Lower Eocene Hyperthermal and Transgressive Events as Revealed from Stable Isotopic Analysis of Lignite Bearing Coastal Deposits from Kutch Basin, Western India

ANIKET MITRA[1], KALYAN HALDER[1], YOGARAJ BANERJEE[2,3], S, THAMIZHARASAN[3,4], PROSENJIT GHOSH[2,3,4]

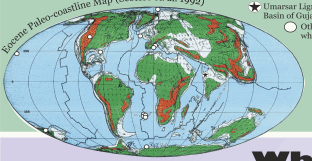
1 Department of Geology, Presidency University 2 Centre for Earth Sciences, Indian Institute of Science 3 Interdisciplinary Centre for Water Research, Indian Institute of Science 4 Divecha Centre for Climate Change, Indian Institute of Science

What

Paleocene- Eocene thermal maximum (PETM) is one of the most significant global warming events in the earth's history. During the period of late Paleocene to early Eocene (~56 - ~50 ma) PETM struck the earth followed by a series of hyperthermal events of lesser magnitude during early Eocene. Negative carbon isotopic excursions (CIE), recorded from many places of the earth, demarcate these hyperthermal events.

Due to depletion in the level of ^{13}C in the long term carbon cycle of the atmosphere during hyperthermal events, sharp spikes of negative excursion in the $\delta^{13}C$ curve have been attributed as a marker to identify hyperthermal event.

The Cenozoic sedimentary succession of Kutch basin, Gujarat, western India includes this time boundary (Saraswati et. al 2016).

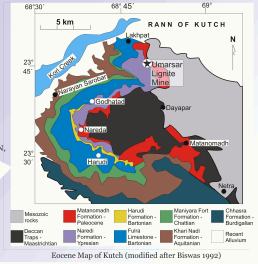


Where

Kutch is a pericratonic rift basin in the western part of India just beside the Arabian sea.

Umarsar lignite mine is located in the western part of Kutch basin, near greater Rann of Kutch, Gujarat adjacent to Umarsar village, on the way to Lakhpat from Dayapar.

The sampling has been made from drill-core no. CH 154 (23° 43'33.91"N, 68° 49'15.00"E), of Umarsar Lignite Mine.



How

Sampling:

Samples have been collected at 1m interval from an 82m drill-core of Umarsar mine. Closer sampling has been done where there is a change in lithology.

Preparation and analysis:

Rock samples:

The samples have been collected from the drill cores using a narrow-bit drill machine. The powdered samples were then treated with 0.5 N HCl overnight (12 hours). Then the samples were rinsed with water to remove its acid content. Then the samples have been analysed in Organic Carbon Thermo Delta V.

Carbonate (Shell fragment) samples:

Shell fragments have been cleaned with 50% diluted H_2O_2 solution, and then powdered by agate mortar. The powdered samples have been analysed in Carbonate Thermo MAT 253.

Amber samples:

Ambers have been extracted by narrow-bit drill machine from the rock-samples. The extracted amber has been powered and then analysed in Organic Carbon Thermo Delta V. All the stable isotope analysis have been carried out in the isotope geochemistry laboratory of IISC Bangalore, India.

Why

Carbon from $CaCO_3$ (marine shell fragments) and terrestrial Rock samples :

Large amount of ^{12}C rich carbon, released from methane hydrate reservoirs of the sea floor, caused the thermal maximum at Paleocene-Eocene boundary. This increased amount of ^{12}C has been recorded in $CaCO_3$ shells of marine organisms, ocean sediments and terrestrial soil as well. But, the terrestrial soil is a more reliable proxy to identify these hyperthermal events.

Plants intake larger proportion of lighter carbon (^{12}C) with respect to heavier carbon (^{13}C) because the diffusivity of ^{12}C is 4.4 ‰ higher than ^{13}C. During hyperthermal events, the leaves of trees keep their stomata closed, to prevent water loss. The fractionation between ^{13}C and ^{12}C gets increased as the water use efficiency decreases during hyperthermal. Due to this fractionation mechanism, adopted by terrestrial plants, the increased amount of ^{12}C is better recorded in terrestrial soil. Any negative excursion greater than -2‰ has been attributed to hyperthermal event. PETM has a magnitude of ~ -3o‰.

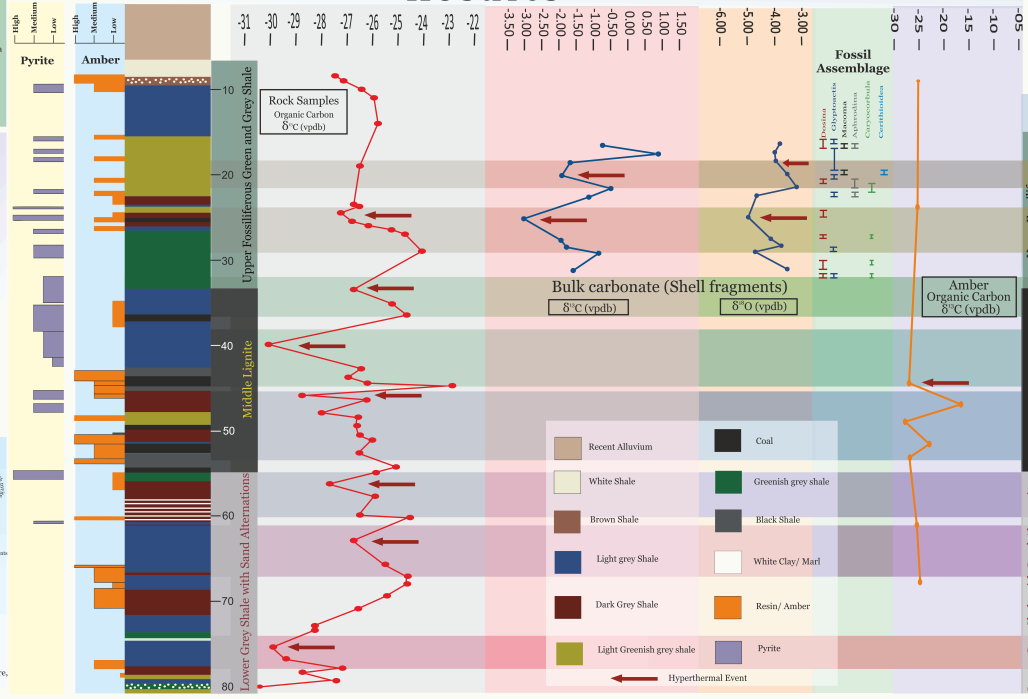
Oxygen from Carbonate ($CaCO_3$) of shell fragments :

During evaporation of water, ^{18}O is favored over ^{18}O, because of its weaker covalent bond. So the cloud is richer in ^{18}O. The relative proportion of ^{18}O is larger in oceanic water than atmosphere. During precipitation, as the clouds move towards higher latitudes, the proportion of ^{18}O decreases in the rain water, because of its quick precipitation in lower latitudes. So, the polar ice is depleted in ^{18}O. All these fractionation events have been recorded in the $CaCO_3$ shells of the marine organisms.
During a hyperthermal event, due to melting of ice, large amount of ^{16}O rich water get mixed in the ocean. Hence, negative excursion of $\delta^{18}O_{sw}$ signifies hyperthermal event. However, mixing of fresh water with ocean water can also give similar signatures.

Organic carbon of amber :

Resin records climatic changes in a similar way as other parts of a plant. However, the volatiles like monoterpenes and sesquiterpenes are much more enriched in ^{13}C whereas the non-volatiles like diterpenoid and triterpenoid acid are enriched in ^{12}C. Hence, during a hyperthermal event, the proportion of ^{12}C is better recorded in Amber.

Results



Discussion

The three litho-units of the succession - (1) Lower grey shale with sand alternations, (2) middle lignite and (3) upper fossiliferous green and grey shale - broadly indicates a transgressive systems tract. This lignite bearing succession with marine mega-invertebrates in its upper part was a coastal deposit of lagoon-marsh environment.

Seven hyperthermal events are recorded from this succession by the $\delta^{13}C_{om}$ curve. Among these the first one, with a CIE of 2.7 and reaching a magnitude of -30.6 ‰ can be considered as the PETM. These values broadly match other recorded values from different parts of the world. However, no area in the world recorded six lower Eocene hyperthermals.

The $\delta^{13}C_{om}$ values of rock samples and amber vary between -22 ‰ to -31 ‰, which indicates the source of OM was primarily C_3 plants.

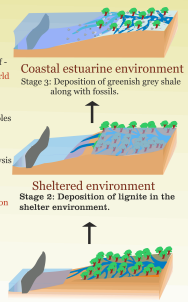
Amber is present in almost all the lithounits. However, only 9 samples have been analysed so far for isotopic ratios. The five relatively closely spaced samples from 55m to 45m depth yielded $\delta^{13}C_{amb}$ values, which support the fourth hyperthermal event (EEHT4) with a CIE of 12.

Marine mega-invertebrate fossils appear in the uppermost lithounit for the first time. The EEHT7 is supported by $\delta^{13}C_{bc}$ and $\delta^{18}O_{bc}$ curves.

These curves indicate presence of another hyperthermal event (EEHT8), which was not revealed in the $\delta^{13}C_{om}$ curve because of low frequency sample analysis at this level.

In this trangressive systems tract small scale transgression-regression cycles have affected the depositional environment that resulted in quick changes in litho-units including thin lignite seams and black shales. Deposition of the marine fossil bearing upper litho-unit follows EEHT6. This demarcates incursion of the sea in this restricted basin. The close association between the hyperthermal and the transgression suggests their causal link.

Interestingly, there are records of transgression preceeding the PETM (Pujalte et al., 2014), which posed doubt as to their causal link.



Interpretation

Upper Fossiliferous Green and Grey Shale

This 25.5 meter thick fossiliferous green and grey shale contains moderate amount of resin and pyrite.

The presence of marine mollusc fossils indicates a shallow shelf environment.

Clay matrix of the fossil bearing levels and intercalated lignite and shales indicate continuation of a restricted condition.

A coastal estuarine environment

Middle Lignite

This 22 meter thick coal and black shale dominated litho-unit is rich in amber and pyritised plant matter. No marine fossils are found from this unit.

A swamp-marsh setting with ample vegetation.

Presence of pyrite reflects anoxic environment.

A sheltered depositional setting with thick vegetation

Lower Grey Shale with Sand Alternations

This 26.5 meter thick alternation of shale and fine laminated sand is rich in plant remains like leaf imprints and varying concentration of amber.

Marine organisms are not found.

The succession indicates a restricted supratidal zone.

CIE 8		The $\delta^{13}C_{om}$ curve, having a negative excursion of 2.0 ‰, accounts for another hyperthermal event in early Eocene, supported by the $\delta^{13}O_{bc}$ curve as well.
CIE 7	EEHT7	The hyperthermal event is supported by the curves of $\delta^{13}C_{bc}$ (neg. excursion 3.20 ‰) and $\delta^{13}C_{om}$ (neg. excursion 2.14 ‰). The $\delta^{13}O_{bc}$ also supports the hyperthermal event, showing negative excursion.
CIE 6	EEHT6	This hyperthermal, indicated by a negative excursion of 2.06 ‰ in the $\delta^{13}C_{om}$ curve, accounts for a transgressive event that brought marine molluscs in this restricted basin.
CIE 5	EEHT5	The next hyperthermal is noted by the largest negative excursion of $\delta^{13}C_{om}$ curve (4.10 ‰).
CIE 4	EEHT4	The fourth hyperthermal event, shown by a negative excursion of 2.7 ‰ of the $\delta^{13}C_{om}$ curve is also supported by $\delta^{13}C_{amb}$ ($\delta^{13}C$ of Amber).
CIE 3	EEHT3	This third hyperthermal event is identified by a 3.1 ‰ negative excursion in the $\delta^{13}C_{om}$ curve.
CIE 2	EEHT2	With a negative spike of 2.1 ‰ in the $\delta^{13}C_{om}$, this CIE accounts for the second hyperthermal event in early Eocene.
CIE 1	EEHT1	The CIE identified by a negative excursion of 2.7 ‰ of $\delta^{13}C_{om}$ (organic matter $\delta^{13}C$) curve with a spike reaching -30 ‰. This CIE can be inferred as the PETM because the values match data from other regions of the world.

Abbreviations

CIE- Negative Carbon Isotopic Excursion
$\delta^{13}C_{oc}$- $\delta^{13}C$ of Organic Carbon
$\delta^{13}C_{bc}$- $\delta^{13}C$ of Carbonate Carbon (Bulk carbonate)
$\delta^{18}O_{bc}$- $\delta^{18}O$ of Carbonate (Bulk carbonate)
$\delta^{13}C_{amb}$- $\delta^{13}C$ of Amber/ Resin
PETM- Paleocene-Eocene Thermal Maximum
EEHT- Early Eocene Hyperthermal

References:

1) Biswas, S. K. (1992). Tertiary stratigraphy of Kutch. Journal of the Palaeontological Society of India, 37, 1-29.

2) Samanta, A., Bera, M. K., Ghosh, R., Bera, S., Filley, T., Pande, K., & Sarkar, A. (2013). Do the large carbon isotopic excursions in terrestrial organic matter across Paleocene–Eocene boundary in India indicate intensification of tropical precipitation?. Palaeogeography, Palaeoclimatology, Palaeoecology, 387, 91-103.

3) Scotese, C. R., & Golonka, J. (1997). Paleogeographic atlas (pp. 1-45). Arlington: PALEOMAP Project, University of Texas at Arlington.

4) Pujalte,V., Schmith, B., & Baceta, J. I (2014). Sea-level changes across the Paleocene-Eocene interval in the Spanish Pyrenees, and their possible relationship with North Atlantic Magmatism. Palaeogeography, Palaeoclimatology, Palaeoecology, 393, 45-60.

Acknowledgements

We are obliged to our colleagues and co-workers of the Palaeontology Laboratory of Presidency University, and Geochemistry laboratory of IISC Bangalore especially Sayoni Banerjee, Ankita Ghosh, Sreetama Aich, Sanchita Ghosh, Poushali Pathak and Rachana Subba, without whom this work could not have been completed. The study was funded by Science and Engineering Research Board - Department of Science and Technology, India (EMR/2016/002583).