neogloboquadrina acostaensis* senestral coiling permit an accurate correlation between all the sections. As previously described in the Eraclea Minoa section, lithological cycles, fluctuations of abundance of *Globigerinoides* spp., $\delta^{18}O$ values and carbonate contents are controlled by the precessional forcing. All the bioevents and each cycle were also calibrated to Laskar astronomical solution.

It is shown that the Vera-Almanzora section contains only the uppermost Messinian and the first 6 cycles of the lowermost part of MPl1 biozone while the other sections contain the whole MPl1 and part of the MPl2 biozone. Benthic foraminifers slowly repopulated the Mediterranean from cycle 1 to cycle 3 of MPl1 biozone; in fact in cycle 1 the first specimens of *Epistominella exigua* and bolivinids were followed in cycles 2 and 3 by *Oridorsalis stellatus, Cassidulina subglobosa*, *Uvigerina peregrina and Gyroidinoides spp.*.The first occurrence of *Siphonina reticulata* has been recognized in the uppermost part of *Sphaeroidinellopsis* spp. acme zone (cycle 5) with an age of 5.22 Ma, i.e. 110 ky after the base of Zanclean. Since *S. reticulata* disappeared from the Mediterranean in lower Messinian at 7.16 Ma, i.e. 1.2 My before the Messinian Salinity Crisis, its reappearance in cycle 5 of MPl1 biozone indicates a good ventilation of the bottom waters which is also witnessed by stable $\delta^{18}O$ and $\delta^{13}C$ values.

The post-evaporitic Messinian deposits of the Mediterranean area: rock magnetic properties and isotope analyses of the upper Messinian Maccarone section (Apiro, northern Apennines)

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In the Cingoli area (Marche, northern Apennines), the well-known uppermost Messinian Maccarone section (Carloni et al., 1974; Casati et al., 1976) crops out. In the lower-middle part, it consists mainly of marls with thin intercalations of sandstone. The volcaniclastic layer, which is at the base of the section, and three organic-matter-rich horizons, with ankerite levels, characterise the lower portion of the Maccarone section. In the uppermost part, four carbonate-rich horizons ("colombacci"), which are intercalated within well-laminated marls, define the stratigraphy of the upper post-evaporitic deposits.

A 50 cm regular-spaced sampling has been performed on a total thickness of about 200 m, which in the uppermost part encompasses the Messinian/Zanclean boundary. On the 400 collected samples the rock magnetic and the oxygen and carbon isotope analyses have been performed.

Rock magnetic analyses were made at the paleomagnetism laboratory of the Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome. A range of rock magnetic measurements was used to investigate the magnetic mineralogy throughout the investigated section. The low-field mass-specific magnetic susceptibility (c) was measured with a Kappabridge KLY-2 magnetic susceptibility meter. On the same samples, we determined calcium carbonate content using an OFITE gauge calcimeter. On selected samples, the temperature dependence of magnetic susceptibility was measured up to 700°C using a furnace-equipped Kappabridge KLY-3 magnetic susceptibility meter. Hysteresis properties were analysed on sediment chip samples, using a Princeton Measurements Corporation MicroMag vibrating sample magnetometer.

The magnetic susceptibility record is characterised by very low values with both large and small-scale cycles. The small-scale cycles maybe associated to sub-milankovitch astronomical forcing. The susceptibility record is also characterised by sharp changes related to the levels of volcanic origin. In addition to magnetite, thermomagnetic analyses indicate the presence of iron-sulphides throughout the studied sequence. This may indicate that the ferrimagnetic magnetite (Fe_3O_4), which is the most common terrestrial magnetic mineral, was partially dissolved during anoxic diagenesis via bacterial reduction of sulfate (SO_4^{2-}) (Canfield and Berner, 1987).

Bulk sample oxygen and carbon isotope analyses were carried out on sediments where carbonate phase is prevalently calcite (dolomite concentration lower than 3-4%). Oxygen isotope values show an evident continental control on the studied sediments (average values of -2.5‰) with three stratigraphic intervals characterised by more evaporative conditions (average $\delta^{18}O$ values of 0.5-1‰).

Both the oxygen and carbon isotope records show high-frequency oscillations superimposed on longer-term trends in turn interrupted by abrupt and consistent shift. The two signals show a general short-term covariance, suggesting a hypothetical E-P budget control on the paleoproductivity system of the studied environment, such as suggested by the $\delta^{13}C$ oscillations. Conversely, during the three $\delta^{18}O$ positive excursions, carbon isotope show strong negative shifts which may indicate high organic matter preservation at the bottom of the basin induced by reduced ventilation of the column water.

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Pre-, syn- and post-evaporitic Messinian deposits in the central Apennine orogenic system: stratigraphy, palaeogeography and tectono-sedimentary significance

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During the Messinian stage, in the central Mediterranean area, compression- and extension-related basins developed as a consequence of the post-Tortonian evolution of the Tyrrhenian-Apennines system. In particular, pre-, syn- and post-evaporitic Messinian deposits sedimented both in foreland basin systems, migrating towards the Adriatic foreland, and in extension-related basins, at the Tyrrhenian side of the Apennines.

In the outermost part of the study area (Maiella Mts), pre-evaporitic Messinian deposits (*Marne a T. multiloba*) are part of a foreland succession, whereas, moving to the west, the occurrence of siliciclastic deposits denotes the presence of a pre-evaporitic Messinian foredeep in the Marche-Latium-Abruzzi area.

Both in the Simbruini-Ernici Mts and in the Latina Valley, lower Messinian coarse-grained deposits and massive sandstones (*Arenarie di Torrice*) rest unconformably on highly deformed pre-Messinian deposits (thrust-top basin). At that time, the leading edge of the Apennine chain was located at the eastern margin of the Simbruini-Ernici Mts. In the innermost part of the central Apennine chain, no evidence of pre-evaporitic Messinian deposits has been found.

At the Adriatic margin of the Apennines, the Gessoso-solfifera Fm, which consists, at least in part, of selenitic gypsum deposits (Maiella Mts), represents the deposition in a foreland setting during the MSC. In the central part of the chain, which contains remains of the Apennine foredeep domain, the syn-evaporitic Messinian deposits consist mainly of euxinic deposits, arenites and gypsarenites (Laga Flysch). The occurrence, in the Simbruini-Ernici Mts and in the Latina Valley, of clays with gypsum, which rest unconformably on a highly deformed substratum (thrust-top basins), allows us to reconstruct the Messinian central Apennine chain and to locate its leading edge at the base of the eastern slope of the Simbruini-Ernici Mts. At the Tyrrhenian side of the central Apennines, clays with selenitic gypsum showing $^{87}Sr/^{86}Sr$ ratio similar to that of the Messinian ocean water, deposited in a syn-rift basin, tectonically controlled by N060° trending normal faults.

At the Adriatic side of the central Apennines, in the Maiella area, the late Messinian post-evaporitic deposits, which are part of the Adriatic unflexured foreland succession, have been studied from several sections. >From all these sections, ostracod assemblages with Paratethyan affinity have been detected (Lago-Mare biofacies). The post-evaporitic Messinian foredeep deposits were recognized west of the Maiella unit, where hypohaline ostracods fauna with Paratethyan affinity were found (Patacca et al., 1992). Farther westward, at the eastern margin of the Fucino Plain, coarse-grained terrigenous deposits and clays unconformably overlay a Meso-Cenozoic deformed substratum. The best exposures of these terrains occur at the Le Vicenne section, where hypohaline ostracods with Paratethyan affinity have been found (Cipollari et al., 1999; Gliozzi, 1999).

Moreover, during the late Messinian Apennine building processes, in the internal zone of the chain, extensional tectonics was responsible for the onset of syn-rift basins connected with the origin of the Tyrrhenian area (Cosentino et al., 2006).

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The tectonic-sedimentary evolution of the Northern Crotone basin, Italy

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The study area is located in the northern part of the Crotone Basin that represents the wedge-top depozone of the foreland basin system developed on the Ionian side of Calabria. The north-western stratigraphic succession consists of Middle Miocene shallow marine conglomerate of the San Nicola Fm. passing upward into the offshore Ponda Clays (Tortonian), which underlie organic-rich laminites (Tripoli Fm.) at the Tortonian/Messinian boundary. During the Messinian the sedimentation in the area was dominated by evaporitic conditions producing selenite deposits and halite. In the studied area such conditions are recorded only by clastic evaporite deposits, such as limestone breccias, thick gypsrudites and gypsarenites (resedimented evaporites), which overly the pre-Messinian deposits by the basinal correlative conformity of the marginal unconformity (not visible in the study area). An intra-Messinian shortening affected this north-western succession, which now forms a SE-verging anticline and an E-dipping monocline. The anticline is characterized by a low amplitude/axial length and both its geometry and minor faulting suggest a trishear faultpropagation folding kinematics (Hardy and Ford, 1997) with low propagation/slip ($P/S \cong 0$) and large ramp angle (about 70°). A south-eastern salt-bearing succession, onlaps to the north and west these structural highs, which are composed of a sedimentary chaotic complex followed by arenites, pelites and minor, fine-grained gypsarenites topped by sediments containing a Lago Mare fauna. A local angular unconformity marks the boundary between the north-western, older succession and the southeastern one. The overlying Carvane conglomerates and early Pliocene units also onlap the structural highs, indicating that their deposition was also spatially constrained by these intra-Messinian structures.

The intra-Messinian shortening was followed by extension, which triggered salt diapirism and caused the progressive tilting of the overlying Lower Pliocene succession.

Halite is strongly modified by folding and recrystallisation, but a few primary features are preserved suggesting deposition in a saline lake, salt pan and saline mudflat (Lugli et al., in press). The $^{87}Sr/^{86}Sr$ of sulfate clastic deposits, suggest that most of the Crotone basin clastic filling derives from the dismantlement of the Lower Evaporites of the Mediterranean (Flecker et al., 2002). The $^{87}Sr/^{86}Sr$ of halite is as well in the range of the Lower Evaporite. The primary sulfate evaporites on the margin were completely eroded and redeposited in deeper portions of the basin, whereas halite was preserved and buried below the chaotic complex. The subsequent Middle Pliocene compression formed only gentle anticlines, but did not change the relationships caused by earlier deformation. Residual facies formed from halite dissolution are present as both, weld- and cap-rocks (Jackson and Cramez, 1989). Weld-rocks are thick, undeformed, and composed only of insoluble phases originally included in the salt, whereas cap-rocks are thin, strongly sheared and include clasts from the cover rocks.

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The clayey salts of epicontinental and foredeep basins (examples of the Upper Permian and the Middle Miocene from Poland)

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The clayey salt rocks (called also "salt breccia") are frequent in the evaporate formations of Upper Permian (Zechstein) and of Middle Miocene (Badenian) age from Poland (Bukowski K. et al., 2002) and they consist of halite (Ha) and insoluble components (terrigenous material TM: clay minerals, quartz grains and lithoclasts), less soluble minerals (carbonates and sulphates) and additionally – fossil remains (in the Badenian ones). Salts with lower TM content (< 15%) are called "***C**layey **Ha**lite*" (**CHa**) and with higher - "***Z**uber*" (**Z** ;15% < TM <85%). In both lithological varieties were distinguished after structural features the several sedimentary types originated in specific evaporitic environments. They are:

(1) stratificated rocks, including: **A-type** build of mono– to heteromorphic halites, rhythmically stratified with TM, sulphate admixtured, with frequent dissolution features or linearly arranged TM clasts, local zonal and "cloudy" (post-zonal) halite crystals; type was deposited in a marine setting (CHa with a high bromine [Br] content: 100–200 ppm - in deeper saline basin and deeper salt lagoon/salt pan environs; Z with Br of 50-100 ppm - in a nearshore zone of salt lagoon/pan) but submitted to periodic influxes of continental clastics (seaward winds and/or floods due to rainfalls). Low Br (0-30 ppm) salts were generated within a deeper (CHa) and a shallow nearshore (Z) zones of saline lake; **B-type** is composed of halite clasts (arenite to rudite size), graded upward or downward, with clay matrix and fine sulphate nodules, low Br (< 50 ppm); interpreted as distal mud-salt clasts flow deposits of slope slumps (initiated by intensive floods and/or seismic phenomena);

2. stuctureless (chaotic) rocks, including: **C-type**, comparable to B-type but structureless, representing proximal slump deposits accumulated from overloaded mud-clasts flows in a toe-slope and an upper slope zones; **D-**type as heteromorphic halites with dissolution features, sulphate nodules, zonal and "cloudy" halite crystals; they accumulated in a shallow costal marine zone (Br 50–200 ppm, salt lagoon/pan) or in a saline lake (Br < 30 ppm) with a constant supply of pelites (seaward winds and fresh floods) and recycling: and **E-**type as heteromorphic halites of Z-variety, with dispersed numerous chips to blocks of massive/laminated claystones and Br <30 ppm; type generated by trapping TM clasts from flood flows within bottom chlorides in a saline lake margin.

Interbeds of structureless and/or laminated salty claystones (Ha <15%, frequent intrasediment grown halite crystals) registered the periods of brine refreshing (marine or meteoric waters) and dominant TM accumulation within a salt basin (both marine and continental). Three salt types (A, D, E) are common in successions of a shallow epicontinental evaporitic basin (marine to saline lake setting), with a relatively low subsidence and TM supply form the adjacent land (the Upper Permian examples). Thickness of such deposits is several m to tens of km and they have a large extend. Types B and C are typical for an evaporitic basin in the active foredeep (the Middle Miocene profiles), characterised by frequent tectonic/seismic phenomena and a high continental supply. Thickness of salt bodies is several m to km and they form lenticular bodies (marginal fans) along a foredeep margin.

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Salt facies and their geochemistry – a review of the Upper Permian and the Middle Miocene examples of from Poland

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Salt facies (with characteristic structural features) distinguished in the sections of the Upper Permian (Zechstein) and the Middle Miocene (Lowest Serravalian/Badenian stage) deposits from Poland have represented various evaporite subenvironments: a deep and a shallow salt open basin, a deep to a shallow salt lagoon, a coastal salt pan/salina, a coastal salt-mud flat and an inland salt playa. Their geochemical characteristics (content of main elements and compounds) reflected the geochemistry of mature brines, the character of salt accumulation processes (precipitation and recycling) and ion-clastic supply, all the factors also highly depended from local palaeogeographic conditions.

Review of geochemical parameters of these facies (data from over 10 thousands of samples – Czapowski et al. 2001) evidenced that the most stable content of analyzed components is typical for both deep to shallow open basin and deep lagoon, due to a dominant precipitation process and a low continental supply. High content variations with increased sulphate-clay admixture are characteristic for shallow facies of lagoon and salt pan, with frequent deposit recycling and a higher continental input. Such processes best functioned for a continental salt playa facies with a lowest bromine and commonly very high clay content. Facies of coastal salt-mud flat is a transitional one with a high sulphate-clay admixture and relatively low but variable bromine content.

Absolute values of components differ significantly for the same facies samples studied in various parts of the single evaporate basin (the same stratigraphic unit but different local conditions) as well as for each facies type but of various age (other geochemistry primary brines for the Permian and the Miocene basins). So the definition of standard (unrelated to age) intervals of geochemical parameters for each of analyzed facies is impossible but the described tendencies of component contents seem to no accidental.

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Sedimentary and tectonic evolution of the late Messinian Irpinia-Daunia basins (Southern Apennines, Italy): interplay between foreland basin evolution and salinity crisis

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During the late Messinian, a complex scenario of evaporitic and Lago-Mare basins developed all around the Mediterranean and the southern Apennines thrust belt experienced a period of strong tectonic rearrangement and accretion, characterized by activation of overthrusts and consequent migration of depocenters. The upper Miocene successions cropping out in the Irpinia-Daunia Mts. (northern segment of the southern Apennine thrust belt) present good potential for improving our understanding of the interplay between foreland basin system evolution and Messinian salinity crisis events.

A complex east-verging imbricated system occurred within the studied sector of the thrust belt, formed by Middle Triassic to Upper Miocene shallow-marine to deep-marine carbonate and pelagic successions of the Frigento, Fortore, Daunia and Vallone del Toro tectonic units. Upper Messinian (Altavilla Basin) and Lower Pliocene (Ariano Irpino Basin) thrust-top-basin clastic sequences progressively cover these tectonic units, which are folded and thrust eastward over the buried Apulian thrust system, and illustrate the progressive eastward migration of deformation and accretion. The tectonic relationships are complicated by a polyphased structuration, which occurred both previously than following the juxtaposition of the Frigento and Fortore units onto the Daunia and Vallone del Toro units and contemporaneously to the deposition of Late Miocene and Pliocene siliciclastic deposits. The fault cut-off structures involving Frigento and Fortore units and the presence of the Apulian thrust system only at a depth of ca. 500 m in the study area testify their assemblage as resulting from breaching developed after duplexing of the Inner Apulian unit.

During the salinity crisis, the following palaeogeographic scenario is assumed: the Frigento and Fortore units were already deformed and assembled within the thrust belt, while Daunia and Vallone del Toro units were located in the undeformed foreland region beyond the chain front. Evaporitic deposits, which are conformably present only within Daunia and Vallone del Toro units, can therefore be referred to foredeep and forebulge depozones and deposited before their tectonic deformation and assembling in the orogenic wedge.

In the Daunia unit the local Messinian stratigraphy is strongly influenced by salinity crisis events and includes: (1) pre-evaporitic thin-bedded euxinic marly clay, interbedded with diatomaceous marls; (2) evaporitic limestone, selenites and redeposited gypsum; (3) post-evaporitic deposits formed by dominantly coarse-grained strata with lacustrine and alluvial facies grading upward into ostracod-rich deposits (Lago-Mare facies). The evaporitic and post-evaporitic sequences are separated by a strong angular unconformity related to the intra-Messinian tectonic phase, which caused the deformation of the Daunia unit.

The studied successions record both the effects of foreland evolution and Mediterranean salinity crisis. The intra-Messinian tectonic phase caused the depocenter migration in the study area just during the salinity crisis development. The Monte Castello Evaporites can be relate to Lower Evaporites of Mediterranean but represent an evaporitic deposition in a basin located in the Messinian Apulian foreland region, in contrast with the northern Apennines and Sicilian Messinian evaporitic basins (e.g. Vena del Gesso and Caltanisetta basins), which are referred to thrust-top to foredeep basins of the Apennine-Maghrebids foreland basin. Post-evaporitic successions (Anzano Molasse and Fiumarella unit) represent late Messinian thrust-top basin infillings located in a wedge-top depocenter of the southern Apennines foreland basin system.

Was eustacy the trigger for initial salt precipitation in the Mediterranean after all?

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Three possible causes of the Late Miocene evaporite event in the Mediterranean known as the Messinian Salinity Crisis have been discussed in the literature. These are tectonic closure of the Betic-Rifian Straits; eustatic sea level fall and increasing aridity. Decades of pollen work have indicated little variation in Mediterranean vegetation across this time period (Suc and Bessais, 1990). As a result it is difficult to attribute initiation of salt precipitation solely to climatic change. Similarly, comparison of oxygen isotope records from outside the Mediterranean (Hodell et al., 2001; Vidal et al., 2002) and the timing of salinity crisis events (Krijgsman et al., 1999) suggests that the restriction of Atlantic-Mediterranean exchange was not caused by a global eustatic sea level fall (e.g. Krijgsman et al., 2005). By a process of elimination therefore, the most likely trigger for salt precipitation in the Mediterranean at 5.96 Ma is considered to be tectonic.

While no one questions the progressive tectonic restriction associated with the Messinian Salinity Crisis, new information from a variety of sources leads us to challenge the exclusion of eustatic sea level change from the discussion of initial salt precipitation. We examine the isotopic, palaeontological and sedimentological evidence for changes in Mediterranean sea-level associated with the basal salt layers. Interpretation of these datasets is apparently contradictory. They indicate that a relative sea-level fall occurred within the Mediterranean immediately prior to the first salt precipitation at the same time as the Mediterranean received an additional influx of Atlantic water. This influx could be attributable to a eustatic sea level rise indicated by the oceanic oxygen isotope record. With recourse to recent modelling results for salt precipitation, we illustrate the magnitude of the oceanic influx and provide a coherent model for triggering salt precipitation that unifies these apparently conflicting interpretations.

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Messinian/Zanclean boundary in Northern Apennines

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In the present study, the stratigraphic data concerning several outcropping sections (Monteglino, Buttafuoco and Botteghino) and two boreholes (Montepetra and Ca' Fornaci) of the Northern Apennines succession show the presence of the basal MPl1 biozone (Cita, 1975) and therefore the very base of the Zanclean stage. The presence of early Pliocene deposits in the study area was pointed out in several works about Piedmont, Emilia-Romagna and Marche regions (Iaccarino & Papani, 1979; Borsetti et al., 1975; Carloni et al., 1974 among the others). In these papers only the FCO of *G. margaritae* and the presence of *Sphaeroidinellopsis* spp. allow the recognition of the early Pliocene record. The Messinian/Zanclean (M/Z) boundary is dated at 5.33 My in the Zanclean GSSP at Eraclea Minoa (Sicily, Italy) (Van Couvering et al., 1999). The boundary approximates the base of the Thvera magnetic event (5.24 My) at the top of precession cycle 5 (Hilgen, 1991); moreover the planktonic foraminiferal bioevents within the MPl1 are 2 sinistral coiling shift of *Neogloboquadrina acostaensis* at the base of cycles 2 and 3, the *Sphaeroidinellopsis* spp. acme from the top of cycle 2 to the top of cycle 6 and the FCO of *Globorotalia margaritae* at cycle 10 (Di Stefano et al., 1996). These events are recognized in several Mediterranean localities (ODP sites and land sections) and prove the sinchroneity of the Pliocene marine trasgression (Iaccarino et al. 1999) that marks the return of the fully marine conditions at the end of the Messinian Salinity Crisis (MSC). The Messinian deposits of the Northern Apennines area are well characterized by physical-stratigraphic means (Ricci Lucchi et al., 2002; Roveri et al., 1997, Gennari, 2003), the studied sections yield the "Lago-Mare" ostracods and foraminifera, and the M/Z boundary is usually marked by the presence of a dark, organic rich horizon characterized by different lithologies and thickness. Above this regional stratigraphic marker level the clayey Argille Azzurre Formation is present, and its basal part was investigated by means of biostratigraphic and paleomagnetic tools (the latter only in subsurface drills); they allow the recognition of the base of Thvera normal polarity interval in Montepetra and Ca'Fornaci boreholes and the two sinistral *Neogloboquadrina acostaensis* influxes in all the sections except Termina and Riccò ones. The *Sphaeroidinellopsis* spp. distribution does not show a true acme, anyhow its presence is interpreted as equivalent to the acme interval. Finally, biostratigraphic and paleomagnetic tools provide a precise, astrochronologically tuned correlation of the Argille Azzurre Fm. of the Northern Apennines with the Trubi Fm. of Sicily, thus proving that the return to normal marine condition at the end of the "Lago-Mare" phase was coeval in the two areas.

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Late Messinian biozonation in the Mediterranean area using Ostracods: a proposal

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The detailed integrated stratigraphic analyses carried out on nine late Messinian Italian sedimentary successions [Ponte Ginori (Tuscany), Campea, Ca' Blindana, Montepetra (Romagna) and Mondragone (Latium) sediment-cores, Buttafuoco (Romagna), Perticara and Maccarone (Marche) and Fonte dei Pulcini (Abruzzo) sections] supplied reliable data on the ostracod assemblages to support the definition of two ostracod biozones for the late Messinian evaporitic and post-evaporitic interval. The new *Loxoconcha muelleri* Zone is here established for the evaporitic and lower post-evaporitic interval, while the *Loxocorniculina djafarovi* Zone (Carbonnel, 1978), corresponding to the upper post-evaporitic interval, is re-defined and subdivided in two sub-zones.

The *Loxoconcha muelleri* Zone is defined as an interval biozone: its lower boundary corresponds to the FOD in the Mediterranean area of the Paratethyan species *Loxoconcha muelleri* (Mehés), while its upper boundary is represented by the FOD in the Mediterranean area of the Paratethyan species *Loxocorniculina djafarovi* (Schneider in Suzin). In the lower part (corresponding to the evaporitic interval) the ostracod assemblages are very scanty and *L. muelleri* is accompanied by scarce *Cyprideis*; in the upper part (corresponding to the lower post-evaporitic interval) *Cyprideis,* rare *Amnicythere* and *Tyrrhenocythere pontica* (Livental) are present.

The *Loxocorniculina djafarovi* Zone is defined as a local "total distribution" biozone and is limited, below and above, respectively by the FOD and LOD in the Mediterranean area of the homonym taxon. At its lower boundary also the increase of the Paratethyan contingent occurs, including, among other species, the common taxa *Euxinocythere* (*Maeotocythere*) *praebaquana* (Livental in Agalarova et al.), *Pseudocythere limata* Schneider in Agalarova et al. and *Caspiocypris alta* Zalanyi. Within the *Loxocorniculina djafarovi* Zone two sub-zones, A and B, can be detected. The lower sub-zone A is characterised by low-diversity ostracod assemblages, while the upper sub-zone B displays high-diversity ostracod assemblages. Within the sub-zone B a new contingent of Paratethyan species enters the Mediterranean, among which the more common are *Amnicythere costata* (Olteanu), *Amnicythere subcaspia* (Livental in Agalarova et al.), *Amnicythere litica* (Livental), *Amnicythere multituberculata* (Livental) and *Caspiocypris pontica* (Sokać).

The *Loxoconcha muelleri* and *Loxocorniculina djafarovi* ostracod biozones are partly correlated with the Non-Distinctive Zone of the Planktic Foraminiferal Zonal Scheme of Iaccarino (1985). The upper boundary of the *Loxocorniculina djafarovi* Zone approximates well the M/P boundary. Moreover, within the *Loxocorniculina djafarovi* Zone, the sub-zone B encompasses the last precessional cycle of the Messinian stage.

The *Loxoconcha muelleri* and *Loxocorniculina djafarovi* ostracod biozones include, respectively, the Lago-Mare Biofacies 1 and Lago-Mare Biofacies 2 of Bonaduce & Sgarrella (1999) and the Lago-Mare Assemblage (*Cyprideis* assemblage) and Paratethys Assemblage (*Loxoconcha djafarovi* assemblage) of Iaccarino & Bossio (1999).

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Solid earth response to MSC events as predicted from a 3D regional isostasy model

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The reconstruction of Mediterranean canyon and margin profiles 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, and of the deposition of Lower Messinian evaporites. The typical time scale of dessication events is probably approximately 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. Our results can be understood best if we simplify the history of loading or unloading. We find that regional isostasy may have resulted in vertical deformation of the margins of 100s of meters, substantial crustal stress changes (tens of MPa near the basement top) and basement tilting up to several ‰. The model further predicts a substantial increase in erosion rates in some regions. 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.

A case history for Messinian evaporite syntectonic deposition: the Corvillo basin of central-north Sicily

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The Corvillo sub-basin is a synformal structure that was tectonically active during and after the accumulation of Messinian deposits (Butler et al. 1995). It lies to the north of Marcasita anticline, a hanging-wall anticline, which separates two depocentres for Neogene sediments, well constrained from drill-hole data. The Corvillo Basin, a First Cycle depocentre, was in part inherited from renewed subsidence, relative to the anticline, as indicated by facies and thickness variations in the Terravecchia Formation (Butler and Grasso, 1993; Grasso and Butler, 1993). Over 300m of halite and K-salts accumulated in the centre of the basin (Mandre and Corvillo depocentres), exploited until the late 1980s by Italkali. Only the marginal carbonates and local gypsiferous deposits are preserved at outcrop (chiefly the transgressive Calcare di Base Formation) although mine/well records from Italkali may be used to build up a basin-wide model. The “First Cycle” evaporites are overlain unconformably by the upper Messinian Second Cycle strata that are predominantly clastic, reworking earlier deposits including “First Cycle” gypsum and carbonates. Conglomeratic parts of the “Second Cycle” are restricted to earlier incised valleys. These strata pass up into more sheet-like sands that onlap the substrate (including tilted “First Cycle” strata) and in turn show deepening upwards, waning clastic input trends with local lacustrine (Congerie) fauna and primary alabastrine gypsum deposits.

The northern flank of Corvillo Basin is particularly informative: here the “First Cycle” Calcare di Base Member dips steeply southwards, overlain by more gently-dipping “Second Cycle” gypse-arenites and conglomerates. The gypse-arenites are interbedded with fossiliferous silts with an abundant brackish-water fauna (Roveri et al., 2005). The outcrop of the angular unconformity between the “First” and “Second Cycle” is one of several that inspired Decima and Wezel (1973) to suggest a tectonic control on the development of the two cycles. The Corvillo Basin was active tectonically from at least late Tortonian times through deposition of “First Cycle” evaporites in the Messinian as indicated by variations in facies and thickness of these rocks. Intra-Messinian tilting appears more dramatic because it was not accompanied by sedimentation. Deformation continued during “Second Cycle” deposition and later, in Pliocene times. The Pliocene deposits (Trubi chalks, marls, bioclastic packstones) predate the last deformation event of the area.

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Gas Chromatography-Mass Spectrometry in geochemical investigation of organic matter of the Messinian Calcare di Base formation (Rossano basin, Northern Calabria, Italy)

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The Messinian Calcare di Base of the Rossano basin has been studied from sedimentary, petrographic, geochemical and biochemical point of view. This multidisciplinary approach has been carried out to clarify the depositional conditions of these peculiar carbonate sediments, up to now interpreted essentially as evaporitic limestones.

The studied sediments preserved the original mineralogy (aragonite) and microstructures. The prevailing microfacies is represented by a peloidal wackestones. Most of peloids are fecal pellets of two distinct types: those containing mainly siliciclastic particles and those with moulds of coccolithophorids but without relevant terrigenous component. We attribute the coprolites with terrigenous component to deposit feeders or grazer organisms and those with coccolithophorids to suspension-feeders and/or planktonic organisms. Stromatolitic microbialite microfacies is much less common, representing a few percent of rock volume (1%÷3%). Both peloidal and stromatolitic microbialite microfacies display a strong fluorescence indicate high organic matter content.

Palynological observations testify an abundant and diversified community of biota, which are documented by amorphous organic matter (algal or bacterial origin), vascular plants, algae, bacteria and arthropod exoskeletons. Arthropods (copepods ?) could be one of the main producers of the fecal pellets. These results are confirmed by both global and molecular biogeochemical data (Rock-Eval pyrolysis and Gas Chromatography-Mass Spectrometry). Rock-Eval pyrolysis revealed a transitional composition between types II and III kerogen, suggesting a mixture of marine and terrigenous organic matter. *n*-alkanes distribution enables the distinction of three main biological signatures: algal (mode in nC_{18}-nC_{20}), terrestrial (mode in nC_{27}-nC_{29}), and bacterial (nC_{26}-nC_{28} with no odd-even carbon number predominance). These different origins are also supported by short chain ($<C_{22}$) fatty acids and the predominance of C_{27} steranes (algal signature), as well as hopanes, branched *n*-alkanes, and unsatured fatty acids (bacterial input). While long chain fatty acids ($>C_{22}$), indicates a vascular plant input. The evidence of a rich community of organisms and the absence of hopanoids, typical of anoxic and/or hypersaline sediments (isorenieratane, pentakishomohopanoids and gammacerane), corroborates the view of normal sedimentation environment for the Calcare di Base.

The presence of a widespread and diffused organic matter remains, put in evidence by observations in natural epifluorescence, and the abundant and diversified evidence of biota from biochemical and organic petrographic data allow to interpret the conspicuous micrite matrix (30% ÷ 60%) as a deposit biologically induced.

Variations of continental input in the depositional environment are recorded in the studied section probably correlated to oscillation of the sea level. These oscillations could have caused variation of oxygen concentration in the sea water. They are testified by the presence of bioturbations, during longer periods of oxic conditions, and by the occurrence of well preserved spores and pollens, during periods of dysoxic/suboxic conditions at the sea bottom.

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Physical stratigraphic scheme of the Messinian succession of the Tertiary Piedmont Basin (TPB): new data from the Langhe region

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The TPB is a classical area for Messinian stratigraphy. The work of Sturani (1973) provided a fundamental contribution to the debate on the Messinian Salinity Crisis in the 70's. The "normal" succession that he described at Alba, was for long time considered as representative of the Piedmont Messinian stratigraphy. Further researches have shown that Piedmont Messinian sediments mainly consist of chaotic deposits and that the "Alba-type" succession is only a local exception.

The application of a physical stratigraphic approach, on the sediments exposed along the northern edge of Langhe, has allowed to propose a new stratigraphic scheme for the Messinian succession of the TPB. Three mappable unconformity bounded stratigraphic units have been recognized.

Unit 1 groups the marine pre-evaporite sediments and the primary evaporites (Gessoso-solfifera Fm. of Alba).

Unit 2 is floored by an erosive surface, associated with an angular unconformity, correlated to the "intra-Messinian unconformity" (IMU), cutting into the primary evaporites and down to the marine pre-evaporite and pre-Tortonian sediments. This unit is entirely represented by chaotic sediments, that consist of resedimented blocks of evaporites and carbonates (including CH4-derived carbonates), floating within a poorly exposed fine-grained matrix. It forms an irregular body, several kms wide and with a maximum thickness of 300 m, and is referable to the lower part of the "post-evaporitic stage". The chaotic sediments are the proximal portion of coeval chaotic facies, imaged by seismic data (Mosca, 2006) north of the study area, where they are buried below a thick Plio-Quaternary cover. The genesis of these sediments has been referred to large scale gravity driven phenomena, even if a concomitant contribution of shale diapirism and CH4-rich fluid expulsion has been also hypothesized for their origin (Dela Pierre et al., 2002; Irace, 2004; Irace et al., 2005).

Unit 3 consists of terrigenous sediments, correlatable to the "Lago-Mare" deposits, and rests unconformably on both Units 1 and 2.

The main results of this contribution can be summarized as follows:

- in large sectors of the TPB, the Messinian succession is made up of chaotic sediments. Their common occurrence reflects a large-scale sedimentary instability during the lower part of the "post-evaporitic stage";
- the chaotic deposits are bounded at the base by an erosive surface, correlatable to the IMU, that is associated with an angular unconformity, clearly suggesting its tectonic nature;
- the triggering mechanism that favoured sediment failure must be looked for in the ongoing tectonic deformation. However, a not negligible role, in promoting sedimentary instability, could have been played by the upward rise of CH4-rich fluids.

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Constraining pre-MSC Mediterranean environments

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Deriving reliable paleoenvironmental information from Messinian Mediterranean sediments is problematic: diagenetic effects are common and multiple changes affected the basin long before the actual onset of the MSC. As a result the sequence of events preceding the late Messinian evaporative phase is still not fully resolved. A generally accepted scenario is that severance of the Betic and Rif Corridors (SE Spain and NW Morocco, respectively) isolated the Mediterranean more or less completely from the Atlantic. Different stages in the Messinian restriction of the Mediterranean basin are tentatively correlated with uplift in different areas of the Corridors. Astronomical forcing is considered to have played a role as well. It is still not fully clear what the precise effects of each of these factors were of on, for instance, salinity, sea level etcetera.

Data derived from benthic foraminiferal faunas, covering the Messinian up to the start of the evaporative phase may help in reconstructing pre-MSC paleoenvironments. Aiming at development of a more accurate scenario of the pre-MSC events, reconstructions were made at several locations and at different paleo-water depths.

The Messinian salinity crisis: where do we stand today?

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The Messinian salinity crisis (MSC) is widely regarded as one of the most dramatic episodes of oceanic change of the past 20 or so million years. Earliest explanations were that extremely thick evaporites were deposited in a deep and desiccated Mediterranean basin that had been repeatedly isolated from the Atlantic Ocean, but elucidation of the causes of the isolation – whether driven largely by glacio-eustatic or tectonic processes – have been hampered by the absence of an accurate time frame. During the last decades significant progress has been made on the chronology of the Messinian deposits and accurate time scales have been developed for marine, lacustrine and continental realms. Here we will present the state of the art of the chronological data regarding the Messinian Stage. This will (hopefully) help us to solve, elucidate and discuss many of the long-standing problems and controversies related to the causes and consequences of the deposition of the so characteristic pre-evaporite, evaporite and Lago Mare facies of the Mediterranean Messinian.

Mare versus Lago-mare: stable isotope measurements on fossils from the uppermost Messinian, Serredi Quarry, Northern Tuscany, Italy

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According to the current considerations on the palaeoenvironmental evolution of the Mediterranean, after the Messinian evaporitic sedimentation and before the Pliocene flooding, non-marine sediments were deposited in a series of basins characterized by freshwater to brackish water faunas. These deposits are widespread in the Mediterranean basin and are currently termed “Lago-mare”. They should be the result of a marked inflow of freshwater into the Mediterranean basin related either to particularly humid climatic conditions and/or to an important drainage of Paratethyan waters. The Upper Messinian post-evaporitic succession of the Serredi Quarry (northern Tuscany, Italy) has been repeatedly studied and generally referred to lacustrine, laminated mudstones and other lithofacies typical of marginal-lake cyclical stacking patterns. A recent study of fish otoliths from the Serredi Quarry sediments was in rather sharp contrast with the current conclusions suggesting the existence of normal marine conditions during the upper interval of the Lago-mare event in this area. A stable isotope study has been carried out on gastropods, fish otoliths and ostracods coming from various levels of the Serredi Quarry sequence. The results obtained show no evidence of fresh water or brackish water influence and can be related to normal marine conditions. More samples will be studied from the Serredi Quarry sequence and from other sequences related to the upper Lago-mare event to check with some detail the palaeoenvironmental conditions during the post-evaporitic Messinian and pre-Pliocene events.

The end of a saline lake: an example from the Permian Rotliegend of Northern Germany

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During late Permian times a huge sedimentary basin existed in Europe, which spread from England over the North Sea and Germany to Poland. The so called Permian Basin was affected by arid climate. A large saline lake existed in the basin centre, salt and sand flats, dune fields as well as alluvial fans existed towards the basin margins. Up to 2000 m thick non-marine siliciclastics and evaporates were deposited during the Upper Rotliegend. This evolution was finished by the Zechstein marine transgression, which flooded the basin completely. Because the base level of the Southern Permian Basin was lower than the sea-level, the basin was flooded very rapidly. Afterwards extensive carbonate and salt formation started. However, several short termed marine ingressions occurred as precursors of the Zechstein transgression during Rotliegend deposition.

These marine Pre-Zechstein ingressions are characterised by an inflow of a limited amount of sea water into the saline lake. These resulted in a mixing of highly saline lake water and sea water, an enlargement of the saline lake and therefore in a changing lake-level cyclicity. Above all Rotliegend salt precipitation in the Southern Permian Basin was almost completely finished by the two latest ingressions. However, the basin was not completely connected to the Proto-Atlantic until the Zechstein-transgression.

The marine ingressions can not be proven easily in the sedimentary record; therefore they were neglected over a long time. But marine lamellibranches (*Libea reichei*) and fishes (*Acentrophorus* sp.) occur very sparsely. Above that, it is possible to detect the ingressions by $\delta^{34}S$-investigations of anhydrite which was formed within the saline lake. Other geochemical methods failed: The $^{87}Sr/^{86}Sr$-values of the same anhydrite samples give continental signatures. The interpretation of $\delta^{13}C$- and $\delta^{18}O$-studies of calcareous claystones was hampered by diagenetic overprinting. The boron content of illite depends clearly on the salinity of lake water, and is a good indicator for evaporation rates.

The triggers of these ingressions are not completely understood up to now. The sea water flew from the "Proto-Atlantic" (marine flooded basins between Greenland and Scandinavia) in the North into the Southern Permian Basin. The most likely ingression path used the Viking-Central North Sea-graben system, although a distance of about 700 km had to be bridged. But it is the same pathway, which was also used by the Zechstein transgression few million years later. The pre-Zechstein marine ingressions, except the latest one, occurred during sea-level highstands. Tectonic movements possibly resulted in the latest ingression. The marine inflows into the Southern Permian Basin were triggered by short termed events; storm tides and tsunamis can be discussed. They seem to be no single, but multi-phase ingressions. In contrast to these early inflows, the Zechstein transgression resulted from a reactivation of the Viking-Central North Sea-graben system, which allowed a long-lasting inflow of marine water.

Halite facies in the Racalmuto mine (Agrigento): further evidence of an exposure surface in the Messinian salt of Sicily

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The Racalmuto deposit (Agrigento) is one of the several halite bodies present in the sub-surface of central-western Sicily within the Caltanissetta basin. The salt deposit reaches a maximum apparent thickness of more than 1000 m and can be roughly divided into two main parts: 1) a lower halite unit with minor kainite and carnallite layers, and 2) an upper halite unit.

These two units are separated by several mud/halite cycles with a maximum tickness of ~10 m.

We have examined the sedimentology and petrography of these halite and kainite units. The lowermost sample that we were able to collect comes from the kainite zone of the lower unit and consist of halite plate cumulate. These salt layers show no evidence of current structures, dissolution and/or truncation surfaces and bottom overgrowth of the halite crystals. These characteristics indicate that evaporite precipitation took place in a stratified water body, a feature that suggests the existence of a relatively deep basin (below wave base).

Going upsection the halite rocks consist of cube and inverted pyramid cumulates with variable presence of large rafts (a few mm across). These features suggest a shallowing upward for the halite sequence.

The halite layer immediately below the mud/halite layer separating the two main evaporite units is strongly modified by closely spaced dissolution pipes, a few centimeters across, filled by clear halite cement and black mud to such an extent that it appears extremely difficult to reconstruct the original facies. This piped zone extends down up to a maximum depth of 10 m and can be interpreted by the effect of meteoric dissolution on subaerially exposed salt layers.

A similar zone has been described in the halite of Realmonte mine (some 22 km apart) were the piped salt layers are commonly upturned to form tepee structures and are cut by spectacular vertical fissures interpreted as the bordering surfaces of giant contraction polygons which developed by the effect of annual temperature fluctuations on exposed salt layers (Lugli et al., 1999).

The exposure of the basin was interrupted by several floods which deposited argillaceous layers intercalated by newly formed halite.

The upper halite unit consist of cumulates of halite skeletal hoppers showing further vertical overgrowth (chevron) that occurred at the bottom of the basin after initial growth at the brine surface. This halite shows dissolution pipes and irregular truncation of the halite crystal terminations, indicating precipitation from a non-stratified, relatively shallow water body, characteristics very similar to the upper halite unit of the Realmonte mine, immediately above the cracked surface.

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New facies interpretation of the Messinian Lower Evaporites in the Mediterranean

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The only available facies model for the Messinian Lower Evaporites in the Mediterranean is the "ideal cycle" of Vai and Ricci Lucchi (1977) for the Vena del Gesso basin. A revision of these sulfates and a comparison with other basins (Tuscany, Sicily, Calabria, Spain and Crete) and elsewhere (Babel, 2004) suggest a new facies model for their deposition.

The Vena del Gesso consists of 16 gypsum cycles separated by argillaceous sediments. The basal portion is made of thick beds of vertical massive selenite grading into banded selenite (F3 and F4 facies of Vai and Ricci Lucchi, 1977). The upper part of the section (from the 6th to the 15th bed) consists of thinner beds showing a basal massive and banded selenite, followed by nodular and lenticular selenite (F5). This nodular and lenticular selenite was considered as a clastic deposit that developed sabkha features by subaerial exposure (anhydrite nodules). The study of this facies shows no such features, but reveals that clusters of selenite crystals grew laterally, grouped in branches projecting outward from a nucleation zone into a gypsiferous carbonate-marly matrix. We interpret this facies as an extreme evolution of subacqueous selenite supercone structures described by Dronkert (1985) in the Sorbas basin (Spain). Becase no obvious conical shape may be recognized, we proposed the use of the term "branching selenite" for the F5 facies.

The stacking pattern of these facies describes a complete small scale cycle made up of regressive and transgressive phases. The depositional cycles can be described as follows:

1) Initial evaporite precipitation at relatively low salinity produced the vertical massive selenite in a relatively deep setting (initial fall, F3);

2) Continuous evaporation and drawdown produced relatively higher salinity conditions with an oscillating brine level and variable saturation conditions (lowstand, banded selenite, F4);

3) A general brine level rise and dilution introduced significant carbonate material in the system; selenite crystals formed large supercones with peripheral branches spreading laterally (transgression, branching selenite, F5); growth of cones and branches was controlled by brine level, spacing of cones and amount and composition of matrix surrounding the cones (fine-grained gypsum, carbonate and/or marls);

4) Flooding by undersaturated water stopped gypsum precipitation with the deposition of argillaceous sediments (highstand, F1);

The cyclic occurrence of the F5 facies within the the Messinian evaporites of the marginal Mediterranean basins can be related to a generalised climate change coinciding with a minimum in the Earth eccentricity (Krijgsman et al., 1999). The end of the sulfate precipitation coincides as well with a minimum in the Earth eccentricity.

Evaporite geochemistry indicates that the F5 facies appears in correspondence of major oceanic influxes in a general setting dominated by solutions strongly modified by continental waters (Lugli et al., in press).

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The deep-water counterpart of the Messinian Lower Evaporites in the Apennine foredeep: the Fanantello core (Northern Apennines, Italy)

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A general consensus has been reached in the last years in placing the onset of the MSC at 5.96 Myr, with the precipitation of evaporites in marginal peri-Mediterranean basins. More controversial is the definition of what happened in deep-basins during the Lower Evaporites deposition, due to the lack of outcropping basinal successions and well-data from the deepest Mediterranean basins. To this respect the Apennine foredeep represents an exception; both marginal and deep-water successions crop out extensively and can be compared. The main depocenters are dominated by clastic evaporites deposited in relatively deep-water settings. Primary evaporites only precipitated in shallow-water, semi-closed wedge-top basins. Their top is cut by an angular unconformity related to an important deformational phase affecting the whole Apenninic-Maghrebid chain. Biomagnetostratigraphic studies carried out in the last years show that primary evaporites of the Apennine developed synchronously with the other Mediterranean successions at 5.96 Myrs; based on cyclostratigraphic considerations, a maximum age of 5.6 Myrs has been calculated for the top unconformity. Physical-stratigraphic considerations based on regional-scale study of the Messinian successions throughout the whole Apennine foredeep (Roveri et al., 2001) suggest that this unconformity could be traced basinward at the base of the resedimented evaporites complex, thus implying the occurrence in basinal settings of a deep-water counterpart of the Lower Evaporites. Preliminary studies carried out in outcrop sections (Manzi, 2001) in the Sapigno syncline led to the recognition of a 40 m thick barren unit consisting of organic-rich clays underlying the resedimented evaporite unit that could be a time-equivalent of the Lower Evaporites. In order to have a complete record of such unit and of the underlying deposits for detailed biomagnetostratigraphic and paleoenvironmental studies, a 140 m long core was recovered in the Sapigno syncline starting from the base of the resedimented evaporites. The occurrence of the most significant calcareous plankton events documents an upper Lower Messinian age for the lower half of the core allowing the calibration of the magnetic reversal observed at 73 m as the C3r-C3An.1n transition. The upper part of the core (73 m - top), falling in the C3r chron, shows a peculiar sequence of bioevents, recording a biological crisis, with the disappearance of dynocists at 100m, foraminifera at 60 m, molluscs at 45 m (from 60 to 45 m only high-salinity tolerant pteropods assemblages are found) and nannoplankton at 36 m, more upward (36 - top) the succession is totally barren. The anomalous thickness of the C3r unit below the resedimented evaporites, which has no equivalents in pre-evaporitic successions capped by primary evaporites, as well as the peculiar sequence of observed bioevents, suggests that at least the barren deposits could be considered a basinal equivalent of the Lower Evaporites, thus confirming the preliminary interpretation of outcrop data. According to this interpretation, the disappearance of Foraminifera and the occurrence of high salinity tolerant pteropods could record the onset of evaporite precipitation within restricted marginal basins. These data confirm the hypothesis previously made that the resedimented evaporites complex completely postdates the Lower Evaporites.

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The Levant margin since the Messinian salinity crisis: the consequences of flow and dissolution

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The distal continental margin of the Levant is characterized by extensive slumping of the Plio-Quaternary sedimentary sequence. The slumps overlie the eastern edge of the Messinian evaporitic series where seismic reflectors M and N merge. The pinching-out zone of the evaporites is very rough and irregular, and forms a belt along the base of the continental slope that is nearly 200 km long and 20 km wide. The deformation of the overlying Plio-Quaternary sequence occurs where it is the thickest, and comprises slumped sedimentary series, tilted blocks and detachment faults. Numerous previous studies suggested that the Plio-Quaternary slumps, as well as the underlying irregularities in the bedding of the edge of the Messinian series, are structural features derived from a large tectonic lineament that constrains the distal continental slope of the Levant. Neev (1977) termed the phenomena "the Pelusian Line". That tectonic lineament was never observed.

Recent discovery of numerous reverse faults in the Levant Basin that offset only the upper part of the Messinian evaporites and the overlying strata, some 20-50 km west of the deformation zone, seems to illuminate the processes that formed the enigmatic Pelusian structures. The small reverse faults can be grouped into broad sets striking NE, NW and E-W, and most of them seem to affect only the Plio-Quaternary sequence and the upper part of the Messinian series, namely they offset reflector M and not reflector N. While some investigators accounted for these faults as a product of the large sedimentary load of the Nile deep-sea fan, we find this explanation incomplete, and suggest that the Nile was the largest source of loads on the Messinian evaporites, but not the only one. Additional fluvial sedimentary accumulations can be discerned also off central Israel, which contributed to the depositional lithostatic load on the Messinian evaporitic series as well. The load of these depocenters made the salt component in the evaporitic series of the Levant basin flow basinward. This flow tapered off at the eastern edge of the salt deposit, where the flow of the pinching-out salt was compensated by subsidence of the overlying strata. This subsidence, in turn, generated geotechnical faulting that enabled the penetration of seawater into the evaporitic layers and dissolved them gradually. As the dissolution removed portions of the evaporites, it left behind irregular relicts of the evaporitic layer, further enhancing the subsidence of the overlying strata, so that slumping was enhanced. We believe that the structures at the base of the continental slope of the Levant were initiated by basinwards flow of the salt component of the Messinian evaporite series due to fluviatile depositional load of a few contributing rivers. The flow of the salt led to the penetration of seawater into the evaporitic series and dissolved large parts of them. The Plio-Quaternary sedimentary strata collapsed into the voids formed by the dissolved evaporites.

Primary precipitated and resedimented gypsum facies in Late Messinian "Evaporiti di Monte Castello Fm." (Southern Apennines foredeep, Italy)

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An evaporitic limestone-gypsum succession, belonging to the Evaporiti di Monte Castello Formation, is recognized in the late Messinian of the Irpinia-Daunia Mt. (Southern Apennines, Italy). The unit is formed by massive and laminated evaporitic limestones and by primary and clastic gypsum showing a complex depositional and diagenetic history. Detailed stratigraphical, sedimentological and strontium geochemistry data permitted reconstruction of stratigraphic and facies relations of gypsum deposits, depositional environment and basin evolution.

Genetically related gypsum lithofacies can be grouped into two facies associations. The autochthonous gypsum consists of shallow water selenitic, acicular, granular and laminated gypsum facies and is characterized by the absence of high-energy sedimentary structures. The redeposited gypsum consists of shallow- to deeper-water fine-grained laminated gypsum, gypsarenites, pebbly gypsarenites and gypsrudites, showing common features of resedimented deposits. Nodular structures occurring in the laminated gypsum facies could be mostly related to late diagenetic processes. The gypsum sections show an extensive development of reworked clastic gypsum, varying from 60% to 100% of total thickness. The gypsum was deposited from mainly marine brines, based on their Sr isotopic compositions. Gypsum facies usually preserve evidences of variability from shallow-water to deeper-water deposition conditions in an extensional evaporative basin. Frequent vertical changes of gypsum facies associations record variations in brine depth (flooding events) and tectonic activity in the basin; Sr content and facies variations in autochthonous gypsum record minor variations in salinity.

Evaporitic facies successions observed in outcrops are probably related to interplay of base-level oscillations, local tectonics, hydrodynamic events and rates of evaporation, which control water depth and basin dynamics. Three main types of evaporite successions have been found in the study area: a) the first type consists entirely of 30 to 70 m thick evaporitic limestones, which are commonly brecciated and truncated at the top by an erosive unconformity, b) the second type is formed of evaporitic limestones passing upward to gypsum up to 180 m thick, and c) the third type is formed entirely of gypsum, 40 to 100 m in thickness. All the types of successions are locally characterized by the presence of diatomaceous and euxinic marls at their base. The differences among the three types of evaporitic successions have interpreted to be related to their position in the basin and to the morpho-structural evolution of the basin, which strongly conditioned the sedimentary evolution in the different sectors along the foreland ramp; in particular type-a corresponds to basin margin, type-b to a proximal sector and type-c to a distal basin sector.

An erosional angular unconformity, as a consequence of the intra-Messinian tectonic phase, which cut-off evaporitic deposition in the study area, marks the base of the post-evaporitic alluvial and lacustrine deposits where primary evaporites are absent. The Messinian Formation of Evaporiti di Monte Castello represents an uncommon type of evaporitic succession, probably developed in a extensional setting in a basin located along the Apulian foreland ramp, in contrast with the northern Apennines basins (e.g. Vena del Gesso basin), which are considered to be thrust-top or foredeep basins of the Apennine foreland basin system. This sedimentary series is an equivalent of the Lower Evaporites of other parts of the Mediterranean.

Quantitative analyses of sea level, salinity, and strait transports during and preceding the Messinian salinity crisis

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We aim to achieve quantitative physics-based insight into the processes that played a role during, as well as preceding, the Messinian Salinity Crisis of the Mediterranean basin. To this extent we first study in isolation two configurations that are part of many of the proposed evolutionary scenarios for the crisis proper: (1) that of sea-level drawdown or desiccation (and subsequent re-filling), (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.

In addition to the calculations described in the above, which relate to the salinity crisis proper, we will present preliminary results of an analysis of the dynamics of the double-gateway configuration that existed prior to the crisis. In this, a general circulation model is used to determine how strait transports evolve in response to the proposed non-synchronous closure of the Betic and Rif corridors.

Calcareous nannoplankton bioevents in the pre-evaporitic Messinian and their paleoenvironmental implications

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During the Messinian (7.2 to 5.3 Ma) the Mediterranean area experienced fast and deep climatic and eustatic structural changes. The stratigraphic framework for this interval is relatively well constrained and the base of evaporites dated at approximately 6 Ma determines duration of at least 1.2 Ma for the pre-evaporitic Messinian that are object of this study. Aim of our work is to compare the calcareous nannoplankton data from the Fanantello borehole to other Messinian sections where the pre-evaporitic marls occurs and show biovents that are clearly related to the paleonvironmental changes affecting the Mediterranean basin.

In the Fanantello section autochtonous calcareous nannofossil occur continuously from the very base of the section to the depth of 54.68 m, more upward the succession is characterised by the rare occurrence of autochtonous nannofossil (mainly *Sphenolithus* spp.) and by allochtonous assemblages of reworked Mesozoic to Cenozoic species alternated to barren intervals.

The occurrence of *Amaurolithus primus* and *Amaurolithus delicatus* occur since the core bottom allow to refer the whole core to the zone MNN11b proposed by Raffi et al 2003. Due to the lack of *Amaurolithus amplificus*, (Whose total range indicates the MNN 11c) we cannot exclude to be above the *A. amplificus* interval. An interesting feature is the occurrence of strongly oligotypic assemblage between 70 m and 36 m. Three main peaks of Sphenolithus spp. have been recognised at 38.47 m, 43,44 m and 62,77 m depth.

Similarly to what observed in of Cyprus Messinian sections of Polemi (Wade and Bown 2006) and Pissouri (Kouwenhoven et al, 2006) this assemblage suggests highly unstable environments probably related to increased salinity conditions.

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New insights on the onset of the Messinian salinity crisis in Cyprus (East Mediterranean)

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A.37 SS.1

In the South Cyprus basins (Polemi, Pissouri and Psematismenos), previous studies, in the 1980's, including mapping, tectonics, biostratigraphy and environmental analysis, led the majority of searchers involved to the conclusion that the Messinian evaporites were preceded by a progressive decrease in the depth of the marine waters, from approximately 500 m to the very shallow conditions when they deposited. The restriction of the environment was related to the continuous tectonic events which affected the Cyprus basins, and the progressive closure of the connexion between the Mediterranean and the Atlantic Ocean, together with changes in the climate (Orszag-Sperber *et al*., 1980; Robertson *et al.,* 1995; Merle et al., 2002; Rouchy and Caruso, 2006).

Recently acquired data allowed, thanks to an high resolution integrated stratigraphy of the Pissouri Basin (Krijgsman *et al*., 2002), to precise the onset of evaporites precipitation and document the chronology of several biostratigraphic events, in correlation to the other well dated Mediterranean sections. Studies on the calcareous plankton (Morigi *et al*., in press) and the benthic foraminifera (Kouwenhoven *et al.,* in press) made possible to precise the paleo-environment of the infra-evaporitic sediments in this Pissouri section, and led these authors to moderate the notion of a progressive decrease of the water depth in the basin.

A new step in the stratigraphic knowledge of the infra-evaporitic succession is now well established in the Psematismenos Basin. In particular the Tochni section covers an interval from the lowermost marine Messinian (*G. miotumida* FO) to restricted evaporite conditions (5.96 Ma). In the lowermost part *Siphonina reticulata* LO was recognized; this disappearence, astronomically dated at 7.16 Ma (Kouwenhoven *et al.,* in press), corresponds to a drastic paleoenvironmental change of the Mediterranean Basin. The Tochni section also shows *N. acostaensis* coiling changes from senestral to dextral, astronomical dated at 6.34 Ma (Blanc-Valleron *et al*., 2002; Krijgsman *et al*., 2002). In the upper part the decrease of planktic foraminifera and by the increase of shelf-upper shelf benthic foraminifera testify the progressive decrease of the water depth. Like for other Messininan Mediterranean sections the precessional forcing controls sedimentary lithological cyclicities. In fact, a good correlation cycle by cycle with Pissouri and other Mediterranean sections has been proposed.

All these data conduct to question the paleo-environment which prevailed in the basins since the lower Messinian marine conditions, up to the onset of the evaporitic deposition. Particularly the progressive decrease in depth of the water in these basins versus periodic environmental stresses is discussed, and the roles of the tectonics and sea levels changes are analysed.

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Balatino-like laminated evaporites: some examples and criteria of chemical origin

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Many evaporite formations made up of laminated sulphates have undergone severe diagenetic modifications in both texture and mineralogy. Traditionally, this fact has made it difficult to interpret them either as chemical (primary) precipitates or as clastic (resedimented) deposits. An example is the “balatino” facies of the Italian Messinian. In Sicily, where balatino is partly preserved as primary gypsum, Ogniben (1955) observed the existence of reverse grading and interpreted this feature as resulting from chemical deposition controlled by annual rhythms. In the Adriatic zone, however, where this facies has been totally transformed into anhydrite and secondary gypsum, Manzi et al. (2005) have recently reinterpreted almost all the laminar balatino as originated by deep-water turbiditic currents. From the point of view of these authors (and also other authors), a clastic origin cannot be ruled out for this facies in Messinian areas different from the Adriatic zone.

In order to make progress on this type of debates, a more detailed textural information of chemical-evaporitic laminites would be required. In general, these evaporitic laminites alternate with non-evaporitic laminae. For the present contribution, examples of laminated facies made up of gypsum, anhydrite, glauberite, halite, sylvite and borax were selected. In all of them, both the textures and the sedimentological context suggest that they are primary precipitates. The main components in these laminae are crystals and, subordinately, sediment matrix. In the former, clear (without inclusions) and cloudy (with fluid or solid inclusions) textures are differentiated. The crystals currently forming the laminae, might have nucleated in the air-brine interface or within the brine (settled down cumulates), in the brine-sediment interface (bottom-nucleated; bottom-grown), and underneath this interface (interstitially-grown).

In the chemical-evaporitic laminae, single laminae can be monomineralic, polymineralic, and matrix-rich. *Monomineralic laminae* involve: texturally homogeneous types (cumulate laminae; palisade laminae; laminae formed by bottom-grown, non-competitive crystals) and texturally heterogeneous types (some sedentary laminae; laminae alternating clear and cloudy crystal horizons; laminae with normal, reverse and symmetrical grading). *Polymineralic laminae* involve horizons of two or more evaporitic minerals. *Matrix-rich laminae* bear interstitially-grown crystals, either texturally homogeneous or displaying grading.

Some particular textures and laminae, for which a clastic origin can hardly be assumed, are here emphasized, and their depositional mechanisms are discussed.

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Fossil microbial communities in the evaporite deposits of the Vena del Gesso (northern Apennines, Italy)

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Many open questions in the "Messinian puzzle" are related to the paleoenvironmental aspects of evaporites deposition. In order to provide further insight for a paleoenvironmental reconstruction of the onset of the Messinian salinity crisis in the Mediterranean, a study of the microbial communities preserved in the Lower Evaporites deposits has been performed. All the samples have been collected in the gypsum quarry of Monte Tondo (Vena del Gesso, Northern Apennines), a 230 m-thick succession consisting of up to 16 gypsum-shale cycles (Roveri et al., 2006). Our preliminary study focus on filamentous structures previously reported as "spaghetti-like" included into calc-gypsum algal laminites (Vai and Ricci-Lucchi, 1976) and gypsum crystals belonging to the 6th cycle (30 m-thick).

Samples analyzed belong to banded selenite (lower part of the cycle) and branching selenite (upper part of the cycle) gypsum facies (Roveri et al., 2006). As shown by XRD and EDS analyses, gypsum crystals of the first facies contain traces of dolomite and clay minerals, whereas the carbonate laminae consist of dolomite with pyrite traces. The bulk mineralogy of the branching selenite is mainly constituted by calcium sulphate, dolomite and traces of clay minerals. A notable characteristic of the banded selenite is that gypsum crystals host abundant filamentous forms resembling cyanobacterial populations.

In order to decipher the enigmatic "spaghetti-like" structures several analyses have been performed: light, fluorescence and scanning electron microscopy associated with energy dispersion spectra of the characteristic X-ray radiation (EDX), and HPLC. All the analyses performed permit to recognize that the "spaghetti-like" population is constituted by cyanobacteria (>100 µm length; when not broken). Visible under low magnification as white tubes, occasionally with black grains. Many of them are oriented along the c-axes of gypsum crystals whereas others do not show any orientation. According to our observations at least three different populations are present in cycle VI: Scytonematacean cyanobacteria, filamentous organism Type 1, and Type 2. Scytonematacean cyanobacteria were recognized according to: a) size (30-50 µm diameter), b) characteristic filament structure (inserted funnel shaped units, "zigzag"), c) auto fluorescence and d) comparison with material degradation in modern microbial ecosystems. The mineralogical composition of Scytonematacean cyanobacteria appeared to be only gypsum. Filamentous organism Type 1 consist of filaments filled by clay minerals, small portion of gypsum, and several pyrite grains occurring only on the outer sheath. Filamentous organism Type 2 are filled with a more homogeneous material composed of Si, Ca, Fe and in some areas are Mg-rich. Performed analyses on HPLC and spectrophotometer showed traces of polysaccharides (possibly EPS). Ongoing molecular approaches are promising. The results of our observations and analyses have to be considered preliminary and are open for discussion.

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Sulphur and carbonate microbialites in the "Calcare Solfifero" from Sicily

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The sulphur-rich "Calcare solfifero" are one the pecularities of the Messinian deposits from Sicily, both from economical as well as geobiological perspective. Dessau et al. (1962) proposed a bacterial origin for the native sulphur and some of the associated carbonates. Other examples for microbial sulphur deposits include the salt-domes along the cost of the Gulf of Mexico (Feely & Kulp 1957), the Polish Carpathian foredeep (Pawlowski et al. 1979), or Zechstein strata of Germany (Peckmann et al. 1999). Sulphate-reducing bacteria like *Desulfovibrio* species use dissolved sulphate to oxidize organic matter, particularily crude oil and short-chain hydrocarbons. Subsequently, the produced bicarbonate causes carbonate precipitation and hydrogen sulphide may be oxidized to native sulphur.

$CaSO_4 \times 2H_2O \rightarrow Ca^{2+} + SO_4^{2-} + 2H_2O$
$SO_4^{2-} + 2CH_2O \rightarrow 2HCO_3^- + H_2S$
$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + H_2O + CO_2$

Here, we present new data on microbial carbonates from the "Calcare solfifero". During a field trip to Sicily in June 2005 rocks from four localities have been sampled. They can be crudely divided into three groups, which are (i) sulphur-bearing micrite to microspar crosscut by spar-filled veins, (ii) celestine associated with sparry calcite and sulphur accompanied by minor micrite, and (iii) gypsum with sulphur and only few very small dolomite nodules. Rocks of the first group contain accessory sparry calcite pseudomorphing lenticular gypsum crystals, revealing that deposition occurred under evaporative conditions. Stable isotope ratios of distinct carbonate mineral phases confirm that carbon is derived from the microbial remineralization of hydrocarbons and that some carbonates were precipitated under evaporitic conditions.

The limestone at one of the localities contains abundant filamentous structures embedded in a microspar matrix. A microbial origin of the filaments is feasible, but at this point we cannot exclude that they represent brine-shrimp faecal pellets. The same limestone also contains carbonate pseudomorphs after halite and secondary gypsum. In order to further classify the bacteria involved in sulphur and carbonate authigenesis and the nature of the filamentous fossils, we will present preliminary results of lipid-biomarker-analyses including compound-specific stable isotope ratios.

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Paleoenvironmental changes during the Calcare di Base deposition: a prelude to the Messinian salinity crisis

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The Calcare di Base Formation corresponds to a transitional sedimentary unit between the Tripoli Formation and the main Messinian evaporitic deposits. Previous studies in the central Sicilian Basin have shown that the Calcare di Base was deposited in brackish to hypersaline environmental conditions and was thus considered to represent the true onset of the Salinity Crisis (McKenzie, 1985; Bellanca et al., 2001).

We present here an integrated sedimentological and stable isotope study of the Calcare di Base from different sections from Sicily (Contrada Gaspa, Capodarso, Monte di Drasi, Torrente Vaccarizzo, Serra Pirciata) and Calabria (Cropalati, Verzino) in an attempt to better constrain the paleoenvironmental significance of this sedimentary unit during the Messinian Salinity Crisis. The Calcare di Base displays various lithofacies: finely laminated limestone, stromatolitic limestone, fine-grained peloidal limestone, massive limestone, brecciated and travertine-like limestones, sulfur-rich and organic-rich limestones (the so-called "calcare solfifera"). These limestones often contain diagnostic structures of evaporitic conditions, as molds of gypsum or halite crystals, pseudomorphs of gypsum or halite replaced by carbonate or native sulfur, and sometimes relict gypsum crystals. The carbonate mineralogy is variable: aragonite, calcite, dolomite and occasionally strontianite, occur either as a single mineral or in mixtures of these different phases. Celestite is a common mineral in all the studied sections, excepted in Capodarso where it is absent whereas barite is detected as a minor component by SEM observations.

The oxygen and carbon isotopic compositions of the carbonates exhibit a very wide range of variations ($-4.11<\delta^{18}O$‰ V-PDB<9.3; $-48.78<\delta^{13}C$‰ V-PDB<1.2), where the highest $\delta^{18}O$ values are measured in dolomite as expected for this carbonate, which is enriched in ^{18}O relative to calcite or aragonite precipitated in similar conditions. Moreover, the isotopic values define three main different groupings: the first group including the values of Torrente Vaccarizzo, Cropalati and Verzino sections is characterized by positive $\delta^{18}O$ values and positive to slightly negative $\delta^{13}C$ values, the second group including the values of Serra Pirciata and Monte di Drasi sections is characterized by negative $\delta^{18}O$ values and negative (but higher than –17‰) $\delta^{13}C$ values, the third group including the values of the calcare solfifero sections is characterized by negative (Monte Muculufa) or positive (Contrada Gaspa, Capodarso) $\delta^{18}O$ values and by very negative (lower than –27.9‰) $\delta^{13}C$ values.

The sedimentary and diagenetic history of the Calcare di Base appears very complex: primary carbonate and gypsum layers were deposited in marine to hypersaline solutions with major freshwater dilution in the marginal parts of the basins; bacterial sulfate reduction was fuelled by organic matter or hydrocarbons and was responsible for the replacement of gypsum by carbonate; the sulfide released by this process was further oxidized as native sulfur or as sulfate (celestite, barite, gypsum) depending on the redox conditions in the bottom waters.

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Paleogeography of Euxinian-Caspian basin during the Pontian and Mediterranean - Euxinian connections

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Correlation of the Pontian with the Mediterranean scale is disputable. According to magnetostratigraphic results, calcareous nannofossil data from the Dacic Basin (NN11, NN12), and correlation with the current Astronomical Polarity Time Scale, as well as biogeographic data on the origin of the Pontian fauna, the Pontian corresponds to the upper Messinian and correlates with the salinity crisis.

The Early Pontian (Novorossian) Eastern Paratethys was strongly enlarged (Popov et al., 2004). Deep-water environments existed only in the Black Sea and South Caspian depressions. Based on the prevailing brackish fauna, the salinity of the basin was low, but it did not fall under 5-8 ppt. Presence of marine nannoplankton testifies for episodic ingression of marine water. A pronounced regression at the beginning of the Late Pontian (Portaferrian) led to the emergence of the Euxinian Basin shelf, closing of the Ciscaucasian Strait and separating the Caspian Basin. This fall in sea level approximately corresponded in time with a drastic sea level drop in the Mediterranean (5.7-5.6 Ma). New sharp regression took place at end of the Pontian when all recent shelf of the Black and Azov seas was emerged.

The brackish fauna and microflora of the "Lago Mare" facies included numerous genera and species, common with the Paratethys: endemic lymnocardiins, *Congeria, Melanopsis* among mollusks, *Loxoconcha djaffarovi* and *Cyprideis pannonica* ostracod associations, *Galeacysta etrusca* among dinocysts, but contained euryhaline marine genera, which were absent in the Paratethys (*Cerastoderma, Mactra* among the mollusks - Popov, Nevesskaya, 2000). Probably, origins of the "Lago Mare" brackish elements are related to the oldest - Pannonian Paratethyan biota, but their subsequent development unfolded independently. Some components of this specific biota, together with more rare Pannonian elements, were ancestral for the younger Pontian fauna of the Euxinian-Caspian Paratethys. They moved from the Mediterranean to the Eastern Paratethys through intermediate basins (? Aegean and Dacic).

Well-preserved Pontian-like mollusks were studied from the Serres basin, Northern Greece, Choumnikon formation (22 species of bivalves and 1 species of gastropods - Popov, Nevesskaya, 2000). From paleogeographic and biogeographic point of view the North Aegean basin was more closely connected with the Mediterranean Messinian basin. It is possible, the North Aegean Basin was the intermediate one, where the Maeotian and Pontian mollusk associations had been formed.

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The Miocene/Pliocene boundary in Tuscany (Italy): micropaleontological evidence from the Serredi Quarry succession

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The Miocene/Pliocene (M/P) boundary coincides with the "…*first appearance of permanent open marine condition in the Mediterranean…after the Late Miocene <<salinity crisis>>*" (Cita, 1975). According to the most recent ratification, the GSSP of the M/P boundary, which is located at the base of the Trubi Formation of the Eraclea Minoa Section (five cycles below the Thvera Subchron), has an astrochronological age of 5.33 Ma (Van Couvering et al., 2000). As a consequence of this ratification, the M/P boundary recorded within Tuscan sections needs to be both reconsidered through a multidisciplinary approach (high resolution biostratigraphy, cyclostratigraphy, magnetostratigraphy, etc) and compared with the most significant Mediterranean successions.

In this work, we report the results of micropaleontological analyses performed on the Pliocene deposits exposed in the Serredi Quarry (Fine River Basin, Tuscany - Italy), since magnetostratigraphic analyses carried out in the same samples failed.

In the Serredi Quarry succession, the M/P boundary has been traditionally (Bossio et al., 1981) correlated to the surface which marks the abrupt change in depositional setting between open marine fines and underlying lacustrine deposits (post-evaporitic phase). The latter contain a typical Lago-Mare fossiliferous assemblage, characterised by Paratethyan brackish ostracods, and rare benthic foraminifera (*Ammonia beccarii tepida*, *Bolivina paralica* and a small discorbid).

The open marine deposits include rich and well diversified assemblages, which document 1) an outer neritic-upper epibathyal setting, and 2) the occurrence of the Pliocene basal zones both in foraminifer and nannofossil biostratigraphy. Moreover, the main bioevents recorded within the most significant and astrochronologically calibrated lower Pliocene Mediterranean sections (Eraclea Minoa section: Di Stefano et al., 1996; Sgarrella et al., 1997, Holes 975B and 974B: Iaccarino et al., 1999, Pissouri Section: Di Stefano et al., 1999) have been recognised also in the Pliocene fines of Serredi Quarry.

Specifically, the main planktonic events recognised within such deposits are enumerated as follows: 1) two short shifts of *Neogloboquadrina acostaensis* sinistral, at 2.40 m and 7.40 m above the base of Pliocene, respectively; 2) a peak of abundance of *Globigerina nepenthes* at 5 m (this peak precedes the base of the *Sphaeroidinellopsis* acme); 3) the common occurrence of *Globorotalia scitula* dextral at 12 m above the base.

Some benthic foraminiferal events recognised in this interval are: 1) the presence of *Buliminella inauris* in the basal samples of the Pliocene succession and its absence upward; 2) the appearance of *Globocassidulina subglobosa* and *Oridorsalis stellatus* at about 3 m; 3) the appearance of *Anomalinoides helicinus* at 14 m.

Based on the above mentioned micropaleontological observations, it follows that the base of the Pliocene deposits exposed in the Serredi Quarry is coeval with M/P boundary as formally ratified at Eraclea Minoa Section.

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Geological transect from the Ligurian Sea to the Po plain

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A geological transect from the abyssal plain of the Ligurian Sea to the Po Plain, realised integrating seismic profiles (ENI, BG Group and CROP data set), well data and surface geology, is presented and discussed in order to highlight Messinian deposits and their structural-stratigraphic features in different structural domains, as a contribute to better define the geodynamic and tectonic implication of the Messinian salinity crisis (MSC) within the Northern Apennines (NA) evolution.

In late Tortonian-early Pliocene time three main tectonic pulses caused the uplift of the emerging NA orogenic wedge and the outward migration of its associated basins (foredeep and wedge top basins), while a coeval extensional tectonic regime developed in hinterland areas (Tuscany region and Northern Tyrrhenian sea).

The frontal zone of the NA orogenic wedge, thrusting over the west-dipping Adriatic monocline, is imaged in the NE part of the transect. Its thrust front is now buried under a thick succession of Plio-Pleistocene synorogenic deposits in the subsurface of the Po Plain. The Ligurian Units, the uppermost nappe of the tectonic pile, overly Oligo-Miocene foredeep turbidites which are tectonically stacked and accreted to the chain, together with their Mesozoic carbonatic substratum. In the NA foreland basin system two distinctive wedge-top basin types, with different morphostructural setting and Messinian stratigraphy, have been recognised: 1) closed marginal basins, where shallow-water primary evaporites, deposited during the first phase of the MSC, underwent deformation, uplift and erosion during the intra-Messinian tectonic phase (i.e. the Vena del Gesso basin, western Romagna area); 2) deeper and more subsiding basins where organic-rich shales and thin limestones, coeval to marginal basins evaporites, were overlain by relatively deep-water resedimented evaporites during the intra-Messinian tectonic phase (i.e. the Cortemaggiore basin, in the Emila area). In deep basinal settings primary evaporites are never found. During the intra-Messinian tectonic phase the main foredeep depocentre shifted toward the NE and the late Tortonian-early Messinian foreland ramp areas were drowned.

The axial zone of the chain occurs in the central part of the transect. No Messinian deposits are found here because this area underwent strong uplift and emersion during this time interval.

Hinterland areas of the NA chain, characterised by peculiar Messinian deposits, occur in the SW portion of the transect: the Ligurian Basin and extensional basins pertaining to the Northern Tyrrhenian Sea and Tuscany region.

The late Oligocene-early Miocene Ligurian Basin syn-rift sequences are highlighted in the Ligurian Basin. The Alpine units are interested by extensional west-dipping listric faults. An undifferentiated Messinian unit, including evaporites, salt and late Messinian deposits, has been recognised. Its deposition is related to a post-rift thermal subsidence regime that took place after the counterclockwise rotation of the Corsica-Sardinia Block. This well-stratified seismic unit shows evidence of deformations due to salt diapirism and gravitational tectonics, driven by shallow low-angle listrict faults that sole out at its base or immediately beneath.

Moving NE-ward the intra-Messinian unconformity is sealed by the latest Messinian “Lago Mare” units, as recognized in the Gorgona High.

The Northern Tyrrhenian Sea and Tuscany region in upper Tortonian-lower Pliocene time underwent extensional tectonic regime, with the developement of basins bounded by main west-dipping low-angle listric faults. In these basins, actually poor represented in our transect, primary evaporites are preserved under upper Messinian-Pliocene deposits. The Viareggio basin, imaged on this transect, displays evidence of important extensional tectonic regime only in Plio-Pleistocene time. At the base of these syn-rift deposits a probable undifferentiated Messinian unit has been traced. These sediments may represent the onset of the extensional tectonic phase in this area.

The Messinian salinity crisis in the Mediterranean: new concepts and scenarios

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The debate about the interpretation of the Messinian salinity crisis (MSC) has been reactivated in the last decade due to the availability of an accurate time-scale, to new conceptual models supported by intensive researches carried out both on marginal and deep offshore basins, as well as to innovative modelling approaches. If there is a relative consensus on the age of the major boundaries i.e., the onset and the end of the MSC although with some slight differences, the debate is focused nowadays on timing and spatial distribution of the different evaporitic units (synchronism *versus* diachronism at the Mediterranean scale), on depositional settings in which the evaporites precipitated (deep *versus* shallow water, marine *versus* continental, primary *versus* resedimented evaporites), on the significance of the lago-mare conditions (generalised freshwater to brackish lakes at the Mediterranean scale or small scale low salinity settings along the shores of an already re-established open sea) and on the timing of restoration of the marine conditions (abrupt marine inundation in the earliest Zanclean, progressive, episodic or permanent reestablishment during the upper Messinian).

Notwithstanding the exceptional quality of the dataset acquired on the MSC since its discovery more than 35 years ago, the rise of so opposing interpretations demonstrates that a great number of crucial points still remain poorly documented and therefore understood, such as the stratigraphic and regional correlations of the evaporites located in the deep offshore and land basins, the very different resolution scale in time and space between the different studies, the results obtained from different types of approaches and performed on separate basins and which are not crossed enough and generally not integrated at a global scale. Surprisingly, very little attention is brought to the mechanisms of deposition of the evaporites themselves which are however the major sedimentary expression of the MSC and at the heart of its interpretation. The understanding of the evaporite settings increased considerably in the meantime due to thorough studies of modern environments. Interpretation of the Messinian evaporites results sometimes from the study of basins where they are poorly developed and even completely absent.

This introductive talk is aimed as a re-examination of the major data and an attempt of assessment of the viability of the different models in order to progress towards a better integrated scenario at the global scale. The final understanding of the MSC however will not be fulfilled as long as the whole evaporitic sequence present under the bottom of the deep basins is not recovered, providing then definitive data on the age of the MSC and the hydrological changes that this unusual event involved.

The end of the Messinian salinity crisis: new insights from the Chelif Basin (Algeria)

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How did the Messinian Salinity Crisis end is now matter of intense debate between two opposite concepts: (1) a generalised dilution event, the so-called Lago-Mare, followed by the sudden restoration of the marine conditions at the base of Zanclean, (2) a complete or partial marine refill that would have happened earlier during the upper Messinian.

The Chelif Basin of Northwestern Algeria, one of the greatest Messinian marginal basins of the Mediterranean, provides an exceptional opportunity to study in detail how this major paleoenvironmental change occurred through continuous sedimentary records of the Miocene Pliocene boundary. Five sections representative of both the central and marginal areas of the basin have been analysed in detail for sedimentology, mineralogy, foraminifer and ostracod assemblages, and stable isotope composition of the carbonates. The late Messinian deposits exhibit a great lithological variability with predominant clastic deposits (sandstones, siltstones, conglomerates) locally associated to carbonates including stromatolites and, in the marginal areas, to large slided masses of lower Messinian (Tripoli Unit) that settled just before the base of Zanclean. Most sediments are barren of fossils or characterized by microfossil contents typical of predominantly hyposaline conditions (ostracods, characeae) mixed with benthic foraminifers known to be able to live in stressed environnements and even in lacustrine conditions. Fewer samples contain assemblages of reworked planktonic foraminifers. The stable isotope composition of carbonates exhibit very low $\delta^{18}O$ values which confirm that the depositional environments were dominated by low salinity conditions. In contrast, communities of benthic and planktonic foraminifers reappeared suddenly at the base of Zanclean coevally to a rise of the $\delta^{18}O$ values that both typify marine conditions. The beginning of the marine flooding is marked by quite unfavourable conditions recorded by poorly diversified assemblages of planktonic foraminifers and of benthic communities tolerant to hypoxic bottom water conditions; more stable marine conditions with better bottom water ventilation set up only after one precession cycle. Except for the more marginal areas where conglomerates and erosional features are observed, the restoration of marine conditions occurred abruptly but with no evidence of erosion in the more central areas where the contact is only marked by the strong burrowing activity of benthic macrofossils indicating that the hydrological change corresponded to the replacement of low-salinity waters by marine waters. The mixing of these two kinds of waters and the permanence of freshwater inputs in the initial stage of the transgression may explain that the community of planktonic foraminifers hardly survived in such unfavourable ecological conditions and reached a normal development later when more stable marine conditions settled.

This study from the Chelif Basin and the comparison with coeval sections from both marginal and deep Mediterranean basins confirm that the Lago-Mare was a widespread dilution event in the whole Mediterranean at the end of Messinian, which was abruptly interrupted by the marine inundation at the base of Zanclean.

A high-resolution stratigraphic framework for the latest Messinian events in the Mediterranean area

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The integration of physical- and ecobiostratigraphic approaches allowed to define a high-resolution stratigraphic model for the uppermost Messinian deposits of the Mediterranean, thus providing new constraints for calibrating the time and space distribution of palaeoenvironmental proxies of the final phase of the Messinian salinity crisis (MSC). Following the massive deposition of marine evaporites, upper Messinian deposits record the transition toward non-marine conditions, culminating in a dilution event, the so called 'Lago Mare' phase. Two surfaces associated with sharp facies changes define the boundaries of the corresponding stratigraphic unit: the intra-Messinian unconformity (MES) and its correlative conformity at the base (~5.6 Ma) and the M/P boundary at top (5.33 Ma).

This interval records the development of skizohaline to freshwater basins in a Mediterranean largely disconnected from the ocean. However, normal to stressed marine conditions have been claimed by several Authors, based on geochemical and paleontological evidences. It follows that late Messinian palaeohydrology, connections and elevation of Mediterranean sub-basins are still not fully understood. The lack of high-resolution stratigraphic schemes does not allow to compare palaeoenvironmental proxies from coeval time slices across the Mediterranean basins. In our model Upper Messinian deposits are split into two sub-units by a minor unconformity marking a sharp facies change. The lower sub-unit is localised in deep and/or strongly subsiding basins and is commonly characterized by 'regressive' depositional trends. It also records the transition from hyper- to hypohaline conditions over a short time span characterized by an acceleration of tectonic processes in many Mediterranean geodynamic contexts. Its lower half corresponds to the hiatus associated to the MES (the 'Messinian gap').

The upper sub-unit is basin-wide distributed and shows remarkably similar depositional trends and facies characteristics throughout the Mediterranean basins; it records the generalized activation of catastrophic flood-dominated fluvio-deltaic depositional systems transferring very coarse-grained sediments to the basins, suggesting important modifications in the drainage areas and/or in fluvial runoff. A clear high-frequency cyclic pattern is commonly observed, superposed to a longer-term 'transgressive' trend, testified by backstepping stacking patterns and onlap against the MES. The analysis of cyclicity patterns suggests a control by precession and this allows high-resolution Mediterranean-scale correlations; in this sub-unit four to five precessional cycles are usually recognized below the Miocene/Pliocene boundary; tuning to astronomic curves suggests that its base could be placed at 5.42/5.44 Ma. While the lower sub-unit records the local and ephemeral development of Lago Mare environments with low-diverse, pioneer taxa, the upper one is marked by the diffusion of conspicuous Parathetyan assemblages (ostracods, dinoflagellate cysts, molluscs) of increasing diversity and complexity upwards. This change is best approximated by the boundary between the two sub-units, actually occurring in the topmost part of the lower one. The late Messinian erosional features observed along the Mediterranean margins point to a rejuvenation of drainage systems, usually related to a large sea-level drop occurred at the acme of the MSC. However, such features could also have been caused or enhanced by the late Miocene uplift of peri-Mediterranean mountain belts. The relationships between geodynamic processes and late Messinian climate in the Mediterranean area and their effects on precipitation and fluvial regimes has not been deeply explored yet and may lead to envisage different scenarios for the final phase of the MSC. Converging sedimentary evolution and paleontologic record suggest that the Lago Mare event likely resulted from a positive feedback loop between processes (increase of fluvial runoff, generalized subsidence, base-level rise, enlargement of shelf areas) which promoted the establishment of progressively larger, more stable intra-Mediterranean connections and water exchanges with the Parathethyan basins, up to the final reopening of the Atlantic gateways.

The Messinian stratigraphy of Central Sicily basin revisited: new insights for a scenario of the Messinian salinity crisis of the Mediterranean basin

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Several scenarios of the Messinian salinity crisis (MSC) have been proposed in the past few years, all envisaging the desiccation of deep Mediterranean basins. Controversial points of these models concern the chronology of Messinian events, the correlation of marginal and basinal successions and the age and origin of the Messinian erosional surface (MES). This is largely due to the unknown nature and age of the evaporitic bodies of the Mediterranean abyssal plains; however, uncertainties also arise from the remaining poor knowledge of 1) the regional-scale geologic evolution of many Messinian basins, 2) the sedimentology and stratigraphy of evaporitic and clastic deposits, 3) the role of tectonics in controlling the MSC evolution and its stratigraphic patterns.

Little attention usually has been paid to the significance of resedimented evaporites, largely represented within the so called 'Lower Evaporites' (LE) in many basins, and to their genetic and stratigraphic relationships with *in situ* evaporites. In the Apennine foredeep basin, LE in main depocenters consist of deep-water clastic gypsum derived from the tectonically-induced dismantlement of *in situ* evaporites. Regional-scale correlations show that LE actually consist of two distinct gypsum bodies separated in both space and time by the MES.

In this work we briefly revisit the Messinian stratigraphy of Sicilian basins, usually considered the best analog for the deep Mediterranean basins. In classic stratigraphic models of the Caltanissetta basin, the Lower Evaporites, mainly consisting of selenites with lateral transitions to Calcare di Base limestones (CdB) and halite, are unconformably overlain by Upper Evaporites and then Lago Mare deposits. However, such stratigraphic relationships are not easily recognizable in the field.

When considering the Maghrebian-Sicilian foredeep system as a whole, it appears that surely *in situ* LE selenites only occur in the innermost wedge-top basins (Ciminna, Calatafimi) and in the Pelagian-Hyblean foreland ramp extensional basins (Licodia Eubea); they are not associated with halite or typical CdB and are unconformably overlain by uppermost Messinian clastic deposits or by lower Pliocene Trubi.

Lower Evaporites of the Belice basin and of the inner Caltanissetta Basin (the main foredeep, actually comprising several subbasins) mainly consist of deep-water resedimented gypsum deposits, emplaced by a variety of mass-flows ranging from low-density turbidites to olistostromes and giant submarine slides, and distributed according to a tectonically-controlled topography. In the Caltanissetta Basin, these deposits are associated with CdB and halite; rapid facies and thickness changes and the basin fill geometries suggest their syntectonic deposition. The envisaged lateral transitions between halite and *in situ* selenites are not obvious: halite units do not show the clear precessional cyclical pattern of the Lower Gypsum, casting some doubts on their true stratigraphic relationships.

In our reconstruction, *in situ* Lower Gypsum in Sicily formed during a first MSC step, between 5.96 and 5.6 Ma, in shallow basins with periodically oxygenated bottom waters within the wedge-top and foreland ramp depozones. In a second MSC step, following a important tectonic pulse started at around 5.6 Ma, likely coupled with a base-level change, the evaporitic basins of the previous phase underwent subaerial erosion and large-scale gravity collapse. Deposition switched to outer wedge-top basins (Belice, Petralia) and to the main foredeep, where a large volume of clastic gypsum accumulated. The CdB likely formed mainly during this phase above growing anticlines; halite accumulated in synclines in a very short time span(s), during an acme of the tectonic pulse possibly coupled with climatic forcing during isotope stages 14 or 12. Basin narrowing, higher brine concentration, severe water stratification and bottom anoxia characterized this selenite-free phase; the high rate of salt aggradation caused rapid basin infill and local subaerial exposures. The third MSC step (~5.5-5.33 Ma) was characterized by a decrease of tectonic activity, a more generalized subsidence and basin widening; selenite gypsum precipitated in shallow, oxygenated, subbasins of the Caltanissetta Basin, while terrigenous deposits mainly accumulated in wedge-top basins leading to a overall 'transgressive' pattern. This culminated with the Zanclean flooding.

Can sills acting as spillways resolve the paradox of marginal and deep-basin evaporites?

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The Lower Evaporite Series is found in marginal settings of the Mediterranean including Spain, Sicily, the Apennines, Crete and Cyprus. For the most part the selenite is considered a primary deposit diagnostic of very shallow hypersaline marine environments. In Sicily the first gypsum bed rests on a "calcare di base" that has features of subaerial diagenesis and can be used as a marker of the ancient coast. These deposits, with fossil microbial mats suggestive of stramotolites, appear directly above euxinic shales formed in anoxic environments deeper than the typical continental shelf. Considering that individual gypsum beds in the Lower Evaporite Series were precipitated during precession cycles of 20 ka in duration, it would have required enormous subsidence rates >250 m/ma to produce the necessary accommodation space for the Lower Evaporite Series. Such rates are rarely experienced except in the early phases of passive continental margin rifting. Surely, the surface of the water can move at these rates. Calling upon a circum-Mediterranean tectonic event to rapidly elevate and drop the seafloor seems extreme. Seismic reflection profiles across Mediterranean margins show that marginal evaporates are rare and that the salinity crisis is represented mostly by an erosion surface extending from the shelf to the basin interior. Reflection profiles, calibrated by drilling, will be presented. They show different developments of the erosion surface and its relationship to the thick basin floor evaporates and salt for the regions separated by sills that acted as spillways for marine waters entering from the Atlantic and eventually reaching the Levant. As the Atlantic entrance restricted to the point that evaporation across the whole Mediterranean surface exceeded input, the surface began to drop and hypersaline conditions commenced. Fluctuations in water level were then controlled by the precession cycle's influence on the hydrologic balance. The fluctuations modulated the cyclic Lower Evaporites with their interbedded marls preserved in depressions where they were sheltered from later erosion once the water level dropped substantially. As restriction increased, the water surface eventually dropped to the level of the highest spillway to the east. At this point the greater surface area of the eastern Mediterranean meant that its could experience large drops in water-level while the surface of the upstream basins remained pinned for awhile at the spillway. Only when the Atlantic restriction became very small, or became cut off altogether, did the upstream western basin desiccate. The phase difference in the timing of severe base-level lowering and massive salt deposition in the east and west is evident in the reflection profiles. Canyon-incision commenced with the initial base-level fall. The evaporates and salt fill the excavations. In the west, the initial base-level drop led to erosion of deep-valleys into the Gulf of Lion shelf. The sediment removed lies primarily under the salt. There is little evidence of any significant amount of the material removed from the margins either within the salt body or within the Upper Evaporites. This is the case for both the east and west, where the debris appears in the profiles as large subsalt fans. Lesser amounts are evident in channels and small fans within the lowermost salt. Subsea plateaus display no cover at all of the Lower Evaporites Series. Instead they developed a karst surface in exposed carbonate sediments. Extreme desiccation in the east is expressed by erosion or dissolution of the salt layer along the foot of the margin and by the development of alluvial fans on the exposed salt. As freshwater was captured from the ParaTethys during the later stages of the salinity crisis, lakes developed first in the east, and then, as the lakes filled and expanded to eventually drown the Mediterranean Ridge, water flowed back to the west through the same spillways that earlier had supplied the marine water for the Lower Evaporite Series and salt.

The birth of the Deep Basin Desiccation hypothesis

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Ken Hsu, Maria Cita and I crafted the initial working hypothesis for deep-basin desiccation aboard the *Glomar Challenger* during July-September 1970 as the most plausible explanation for the pan-Mediterranean Messinian-age salt and evaporates. The spark for a radical new mechanism sprang directly from our observations on the cores, the available geophysical data, firsthand experience with sedimentation in the sabka environment of the Persian Gulf and rudimentary knowledge of the Gessoso-solfifera Formation in Sicily. The many and often disparate facts jellied into a rough, yet elastic framework, though hours of conversations among the members of the scientific party. The first, but initially unrecognized, clue was the regional unconformity separating the early Pliocene from the Tortonian that we encountered in the first drill site in the Alboran Sea. The second was shallow-water dwarfed fauna in association with gypsum crystals and clastics in the Valencia Trough. That was soon followed by the discovery of anhydrite above the flowing salt layer (couche fuante) on the distal margin of Menorca with all the characteristics of the 'supra-tidal' and 'intra-tidal' setting. It was at that site where we recognized transgressive and regressive cycles of shale, marl and anhydrite ranging from deposition in subaqueous (anoxic) environments to full exposure and back again. A little more than a week later in the eastern Mediterranean we sampled elements of the "Lago Mare" assemblage in the Strabo Trench. Interstitial salinities >30% in the Pleistocene turbidites of the deep Hellenic Trough forecast the presence of halite that was latter recovered at the last site west of Sardinia. Desiccation cracks and dissolution features indicated that even the edge of the abyssal plain had been terrestrial. Soils and fluvial conglomerates on the Sardinia slope verified the emergence of most of the Mediterranean margin during a major part of the salinity criss. Although I dated the terminal flood at 5.4 Ma, which is close to today's accepted date, it was entirely for the wrong reasons. Upon completion of the leg and while Ken, Maria and I were working on samples and our chapters in the Initial Reports that I learned of the deep incisions of the Nile and Rhone Rivers and the ubiquitous erosion surface beneath the Gulf of Lion that had been calibrated by exploration drilling. The back-stripping of those boreholes and my calculations for thermally induced subsidence required the floor of the evaporating basin to have been at a depth more than 2 km below the surface of the Atlantic. My talk will take the audience through the highlights of the expedition and into our thought processes that resulted in Ken's masterful chapter of the Leg 13 Reports titled "The Origin of the Mediterranean Evaporites".

The Messinian and the Early Pliocene in the southern Aksu basin (Antalya, SW Turkey)

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In SW Turkey, the Antalya marine Late Neogene basins (from west to east, the Aksu, the Köprü and the Manavgat basins) occupy the northern margin of the Antalya Gulf and are largely open to the south towards the east Mediterranean area. From the early Miocene up to the early Messinian these basins were filled by clastics derived from the Taurus belt composed of autochthonous carbonate sequences and allochthonous units including carbonate and ophiolitic sequences. During the regression of the Messinian Salinity Crisis (MSC), in the Mediterranean, the Taurus area was intensively eroded and deep valleys were incised in the pre-Upper Miocene deposits. Then, only the southern part of the Aksu basin was invaded by shallow marine waters and shows contrasted deposits from north to south. **In its northern part**, the Aksu basin is restricted to a canyon (the Eskiköy Mahalle canyon, with a depth of 200m), which was infilled by green marls overlain by coarse conglomerates, the top of which including lignites and travertines. This canyon corresponds probably to a paleo-valley incised through the Miocene sediments during the lowstand of sea-level related to the MSC. The deposits filling this paleo-valley are well dated by planktic foraminifera (N19-N20 boundary) and nannofossils (NN15-NN16). In the northern part of this area the present Aksu River follows a deep narrow gorge (100m deep; 5 to 20m in width) through the Mesozoic limestones of the basement. This active valley is parallel to the Messinian paleo-gorge. **The southern part** of the Aksu basin exhibits shallow open-marine deposits fringed by coral reefs eastward. The dominant facies are marls and silts containing abundant faunas of molluscs, foraminifera and nannoplankton. Previous studies established a Pliocene age, thanks to the planktic foraminifera (*Globorotalia margaritae* and *G. puncticulata* zones) and nannofossils (NN15- NN16 zones). Our new data (nannofossils from NN12 to NN14) indicate that the base of the sequence corresponds to the transition from Messinian to Pliocene in the southeast (Gebiz area) but the lowermost beds (5-10 m, sandy limestones with ostrea), are not yet precisely dated.

In conclusion a part of the southern Aksu valley was a paleo-valley incised during the Latest Messinian and then filled by the marls and coarse clastics sediments of the Pliocene marine transgression as observed all around the Mediterranean

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Gamma-ray log profile and spectral gamma-ray characterisation of the p-ev$_1$ deposits in the Maccarone section (northern Apennines, Italy)

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This paper deals with the characterisation of the natural radioactivity and the reconstruction of the gamma-ray log profile for the lower portion of the well-known uppermost Messinian Maccarone section (Carloni et al., 1974; Casati et al., 1976). In the Maccarone section, the post-evaporitic unit (p-ev$_1$, *sensu* Roveri et al., 1998; 2004) consists mainly of marls with thin intercalations of sandstone. Moreover, in its lowermost part the section shows a characteristic and distinctive 1.2 m-thick volcaniclastic layer with $^{39}Ar/^{40}Ar$ ages of 5.44 and 5.51 ± 0.04 Ma (Odin et al., 1997).

The natural radioactivity measurements were performed using an integral 2" x 2" NaI (Tl) Gamma Scintillator, equipped with a field spectrometer, which detects the contribution of each radioactive element (^{238}U, ^{232}Th and ^{40}K). The γ-ray measurements were taken every 20 cm, for 75 m of total thickness, with count times of 120 seconds.

In the Maccarone section, the p-ev$_1$ γ-ray log profile shows a steady trend with small deflections. The background of the p-ev$_1$ natural radioactivity reaches average values of 34-38 Cps (counts per second). The γ-ray peaks, 36-45 Cps, comes from grey and black laminated shales, while minimum values of γ-radioactivity comes from thin sandstone horizons and by a few ankerite-bearing layers. In the p-ev$_1$ deposits, the highest γ-ray values are from the volcaniclastic layer (52-65 Cps), at the base of the section.

Field natural radioactivity spectra were acquired on different lithofacies, such as: grey shale, black laminated-shale, ankerite layer and volcaniclastic level. For these lithofacies, the spectral analyses show different contributions from each single natural radioelement. The grey shales are characterised by natural radioactivity mainly due to ^{238}U, with contributions from ^{232}Th and ^{40}K. The black shales show higher ^{238}U values, which can be explained by the enrichment in organic matter, while ^{40}K and ^{232}Th activities could be tied to the clay fraction.

In comparison with the p-ev$_1$ shales, the ankerite layers have a lower γ-activity and show a relative high value of γ-radioactivity if compared with carbonate strata. The ankerite field spectra indicate the ^{238}U as the main radioelement responsible for its radioactivity. This can be explained either with poorly oxygenated environment, or with secondary fluids migration due to burial diagenesis. At the base of the Maccarone section, Th-dominant peaks characterize the radioactivity of the volcaniclastic horizon.

Comparing these results with the lowermost p-ev$_1$ deposits of the Maiella area, the Maccarone section shows higher values of natural radioactivity. In fact, the activity of the organic-rich layer in the p-ev$_1$ of the Maccarone section (36-45 Cps) is higher than the emission from black shale of the Maiella area, where up to 30-35 Cps have been counted. To understand these differences in terms of environmental-change and/or source area for sediment supply, we need more geochemistry investigations to detect the partial contribution of ^{40}K, ^{232}Th and ^{238}U on the total radioactivity of the study sections.

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Messinian palaeoenvironment of the Marche Apennines (ITALY)

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In the last years a complete description of the Messinian Northern Apennine deposits has been carried out by many authors. It is now recognized that the Messinian lithologies in the Apennines are basically the same as in other Mediterranean basins and that the boundaries between the main units appears to have the same age (Bassetti et al., 1994; Krijsman et al., 1999; Manzi, 2001; Roveri et al., 2001; Bertini, 2006). However the palaeogeographic evolution during the Messinian Salinity Crisis of some sector of the Northern Apennines still remains poorly understood. We focused our attention on one of these sectors located between the Metauro and Musone Rivers (Marche Apennines). Sedimentological and stratigraphic records of this area have been integrated to provide data for reconstruction of depositional environments and palaeogeography during the Messinian.

The preliminary results highlight that the area evolved from an initially marine to a continental depositional environment during the Lower-Middle Messinian. The ~1000m sea level fall (5.96-5.6 Ma;) caused the emersion of large areas and the deposition of evaporitic sequences (Gessoso Solfifera) distributed in narrow and isolated deep basins. The post-evaporitic phase (5.6-5.55 Ma, Roveri et al., 2003; Bertini, 2006) is characterized by re-sedimented evaporites (re-sedimented Gessoso Solfifera, Roveri et al., 2001, 2003). The period of emersion was followed, during the Middle-Upper Messinian by a recharge of fresh water. At 5.55 Ma (Odin et al., 1997) an ash horizon marks the boundary between the Gessoso Solfifera and the Formazione di Tetto. The Formazione di Tetto records a change in depositional environment recognized by the development of fluvial and deltaic systems, and in the climatic conditions, indicating a dominantly humid, subtropical temperate climate. During the deposition of the Lago Mare Formation (5.44-5.33, Krijsman et al., 1999) a change in depositional environment from continental to brackish water/marginal marine is recognized associated with recharge of fresh water and sea water. The re-establishment of open marine conditions marks the boundary between the Upper Messinian (5.33 Ma, Krijgsman et al., 1999) and the Lower Pliocene.

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The origins of evaporites and their facies –the recognizable and the enigmatic!

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The deposition of major volumes of evaporites (up to 2 km in thickness), deposited within the short time interval of less than 1 million years (the Messinian), seems to require the action of a "saturation shelf"- a vast shallow area with a high evaporation rate per volume together with high ionic inflow. There are 3 sources of such ionic inflow, mineralized continental water (and dissolution of older evaporites), marine water, and hydrothermal/volcanogenic (effusive) influx. Each of these sources should provide relatively distinct trace-element and isotopic signatures, and can be tested. They must all be considered as source-waters within the Mediterranean of the Miocene.

The earliest stages of Messinian constriction actually begins with the basinal stratification evidenced in the diatomite accumulation that underlies the evaporites, the Tripoli. At the base it is a fairly normal assemblage of fauna/flora, but up-section it becomes more and more restricted and has several levels of Fe/Mn–rich marls suggesting periods of stagnation and restricted circulation. The first steps in basinal closure.

The extended shallow-water setting that is needed to accomplish the necessary evaporation to produce high ionic concentration (producing evaporites) requires a combination of shelfal flooding, restricted basinal inflow, very high evaporation rates, plus a measure of sporadic drawdown. A steep-sided basin, full of water, only permits evaporation from a restricted surface area, limiting both rates of precipitation and of oxygenation of the bottom water. While halite can form in any water depth or degree of anoxia, gypsum requires oxygenated water- at least sporadically. From studies of modern settings, we now can predict the various facies produced in shallow water, and as long as evaporites remain in their primary condition (not deeply buried or deformed) those facies are relatively identifiable.

Not only are these facies physically recognizable relative to their specific environments, but the optimum intervals of accumulation may be short, commonly forming marker beds, correlative across long distances, deposited in limited time spans (perhaps a few thousand years). Most bottom-growth gypsum is a shallow-water feature, but what happens in the same basin but in the deeper portions (below oxygenation)? Do we recognize them for what they are? In a number of well-studied non-Mediterranean basins the deep-water sulphate deposits are laminar (precipitated in the upper water and sinking to the bottom as cumulates), and these basinal facies are commonly underlain and interfinger with organic-rich anoxic shales and micritic carbonates. What about the halite environmental equivalents? Shallow-water halite crusts form with large quantities of fluid inclusions but deeper-water halite is composed of cumulate laminites. There are marked facies differences!

Shallow-water evaporites accumulate rapidly, and in the active tectonic milieu of the late Miocene Mediterranean, these great piles of shallow-water sediment become unstable and in the most tectonized areas they are moved downslope en mass as slide-blocks, mass flows, turbidites and density flows (exemplified by much of the Apennines, some of the Sicilian basins, and most certainly within the intra-Betic basins). Seismic studies and some coring demonstrate such massive reworking on the proximal floors of deeper basins. But what of the less tectonized, deep basin deposits of the Mediterranean? Are they shallow water, reworked evaporites, deep-water cumulates, or are they possibly formed from bottom deposition by hydrothermal-volcanogenic fluids and effusives, as suggested by Hoveland et al. (2006a, b). So far- no definitive answers.

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The Messinian record in the southern Bajo Segura basin (Betic Cordillera, Spain)

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The record of the salinity crisis in the northern Bajo Segura Basin shows two erosive surfaces (intra- and end-Messinian unconformities) associated to sea-level falls, which were followed by subsequent marine refloodings (Caracuel et al., 2004; Soria et al., 2005). Assuming the hypothesis of deep-desiccated basin (dogma for many authors), any of these two unconformities would stand for the main sea-level fall that caused the precipitation of evaporites in the abyssal plains of the Mediterranean. We advance a study of the Messinian and Pliocene units in the southern Bajo Segura Basin, in order to evidence the salinity crisis in the area. The stratigraphic framework is composed by three unconformity bounded units:

Messinian I Unit (MI). It is composed by an upper formation of shallow marine sandstones (La Virgen Fm), deposited in an storm-dominated shelf that progrades onto a lower Formation of open marine marls (Torremendo Fm), dominated by pelagic sedimentation with frequent turbiditic flows and slumps. The calcareous nannoplancton species *R. rotaria*, *A. amplificus,* and *R. pseudoumbilicus* >7μm aged this stratigraphic unit as Messinian. Magnetostratigraphy points out that this unit encompassed all the Messinian chrons (from C3Br.1r to C3r) and also the Tortonian/Messinian boundary, which is registered in its lower part.

Messinian II Unit (MII). This unit overlie the previous one by an erosive surface, intra-Messinian unconformity, which means a subaerial exposure phase characterized by the presence of brecciated levels and carbonate crusts (caliche-like). The MII Unit consists in lacustrine marls with cyclic episodes of beach sandstones (Garruchal Fm). This formation change laterally to a shallow marine evaporites (San Miguel Fm) in which alternates selenitic gypsum beds and sand-marl rhythmic intervals; the latter organized in typical sedimentary sequences of storm ebb surges. The intra-Messinian unconformity and the complete MII Unit fits within the chron C3r. They are interpreted, respectively, as a lowstand erosive surface and the subsequent deposition during the complete reflooding of the basin under highstand sea-level conditions.

Pliocene Unit (P). The MII Unit is truncated by an erosive surface, the end-Messinian unconformity, that carved a vast paleovalley which erodes, locally, the entire MII and the uppermost MI Unit (La Virgen Fm). Over this unconformity lies the P Unit, which is composed by the stacking of three marine formations. The lower formation (La Pedrera Fm) includes conglomerates, sandstones and marls, deposited under shallow marine conditions inside the above-mentioned paleovalley, where the sedimentary sequences point to an interplay of high energy fluvial discharge and shallow water oscillatory flows. These shallow marine deposits evolve to the intermediate formation (Hurchillo Fm), dominated by open marine marls rich in planctonic faunas. The upper one (Rojales Fm) is composed by shallow marine sandstones, which prograde over the underlying Hurchillo Fm. The P Unit contains the calcareous nannoplankton species *C. acutus*, a marker of the Zanclean (early Pliocene). Magnetostratigraphy evidences that the end-Messinian unconformity is locates within the chron C3r. After this lowstand unconformity, the P Unit records the definitive reflooding of the basin and consequently the entire Mediterranean.

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Biostratigraphic calibration of the evaporitic events in the Fortuna basin (SE Spain)

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The Fortuna Basin is a intramontane basin developed in the eastern Betics (southern Spain). It was formed in the early Tortonian as a pull-apart basin associated to the Puerto de Barinas Fault and developed on the suture zone between the South-Iberian Paleomargin (External Zone) and the Alborán block (Internal Zone). Two infill periods can be distinguished; the Tortonian, when was sedimented the marine Fortuna Marls; and the Messinian - Pliocene, characterised by continental marls, gypsum and conglomerates.

In the Fortuna Basin three evaporitic assemblages are registered. The lower one, Rillamo Gypsum, appears over the marine Fortuna Marls, and is overlain by the marine marls of the Fenazar Fm. The second assemblage, which is composed by the Tale Gypsum and the Chicamo Cycles, is also marine. The third, Rambla Salada Fm, lays over the Wichman conglomerate bed. This is developed on the top of a major erosive surface, and deposited in a mainly continental evaporitic setting (playa-lake). The Tale Gypsum was interpreted as an early restriction phase in relation to the Messinian Salinity Crisis, probably due to tectonics (Dinarès-Turell et al., 1999), lately named as the Tortonian Salinity Crisis (TSC) by Krijgsman et al. (2000).

The present work offers the first biostratigraphic calibration based on calcareous nanoplankton of the three evaporitic assemblages in the Chicamo section. The *A. primus* FAD is registered at the upper part of the Fenazar Fm, above the Rillamo Gypsum. The *A. delicatus* FAD, which marks the Messinian, occurs in the lower part of the Chicamo Cycles, above the Tale Gypsum. The Rillamo Gypsum, which marks the onset of the basin restriction and the evaporitic sedimentation, is 80 m below the *A. primus* FAD (ca. 7.47 Ma). Finally, the Tale Gypsum is below the *A. delicatus* FAD (ca. 7.22 Ma).

Two magnetoestratigraphic studies of the same Chicamo section have been published (Dinarès-Turell et al., 1999 and Krijgsman et al., 2000). Nevertheless, both interpretations differ. Dinarès-Turell et al. (1999) proposed two alternatives: A) Tale Gypsum within the C3Bn (7.14-7.21 Ma, or earliest Messinian), and B) Tale Gypsum within the C3Br.1n (7.25-7.28 Ma, or latest Tortonian). On the other hand, Krijgsman et al. (2000) assigned the same normal interval to the C4n.2n (7.7-8.1 Ma, Late Tortonian). Our record of *A. primus* FAD just below the Tale Gypsum, matching with the chron C3Br.1n, points to the alternative B on Dinarès-Turell et al. (1999).

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Chemostratigraphy of the rock salts: a case of Zechstein (Upper Permian) in Poland

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Salinity of mother brines registered by bromine content (Holser, 1966, 1979; Raup & Hite, 1996) can be used as the criterion to distinguish the salt rocks deposited in various conditions and time and becomes the principle of most modern chemostratigraphic method, applicable for division of successions of almost lithologically homogenous salt rocks without any paleontological evidence. Such studies were succesfully realized on the Upper Permian (Zechstein) salts both in Germany (Schramm et al., 2002) and Poland. Data from Poland evidenced the distinct differences between bromine content in various age units and areas. Rock salts of the Oldest Halite unit (Na1) are characterized with generally lower minimum and average (mediana) bromine values (<10-30 ppm and 40-74 ppm respectively) comparing to salts of the Older Halite unit (Na2) (18-62 ppm and 57-120 ppm) and the Younger Halite unit (Na3) (<10-45 ppm and 68-95 ppm). Also halites of the Lower Youngest Halite Unit (Na4a) evidences higher values of these parameters (19-44 ppm and 62-109 ppm), located in the interval comparable to salts of the Older Halite unit (Na2). Distinct difference is observed between bromine contents from the two units of mixed salt-clay rocks (zubers) belonged to the Z3 (the Brownish Zuber unit – Na3t; average bromine content: 146 ppm) and to Z4 (the Red Zuber unit – Na4t; average bromine content: 33 ppm) cyclothems, enabling distinguishing these both rock units in sections when their color is not clearly diagnostic. In the sections of stratiform non-tectonised salt deposits of Polish Zechstein basin the vertical bromine content distribution allowed to distinguish the correlable and almost isochronous units with the same bromine characteristics (content interval and change tendency (Tomassi-Morawiec, 2003). For the salt sections from diapirs, where primary rock features are practically eliminated due to tectonic events and the rock succession is highly disturbed, the bromine content distribution in salt profile is very useful tool for lithostratigraphic allocation.

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The Miocene-Pliocene boundary in Piedmont (North-Western Italy): subsurface (Narzole corehole) and outcrop (Moncucco quarry) data

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Almost thirty years ago a corehole carried out in Narzole (Langhe Region, Central Piedmont) by Sturani (1975) intercepted the boundary between lacustrine-brackish ipohaline deposits referable to "Facies a *Congeria*" (correlated with well-known post-evaporitic Messinian "Lago-mare" deposits), and marine hemipelagic Lower-Pliocene deposits. This boundary was described as extremely sudden and characterized by the presence of a black arenitic bed (Sturani, 1976).

Afterwards the untimely death of Sturani some months after the Narzole drilling, the study of the corehole was never completed. The renewed interest for the Messinian Salinity Crisis had led to new researches in the Piedmont region (North-Western Italy), where the preliminary study of micropalaeontological assemblages pointed out that hemipelagic sediments overlaying messinian post-evaporitic deposits are referable to the Zanclean MPl1 biozone. Moreover, biostratigraphical and sedimentological studies are in progress on the Miocene-Pliocene boundary outcropping at Moncucco quarry (Turin Hill, Northern Piedmont), where the boundary is marked by a 0.7-1 meter thick black arenitic bed separating Messinian post-evaporitic deposits (with typical ostracoda of "Lago-mare" facies) from Lower-Pliocene marls (Argille Azzurre Fm.), whose lower portion is also referable to the MPl1 biozone.

Both at Moncucco quarry and in the Narzole corehole, micropalaeontological content of the "*Congeria*" beds consists of Tortonian and Lower Messinian planktonic foraminifers (*Globorotalia conomiozea*, *Gt. suterae*) and rare deep shelf to bathyal benthic species (*Uvigerina rutila*), all interpreted as reworked; brackish ostracods (*Loxochonca djaffarovi*) are very rare. The black arenitic bed, observed for the first time in the Northern Piedmont, is generally barren, very rich in organic matter and is composed of a terrigenous fraction (quartz and lithic fragments of metamorphic rocks) with subordinate intrabasinal grains (glaucony and phosphates). At the top of the bed, a network of firm ground burrows, infilled by the overlying Pliocene marls, has been observed and corresponds to an omission surface (*sensu* Bromley, 1990). Foraminiferal assemblages of the Pliocene marine succession are rich and diversified. Both in the outcrop and in the corehole samples, the marls basal part contains rare to common *Sphaeroidinellopsis dehiscens*. Planktonic specimens are frequent (P/(P+B=60-70%), deep outer neritic to bathyal benthic foraminifers are common; ostracods are rare, with typical open-marine taxa (*Bythocypris obtusata*).

It is noteworthy that also in Piedmont the Miocene-Pliocene boundary appears characterized by the black arenitic bed described in many circum-mediterranean areas (Cita *et alii* 1978; Roveri *et alii*, 2004); this boundary corresponds to the facies change usually related with the end of the Messinian Salinity Crisis (Iaccarino *et alii*, 1999).

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The tephra layers in the post-evaporitic Messinian deposits of the Apennines foreland: mineralogical and chemical investigations

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A petrological and geochemical study has been carried out on tephra layers interbedded in the post-evaporitic Messinian deposits of the Apennines foreland. The studied tephra layers belong to three sedimentary sequences (i.e., Maccarone, Campea, and Castel di Mezzo) outcropping in the Adriatic side of the Apennines. According to their stratigraphic position, these layers could represent different outcrops of the same volcanic event, probably occurred 5.5 Ma ago, as suggested by dated layer from the Maccarone section (Odin et al., 1997).

The co-genetic character of these tephra layers has been confirmed by this study. Indeed, the studied tephra layers show very similar petrographical and geochemical features. All the studied samples are rich in glass fragments (up to 90 % in volume) with quartz, plagioclase (An38-85), K-feldspar (Or66-95), and biotite as primary magmatic minerals. The glass fragments consist of shards, and micropumice clast up to 400 mm in size. These fragments are fresh, colorless and vesicle-rich. They show a rhyolitic composition ($74<SiO2$ wt%<79) and a primitive mantle-normalized incompatible element patter typical of that for calc-alkaline volcanic arc magmas.

The specific petrological and geochemical features of the Maccarone, Campea, and Castel di Mezzo tephra layers can be used as criteria to identify other corresponding tephra layers outcropping in the Apennines foreland. This should allow to better define the overall spread of tephra deposition and to obtain important information about its possible, still poorly constrained, volcanic source. Indeed, the grain morphology of the glass fragments agrees with a rapid air-fall deposition, occurred immediately after the eruptive event, suggesting a short distance transportation mechanism. Considering that, the Tyrrhenian region seems the most likely source area. But, none of the outcropping calc-alkaline rhyolitic rocks of this region has the same age of these tephra (Serri et al., 2001). Instead, these tephra layers have an age that overlaps a temporal gap observed in the time distribution of the Neogene-Quaternary magmatism of the Tyrrhenian region, suggesting that they represent the only record of an up to now missing volcanic event in the magmatological picture of this region.

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Messinian erosion of the Alps and its implications for Neogene climate change

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At the end of the Miocene, the Alps ceased outward expansion, and tectonic uplift and exhumation shifted into the orogen interior. This shift is consistent with a change from orogenic construction to orogenic destruction reflecting an increase in the ratio of erosional flux to accretionary flux. The coincidence of this change with an increase in sediment yield from the Alps suggests a climate-driven increase in erosional flux. A similar event is observed in the Swiss Molasse basin, which was inverted and eroded with an initiation time in the late Miocene or earliest Pliocene, coincident with an increase in sediment yield. Timing of end of deformation and sediment release from the Southern Alps indicates that the tectonic change occurred synchronous with the Lago Mare phase of the Messinian salinity crisis, supporting arguments that the Lago Mare conditions represent a climatic shift to wetter conditions throughout Europe. This wetter climate persisted into the Early Pliocene. Erosion of the Alps may also have been augmented by the base-level fall that occurred during the Mediterranean dessication (Willett et al., 2006).

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Evolution of the Dead Sea brines

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Since the beginning of its subsidence in late Neogene times, the Dead Sea Rift has accumulated up to 10,000 m of evaporites and clastics. The sea-flooded part of the Rift, the Gulf of Sedom, and accumulated in its distal part a thick sequence of rock salt known as the Sedom Formation. Overlying the bedded rock salt are lacustrine deposits, including evaporites, up to and including the present-day sediments of the Holocene Dead Sea. The entire intra-Rift sequence is defined as the Dead Sea Group.

The Dead Sea Group and the underlying and surrounding pre-Rift formations contain large volumes of stagnant and migrating interstitial brines, much of which have entered into and are interacting with neighboring formations. The so-called Dead Sea brine is the commonest, of Ca-chloridic composition, with over 330 g/l of dissolved salts and with a uniquely high Br content (over 5 g/l). The lake, composed of this brine, fills the over 300 m deep basin of the Dead Sea and may be considered an outcrop of the surrounding underground fossil brine. This water body, and different brines known from springs and boreholes around the lake, can all be derived from the mixing and chemical evolution of three basic brines. The first is a diagenetic brine, originally evaporated seawater of the Gulf of Sedom and later modified by Mg-Ca exchange into Ca-Mg-Na-K-Cl-Br water (with $Ca^{2+} > HCO_3^- + SO_4^{2-}$). In this brine, the original (marine) Mg has been exchanged for the Ca of carbonates of the Dead Sea Group and of the surrounding Cretaceous and older carbonate rocks, and most of the original sulfate has been lost through gypsum and anhydrite precipitation with this sequestered Ca. The $^{87}Sr \backslash ^{86}Sr$ ratios in the Dead Sea brine and in evaporites of the Dead Sea Group demonstrate their evolution from original Pliocene open-sea water, through restricted gulf waters and finally to the land-locked Ca-chloridic diagenetic brines. The second type of brine consists of meteoric waters, dilute to mesohaline, with seawater affinity (airborne sea-salts). The third type is a mix of metamorphic brines, which evolved by incongruent alteration and dissolution of hydrous evaporite minerals (e.g. carnallite and gypsum) of the Dead Sea Group. The highly soluble salts are selectively and alternatingly retained in solution, in successive lakes, or recycled from solid deposits formed during periods of desiccation.

The composition of the present-day lake waters, which are Dead Sea brine in the strictest sense, is continuously modified and retained by interacting with these other solutions and by multiple evaporation cycles, with occasional desiccation. The processes are also contolled by mixing along vertical hydraulic pathways along the rift's marginal faults, whose porosity enables brines to sink to depths of geothermal heating. Brine properties and behavior are explained, illustrated, and predicted by application of Jaenecke's version of Gibbs diagrams. The evolution of the Dead Sea brines provides a characteristic hydrochemical model for continental rift basins temporarily connected with the ocean.

Geological analogues: the geochemical evolution of the Dead Sea may be a meaningful model for continental rift basins that are formed in the course of the early, preoceanic rifting of a continental plate. The geochemistry is comparable to the Ca-chloride evaporites of the proto-Atlantic Sergipe basin (northeast Brazil) and the Congo-Gabon basin (west Africa), and with the recent Ca-chloridic Hot Brine pools of the Red Sea. Indeed, continental rifts are predisposed to endorheic drainage, and as such they are typical, morphotectonic evaporite environments. The often anomalously deep subsidence of continental rift basins favors thick evaporite accumulation and water-rock interaction, and their fault systems enable strong local thermal influences.

Residual caprock and fossil salt table of the Mount Sedom diapir, Dead Sea basin, Israel

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The Mount Sedom diapir, on the SW shore of the Dead Sea, emerges as an N-S trending asymmetric *salt-wall*, evolved parallel to the western boundary faults of the Dead Sea rift. The diapir is a simple structure, exposing steep-dipping to locally overturned slightly deformed beds of rock salt with some non-salt partings (anhydrite, gypsum, dolomite and clastics) of the Sedom Formation, a late Neogene sequence, over 2,000 m thick. Today the diapir forms a long and narrow (11 by 2 km), N-S trending hill, rising 260 m above the Dead Sea shore.

The Sedom diapir, though relatively small, provides superb exposures of a) well-bedded rock salt, overlain by b) *salt-depleted residual caprock*, with c) a *salt table* or so-called *salt mirror,* separating the caprock from the parent salt. These are also visible along the walls of the multitude caves and shafts of the highly developed sub-recent-present karst system, today under an arid environment. Other phenomena are d) an *etched relief*, tracing the facies and strike of the underlying strata. These inter-related features are unique in appearance and extension, and contribute to the understanding of primary non-salt and secondary salt-depleted evaporite facies, as well as to the interpretation of the structure, stratigraphy and deformation processes in the course of diapirism.

The diapir is topped by some 40 m of well-exposed, *salt-depleted caprock*, consisting of the insoluble components of the rock salt sequence, in places preserving the original stratification. A pre-Holocene, fossil dissolution surface, or *salt table*, separates the caprock from the underlying parent salt. The diapir is still rising at an average rate of 4mm/year, and the originally horizontal salt table is presently tilted and faulted tens of meters above Dead Sea level. The salt beds underneath are at present being dissolved by an active karst system.

Where the rising salt diapir enters an active aquifer its head dissolves, and a horizontal to sub-horizontal salt table forms at its top. This dissolution surface is covered by an evolving caprock of the insoluble residue, which develops an inverse restratification, with the newer freed material accumulating underneath the protecting cover of the older freed residue.

The sedimentary and structural features of the Sedom diapir, on its various scales, are usually preserved in the *salt-depleted* caprock. Insoluble layers, freed from the salt matrix, continue un-interrupted across the *salt table*, into the overlying caprock, including their sedimentary and deformational features. Relict structures of folded salt beds appear in the caprock as folded ghosts, occasionally with the rest of the folded salt beds visible under the separating salt table.

The sedimentary and textural features of the salt-depleted caprock often resemble those of less extreme, saltless evaporites. For this reason they may be mistaken as primary deposits of the Ca-sulfate-carbonate-clastic facies.

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