Epicontinental seas as efficient carbon sinks: proto-Paratethys & West Siberian seas during the PETM

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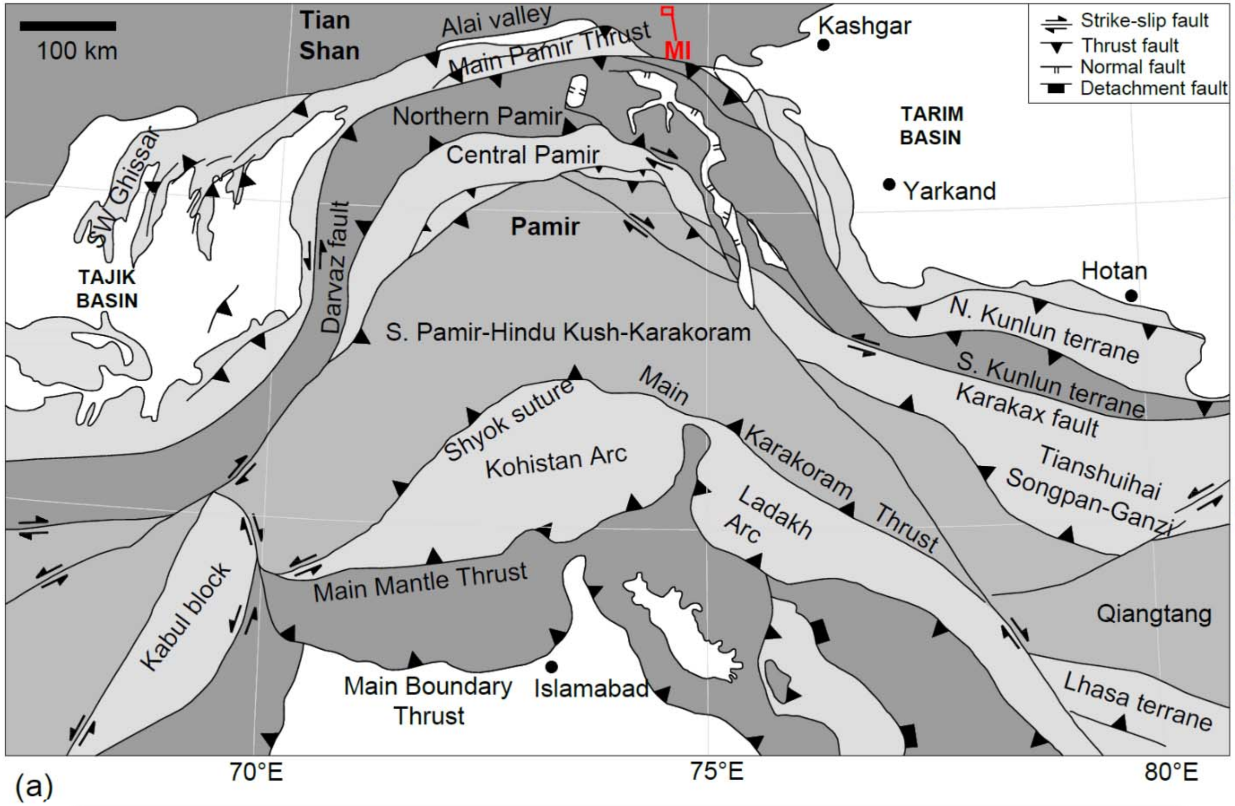
We present here a new PETM record from the organic-rich marine sediments (sapropels) deposited in the epicontinental proto-Paratethys Sea, in the Tarim Basin, China. We also present the relative contribution and preservation efficiency of ancient epicontinental seas as carbon sinks, using the sapropelitic deposits dated to the PETM from extensive epicontinental proto-Paratethys and West Siberian Seas.



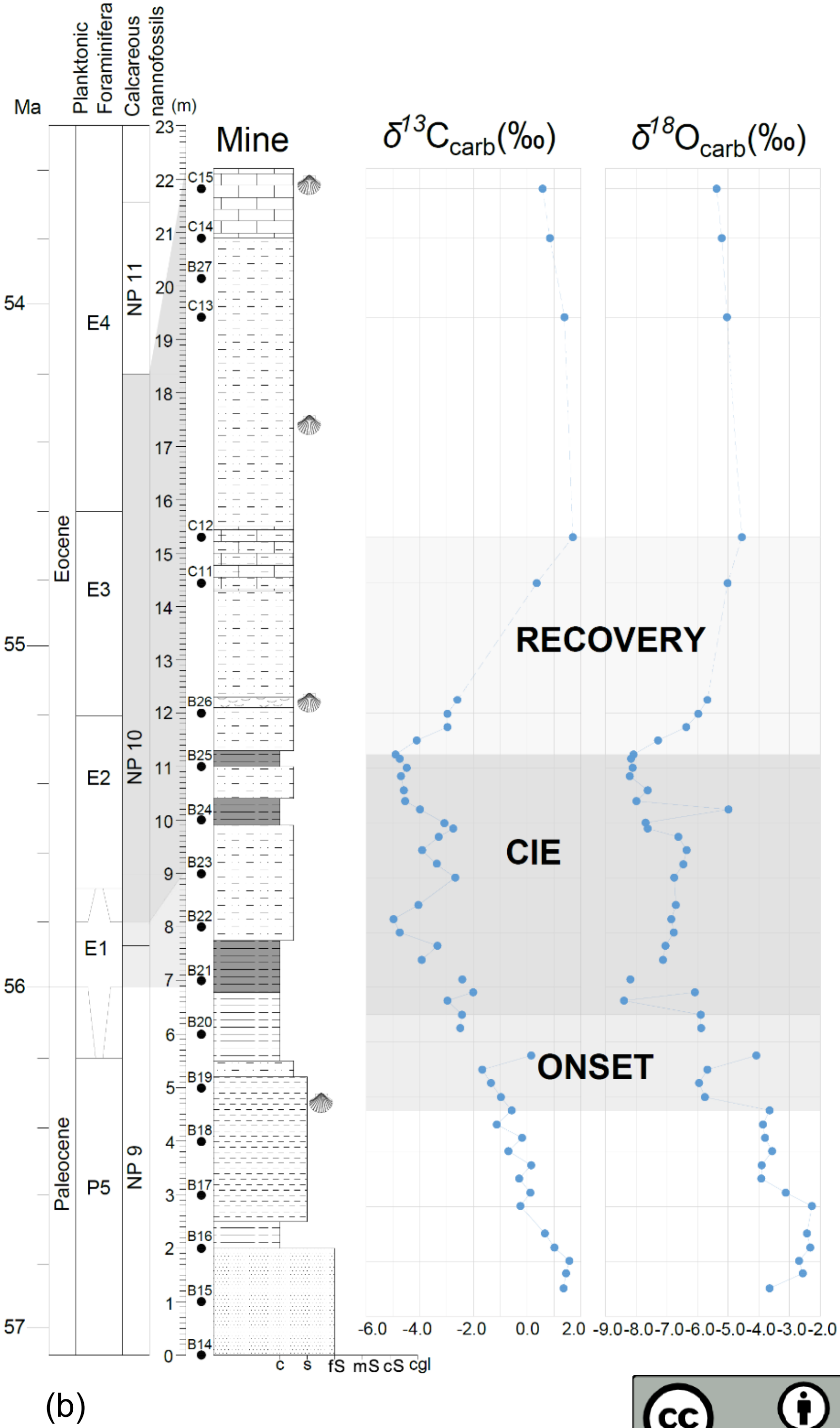


Figure 1 (a) Location of the studied section (MI: Mine) on a schematic map of major tectonic domains within the Pamir and western Tibet (modified from Cowgill, 2010). (b) Bulk carbonate isotope records ($\delta^{13}C$ and $\delta^{18}O$) across the Paleocene - Eocene boundary interval including the PETM in the (a) Mine section.

RESULTS

We have results and interpretations based on the data from isotope, biostratigraphic and sedimentological analyses. We also measured δD n-alkane values and conducted some biomarker analyses for three samples from the Mine section.

- Very High TOC values
- ~21‰ and ~15‰ decrease in δD values of C29 and C31 (between samples B19 & B20)
- Similarity with the other Peri-Tethyan sections

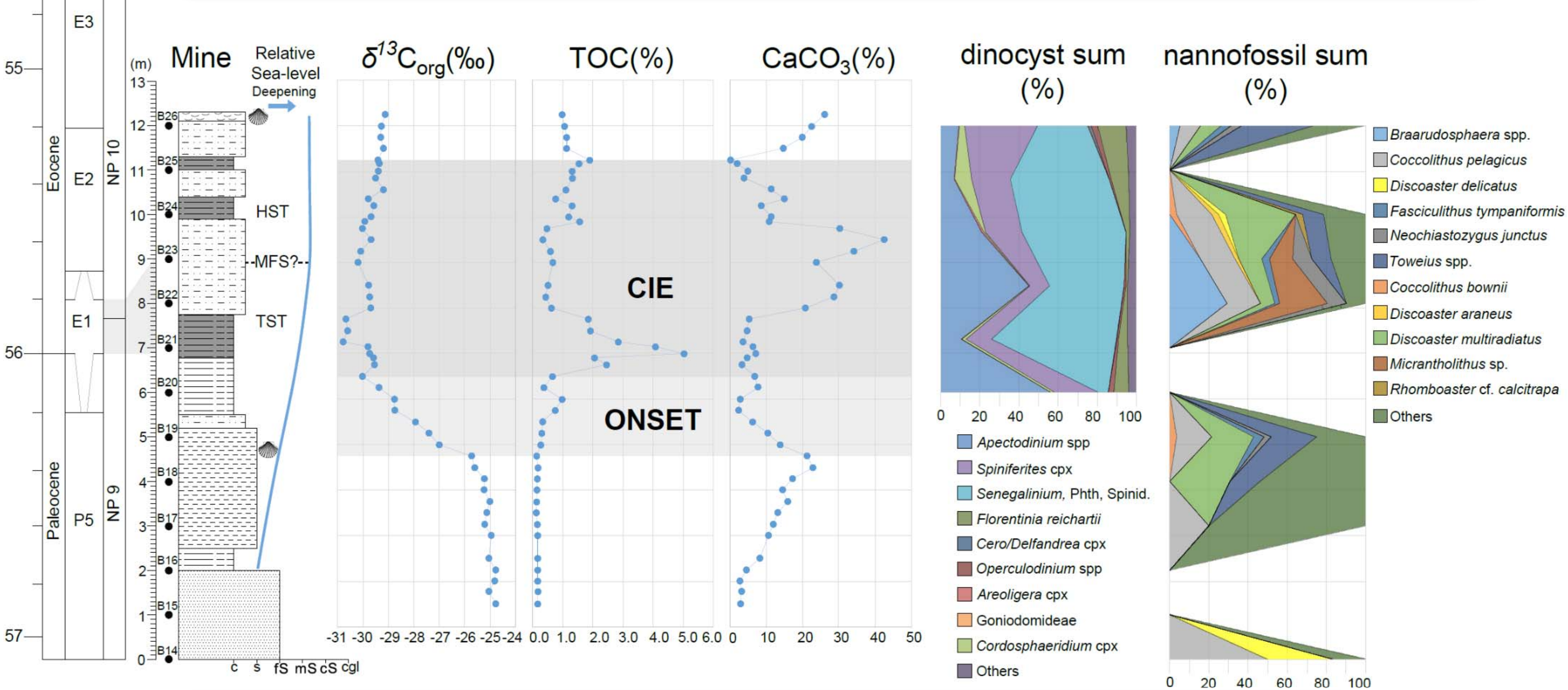
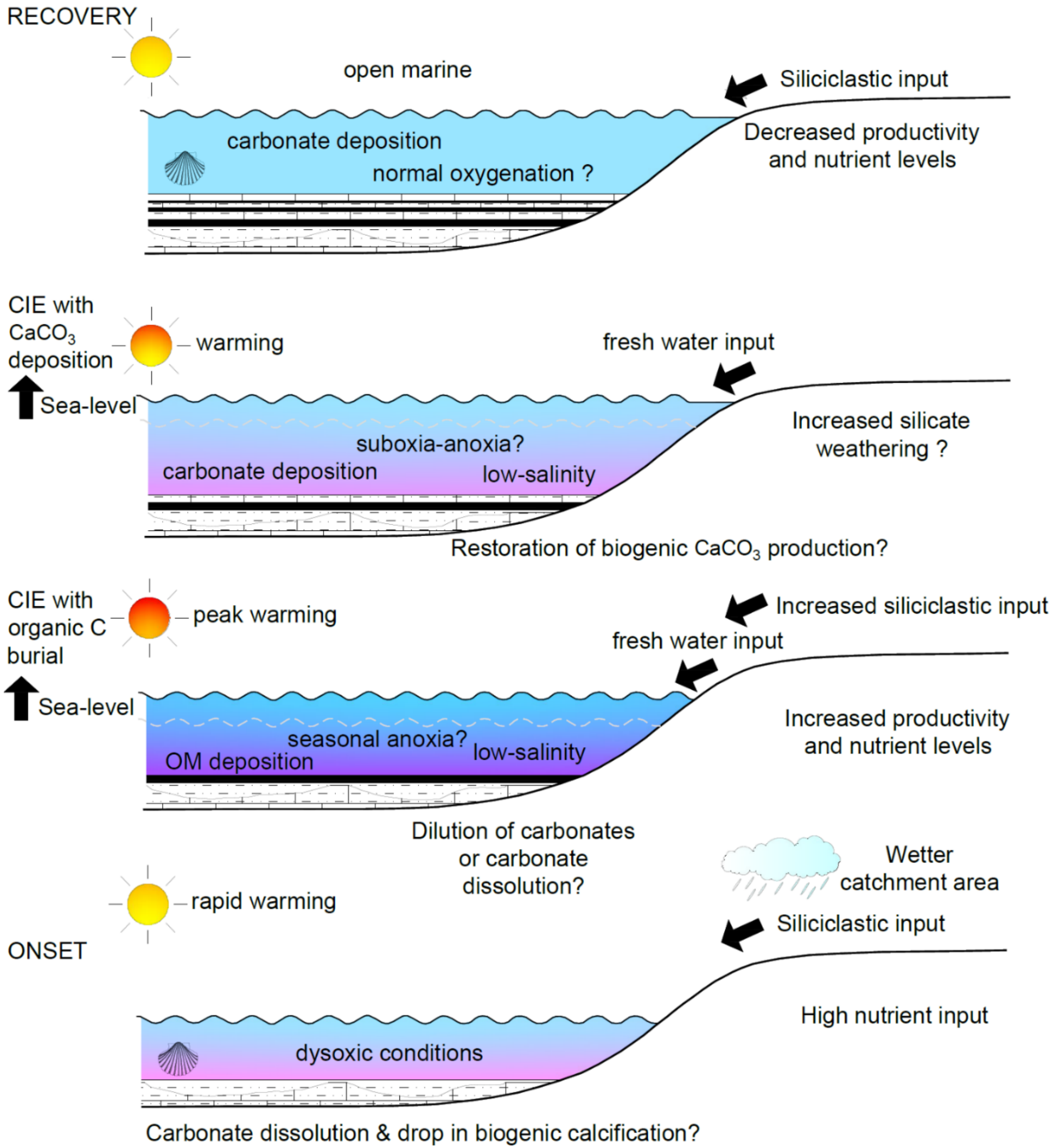


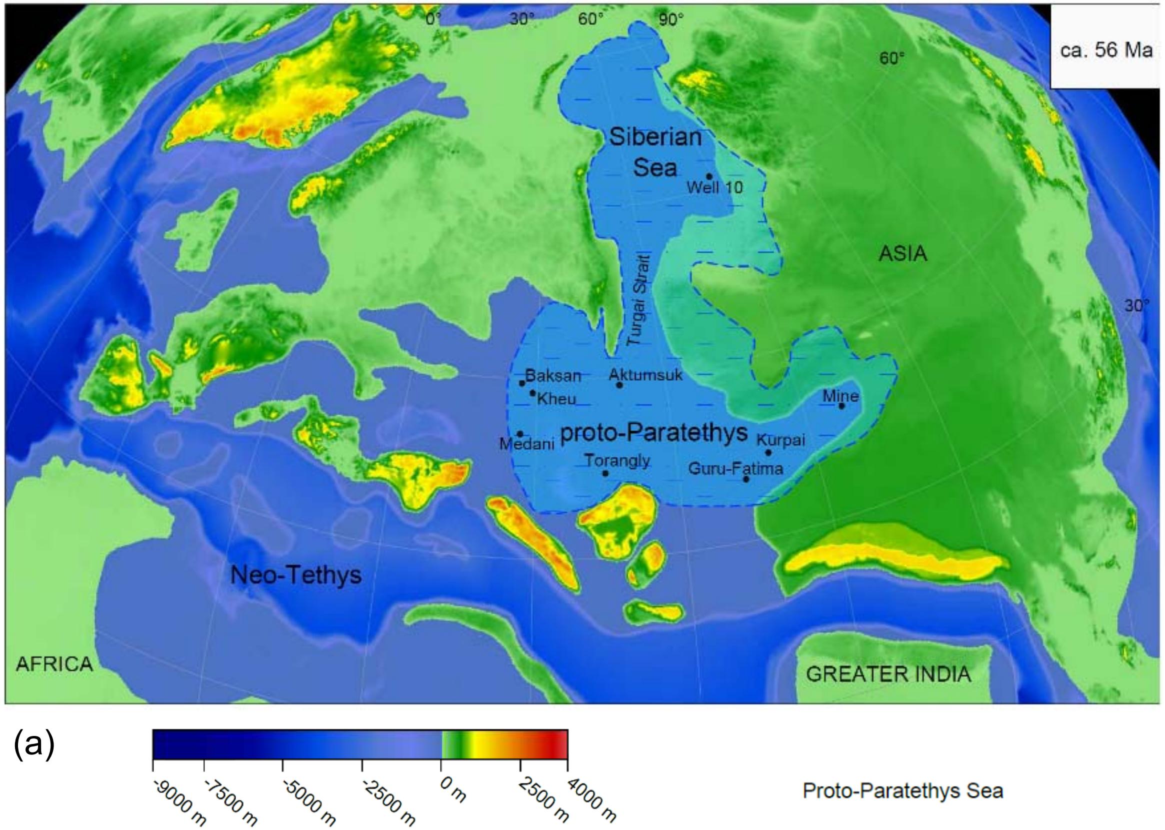
Figure 2 $\delta^{13}C_{org}$ isotope record and Total Organic Carbon (TOC) values and $CaCO_3$ percentages across the Paleocene - Eocene boundary interval including the PETM in the Mine section. Change in the relative sea level, relative abundancies (%) of dinocyst and nannofossil assemblages can also be seen.



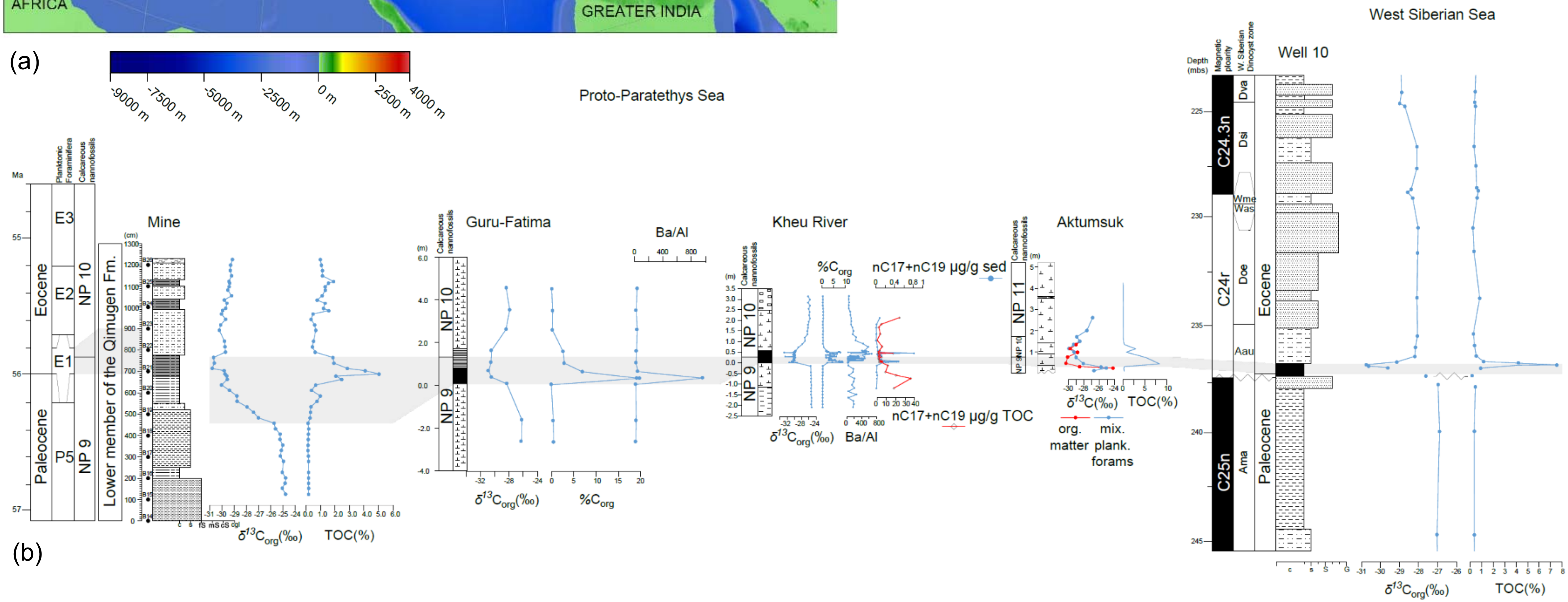
PALEOENVIRONMENTAL CHANGES

We present a conceptual model of environmental changes including a depositional scenario across the PETM based on the results from the sedimentological and dinocyst/nannofossil abundance analyses together with the results of the δD n-alkane measurements.

Figure 3 Schematic representation of paleoecological and paleoenvironmental changes in the Tarim part of the proto-Paratethys Sea during the onset, CIE and recovery phases



(a)



(b)

Figure 4 (a) Paleogeographic map showing the distribution of C_{org}-enriched (sapropel) deposits (blue shaded area) in the proto-Paratethys Sea and Siberian Sea. (b) Correlation of the organic carbon-rich sapropel interval with high TOC peak values from different sections studied in the proto-Paratethys (Mine section, this study; Guru-Fatima and Kheu River sections from Dickson et al., 2014; Aktumsuk section from Bolle et al., 2000), and West Siberian (Well 10 from Frieling et al., 2014) basins.

EFFECTIVENESS OF EPICONTINENTAL SEAS AS CARBON SINKS

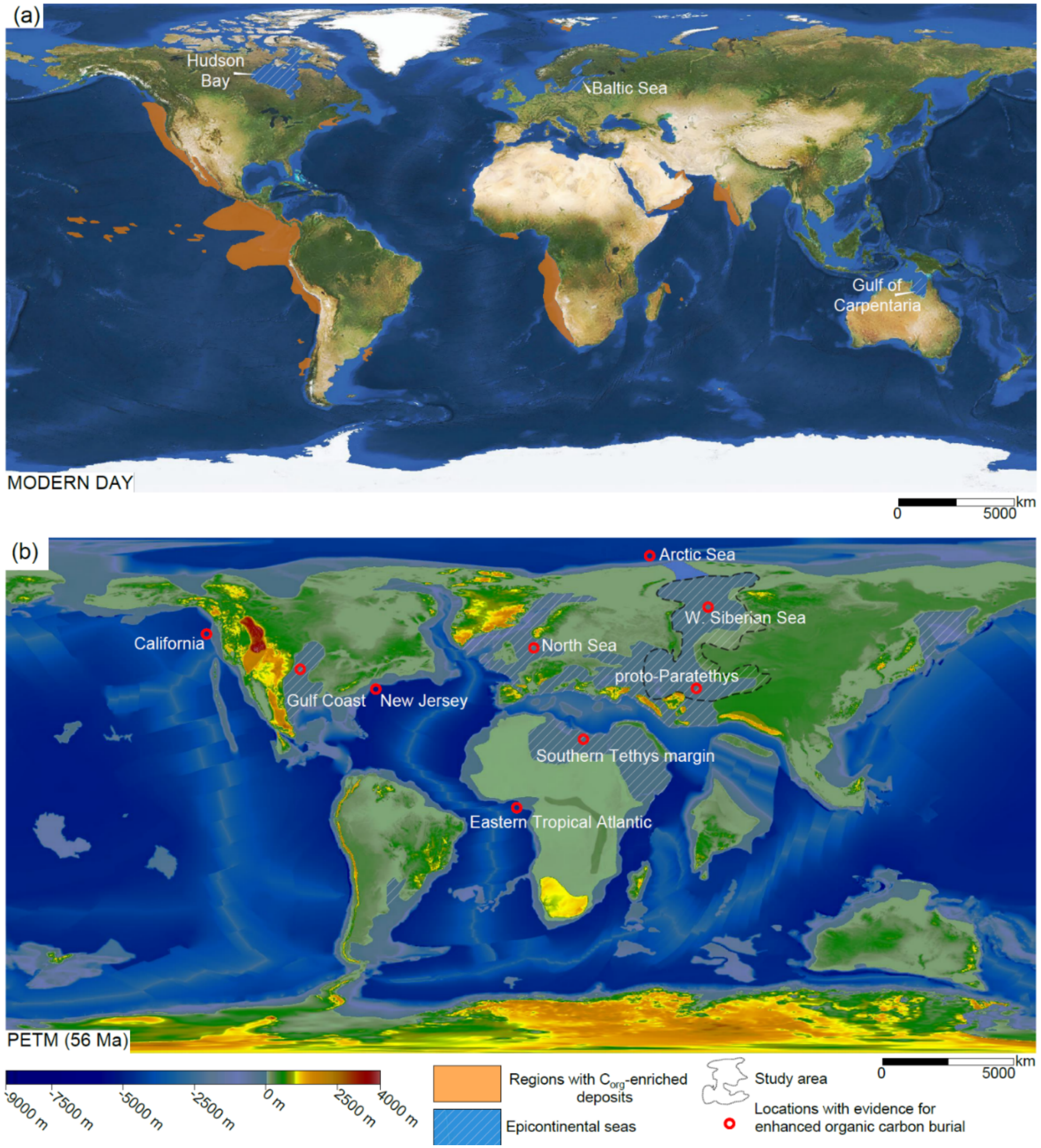


Figure 5 (a) Modern day imagery showing epicontinental seas and regions with high weight percentage (ca. 1.5% or more) of organic carbon in marine sediments (modified from Keil, 2017). (b) Epicontinental seas (areas with diagonal lines) during the PETM. Area with black dashed line indicates the extent of organic carbon-rich sapropel deposition in the proto-Paratethys and West Siberian basins (modified from Poblete et al., 2017). Red donuts show locations of the studied areas with enhanced organic carbon burial during the PETM.

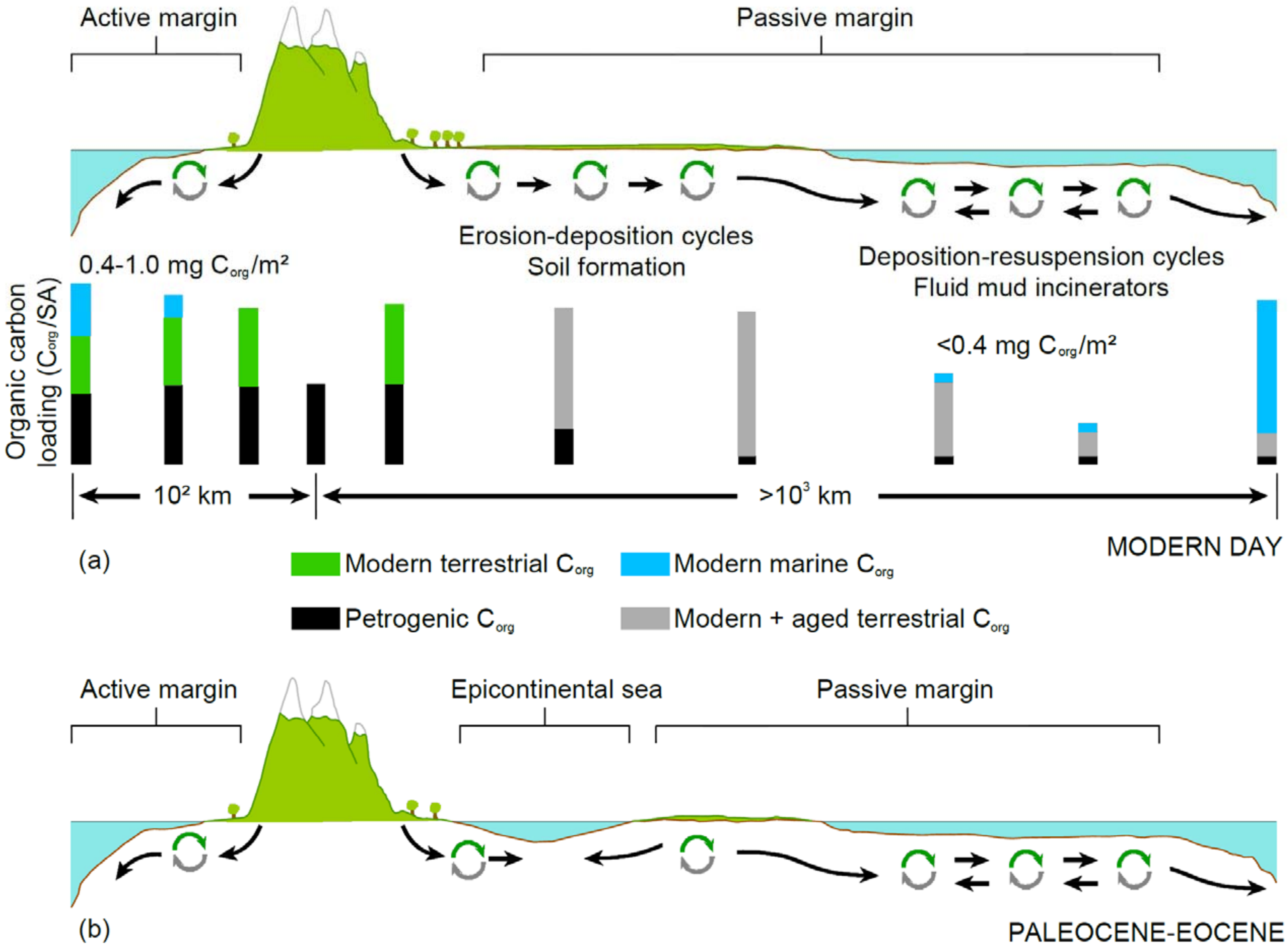
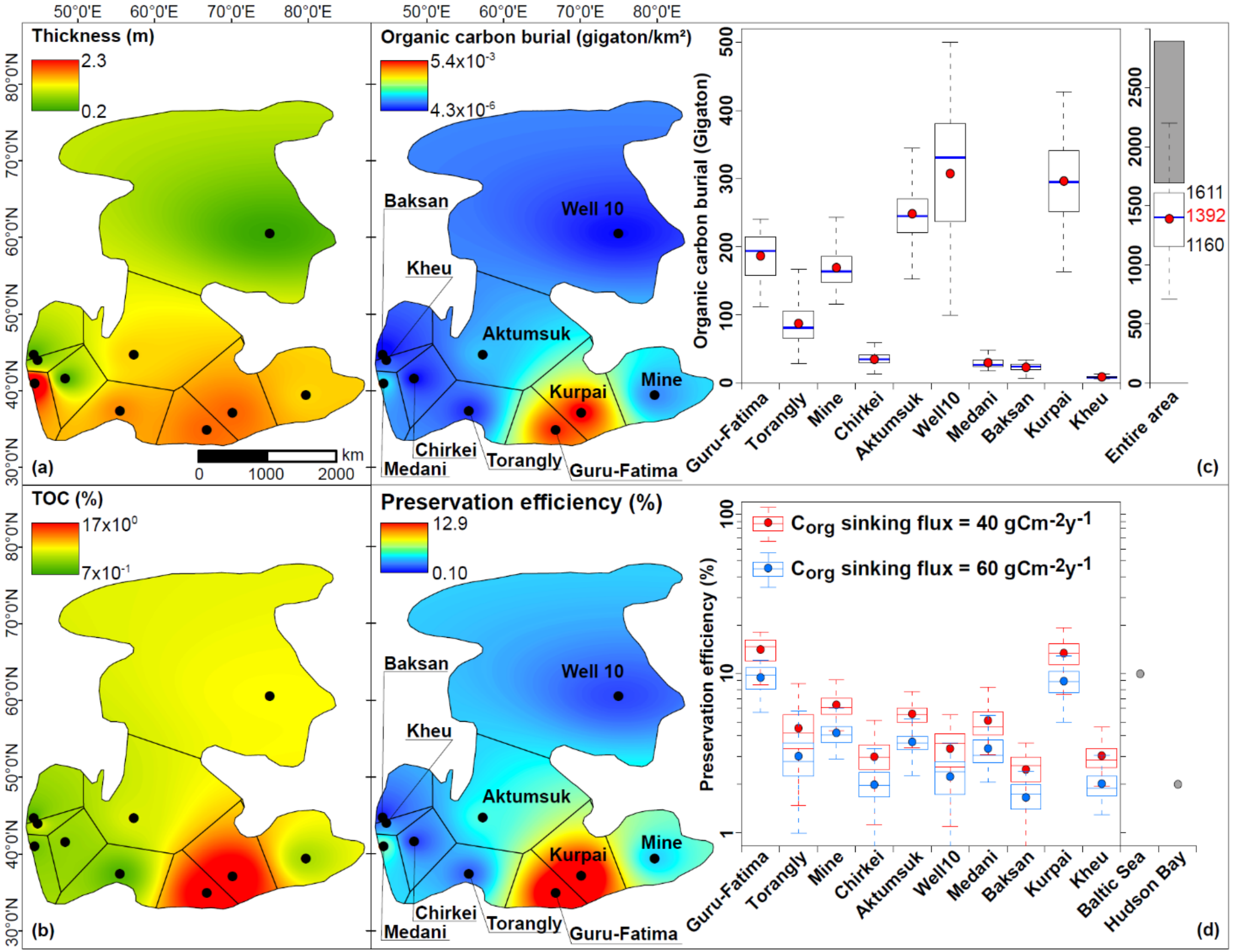


Figure 6 (a) The difference between the modern day active and passive margins in serial transport-reaction systems for different organic carbon sources (modified from Blair & Aller, 2012). Due to a longer path from upland source to burial on sea floor and resulting more cycles of deposition-rest and reaction-remobilization on passive margins, organic carbon source signals varies and active margins generate and bury a relatively larger percentage of petrogenic organic carbon, thus act as a more efficient sink for the global organic carbon. (b) Example of a Paleocene-Eocene marginal configuration including an epicontinental sea covering inner parts of a continent. Epicontinental sea receives all kind of different sources of organic carbon and acts as an efficient sink.



ORGANIC CARBON BURIAL

By using eq. (1) (Xu et al., 2017), it is estimated that ca. **1390 Gt** of organic carbon was extracted from the global ocean-atmosphere system and sequestered in the proto-Paratethys Sea during the CIE of the PETM with the deposition of the sapropel beds. We also estimated the organic carbon preservation efficiency values (eq. 2, Canfield, 1994) for the proto-Paratethys and West Siberian seas as the ratio of C_{org} burial flux (eq. 3) to C_{org} sinking flux (export production values from Ma et al., 2014)

(1) M = Area * Thickness * Density * TOC

(2) Preservation efficiency = (C_{org} burial flux)/(C_{org} sinking flux) x 100

(3) C_{org} burial flux = TOC * Density * Sedimentation rate

Figure 7 Spatial distribution of sapropel thickness (a) and TOC values (b) in the proto-Paratethys and West Siberian basins. Black dots show the locations of the studied sections/wells (Mine section, this study; Well 10, Frieling et al., 2014; Kheu, Baksan, Medani, Torangly, Aktumsuk, Guru-Fatima and Kurpai sections, Gavrilov et al., 1997; 2003; Chirkei section, Gavrilov et al., 2019). Constructed Thiessen polygons indicate sub-sections with a reference section/well. (c) Spatial distribution of estimated total organic carbon burial in each subsection in the proto-Paratethys and West Siberian basins. Box-and-whisker plots on the right side show estimated total organic carbon burial for each sub-section and entire area. Lower and upper limits of the boxplots indicate 1st and 3rd quartiles, respectively. Red dots and blue lines inside the boxes show the mean and median values, respectively. Gray shaded box indicate the estimated global amount of organic carbon sequestered during the PETM recovery from the carbon cycle models (1700 - 2900 Pg C). (d) Spatial distribution of the organic carbon preservation efficiencies in the proto-Paratethys and West Siberian seas. Box-and-whisker plots on the right side show estimated organic carbon preservation efficiencies for each sub-section depending on different values of organic carbon sinking flux as 40 $gCm^{-2}y^{-1}$ and 60 $gCm^{-2}y^{-1}$. Gray dots show the efficiencies for the Baltic Sea and Hudson Bay.

CONCLUSIONS

- Assuming the average value between 2000-2500 Gt C for the amount of the globally sequestered organic carbon, based on our estimation a significant amount of this carbon sequestration (ca. 1390 Gt C, more than half of the global amount) should take place in the proto-Paratethys and West Siberian seas, however during the CIE of the PETM. This supports the hypothesis that alongside the organic carbon burial on other continental margins, the proto-Paratethys and West Siberian basins acted as significant carbon sinks to remove excess CO_2 from the atmosphere during the CIE, contributing to the termination of the PETM (e.g. Gavrilov et al., 2003).

- We compared organic carbon preservation efficiencies for the proto-Paratethys and West Siberian seas with that of the modern day epicontinental seas (Algeo et al., 2008). The maximum efficiency values ca. 13% were estimated in the eastern part of the proto-Paratethys sea whereas the lower efficiency values ca. 2% were estimated in the western part of the proto-Paratethys and West Siberian seas (Figure 7d). The Baltic Sea with anoxic sea floor conditions have a close preservation efficiency, ca. 10% to the maximum efficiency values of the proto-Paratethys Sea however, the preservation efficiency for the Hudson Bay with oxic to suboxic conditions is lower ca. 2% and closer to the lowest estimated values of the western proto-Paratethys and West Siberian seas.

- With an anticipated decrease in global carbon burial in wetland dominated coastal systems and overall carbon preservation in the modern ocean due to anthropogenic forcing and climate change (e.g. Keil, 2017; Hopkinson et al., 2012; Syvitski et al., 2005), absence of large epicontinental seas such as proto-Paratethys and West Siberian seas as significant carbon sinks will further hamper negating current CO_2 emissions through organic carbon storage.

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