APPENDIX 05.1 SELECTED GEOLOGICAL REFERENCES

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SELECTED RELATED ABSTRACTS FROM INTERNATIONAL PUBLICATIONS

Sea-level, humidity, and land-erosion records across the initial Eocene thermal maximum from a continental-marine transect in northern Spain

Publication: *Geology.* August 2003, v. 31, p. 689-692.

Authors: Birger Schmitz and Victoriano Pujalte

Abstract

In two continental sections in the Tremp basin, northern Spain, the initial Eocene thermal maximum (also known as the Paleocene-Eocene thermal maximum) is registered by an 6‰ fall in $\delta^{13}C$ values in soil carbonate nodules. High-resolution correlations, using the $\delta^{13}C$ excursion, can be made to nearby shelf and bathyal marine settings, allowing a detailed reconstruction of soil formation on land and transport of detritus to the sea during the initial Eocene thermal maximum. Soils that formed before and after the initial Eocene thermal maximum in the Tremp region reflect arid to semiarid conditions, with abundant evaporative minerals, whereas initial Eocene thermal maximum soils reflect seasonally wetter but generally dry conditions. During the initial Eocene thermal maximum, land erosion was intensified and accumulation rates of terrigenous detritus in the sea increased. This reflects both increased topographic relief associated with a prominent sea-level lowstand and enhanced seasonal precipitation over a dry landscape with sparse vegetation. Deeper erosion led to an increase in the flux of kaolinite from buried Mesozoic soils to the oceans. The association of the initial Eocene thermal maximum with a sea-level lowstand in northern Spain, as well as at other marginal North Atlantic sites, may reflect coeval large-scale magmatic activity in the northernmost Atlantic.

Ostracode turnover and sea-level changes associated with the Paleocene-Eocene thermal maximum

Publication: *Geology.* January 2002, v. 30, p. 23-26,

Authors: Robert P. Speijer and Abdel-Mohsen M. Morsi

Abstract

The ostracode response to oceanographic changes during the Paleocene-Eocene thermal maximum (PETM, ca. 55 Ma) is largely unknown. The Gebel Duwi section (Egypt) provides a detailed ostracode record across the PETM in a middle neritic setting. Quantitative analysis of this record reveals two significant results. (1) The PETM is marked by a sharp faunal turnover, as indicated by abundance changes, local extinctions, and immigrations. This turnover punctuated a gradual basin-wide faunal transition. (2) During the 60 k.y. period prior to the PETM, relative sea level fell rapidly by 15 m. This sea-level fall was followed by an 20 m sea-level rise during the PETM. A possible eustatic control on these fluctuations suggests the presence of a cryosphere and variations in its size during this time of global warmth.

Multiple early Eocene hyperthermals: Their sedimentary expression on the New Zealand continental margin and in the deep sea

Publication: *Geology.* August 2007, v. 35, p. 699-702

Authors: Micah J. Nicolo, Gerald R. Dickens1, Christopher J. Hollis and James C. Zachos.

Abstract

The Paleocene–Eocene thermal maximum (PETM) ca. 55.5 Ma was a geologically brief interval characterized by massive influx of isotopically light carbon, extreme changes in global climate, and profound variations in Earth system processes. An outstanding issue is whether it was an isolated event, or the most prominent example of a recurring phenomenon. Recent studies of condensed deep-sea sections support the latter, but this finding remains uncertain. Here we present and discuss lithologic and carbon isotope records across two lower Eocene outcrops on South Island, New Zealand. The PETM manifests as a marl-rich horizon with a significant negative carbon isotope excursion (CIE). Above, in sediment deposited between 54 and 53 Ma, are four horizons with similar though less pronounced expressions. Marl beds of all five horizons represent increased terrigenous sedimentation, presumably linked to an accelerated hydrological cycle. Five corresponding clay-rich horizons and CIEs are found in deep-sea records, although the lithologic variations represent carbonate dissolution rather than siliciclastic dilution. The presence of five intervals with similar systemic responses in different environments suggests a mechanism that repeatedly injected large masses of ^{13}C-depleted carbon during the early Eocene.

Evidence of an abrupt environmental disruption during the mid-Paleocene biotic event (Zumaia section, western Pyrenees)

Publication: *Geological Society of America Bulletin.* July 2007, v. 119, p. 785-795.

Authors: Gilen Bernaola, Juan Ignacio Baceta, Xabier Orue-Etxebarria, Laia Alegret, Maite Martín-Rubio, Javier Arostegui and Jaume Dinarès-Turell.

Abstract

An abrupt environmental disruption occurred in the photic zone and at the seafloor during the mid-Paleocene biotic event (MPBE). Calcareous nannoplankton, planktic foraminifer, and benthic foraminifer assemblages at Zumaia section (western Pyrenees) underwent a rapid and remarkable transformation. The major calcareous plankton assemblage changes suggest a shift from relatively cooler mesotrophic to warmer, more oligotrophic conditions, indicating a disturbed environment due to the warming of the ocean. Benthic foraminifer assemblages were also significantly affected by the MPBE; diversity of the assemblages and buliminids show net decline and the low food and opportunistic taxa increase in abundance. The reorganization of the planktic ecosystem possibly involved changes in the food flux (type and quantity) to the seafloor, thus triggering changes in the benthic communities.

A 1‰ negative $\delta^{13}C$ shift and a 30% carbonate content decrease are recorded in connection with the biotic event. This suggests that during the MPBE, as in the Paleocene-Eocene Thermal Maximum (PETM), an input of a large mass of isotopically depleted carbon into the ocean and atmosphere could have lowered the deep-sea pH, triggering a rapid shoaling of the lysocline and contributing to greenhouse warming.

The MPBE was short lived: according to the counting of limestonemarl couplets, the stratigraphic expression of precession cycles throughout the Zumaia section, the MPBE lasted for 52–53 k.y., with the core of the event representing 10–11 k.y.

The Zumaia section is the first land-based locality in which the MPBE is recognized and described in detail. Due to its expanded character and excellent paleontological record, this section may prove to be a global reference section for the study of this short-lived event.

Mode and tempo of the Paleocene-Eocene thermal maximum in an expanded section from the Venetian pre-Alps

Publication: *Geological Society of America Bulletin.* March 2007, v. 119, p. 391-412.

Authors: Luca Giusberti, Domenico Rio, Claudia Agnini, Jan Backman, Eliana Fornaciari, Fabio Tateo and Massimo Oddone.

Abstract

The central part of the Piave River valley in the Venetian pre-Alps of NE Italy exposes an expanded and continuous marine sediment succession that encompasses the Paleocene series and the Paleocene to Eocene transition. The Paleocene through

lowermost Eocene succession is >100 m thick and was deposited at middle to lower bathyal depths in a hemipelagic, near-continental setting in the central western Tethys. In the Forada section, the Paleocene succession of limestone-marl couplets is sharply interrupted by an 3.30-m-thick unit of clays and marls (clay marl unit). The very base of this unit represents the biostratigraphic Paleocene-Eocene boundary, and the entire unit coincides with the main carbon isotope excursion of the Paleocene-Eocene thermal maximum event. Concentrations of hematite and biogenic carbonate, $\delta^{13}C$ measurements, and abundance of radiolarians, all oscillate in a cyclical fashion and are interpreted to represent precession cycles. The main excursion interval spans five complete cycles, that is, 105 ± 10 k.y. The overlying carbon isotope recovery interval, which is composed of six distinct limestone-marl couplets, is interpreted to represent six precessional cycles with a duration of 126 ± 12 k.y. The entire carbon isotope excursion interval in Forada has a total duration of 231 ± 22 k.y., which is 5%-10% longer than previous estimates derived from open ocean sites (210–220 k.y.). Geochemical proxies for redox conditions indicate oxygenated conditions before, during, and after the carbon isotope excursion event. The Forada section exhibits a nonstepped sharp decrease in $\delta^{13}C$ (−2.35‰) at the base of the clay marl unit. The hemipelagic, near-continental depositional setting of Forada and the sharply elevated sedimentation rates throughout the clay marl unit argue for continuous rather than interrupted deposition and show that the initial nonstepped carbon isotope shift was not caused by a hiatus. A single sample at the base of the unit lacks biogenic carbonate. Preservation of carbonate thereafter improves progressively up-section in the clay marl unit, which is consistent with a prodigiously abrupt and rapid acidification of the oceans followed by a slower, successive deepening of the carbonate compensation depth. Increased sedimentation rates through the clay marl unit (approximately the main interval of the carbon isotope excursion) are consistent with an intensified hydrological cycle driven by super-greenhouse conditions and enhanced weathering and transport of terrigenous material to this near-continental, hemipelagic environment in the central western Tethys.

The sharp transition in lithology from the clay marl unit to the overlying limestone-marl couplets in the recovery interval and the coincident shift toward heavier $\delta^{13}C$ values suggest that the silicate pump and continental weathering, the cause of the enhanced terrigenous flux to Forada, stopped abruptly. This implies that the source of the light CO_2 eased to be added to the ocean-atmosphere system at the top of the clay marl unit.

Late Cretaceous–Paleocene formation of the proto–Zagros foreland basin, Lurestan Province, SW Iran

Publication: *Geological Society of America Bulletin.* June 2009, v. 121, p. 963-978, first published on April 24, 2009.

Authors: Stéphane Homke, Jaume Vergés, Josep Serra-Kiel, Gilen Bernaola, Ian Sharp, Miguel Garcés, Ismael Montero-Verdú, Ridvan Karpuz and Mohammad Hassan Goodarzi.

Abstract

Late Cretaceous emplacement of ophiolitic-radiolaritic thrust sheets over the Arabian passive margin was the first manifestation of the protracted closure of the Neotethys Ocean, which ended with the continental collision between Arabia and central Iran and the formation of the present Zagros fold belt. This tectonic stacking produced a flexural basin (the Amiran Basin: 400 × 200 km in size) in the northwest Zagros that was filled with a 1225-m-thick shallowing-upward detrital succession made up of the Amiran, Taleh Zang, and Kashkan Formations. This succession sits unconformably above the Late Cretaceous Gurpi Formation and is overlain by the Oligocene-Miocene Shahbazan-Asmari carbonate succession. Dating of the Amiran-Kashkan succession is based on detailed biostratigraphy using large foraminifera and calcareous nannoplankton.

The Cretaceous-Tertiary (K-T) boundary is located within the uppermost 25–45 m of the Gurpi Formation. The overlying Amiran and Taleh Zang Formations have been dated as Paleocene in age. However, the base of the Paleocene within the Gurpi Formation lacks NP1 and NP2 zones, implying a hiatus of ~2 m.y. at ca. 65.5 Ma, which is inferred to correspond to an early folding phase near the Cretaceous-Paleocene boundary. The upper part of the Kashkan Formation is dated to the earliest Eocene by palynostratigraphy. A large hiatus (or very slow deposition) lasting about 15 m.y. occurs between the Kashkan and Shahbazan Formations in the studied region. The base of the prograding Shahbazan platform deposits is dated by $^{87}Sr/^{86}Sr$ stratigraphy at ca. 33.9 Ma. The upper part of the Asmari Formation is dated as early-middle Miocene using foraminifera associations.

Reconstruction of the Amiran–Taleh Zang–Kashkan succession of the Amiran Basin indicates a thickening of the basin fill from the southern pinch-out along the SE flank of the Kabir Kuh anticline to SW of the Khorramabad anticline, where the flexure is at least 900 m. In contrast, the NE part of the basin underwent coeval contraction and uplift of ~1300 m. Superimposed smaller undulations onto the large-scale flexure are interpreted as Late Cretaceous–Paleocene folds.

Regional comparisons (SE Zagros, Oman, and Turkey) indicate that Late Cretaceous–Early Tertiary deformation affected the entire NE margin of Arabia but that compression was not synchronous, being younger in Lurestan than in the NW Persian Gulf where inversion tectonics occurred from Turonian to mid-Campanian times. The long sedimentary hiatus spanning most of the middle and late Eocene must have been related to deep lithospheric processes linked to the initial events of the protracted closure of the Neotethys Ocean between Arabia and central Iran. The tectono-sedimentary history recorded in the Zagros Basin may help to understand early foreland basin growth in other orogens in which subsequent continental collision has obliterated these early events.