

EUG XI



Symposium CC08

Understanding Global Climate Change:
Clues from the Marine Sedimentary Record

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CC08

Understanding Global Climate Change

Tuesday AM Session

CC08 : TUam01 : G2

Absence of Subtropical and Polar Ocean Fronts in much of the Late Mesozoic and Paleogene

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The modern ocean can be thought of as comprised of four units, three of which are mirrored in each hemisphere. There is an equatorial belt characterized by divergence and shared by the two hemispheres. Poleward of the equatorial belt, to about 45-50° N or S latitude the ocean surface is occupied by the great, stratified tropical-subtropical anticyclonic gyres. Narrow bands of temperate water characterized by convergence and steep meridional temperature gradients bound the poleward margins of the tropical-subtropical gyres at the mid-latitudes. Beyond these lie the deeply convecting polar oceans characterized by cyclonic gyres. The convergences and divergences of the ocean waters are forced by the winds, in particular the subtropical and polar fronts develop beneath the zonal maxima of the westerly winds. From analysis of the distribution of calcareous plankton it is evident that, except during the Maastrichtian, none of the Late Cretaceous, Paleocene, Eocene or Early Oligocene species is restricted to the tropics-subtropics. They all appear to be cosmopolitan, extending to high latitudes in the southern Atlantic and Indian Oceans. Data from land sections in northern Europe and North America suggest that they extended into high northern latitudes as well. What does this changing distribution of calcareous plankton imply? Today the calcareous plankton are essentially restricted to the region between the polar fronts, with most species being restricted to the somewhat narrower band between the subtropical fronts. It was probably during the Middle Oligocene that the subtropical and polar frontal systems developed in the Atlantic and Indian Oceans. A climate simulation for the Cenomanian using the GENESIS V.2 Earth System Model with 6 X present CO₂ may offer an explanation. This simulation shows well developed westerly winds developed only during the winter in each hemisphere, with a much more diffuse circulation in the summer. In summer, the polar regions have only a weakened high pressure system or a polar low. The effect of these changing wind systems is to destabilize the boundaries in the oceanic circulation and to extend the paleobiogeographic limits of the calcareous plankton poleward.

CC08 : TUam02 : G2

Isotopic Tracing of Sediment Transport in the Bay of Bengal: Implication for the Marine Os Record

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The Sr, Nd and Os isotopic compositions of sediments from the Bay of Bengal allow the Himalayan and non-Himalayan sources of detrital material in seawater to be traced. Based on their isotopic compositions, these sediments can be divided into three main groups, which are related to their locations in the Bay of Bengal. The first group is mainly composed of sediments located on the shelf off Bangladesh and in the currently active Fan. The Ganga and Brahmaputra rivers are the dominant sources of material in this part of the Fan. The Os isotopic ratio of about 1.2-1.5 shows that the average Himalayan source of detrital material from the G-B river system is not unusually radiogenic. A large difference in ¹⁸⁷Os/¹⁸⁸Os ratio exists between these Bengal Fan sediments and Ganga bedloads, which may result from mineralogical sorting, addition of a non-radiogenic Brahmaputra component, or loss of radiogenic Os during transport. The second group contains sediments from elsewhere in the Bay, particularly those

located on the continental slope. They display an Os isotopic composition (0.99-1.11) similar to that of present seawater, and higher Os and Re concentrations. These characteristics suggest the presence of a large hydrogenous contribution, consistent with the lower sedimentation rate of these samples. The Sr and Nd data indicate that a significant fraction of these sediments is derived from erosion of non-Himalayan sources, such as the Indo-Burman range. These observations could be explained by the deflection of sediments from the G-B river system by westward currents in the head of the Bay. The third group contains only one sample, but shows that in addition to an Himalayan source, sediment discharge from Sri Lanka influences the detrital component in the distal part of the Fan. Samples from ODP Leg 116 (Reisberg et al., 1997) display the same range of ¹⁸⁸Os/¹⁸⁸Os as the Sonne samples. The similarity between the isotopic compositions of the Sonne samples and those of ODP Leg 116 suggest that the material eroding in the Himalayas has been roughly constant since the Miocene. Finally, the high Os isotopic ratios of leachates of both Sonne and Leg 116 sediments imply that, at most, only minor loss of radiogenic Os occurs during transport through the estuary or through interaction with seawater.

Reisberg L, France-Lanord C & Pierson-Wickmann A-C, *Earth Plant Sci Lett.* **150**, 117-127, (1997).

CC08 : TUam03 : G2

A $\delta^{234}\text{U}$ History of Seawater for the Last 800 Thousand Years

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The $\delta^{234}\text{U}$ of seawater is higher than secular equilibrium due largely to alpha-recoil effects generating high values in river water. The history of seawater $\delta^{234}\text{U}$ therefore contains information about the intensity and magnitude of continental weathering. It is also important to constrain this history as initial $\delta^{234}\text{U}$ ratios are used to assess diagenesis when U/Th dating marine carbonates. Sediments on the slopes of the Bahamas are dominated by aragonite and have U concentrations ranging to greater than 10 ppm making them suitable for U/Th dating. As these sediments have not been subaerially exposed, their diagenetic regime differs from corals and has been constant with time. This makes these sediments less likely to have suffered the diagenetic alteration of $\delta^{234}\text{U}$ commonly seen in corals. Using sediment from ODP Leg 166, taken from the slopes of the Great Bahamas Bank, I have measured the $\delta^{234}\text{U}$ and U/Th ages at high precision using MC-ICP-MS. Initial $\delta^{234}\text{U}$ for over thirty samples taken from marine isotope stages 1, 5e, 7, and 9 show no systematic trend with age and the majority fall within 15% of modern seawater. This suggests that seawater $\delta^{234}\text{U}$ has not drifted systematically during the last 350 ka. Constraining the earlier history of seawater $\delta^{234}\text{U}$ is made difficult because U/Th ages decrease in precision preventing age correction of measured $\delta^{234}\text{U}$ values. But the Brunhes-Matuyama magnetic reversal was recognized in shipboard data from ODP site 1003 and this provides an age constraint at 780 ka. Four samples from close to the reversal have been measured at a precision of 1.7‰ (2 s.d.) and yield initial $\delta^{234}\text{U}$ ranging from 61 to 101, significantly lower than the modern value. This suggests a change in the weathering regime sometime within the last 800 ka. Shore-based paleomagnetic (McNeil and Kislik) and $\delta^{18}\text{O}$ data (Kroon et al.) (Sci. Res. Leg 166) for ODP Site 1006 also reveal the B-M transition and demonstrate that it falls within MIS 19 as expected. This provides the possibility of using the $\delta^{18}\text{O}$ stratigraphy to provide age control and construct a $\delta^{234}\text{U}$ history of seawater for interglacials of the entire Brunhes chron. The history of $\delta^{234}\text{U}$ assessed in this way can be compared with other proxies for continental weathering, such as ⁸⁷Sr/⁸⁶Sr, to provide new information about the nature and mechanisms of Pleistocene climate change.

CC08 : TUam04 : G2

A Cenozoic Record of the Osmium Isotope Composition of Seawater Preserved in a Single Ferromanganese Crust from the Central Pacific Ocean

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It has long been recognised that radiogenic isotopes can potentially provide key information on changes in the rates of erosion, fingerprinting the geographical sources of input into the oceans, and as tracers of oceanic water mass movement. Furthermore, a multi-system approach, using elements with both short and long residence times, offers the possibility of tracing global variations in weathering (for example, as recorded by Sr and Os isotopes) and local variations in source (for example, as recorded by Nd and Pb). However, only in recent years has the potential and significance of the information preserved by these elements been realised. This is partly because of technical advances in our ability to measure isotope ratios on smaller samples with a superior analytical precision. But also because we have discovered new archives of past seawater composition, such as foraminifera, ferromanganese (Fe-Mn) crusts, marine aragonite and barite.

This study presents a high resolution Os isotope record for a ferromanganese crust from the Central Pacific Ocean (sample D11-1; 11°38'N; 161°41'E; 1690-1870 m water depth) for which detailed records of Pb, Hf and Nd have already been obtained (Ling et al. 1997; Christensen et al., 1997; Lee et al., 1999). The outer surface of the crust yields an Os isotope composition, indistinguishable from direct measurements of seawater from the Central Pacific Ocean (Sharma et al., 1997). The overall record shows a remarkable resemblance to that recently obtained from a pelagic clay core, also from the Pacific Ocean (Pegram & Turekian, 1999). This includes, the unradiogenic Os values and pattern of change characteristic of that seen at the K-T boundary (~65 Ma), a general shift towards radiogenic values from around 40 Ma, and a distinct change in the rate of that shift around ~26 and ~11 Ma. Comparison with the published global Sr isotope record and the Hf, Nd and Pb records (from the same Fe-Mn crust) shows that there are clear covariations with the changes seen in the Os isotopes. For example, the K-T, and Oligocene-Miocene boundary (~26 Ma) are both characterised by significant changes in Hf and Pb isotopes, in addition to Os and Sr isotopes. At present, the exact chronology of the crustal growth history remains uncertain, particularly for the older parts of the crust. However, even if the current chronology were incorrect the observed covariations between isotopic variations in different elements remain robust because the measurements have a precise spatial relationship in the crust. Thus, global variations in weathering, recorded by Sr and Os isotopes, are reflected in local variations in source, as recorded by Hf, Nd and Pb isotopes.

Ling HF, Burton KW, O'Nions RK, Kamber BS, von Blanckenburg F, Gibb AJ & Hein JR, *Earth Planet Sci. Lett.* **146**, 1-12, (1997).

Christensen JN, Halliday AN, Godfrey LV, Hein JR & Rea DK, *Science*, **277**, 913-918, (1997).

Lee DC, Halliday AN, Hein JR, Burton KW, Christensen JN & Gunther D, *Science*, **285**, 1052-1054, (1999).

Sharma M, Papanastassiou DA & Wasserburg GJ, *Geochim Cosmochim Acta*, **61**, 3287-3299, (1997).

Pegram WJ & Turekian KK, *Geochim Cosmochim Acta*, **63**, 4053-4058, (1999).

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CC08 : TUam05 : G2 The Pleistocene Climate Change Record from the Australian Sector of the Southern Ocean: Results from *Images* Core MD 97-2108

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Data presented in this study provide the first complete chronostratigraphic and paleoceanographic record from the Australian sector of the Southern Ocean for the past 1.2 Ma. Information from this region is crucial to enhance understanding of the complex oceanographic history of a largely little known part of the marine southern hemisphere. Core MD97-2108 was retrieved from the southern flank of the S Tasman Rise during the 1997 *IMAGES* cruise *Iphis* (2,131 m depth). Samples were analysed every 5 cm for planktic (*G. bulloides*) and benthic (*C. wuellerstorfi*) stable isotopes. The stratigraphic interpretation based on oxygen isotopes and magnetostratigraphy suggests a complete sequence down into MIS 33. The variability of both planktic and benthic oxygen isotope ratios match perfectly other isotope records as of ODP Site 846 and MD 90-963.

Core site MD97-2108 is located in a critical water depth situated in the upper level of the Circum Polar Deep Water, ideally to record sensitively both deep-water ventilation and intensity fluctuations of Intermediate Water. Both benthic and planktic carbon isotopes show a characteristic variability which reflects (1) variable strength of a deep-water source with implications for Southern Ocean ventilation history and (2) effects of oceanic fronts in the vicinity of the core location.

Along a profile from the Atlantic to the SW Pacific other cores show highest $\delta^{13}\text{C}$ ratios during MIS 11. In contrast to this data and also to results from elsewhere the $\delta^{13}\text{C}$ record of Core MD97-2108 yields its highest ratio during MIS 13 and not in MIS 11. This suggests a maximum deep-water ventilation around 500 ky BP. It exceeds that at MIS 11 by far, which was recognized in Cores RC13-229 (S. Atlantic Ocean) and MD94-101 (S. Indian Ocean) as period of maximum ventilation.

Several excursions of benthic carbon isotope ratios to lighter values suggest an influence of a productivity effect ("Mackensen effects"), which potentially is induced by the Subtropical Front, fluctuating at the position of Core MD97-2108.

CC08 : TUam06 : G2 Communities and Microhabitats of Living Benthic Foraminifera from the Tropical South Atlantic: Impact of Different Productivity Regimes

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The great abundance and wide distribution of benthic foraminifera in modern marine sediments, and their good preservation in fossil records, make them important components of the carbon cycle. Fossil benthic foraminiferal assemblages are widely used as tools to reconstruct past environmental conditions in the world's oceans. The use of these micro-organisms appears especially promising in the reconstruction of paleoflux of organic carbon to the seafloor and in the estimation of the benthic conditions of oxygenation.

The key to the interpretation of fossil records is linked to the knowledge of the ecology of modern foraminifera. Benthic foraminifera microhabitats are of special interest, because microhabitat partitioning may be linked to some important environmental parameters such as organic carbon flux and/or bottom water and pore water oxygen content. Moreover, since an important gradient of $\delta^{13}\text{C}$ exists in the first few centimeters of sediment, the knowl-

edge of microhabitat characteristics is also of prime importance in the interpretation of carbon stable isotope records in benthic foraminifera.

In our study, we examine living (rose Bengal stained) benthic foraminifera collected with a multicorer from several stations off west Africa. The faunal analyses suggest that the foraminiferal communities in the investigated area reflect the direct influence of different regimes of productivity, characterized by spatially and seasonally varying upwelling activity.

In general, foraminiferal abundance coincides well with the gradient of surface productivity. However, at one station off the Congo River, the influence of the huge fresh water discharge is documented: whereas this station lies directly in the center of an upwelling area, foraminiferal standing stocks are surprisingly low. It is suggested that the Congo discharge may induce a fractionation of the organic matter in small/light particles of lower nutritive content than relatively fast-sinking aggregates found in the centers of high productivity areas.

The amount of organic carbon to the sea-floor controls the sequence of degradation of organic matter in the sediment and the position of different redox fronts. The vertical foraminiferal stratification within the sediment closely parallels the distribution of oxygen and nitrate in pore-water. Epifauna and shallow infauna colonize oxygenated sediments. Intermediate infauna (*Melonis barleeanum*) is linked to the zone of reduction of the nitrate. Deep infauna shows its maximum distribution in anoxic sediment, where no more easily metabolizable organic matter is available. Different microhabitat preferences suggest different nutritive strategies and adaptation to different types of organic matter. Thus, infaunal foraminiferal species may be selectively attracted to specific bacterial suites in the sediment, and feed directly on bacterial biomass and/or on metabolizable nutritious particles produced by bacterial degradation of more refractory organic matter.

CC08 : TUam09 : G2 Demise of Carbonate Platform and Cool-Water Influx in the Carpathian Paleogene Basins: Climatic Events Related to the Oligocene Icehouse

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Upper Lutetian transgression in the Central-Carpathian Paleogene Basin (CCPB) led to the shallow-marine deposition of nummulitic banks, developed in two third-order cycles. Nummulitic cycles of the CCPB, like a large foraminifera demise, disappeared due to the inversion of the Middle Eocene warm climate to cooler climate in the beginning of the TA4 supercycle. Climatic changes culminated in the "Terminal Eocene Event", which corresponds to the global cooling and glacio-eustatic regression related to the Antarctic cryosphere expansion. Consequently, a carbonate factory turned off during the Zone P16 (latest nummulites), being suffocated by terrigenous deposition. The sediments from above the nummulitic limestones are depleted in CaCO_3 and enriched in organic matter due to continental runoff of land plants. They contain abundant cool-water coccoliths, like *Isthmolithus recurvus* and *Zigrabliuthus bijugatus*, diatom oozes in Menilite facies, Globigerina-rich fauna in the Globigerina Marls and nectonic fishes (Amphisile Shales). A small-scale intercalation of non-calcareous black shales and Menilite facies with Globigerina Marls indicates a short pulse of the high carbonate productivity during the terminal Eocene fertility crisis. The fluctuations in productivity provide the evidence of climatic changes driven by precessional cyclicity. The TA4 supercycle tended toward the gradual rise of relative sea level during the Early Oligocene. Basal sediments of the transgressive formation still show the cool-water influence, salinity decrease and semi-isolation, as indicated by wetzelialleacean dinoflagellates, imprints of diatoms, brackish nectonic fish and ostracods. Higher in the section, the carbonate-free sequence reveals the first pulses of nanofossil blooms, characterized by reticulofenestrids of NP 23 Biozone (Tylawa-like limestones), which flourished due to sea-level rise and renewed circulation. The Lower Oligocene transgression rose up to highest sea-level in time at 32 Ma, which restored the Paratethyan circulation. Consequently, the CCPB became reoxygenated, which led to the increase in carbonate precipitation, productivity and

fertility. The maximum flooding of this sequence falls into horizons of manganese layers, which represent a condensed section of the marine transgression. Successive formation of mud-rich deposits indicates a low-energy environment of highstand phase. Next supercycle TB1 was introduced by the Intra-Oligocene regression. It is in accordance with an abrupt sea-level fall at around 30 Ma (Mid-Oligocene Event), determined as a distinctive drop in sea-level during the major glaciation in Antarctica and subsequent cooling in the Northern Hemisphere. At this time, the CCPB started to fill up by sand-rich submarine fans, as a frequency of related turbidite currents essentially increased during glaciation. The Late Oligocene regression in the CCPB is indicated by shallowing and decrease of salinity with appearance of braarudospherids in nanofossil associations and brackish dinoflagellates in phytoplankton. Therefore, the deposition of the Upper Oligocene submarine fans in the CCPB appears to be forced by glacio-eustatic regression.

CC08 : TUam10 : G2 A Sensitive Recorder of Nordic Sea Thermohaline Activity during the Past 130 ka from the Arctic Ocean

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The past five marine oxygen isotope stages were characterized by strong and rapid fluctuations of the climate system. Warm and cold climate phases on both, long and short time scales left significant traces on land and in the marine realm. Sedimentation rates in the Arctic Ocean are generally too low for high-resolution investigations of short-term climate fluctuations and often signals of climate change are masked by strong regional and local processes. Here we present high-resolution grain-size data of a sediment core from the Yermak Plateau, Arctic Ocean (81°N 2°E, 1042 m water depth). The Yermak Plateau forms a key region within the gateway between the Arctic Ocean and the Nordic Seas. Atlantic surface water masses enter the eastern Fram Strait and pass Svalbard. Water masses deeper than 600 m are forced to flow along the western Yermak Plateau. In particular the Yermak Slope Current that transports primarily Norwegian Sea Deep Water (a product of deep-water production in the Nordic Seas) carries signals of climate change and thermohaline overturn. The core (870 cm) spans the past ca. 130 ka and was continuously analyzed in one-centimeter steps. To eliminate adverse effects of ice-rafted material a correction function was established. The resulting data set yields information on variations in bottom-current speed which can be related directly to climate change and to fluctuations in thermohaline overturn in the Nordic Seas. It turns out that unequivocal cold events such as the Younger Dryas were periods of lower bottom-current speed whereas warmer periods suggest increased bottom-current activity. Holocene climate phases such as the cold "8,200 year Event" and the warm "Roman Climate Optimum" left clear traces in the record. There is evidence for a general weakening of the bottom currents during the times of the North Atlantic Heinrich Events 1-6 and there are also current-speed fluctuations that are related to substages a,b,c,d,e of MIS 5. The Yermak Plateau current-speed record correlates well with sedimentologic records from the North Atlantic that mirror thermohaline activity and climate change.

CC08 : TUam11 : G2 Phosphorus Regeneration and Burial during and after Formation of the Most Recent Eastern Mediterranean Sapropel (S1)

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Eastern Mediterranean Sea sediments consist of an alternation of organic-poor, hemi-pelagic layers and organic-rich, sapropel units. The formation of these sapropels is most likely the combined effect of high surface water productivity and improved preservation of organic matter under anoxic bottom water conditions. The episodes of high productivity were presumably initiated by an increase in the continental runoff of freshwater with nutrients.

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Enhanced regeneration of phosphorus (P) in the oxygen depleted bottom waters may have helped to sustain the high productivity provided at least some water column mixing occurred. The enhanced regeneration is expected because of the redox dependent release of P from organic matter and Fe-oxides and should be reflected in a reduced burial of reactive P relative to organic carbon in the sediment. In this study, we use high resolution pore water and solid phase data for two low sedimentation rate sites in the eastern Mediterranean basin to demonstrate that such a reduced burial indeed occurred during the formation of the most recent sapropel S1 (between 6.0 and 9.0 ky BP). In addition, the diagenetic reactions affecting P during and after sapropel formation are addressed.

Phosphorus fractionation results show that organic P concentrations in the sapropel are only slightly higher than in surrounding layers. Enhanced concentrations of biogenic Ca-P (fish debris) were found in the sapropel at both studied locations. An Fe-bound P enrichment was observed in the oxic sediment above the sapropel. This Fe-bound P enrichment was diagenetically formed and is the result of upward diffusion of dissolved Fe^{2+} and HPO_4^{2-} from below the sapropel and subsequent precipitation at the redox front at the top of the visual sapropel. Organic C/P and organic C/(reactive Ca-P + organic P) ratios in the sapropel are substantially higher than the Redfield ratio and than values in the overlying and underlying sediment. This indicates (1) a reduced burial of organic P relative to organic C during the formation of sapropel S1 and (2) only partial compensation of this reduced burial of organic P by enhanced burial of biogenic Ca-P. The role of fish-debris as a sink for P under different environmental conditions and the potential implications of the enhanced regeneration of P for the water column chemistry in the eastern Mediterranean basin during sapropel formation will be discussed.

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CC08 : TUam12 : G2 What is the Mechanism of Formation of the Manganese Concentration Peaks found in Recent Eastern Mediterranean Sediments?

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In the Holocene sediments of the eastern Mediterranean basin, two distinctly separated Mn peaks are usually observed in the sediments that overlie the last sapropel (S1) which formed between 6-9 ky B.P. It has been demonstrated by van Santvoort et al. (Geochim. Cosmochim. Acta 60 (1996) 4007-4024) that the lower of these two peaks is formed by early diagenesis, as Mn^{2+} from anoxic conditions at depth reacts to form Mn oxyhydroxide with the O_2 which is diffusing downwards from bottom waters. This lower Mn peak immediately overlies the residual dark Corg- and sulfide-rich S1 unit. The genesis of the upper Mn peak, which often but not always contains higher Mn contents than the lower peak, is less certain. On the basis of an extensive collection of cores collected from the crestal Mediterranean Ridge area S/SW of Crete, De Capitani and Cita (1996) have related the upper Mn peak to a hydrothermal fluid expulsion, possibly related to the Bronze age Santorini eruption. In this area, the upper peaks contain concentrations up to 22 wt.% Mn, and are such a prominent visual feature that they have been termed the "Marker Bed" (of the Mediterranean Ridge diapiric belt). Although the upper Mn peaks in most other eastern Mediterranean cores reported to date have much lower contents (<1 wt.% Mn), they nevertheless look remarkably similar to the published photographs of cores from the Ridge area, both in appearance and in position relative to the S1 sapropel. The alternative proposal for these cores from all over the eastern Mediterranean basin is that the upper Mn peak marks and times the point at the end of S1 sapropel formation when bottom waters in the basin were reventilated (Thomson et al., 1995) 3487-3501). New examples of cores from the SAP programme will be presented which demonstrate that high upper peak Mn contents (3.3 wt.% Mn, southern Adriatic Sea; 13.9 wt.% Mn, Medina Rise) can be found in other areas and may be related to water column reoxygenation at the end of S1 times.

De Capitani and Cita, *Mar. Geol.* **132** 215-225 (1996)
Thomson et al. *Geochim. Cosmochim. Acta* **59** 3487-3501 (1995)

CC08 : TUam13 : G2 Uppermost Pleistocene Lithostratigraphic Evidence of Peri-Mediterranean Palaeoclimatic Change as Recorded in the Composition of Mediterranean Sea Sediments

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High resolution work on the textural and compositional characteristics of several carefully selected radiocarbon dated deep sea Mediterranean box cores has revealed the pronounced uppermost Pleistocene palaeoclimatic impact as preserved on the lithostratigraphy of the sediments.

Cores recovered along E-W Mediterranean and S-N East Mediterranean transects consistently show the coarsest grain sizes within the cold-dry glacial intervals caused by the enhanced proportions of aeolian transported constituents. Clearly the African dust influence diminishes with distance from the African shores. During the sapropel S1 deposition in the East Mediterranean Sea textural data are attaining their finest mode and clay sized percentages score their highest levels at all the investigated sites. The petrography of the coarser than 30 μ fraction as well as X-ray bulk mineralogy clearly show a reduction of aeolian transported minerals and sizes marked by a concomitant increase in the fluviually transported clays. Further up in the uppermost Holocene there is a reversal of the trend displayed within the sapropel. In general, Ti/Al profiles versus depth also reflect the dust input into the Mediterranean. Low Ti/Al ratios point at low dust fluxes and humid climatic conditions in the Mediterranean region. With the exception of volcanic ash influenced layers high Ti/Al ratios, in contrast, point at high dust fluxes and a more arid climate.

Chronologically speaking the glacial peak is characterized by a pronounced increase in the median diameter of the sediments, paralleled by enhanced quartz and dolomite contents as well as higher Ti/Al ratios. Similar peaks can be distinguished at the cold Oldest and Younger Dryas intervals. Especially, in the East Mediterranean Sea, the onset of the sapropel deposition S1 and through its duration from ~9500-6000 (uncorrected radiocarbon years B.P.) it is marked by the lowest grain median diameters, low quartz and dolomite contents coupled with enhanced clay mineral proportions. This provides univocal evidence for more humid peri Mediterranean conditions. The uppermost Holocene i.e. the last 2000 years, display a tendency towards higher grain median diameters and wind blown minerals, clearly distinguishable from the mid Holocene humid climatic phase. This suggests an increasingly drier climate over the last two milleniums.

CC08 : TUam14 : G2 Palaeoecosystem Changes during Sapropel S1 Time based on Absolute and Relative Quantitative Analyses of Zooplankton and Phytoplankton Assemblages: The Example of SL9 Box-Core (Florence Rise, Eastern Mediterranean)

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SL9 box-core has been recovered in the Florence Rise area (south of Cyprus) during the R/V Logachev-Cruise 1999. The core represents the typical Holocene sedimentary sequence of the eastern Mediterranean: it is characterised by a well defined visible S1 sapropel, an oxidised S1 and the Marker Bed just above it. Relative quantitative analyses of planktonic foraminifera, pteropods and calcareous nannofossils have been compared to absolute quantitative data performed on the same samples. Relative and absolute abundance trends of zooplankton and phytoplankton analysed species are comparable even if they sometimes appear shifted.

By using the >63 micron fraction of planktonic foraminifera counting it is possible to determine the exact abundance of small species like *T. quinqueloba*, *G. scitula* and *G. rubescens/G. tenella*, usually poorly represented in >150 micron fraction. The planktonic foraminiferal species *G. inflata* and *N. pachyderma* dextral, the marker species usually increasing at the top of oxidised S1, show the same signal using both percentages values and number of specimen for gram of dry sediment. The major increase of *G. ruber* group (var. *alba*) expressed as relative abundance (%), is at the beginning of S1 deposition, whereas the major increase of the same group in the sediment (nr.specimens/gr.) appears within the oxidised S1.

For pteropods counting it has used the >150 micron fraction because they are scarce in the fine fraction. *L. inflata*, a mesopelagic pteropod species actually living in Mediterranean areas where different water masses are in contact, has a clear increase at the bottom of S1.

The absolute abundance of calcareous nannofossils in the less than 32 micron fraction and the species relative abundance have been quantified. The sapropel is characterised by high concentration and high relative abundance of *H. carteri*, *Rhabdosphaera* spp. and *F. profunda*. A discontinuous increase of the more calcified morphotype of *E. huxleyi* and *Reticulofenestra* overcalcified s.l. has been observed in the upper part of the box-core.

Pteropods dissolution characterises almost the whole S1 interval, from the sapropel bottom up to the Marker Bed. A discontinuous decrease in absolute abundance of the upper photic zone calcareous nannofossil assemblage and a simultaneous increase of lower photic zone species were detected in the S1 interval. Also planktonic and benthic foraminifera show an abrupt decrease in absolute abundance (nr.specimens/gr.) within the visible S1. Zooplankton and phytoplankton show the same signal of decrease in absolute abundance within the visible S1, whereas they increase again in the oxidised S1. This suggests two different phases in sapropel deposition.

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Tuesday PM Session

CC08 : TUpm25 : G2 Using Ammonite Provinces to Characterize Palaeoceanographic Changes during Deposition of the Kimmeridge Clay, Dorset

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The distribution of major ammonite groups has been used to define bio-provincial boundaries within the north-south trending seaway that developed during the late Jurassic along the Laurentian continental margin, linking the Boreal Arctic sea with the Tethyan ocean. The extensive continental margins and epic seas supported a cosmopolitan ammonite fauna during the Kimmeridgian that became strongly provincial during the late Tithonian, related primarily to falling sea level. Superimposed on this progressively trend towards provinciality are numerous fluctuations in the geographic extent of certain ammonite groups, associated with periods of rising and/or high sea level that enhanced communication between once discrete faunal provinces. In a general sense, sea-level rise during the early Kimmeridgian is marked by a pronounced northward spread of ammonites with a normally Tethyan distribution, followed by a southward expansion of some Boreal groups. As sea level continued to rise, other Tethyan forms extended into the Sub-Boreal realm. Subsequently, a decrease in sea-level during the late Tithonian led, for example, the Boreal Dorsoplantidae and Tethyan Berriassellidae to form distinct provinces. Our aim is to discuss how the distribution of ammonite provinces can be used to help us understand palaeoceanographic conditions within the Laurasian seaway. The discussion is centred upon the Kimmeridge Clay, Dorset, drawing upon geophysical and geochemical data-sets collected as part of the NERC (Rapid Global Geological Events) "Anatomy of a Source Rock" project.

CC08 : TUpm26 : G2 Trace Elements in the Solid Phase of Southeast Atlantic Sediments- Implications for the Palaeoenvironment

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The solid phase of sediments records primary and secondary signals that can be used for the reconstruction of palaeoenvironments and their climatically induced changes. In this context the geochemical composition of the sediment's solid phase can document primary input variations of organic and terrigenous components, the depositional and/or redox milieu, and the modification of the primary sediment composition by early diagenesis.

In order to learn more about geochemical signals that are recorded in the solid phase of sediments and about their potential for the reconstruction of palaeoenvironments we have investigated the distribution of 30 elements in several gravity cores taken from the Southeast Atlantic in water depths of 1300 to 3200 meters. For all gravity cores pore-water analyses were carried out which allowed the detailed characterisation of recent early diagenetic processes. For some of these cores stratigraphies are available and enable us to relate geochemical signals to climatic changes during the last 240,000 years.

We will demonstrate the impact of early diagenesis on a gravity core taken from the Benguela upwelling region off Namibia. At this site the porewater of the sediment displays a deep sulphate reduction zone and we will discuss to what extent the reduction of sulphate by methane alters the trace element composition of the solid phase. In this context special emphasis will be put on the stability of the barium signal which is of particular importance as a proxy for paleo-productivity. Furthermore we will compare the impact of early diagenesis on the geochemical record with primary input variations that we find in the solid phase of sediment

cores taken from the Benguela upwelling region and from the Niger-Fan. In the latter case our data shows that the climatically induced change of chemical weathering conditions in the river basin can have a significant impact on the geochemical composition of the terrigenous sediment fraction.

CC08 : TUpm27 : G2 Evaluating the Intrinsic Mechanisms of Global Cooling in Palaeozoic Greenhouse and Cenozoic Icehouse Worlds

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The Monterey Hypothesis conceptualises biosphere, geosphere and hydrosphere responses to climate change. The hypothesis predicts CO₂ (atm) drawdown into the oceans by the phytoplankton during global cooling, the result of enhanced thermohaline circulation and eutrophication. The resultant cooling further enhances the thermohaline circulation and in some cases is considered to be sufficient to cause glaciation. At the same time global sea level will fall due to ice build-up or thermal contraction of the oceans. Alternately, global warming and increasing sea level can have the same effects due to increasing shelf area and the associated increase in bioproductivity. Each scenario has a characteristic geological signature and stable carbon and oxygen isotope records. In this presentation we will compare records from the deep-water siliciclastic successions deposited at low latitudes during the end Ordovician glaciation and pelagic carbonate successions deposited in Cyprus during the Mid Miocene, Monterey Event. The former was a short-lived event (<5 Ma) within the Early Palaeozoic greenhouse, the latter part of the developing late Cenozoic icehouse. Preliminary results suggest the end Ordovician glaciation was driven entirely by the thermohaline circulation whereas the Monterey Event in the pelagic succession in Cyprus possibly has a more complex interaction of causative mechanisms.

CC08 : TUpm28 : G2 Inorganic-Geochemical Signatures of Recent Upwelling Sediments from the Peruvian Continental Margin

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Six surface sediment cores recovered during R/V Sonne cruise 147 from the Peruvian continental shelf and slope were analysed for their major and minor element composition by XRF and ICP-AES/MS at high resolution. The terrigenous-detrital sedimentary component is comparable in composition to average shale. Samples from four cores show slight increase in biogenic silica (diatoms) and distinct carbonate enrichments (foraminifera). Furthermore, they are characterised by elevated TOC and high P contents due to enhanced primary productivity, high sedimentation rates (up to 470 cm/ka) and corresponding organic matter preservation. Redox-sensitive and stable sulfide forming elements, such as Mo, U, As and V, are strongly enriched during early diagenesis, whereas Mn is significantly depleted. This element pattern reflects the presence of the distinct oxygen minimum zone. Under suboxic conditions in the water column elements like Mo, U, As and V are less soluble whereas Mn is very mobile in its reduced 2+ state. Moreover, Cr, Mo, V and U tend to be adsorbed to organic matter under reducing conditions. The distinct enrichments in Cd, Ni, Zn and Cu can be explained by a) the association of these elements with marine plankton (enrichment due to input and preservation of planktonic remains), and b) the fact that these elements form stable sulfides (fixation due to anoxic conditions in the sediments). The enrichments of, e.g., P, Mo, U, V, As, Cd, Zn, Cu, are more significant in the sediments from the Peruvian shelf compared to upwelling sediments from the Gulf of California. This results likely from a more severe oxygen depletion in the OMZ off Peru, higher sedimentation rates affecting organic matter burial and/or the higher primary productivity off Peru.

CC08 : TUpm29 : G2 Astronomically Forced Chemical Cyclicality of Pliocene South China Sea Sediments: Implications for East Asian Monsoon Variability

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High precision major- and minor element records of Pliocene core intervals from Ocean Drilling Program Site 1145 located in the northern part of the South China Sea (Wang et al., 2000) were generated in 5 cm, i.e., approximately 2 kyr resolution. From the geochemical data distinct paleoproxies, those indicating changes in detrital matter provenance as well as those indicating productivity variations, could be derived. The K/Si ratio displays a cyclicality that appears to be linearly related to astronomical insolation forcing. This element ratio is proposed to reflect changes in the relative contribution of fluvial versus eolian derived terrigenous-detrital matter with maxima indicating an enhanced East Asian summer monsoon. The K/Si record can be used for astronomical calibration of the sediments leading to an extraordinary precise age model for the time interval from 2.53 to 3.19 kyrs before present. Ba/Al ratios show an opposite behavior compared to K/Si displaying changes in organic matter productivity. Maxima are supposed to mark periods of enhanced upwelling intensity due to stronger winter monsoon. According to the Ba/Al record the winter monsoon over the South China Sea was well established before 3 Myr b.p. and is getting weaker afterwards. This is in contradiction to results from the Loess records of northeast China where the winter monsoon seems to have developed after 2.6 Myrs (Ding et al., 1998). Perhaps a northward shift in the winter monsoon regime occurred between 3 and 2.6 Myr before present. Calcium carbonate records show dominant 41 and 100 kyr cyclicality. Although one might suggest a global signal to be responsible for this, the carbonate content should rather reflect the result of local effects. It is determined by dilution and productivity variations, but not by dissolution because the investigated site must have been located above the CCD during time of deposition. Therefore we suggest that the carbonate content displays an interference signal of eolian dust and fluvial inputs and productivity variations, all of which seem to be directly dominated by insolation (23 kyr dominated) variability. The same must be assumed for color reflectance records which are well correlated with the carbonate content.

Ding ZL, Sun JM, Liu TS, Zhu RX, Yang SL & Guo B, *Earth Planet. Sci. Lett.* **161**, 135-143, (1998).
Wang P, Prell WL, Blum P, et al, *Proc. ODP. Init. Repts. ; Ocean Drilling Program*, **184**, (2000).

CC08 : TUpm30 : G2 Indications for Palaeo-Paths of Neogene Currents in the SE Atlantic

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The Agulhas Ridge, a transform fault oceanic ridge along the Falkland-Agulhas fracture zone, is located in the southeastern Atlantic ocean and characterised by a profound bathymetric relief. Disturbances of the sediments in the adjacent basins by vertical offsets show that tectonic activity lasted at least until Oligocene times, and intrusions affect even Quaternary sediments. This topography forces present day oceanic currents such as the Circumpolar Deep Water and the North Atlantic Deep Water to flow in a direction that follows the contours of the Agulhas Ridge. Nearly 2000 km of seismic data collected over the Agulhas Ridge and the adjacent basins show thick sediment packages in the Cape Basin, north of the Agulhas Ridge. Sheets of mostly biogenically formed sediments of several hundred meters thickness are found on top of a magmatic basement. The sediments in the Cape Basin show patterns which are typical for contourites, fine grained sediments deposited by contour currents which create channels parallel to the ridge. Deposits on the banks of these deep sea channels are asymmetric in nature due to deflection under the influence of the Coriolis force, and are therefore indicators of current direction. Dated with the help of drilled cores of ODP Leg 177, these structures show contour current activity in the Cape Basin that reaches into the Early Oligocene. Sediments that might reflect deposition by contour currents are observed in

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the Agulhas Basin as well, south of the Agulhas Ridge. These sediments, unlike those in the Cape Basin, do not have a lateral extension in the order of tens of kilometres, and thickness of several hundred meters, because in contrast to the flat bathymetry of the Cape Basin, the relief in the Agulhas Basin prevents the development of elongated drift systems. The geometry of the contourites in the Cape Basin shows that these deep water current sediments are deposited by a current much in the same direction as present day Circumpolar Deep Water. The sediments in both basins form the basis for reconstructions of palaeo-paths of deep oceanic currents in the South Atlantic. The Cenozoic is characterised by the development of a global thermo-haline convection system, which had a profound impact on the inter-ocean current activity and enhanced water mass transport between high and low latitudes, coinciding with the progressive cooling of the earth. The seismic records of the sediment sequences near the Agulhas Ridge show that there is a relationship between climatic change and seismic reflectivity. Alternating periods of glacial and interglacials provide different sediment influx in terms of quantity, grain size and composition, and leads to strong reflectors in the seismic sections as the Pleistocene record shows. On the other hand the sediments between Early Oligocene and Late Miocene appear as relatively homogeneous.

CC08 : TUpm33 : G2

Evolution of the Mediterranean Basin during the Late Langhian/Early Serravallian: An Integrated Paleooceanographic Approach

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A multidimensional geochemical and faunal dataset has been generated from the study of a Late Langhian/Early Serravallian sedimentary section outcropping in the Fomm Ir Rih bay (Malta Island, central Mediterranean) and constituted mainly by the Blue Clays Formation and, subordinatedly, by the underlying Upper Globigerina Limestone Formation. A cyclostratigraphic analysis of this section produced a very detailed time framework for the studied interval. Quantitative analyses of benthic foraminifers and ostracods suggest a paleobathymetry of about 500 m. Benthic specimen abundance of the Upper Globigerina Limestone Formation is very high as compared with that of the Blue Clays Formation, testifying a clear drop in the oxygen bottom levels in the latter one. Moreover, in the Blue Clays Formation a decreasing trend (starting from about 13.4 Ma) in the benthic foraminifer $\delta^{13}\text{C}$ signal has been observed. Some bio-events characterized by an oligotypical assemblage with high percentage values of the B.elongata group (40-60%), indicative of stressed bottom conditions and low or very low oxygen content, seem to be related to paroxic and anoxic episodes. Similar but more stressed conditions were already registered in selected easternmost marginal areas of the basin (Serravallian sapropels recorded in the D.S.D.P. Leg 42, Site 375, Antalya basin). Periods of enhanced surface productivity suggested by relatively increasing trends of Ba concentrations and planktonic $\delta^{13}\text{C}$ values are recorded starting from the middle part of the Blue Clays Formation. In the same interval a notable benthic foraminifer bio-event occurs, identified by common and abundance of *U.peregrina*, species related to a high organic carbon bottom content together with low oxygen bottom waters. These periods could be associated to periodic shifts of the pycnocline into the photic zone with consequent generation of a deep chlorophyll maximum. The simultaneous response of the benthic assemblage to surface productivity changes suggests a direct relationship between superficial and intermediate water masses within the Mediterranean basin during the studied interval. These results, combined with information from previously investigated eastern and western Mediterranean successions (Site 375, Site 372), provided a better comprehension of the large-scale thermoaline circulation of the Mediterranean basin during the same interval. Three principal water masses can be recognized: 1) surface Atlantic water, which inflow into the Mediterranean; 2) intermediate outflowing Mediterranean water, originated in the superficial eastern zone; 3) underlying quasi-stable psychrospheric environment previously identified in different areas of the basin.

CC08 : TUpm34 : G2

Inorganic Geochemical Profiles of the Toarcian Oceanic Anoxic Event

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Oceanic Anoxic Events (OAEs) are believed to define periods when much of the world's oceans became severely depleted in oxygen. The OAEs coincided with the deposition of organic-rich mudrock successions (Jenkyns, 1999), and possibly also with species extinctions. There is still much controversy regarding the causal mechanism of OAEs, suggested possibilities include: oxygen minimum zone expansion, water column stratification or gas hydrate release. The aim of the present study is to investigate the inorganic geochemistry of organic-rich mudrocks deposited during the Toarcian OAE. Sedimentary records of this OAE are particularly well preserved in the Whitby Mudstone Formation exposed in Yorkshire, UK, from which we have collected samples at high stratigraphic resolution. The OAE in Yorkshire is marked by a negative $\delta^{13}\text{C}_{\text{org}}$ perturbation and a TOC maximum (Hesselbo et al., 2000).

We have produced detailed geochemical profiles through the OAE showing temporal changes in major and minor elements. Abundances of some elements in detrital phases, such as Al, Rb and Th do not show any significant changes over the sampled interval. Therefore, Al has been used to normalise abundances of elements that are sensitive to changes in the redox state of the water column and/or sediment.

During the OAE itself, the abundances of many elements are elevated relative to background values and 'average shale'. There is a sharply defined enrichment of Co, Cu, Ni, Sc, U, V, Y and Zn that is coincident with the TOC maxima and $\delta^{13}\text{C}_{\text{org}}$ minimum in the *exaratum* Subzone. In addition, there are smaller enrichments of Zn, U, V, and Co in the younger *falciferum* Subzone. This second peak does not appear to correspond with high TOC values, although the sedimentary deposits contain large amounts of disseminated framboidal pyrite. In the case of Mo the younger peak is twice as large as the older peak, while for Ni the two peaks are of about the same magnitude. Elements such as Nb, Zr and Ti that can occur in heavy detrital minerals are depleted during the OAE and gradually increase up-section towards values more typical of 'average' shales, possibly reflecting changes in relative sea level.

Previous work on some of these samples has shown that abundances of Re and Os are elevated in some organic-rich Toarcian mudrocks (Cohen et al., 1999). Current investigations are concentrating on expanding the database to include profiles of the Platinum group element (PGE) abundances. The PGEs are redox sensitive and have varying residence times in seawater, making them potentially highly useful in understanding the prevailing conditions during OAEs.

Cohen AS, Coe AL, Bartlett JM, & Hawkesworth CJ, *Earth and Planetary Science Letters*, **167**, 159-173, (1999).
Hesselbo SP, Grocke DR, Jenkyns HC, Bjerrum CJ, Farrimond P, Morgans-Bell HS & Green OR, *Nature*, **406**, 392-395, (2000).
Jenkyns HC, *Zentralblatt für Geologie und Paläontologie*, 943-949, (1999).

CC08 : TUpm35 : G2

High Resolution Stratigraphy (Calcareous Plankton Biostratigraphy and Cyclostratigraphy) of the Serravallian-Early Tortonian Time Interval in the Mediterranean Area

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Results are presented of an integrated stratigraphic study (planktonic foraminifer and calcareous nannofossil biostratigraphy, cyclostratigraphy) of three land sections cropping out in the Malta Island (Blue Clay Formation), Tremiti Islands (Cretaccio Formation) and south-eastern Sicily (Tellaro Formation). The three sections which show a more or less evident lithological cyclicity, partially overlap and encompass an interval of about 3 million years, from 13.5 Ma (earliest Serravallian) to 10.5 Ma (early Tortonian). The lithological cycles, the abundance fluctuation of the *Globigerinoides* spp. and CaCO_3 content have been tuned to the Laskar et al. (1993) astronomical curves. The astronomical calibration provided the absolute age of several calcareous nannofossil and planktonic foraminifer bioevents throughout the considered interval. The comparison between the absolute ages obtained for the Mediterranean and those available for the low latitudes (Ceara Rise, Atlantic Ocean) confirms that the first occurrence (FO) of *Neogloboquadrina acostaensis* precedes the last occurrence (LO) of *Paragloborotalia siakensis* in the Mediterranean with respect to the Ceara Rise, in agreement with Hilgen et al. (2000). The diachronous ages of the two bioevents compromise the Serravallian-Tortonian boundary as historically recognised. On the contrary, the LO of *Sphenolithus heteromorphus* seems to be a fairly isochronous event both in Mediterranean area and Atlantic Ocean, rendering it a potentially valid event for the Langhian-Serravallian boundary.

Hilgen FJ, Krijgsman W, Raffi I, Turco E, Zachariasse WJ, *Marine Micropaleont.*, **38**, 181-211, (2000).
Laskar J, Joutel F, Boudin F, *Astron. Astrophys.*, **270**, 522-533, (1993).

CC08 : TUpm36 : G2

Astrochronological Calibration of Calcareous Plankton Bioevents in the Upper Serravallian-Lower Tortonian Pelacani Section (Eastern Sicily, Italy)

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The Pelacani section, represented by a lithological alternation of gray marls and blackish level in the lower part and of light gray marls and indurated more carbonatic levels in the upper part, covers the stratigraphic interval from just below the last occurrence of the planktonic foraminifera *Paragloborotalia partimlabiata* to slightly above the first common occurrence of the calcareous nannofossil

Helicospaera stalis. All the main calcareous plankton bioevents included in this stratigraphic interval were identified by quantitative analyses. Application of band-pass filters allowed us to select the classic Milankovitch frequencies recognised in the original faunal signals in turn compared with the same harmonic components of the astronomical curve of Laskar et al. (1993). The reliability of the obtained astronomical tuning has been tested using a procedure of complex demodulation to compare the larger order cyclicity (100-400 ky) present in the geological and astronomical records. The good match of the different records is consistent with the results of the cross-spectral analysis showing high coherency values in all the considered frequency bands. The obtained astronomical calibration of the sedimentary cycles and of the relative abundance fluctuations of *Globigerinoides* spp. provided absolute ages for the calcareous plankton bioevents. Our chronological results are totally comparable with data recently published for the Mediterranean region, if some discrepancies in the species identification and in the interpretation of the first and last common occurrence levels are considered.

**CC08 : TUpm37 : G2
Astrochronological Calibration of an Upper Langhian/Lower Serravallian Record from the Fomm Ir Rih Section (Malta Island, Central Mediterranean)**

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A high-resolution isotopic, geochemical and micropaleontological data set has been obtained for the Upper Langhian/Lower Serravallian marly sediments of the Fomm Ir Rih section (Malta Island). This sedimentary succession is characterized by a cyclic alternation of brown and whitish marly layers showing an evident stratal pattern organization.

A detailed combination of a recorded stratal organization and the spectral analysis results from the geochemical (CaCO₃ contents and planktonic oxygen isotopes) and faunal signals show a dominance of the classic Milankovitch periodicity as modulating forcing of the studied succession. The application of band-pass filters allowed us to select the different Milankovitch frequencies from the original faunal and geochemical signals in turn compared with the harmonic components of the astronomical curve of Laskar et al. (1993). The reliability of the obtained astronomical tuning has been tested using a procedure of complex demodulation to compare the larger order cyclicity (100-400 ky) present in the geological and astronomical records. The good match of the different records is consistent with the results of the cross-spectral analysis showing high coherency values in all the considered frequency bands.

The calibration provides absolute astronomical ages for the sedimentary cycles and consequently for the recorded bioevents.

Laskar J, Joutel F & Boudin F, *Astron. Astrophys.*, **270**, 522-533, (1993).

**CC08 : TUpm38 : G2
Astrochronological Calibration of a Upper Serravallian/Lower Tortonian Sedimentary Sequence in the Mediterranean Area (Tremiti Islands, Southern Italy, Ionian Sea)**

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A high-resolution geochemical and micropaleontological data set has been obtained for the upper Serravallian/Lower Tortonian marly sediments of two sections cropping out in the Tremiti Islands (S.Nicola Island). This sedimentary record, which covers the biostratigraphic interval from just above the *Globorotalia partimlabiata* first occurrence (FO) to above the *Paragloborotalia siakensis* last occurrence (LO), consists of an alternation of indurated, whitish-coloured CaCO₃-rich and grey less indurated, CaCO₃-poor marly beds. Red-coloured CaCO₃-poor marls sometimes replace the grey-coloured marls. Results of spectral methodologies applied on the CaCO₃ and *Globigerinoides* spp. quantitative data, combined with the lithological patterns recognised throughout the sections showed that the classic Milankovitch periodicity represented the modulating forcing of the studied sedimentary record. Different bandpass filters have been applied to extract selected Milankovitch periodicities from the original faunal and geochemical time series. Then each filtered signal has been compared with the same harmonic components recognised in the astronomical curve of Laskar et al. (1993). The reliability of the obtained astronomical tuning has been tested using a procedure of complex demodulation. Furthermore, results of cross-spectral analysis have shown high coherency values in all the selected frequency bands, confirming the correctness of the obtained astronomical calibration. Consequently, the astronomical calibration of the identified cycles provide absolute ages for all the calcareous plankton bioevents (calcareous nannofossils and planktonic foraminifera). They are well comparable with the chronological data recently published for the Mediterranean region (Hilgen et al. 2000).

Hilgen FJ, Krijgsman W, Raffi I, Turco E, Zachariasse Wj, *Marine Micropaleont.*, **38**, 181-211, (2000).
Laskar J, Joutel F, Boudin F, *Astron. Astrophys.*, **270**, 522-533, (1993).

Tuesday PO Session

**CC08 : TUpo01 : PO
New Insights into the Stretching of Sedimentary Series Collected Through Piston Coring: Evidences, Effects on Flux Estimates and Possible Corrections**

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Within the international IMAGES program, a debate has been initiated about possible stretching of upper part of sediments collected with the giant piston corer CALYPSO that equips the R/V Marion Dufresne. Our main objectives were: (1) to collect data to check for possible CALYPSO coring disturbances; (2) to estimate the impact of excess material on the calculation of sedimentation rates; (3) to propose (a) method(s) to restore in situ thickness; and, finally, (4) to check whether such perturbations exist with other (shorter) piston corers.

Penetrometry tests and/or measurements of anisotropy of magnetic susceptibility (AMS) were performed on 14 giant cores obtained during IMAGES V cruise (summer 1999). Our data show that some records present anomalous low cohesion and vertical magnetic lineation down to a maximum depth of about 15 m. Nevertheless, other records do not show any indication of coring-related perturbations. Our results indicate a possible link between disturbance and sediment type and/or corer settings.

To establish whether these anomalies are related to a substantial stretching of the sedimentary column, one needs to determine the true, in situ thickness of the collected series. Inter-comparison with sediments obtained using a different corer is not satisfactory since they may be also perturbed (i.e. gravity coring appears to induce a compaction of the sediments). We propose an approach based on the correlation of 3.5 kHz profiles with synthetic seismograms computed from physical property logs of nearby cores (MST measurements, laboratory pycnometer and velocimeter analyses corrected for in situ conditions). Preliminary results were presented at the AGU Fall Meeting in San Francisco (December 15-19, 2000). Here, new data are added and discussed.

As observed earlier, matching reflectors can be straightforward for certain cores, which implies that stretching is not affecting all the sediments retrieved. On the other hand, in numerous sites, a good matching of deep reflectors requires that the water/sediment interface in synthetic seismograms is shifted upward relative to the corresponding 3.5 kHz profiles. This confirms our preliminary results and indicates sediment stretching in the upper part of many cored series.

Some shorter kullenberg piston cores also show vertical magnetic lineations. Although we do not know yet whether or not some stretching occurs, our results suggest that one may be cautious in interpreting sedimentation rates obtained from any piston cored material.

In order to better understand the mechanism that could explain such stretching, we initiated a collaboration with engineers from ENSIETA (Brest) to develop a model of corer and sediment behavior during the triggering and the subsequent penetration of the system into the sediments. Results of this model, if available in time, will be presented and discussed.

CC08

Understanding Global Climate Change

CC08 : TUp02 : PO Palaeo-Ecosystem Study from Eastern Mediterranean Marine Sequences (Late Pleistocene/Holocene) based on Planktonic Foraminifera, Pteropods and Calcareous Nannofossils Integrated Data

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Five selected box-cores and one gravity core, collected in different areas of the eastern Mediterranean, have been used to detect significant changes in zooplankton (foraminifera and pteropods) and phytoplankton (calcareous nannofossils) assemblages during the Late Pleistocene/Holocene. The study represents an attempt to integrate different micropaleontological data.

Fluctuations of planktonic assemblages have been related to well defined climate changes. Microfossil assemblages clearly show abundance changes in correspondence to cold (Last Glacial Maximum, Dryas glacial phases), interglacial stages (Bølling, Allerød) and Climatic Optimum. The temporary disappearance or increase in abundance of different foraminiferal species allow the definition of "assemblage zones" for the last 40 kyrs that partially correspond to the main "assemblage zones" defined by the relative abundance curves of calcareous nannofossils.

The Last Glacial Maximum and the Dryas stages are characterised by an increase of low-temperature tolerating foraminiferal species *N. pachyderma* (right coiled), *G. scitula* and *T. quinqueloba* and of the pteropods species *L. retroversa*. In the same interval an increase in abundance of the calcareous nannofossil *Reticulofenestra* overcalcified s.l. has been detected. The temporary occurrence of the tropical-subtropical foraminiferal species *O. univerrsa* marks interglacial stages that are characterised also by an increase in abundance of *Rhabdosphaera* spp.

Two zooplankton and phytoplankton "assemblage zones" have been detected within the visible and oxidised sapropel S1. The foraminifera and nannofossil assemblages indicate a Climate Optimum phase as also is testified by the presence of the warm water pteropod species *L. inflata*. The temporary disappearance of the foraminiferal species *G. inflata* and *T. truncatulinoides* with the increase of the subtropical species *G. ruber* marks the bottom of S1, whereas the re-occurrence of *G. inflata* indicates the real top of S1. A significant change in calcareous nannofossil assemblages represented by a gradual increase of *H. carteri*, *Rhabdosphaera* spp., *F. profunda* and of thoracosphaerids (calcareous dinocysts) has been detected just before S1 deposition. The sedimentary record just above the oxidised S1 is characterised by a decrease in abundance of the previous nannofossils assemblage and changes in the percentages of less calcified and more calcified morphotypes of *E. huxleyi*.

CC08 : TUp03 : PO Global Climatic and Environmental Changes in the Pleistocene, Central Asia: Implications from the Study of Sediments in Lake Baikal and Loess-Soil Sequences in West Siberia

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Quaternary climatic changes in Central Asia have been recorded in bottom sediments of Lake Baikal and loess-soil units in West Siberia. The continuous record of paleoclimatic changes in the sediments implies the fluctuation of diatomaceous shell content and its related change of biogenic silica content. Chronostratigraphy of the sediments is based on paleomagnetic, paleontological and U-Th data. A 120 m thick sub-aerial loess unit is widely distributed in southern West Siberia and consists of alternating loess, soil and cryogenic horizons. Chronostratigraphy of this unit is based on paleopedologic, paleomagnetic, and paleontologic studies and radiocarbon and thermoluminescence dating. Nine cycles of sub-aerial sedimentation, including soil- and loess formation, have been established in this unit above the Brunnes/Matuyama boundary. We compared the Baikal biogenic silica records from the BDP96 drill hole for the Brunnes stage (0-780,000 years) and the West Siberian loess-soil unit: the number of Baikal main peaks coincides with that of the main epochs of soil- and loess-formation. The Baikal record shows better weak and/or short cooling periods, whereas the loess unit presents climatic changes in the Late Pleistocene.

In Turn, climatic changes in Inner Asia correspond to global climatic changes caused by the inversion of the Earth's orbital parameters in the Pleistocene, with a dominating 100,000 year cycle. The loess record shows that a clear 20,000 year cycle in the Late Pleistocene resulted in six alternating poorly developed soils. In the pre-Late Pleistocene time this cycle was less expressed and was not recorded in Eurasian mid-latitude loess units. We studied the impact of glaciation time and dust storms on the sedimentation in Baikal and loess formation, as well as the factors controlling the intensity of soil formation.

CC08 : TUp04 : PO Eastern Mediterranean Sapropel S1 Interruption as Indicated by High-Resolution Biomarker Profiles

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Interruptions within early Holocene organic-rich layers (sapropel S1) in the eastern Mediterranean have been documented by planktonic foraminiferal records, Ba/Al ratios profiles and $\delta^{13}\text{C}_{\text{org}}$ and related to temporary improved deep water ventilation. Records of marine and terrestrial biomarkers may possibly contribute to further understand this brief interval of climate deterioration during S1 sapropel deposition.

Four sediment cores of 60-cm length were collected from deep Eastern Mediterranean Basins (Hellenic Ridge, Eratosthenes Seamount, Apulian Plateau and near Atalante Basin), and sliced in 1-cm resolution scale including sapropel, oxidised sapropel and non-sapropel layers. The samples were ultrasonically extracted, and the extracts were analysed by GC-MS. Marine biomarkers (alkenones, loliolide, phytol, dinosterol and C30 diol) and terrestrial biomarkers (stigmaterol and b-sitosterol) were identified and quantified in each sediment layer. All the analysed biomarkers were present in very low concentrations in non-sapropelic layers and their concentrations increased dramatically within sapropel S1. The high-resolution sampling strategy enabled to discern a double peak in the biomarker profiles within S1 in all four sites, which was often not evident from the TOC profile. The double-peak pattern was most pronounced in the Atalante Basin site, with concentrations of most (but not all) marine biomarkers

during the S1 interruption as low as before S1 deposition, indicating decreased marine production, increased bottom water oxygenation and a change of the phytoplankton composition. Alkenone derived temperatures (UK'37) recorded in this site indicate a cooling of surface waters by 2°C during the S1 interruption, which possibly triggered deep-water ventilation.

CC08 : TUp05 : PO New Data on the Late Cenomanian Extinction Event: An Examination of a Potential Impact Ejecta Horizon, in West-Central Portugal

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The late Cenomanian extinction event has long been recognised as one of the major features of Cretaceous successions on many continents. There have been a number of models proposed to account for the event, including an expansion of the oxygen minimum zone, sea level fall caused by a glaciation, or a simple sea level rise induced by climate warming. Two closely spaced iridium peaks occurring in the Upper Cenomanian allude possibly to a large-body cometary impact. Recent research has identified a potential ejecta horizon (containing shocked quartz and microscopic spherules) within Middle-Upper Cenomanian carbonates near Nazaré, Portugal. It has been tentatively suggested that this horizon was generated by meteorite impact and hence could be a primary mechanism to account for the extinction event. The Cretaceous sediments hosting the possible ejecta horizon are interpreted to be shelfal carbonates, although large-scale clinoform geometries elsewhere suggest that the depositional environment may have been characterised by large, low-energy sandbars. Within the section containing the ejecta horizon, there is a pronounced angular unconformity with overlying fluvial clastics, the age of which is presently unknown. The unconformity was probably caused by diapirism, involving salt piercement at the surface, during the Cretaceous. The upper 6 m of the carbonates, close to the ejecta horizon, consist of intraformational breccias, which have previously been interpreted to represent remobilisation during tsunami following the meteorite impact. Our analysis reveals that these breccias are associated with in situ failure of the semi-consolidated carbonates on a slope. Narrow, elongate breccia bodies can be identified which are based by listric failure surfaces, which detach onto bedding-parallel slide-planes associated with clay-rich marls. The most likely cause of submarine slope failure was an increase in shear stress associated with haliconetic tilting of the carbonates. Because the duration of the hiatus above the ejecta horizon is not known we are undertaking micropaleontological and palynological analyses to constrain the age. It is, as yet, not possible to determine whether the exotic clasts associated with the ejecta horizon are penecontemporaneous with late Cretaceous submarine slope failure, fluvial reworking, or meteorite ejecta material falling onto the exposed land surface generated by diapiric uplift.

CC08 : TUp06 : PO Time-Frequency Analysis using Wavelet Transform of In-Situ Physical Measurements from ODP Holes 1095B and 1096C (West Continental Margin of the Antarctic Peninsula) and of High Resolution Signal from Cores of ODP Leg 160, Site 967 (Mediterranean Sea)

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The wavelet transform represents an alternative and a generalization to the basic windowed Fourier transform for time-frequency analysis. Indeed it allows not only time but also frequency localization. Wavelet transform then enable us to analyse nonstationary processes that contain multi-scale features, such as downhole logging or core petrophysical measurements. We present here the application of this method to two different data sets.

1. The various physical properties measured on cores and in-situ for the ODP Leg 178 continental rise sites (Holes 1095B and 1096C, 67°S, 78°W) were processed using

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wavelet transform (Bartes et al., 1999) in order to identify sedimentary cycles. These information are compared to the results provided by the processing of the insolation curve computed at 67°S (Laskar, 1997).

Using the insolation signal, computed using astronomical parameters, combined with the wavelet transform of the physical measurements for these sites, we show that the contribution of some frequencies (e.g. eccentricity at 100 kyr) is sometimes enhanced and that frequencies, different from those of Milankovitch, are revealed (e.g. 30 and 50 kyr). These frequencies essentially appear when we process the insolation signal previously truncated (equal to 0 if the insolation value is less than 385 W/m², true value if not). This result shows that the sedimentation related to the extension or regression of the Antarctic ice sheet responds to a discontinuous climatic attraction. Intervals characterized by different group of frequencies can also be determined, their transition corresponding to stratigraphic limits. Particular frequencies are well-expressed in some units, whereas they are missing in others. This might be the result of the sedimentary record disturbance caused by turbidity or coastal currents. The interaction between these different phases and the alternation of glacial-interglacial periods will be discussed.

2. Many studies showed that sapropels in the Eastern Mediterranean Sea is one of the best examples of correlation between sedimentary record and global climatic changes related to cyclic variations of Earth and other planets orbital parameters. We therefore chose the ODP Leg 160, which all sites, in particular Site 967, revealed sapropels levels. As Site 967 was not logged, we digitalised the pictures of the cores to obtain a high-resolution continuous signal (one point every 3 mm).

The processing of this signal using wavelet transform show the distortions of the astronomical signal record by the sediment. These distortions are essentially the consequence of sedimentary rate changes, though the sediment compaction has also a minor impact. This altered signal, expressed as a depth series, was then corrected when we transformed it as a time series using the wavelet transform.

The frequencies revealed by the processing of this retreated signal are finally compared with the apparent frequencies content of the insolation signal computed at N65 and N34.

Laskar J, *Phil. Trans. R. Soc. Lond. A*, **357**, 1735-1759, (1999).

Bartes D & Mattei JA, *Astron J*, **113**, 373-390, (1997).

CC08 : TUpo07 : PO Millennial-Scale Variations in the Alboran Sea Sediment Record: Fluvial vs Eolian Supply

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The Alboran Sea constitutes the westernmost basin in the Mediterranean Sea and, through the Strait of Gibraltar, its only connection with the Atlantic Ocean. The semi-enclosed location and the relatively small water volume, make this area very sensitive to climate changes. The International Marine Global Change Studies (IMAGES) core MD 952043, from the eastern Alboran Sea, displays sedimentation rates that are high enough to allow comparison with the Greenland ice cores records on a millennial scale. Recent studies have revealed high-frequency climatic oscillations in the Sea Surface Temperature (SST) record of this core that have been related to Heinrich Events (HE)

and Dansgaard-Oeschger (D-O) cycles after correlation with the Greenland ice cores (Cacho et al., 1999). Colder and windy conditions during the D-O Stadials and HE may induce the coolings detected in the Alboran Sea. In addition, pollen studies ascribe similar periodicities to changes in the aridity/humidity balance in the adjacent continent (Sánchez-Go-i et al., 2000). In our study we evaluate the supply of fluvial and eolian sediments to the Alboran basin during the Oxygen Isotope Stage (OIS) 3 and we propose the mechanisms that may explain their variability.

Grain-size analyses of the terrigenous fraction and X-ray fluorescence analyses of the bulk sediment fraction have been carried out to infer the causes of the observed climatic variability. End-member modelling of the grain-size distributions indicates that the sediments can be described as mixtures of three end-members, which represents eolian dust and silty to clayed fluvial sediments. The ratio of contributions of eolian and fluvial sediments is used as an indicator of continental aridity. An increase in aridity has been found during the HE and some D-O Stadials. In addition, some geochemical proxies, as Si/Al and Ti/Al ratios, or Al (%) and Ca/Al ratio, display exceptional correlation with the $\delta^{18}O$ from Greenland Ice Sheet Project 2 ice core (GISP2) and the Polar Circulation Index (PCI).

The high parallelism between MD952043 and GISP2 records suggests a rapid connection between Greenland and the Mediterranean Sea to produce these high-frequency oscillations in the Alboran Sea sediment composition and grain-size. The intensification of the atmospheric circulation during HE and D-O cycles was proposed as the main mechanism for transmitting the climate changes of the North Atlantic region after the study of dust particles in Greenland ice cores (Mayewski et al., 1994; Fuhrer et al., 1999). However, our preliminary results make undistinguishable the effect of continental aridity increments from the action of stronger winds transporting dust to explain the millennial variations in the Alboran Sea record. Therefore, additional studies are needed to infer the possible mechanism that is accounting for the observed variability.

Cacho I, Grimalt J, Pelejero C, Canals M, Sierro FJ, Flores JA & Shackleton N, *Paleoceanography*, **14**, 698-705, (1999).

Sánchez-Go-i MF, Turon JL, Guiot J, Sierro FJ, Peyropouet JP, Grimalt J & Shackleton N, *submitted*

Mayewsky PA, Meeker LD, Whitlow S, Twickler MS, Morrison MC, Bloomfield P, Bond G, Alley RB, Gow AJ, Grootes P, Meese DA, Ram M, Taylor KC & Wumkes W, *Science*, **263**, 1747-1751, (1994).

Fuhrer K, Wolff EW & Johnsen SJ, *Journal of Geophysical Research*, **104**, 31,043-31,052, (1999).

CC08 : TUpo08 : PO Extensional Distortion in a Calypso Piston Core from the Iberian Margin

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At present there appears to be no clear consensus as to the consistent effects of piston, gravity and Kasten coring techniques on the resultant sediment cores, though it is clear that each technique possesses its own set of drawbacks. Here, a correlation and comparison of stratigraphic records obtained from a Kasten core (MD99-2334K) and a piston core (MD95-2042), retrieved from a single location on the Iberian Margin (37°48'N, 10°10'W), reveals a relative 'extension' of >150% in the piston core. The deformation of saturated marine sediments must be considered in terms of the displacement of 'intact' saturated sediment (iso-volumetric shear distortion) or of pore-water only (compression or dilation - non-shear distortion). In the first case, the stratigraphic column will be over- or under-sampled (without affecting the wet-density) while in the latter case the stratigraphic column will actually be 'extended' or 'compressed' through the introduction or expulsion of pore-water. A consideration of average wet-densities in core MD99-2334K suggests that all of the dimensional discrepancy between the two cores cannot be attributed to 'shortening' of the Kasten core. A 'normal' condensation of the Kasten stratigraphy (<20%) is therefore assumed, resulting in the majority of the dimensional discrepancy being attributed to ~100% 'extension' in the piston core over the interval compared. In both cases hydrostatic pressure considerations preclude any significant flow of pore-water (hence non-shear compression/dilation), and therefore 'over/under-sampling' through iso-volumetric symmetrical shear is interpreted as being the primary deformation mode.

Features suggesting a similar elongation effect are identified in two other Calypso piston cores (Hall and McCave, 2000; Thomson et al., 1999), suggesting that the effect is not merely an isolated incident. If unnoticed, such coring artefacts will have a profound effect on our interpretations of past sedimentation rates, and may potentially affect our inferences regarding past depositional processes as a result.

Hall IR, McCave IN, *Earth and Planetary Science Letters*, **178**, 151-164, (2000).

Thomson J, Nixon S, Summerhayes CP, Schönfeld J, Zahn R, Grootes P, *Earth and Planetary Science Letters*, **165**, 255-270, (1999).

CC08 : TUpo09 : PO The Holocene of the Andvord Drift as Recorded by Benthic Foraminifers

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Benthic foraminiferal accumulation rates (BFAR), diversities, and principal component analysis of foraminiferal assemblages from the Andvord drift and adjacent Gerlache Strait are used to establish an 11 ky paleoceanographic record. From 11 to 7.2 ky BP high frequency fluctuations of BFAR indicate periodic intrusions of Weddell Sea Transitional Water (WSTW) into the study area with subsequent blooming of the *F. fusiformis* assemblage.

The conditions appeared unfavorable between 7.2 and 5.7 ky BP for benthic foraminifers, presumably due to a permanent sea-ice cover. BFAR values drop below the modern level, and the WSTW indicator *F. fusiformis* is very rare or absent. The proposed cold event corroborates reports of glacial readvance in the Antarctic Peninsula between 6.7 and 5 ky BP (e.g. Yoon et al., 2000).

Elevated BFAR, diversity, and WSTW fauna values centered around 4.5-2.5 ky BP are interpreted as a Holocene climatic optimum. The last 2.5 ky saw declining BFAR, Diversity and WSTW fauna values, pointing to a weaker influence of the WSTW and colder conditions in the study area.

Yoon et al. (2000), *Palaogeography, Palaeoclimatology, Palaeoecology*, **157(3-4)**, 189-211, (2000).

CC08 : TUpo10 : PO Nd-Sr-Pb Isotopes as Tracers of Potential Sources to the Mediterranean Sea: In the Case of S1 Sapropel

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The formation of sapropels (organic-carbon rich sediment) in the Eastern Mediterranean Sea seems to reflect climate changes such as an increase in rainfall over Africa and southern Europe. This study aims at proposing the mechanism for the sapropel S1 (9-6 kyrs BP) formation using Nd-Sr-Pb isotopes. Ten sediment cores as well as potential terrigenous sources (African dust and Nile river sediments) were analyzed for ¹⁴²Nd/¹⁴⁴Nd, ⁸⁷Sr/⁸⁶Sr and ²⁰⁸Pb/²⁰⁷Pb. As bulk sediments contain a "terrigenous" fraction derived from the continents and a "marine" fraction formed in the water column, we separated them using 1N HCl leaching. The variability in terrigenous inputs during sapropel formation is traced with the isotopic ratios in the residual fraction whereas the variability in the water circulation is traced using the isotopic ratios in the leachate.

The residual Nd and Sr isotopic ratios in the Algero-Provençal and Levantine basins can be explained by a binary mixing of the African dust and the Nile river particles. The influence of the Nile inputs becomes larger towards the eastern basin, in particular, in the sapropel layers. This suggests that an increase in the Nile discharge

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is one of the reasons for the S1 formation (Freydier et al., accepted; Rossignol-Strick et al., 1982). Lead isotopic ratios in the residual fraction are similar in the Algero-Provencal and Levantine basins. No significant difference in residual Pb isotopic ratios is observed in the sapropel and non-sapropel layers in the Algero-Provencal and Levantine basins. In the Adriatic and Aegean Seas, Nd and Sr isotopic ratios in the residual fraction do not plot on the binary mixing line, implying the influence of local sources. The Pb isotopic ratios support this notion.

As for the leachate, Nd isotopic ratios in the sapropel is more radiogenic than the adjacent non-sapropel layers in some cores in the Levantine basin. This may suggest that the circulation pattern changed and/or inputs of radiogenic Nd such as Nile river water increased during the S1 formation. $^{207}\text{Pb}/^{204}\text{Pb}$ in the leachate of the sediment from the South Adriatic is higher in the double sapropel layers determined by Ba/Al (Mercone et al., 2000) than the non-sapropel layers. Changes in potential sources to the eastern Mediterranean and in circulation patterns during S1 formation will be discussed combining the three isotope systems.

Freydier R, Michard A, De Lange GJ & Thomson J, *Mar. Geol.*, **accepted**
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CC08 : Tupo11 : PO Late Neogene Response to Orbital Forcing in the Eastern Equatorial Pacific: Indications for the Closure of the Isthmus of Panama and the Initiation of the Northern Hemisphere Glaciation

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I will present carbonate proxy data (density and sediment color) obtained non-destructively on 26 sediment sites from the eastern equatorial Pacific (EEP) in order to reconstruct paleoceanographic events since the Upper Miocene. Low-resolution chronology is based on measurements of magnetic polarity changes and on biostratigraphy. High-resolution chronology is established by stable oxygen isotope stratigraphy for the Late Pleistocene, and by tuning the carbonate proxy records to the stacked record of orbital eccentricity, tilt, and precession for the time prior to that, resulting in age models with 21-kyr control points. Accordingly, the youngest sediment cores cover the last 1.3 Ma and the oldest cores reach back until the Upper Miocene (7.74 Ma), whereby sedimentation rates range from 2 to 0.1 cm/kyr, respectively. In order to study paleoceanographic events and, in specific, the response to climate forcing on orbital time scales, I stacked the carbonate proxy records of all 26 cores. This step was required since the local variability of climate signals is very high and depends on water depth, relative morphological position (trough, ridge, mountain flank, plateau), depth of the carbonate compensation depth, and bottom-water chemistry. Thus, only a stacked record is capable of providing a regional rather than a local information.

The stacked record shows a pronounced carbonate maximum between 6.8 and 6.4 Ma which is known from other parts of the Pacific as a period of generally good carbonate preservation and increased productivity in surface waters. Until 4.6 Ma, there is a long-term decrease in carbonate content associated with internal 400-kyr cycles that respond to low-frequency eccentricity variations, probably amplified by pulsations of the Antarctic ice sheet. This gradual decrease is most likely linked to the narrowing of the Isthmus of Panama. Spectral analysis of the filtered 400-kyr component of the stack shows very low amplitudes between 4.5 and 3.4 Ma which are presumably associated with the isolation of the EEP from the Atlantic caused by the closure of the Isthmus, and the time required to reorganize the circulation system in the EEP. At 2.7 Ma, carbonate contents began to increase with a peak at 2.4 Ma. This time probably marked the first substantial glaciation of the northern hemisphere as a preservation/productivity spike in the EEP, followed again by a gradual decrease until the Pliocene/Pleistocene boundary, a period that yields a major environmental change from oxic to suboxic conditions, indicative for a distinctive decrease in deepwater oxygen content. This change is accompanied by an 0.7-myr hiatus. During the Pleistocene, the 100-kyr amplitude of the stack increased at 1.3 Ma, suggesting that the response to the 100-kyr eccentricity cycle might have evolved in low latitudes and migrated to higher latitudes at 0.9-0.8 Ma.