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Data report: early Eocene–early Oligocene carbon and oxygen stable isotope data of bulk carbonates, IODP Expedition 390/393 Sites U1557 and U1558, South Atlantic Transect[1]

Chiara Borrelli,[2] Christopher M. Lowery,[2] Andrew McIntyre,[2] Claire M. Routledge,[2] Trevor J. Williams,[2] and the Expedition 390/393 Scientists[2]

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[2] **Expedition 390/393 Scientists' affiliations.** Correspondence author: **cborrelli@ur.rochester.edu**

Abstract

During International Ocean Discovery Program Expeditions 390C, 395E, 390, and 393 (the South Atlantic Transect), seven sites were drilled on the western flank of the southern Mid-Atlantic Ridge. Among these sites, Sites U1557 and U1558 recovered Eocene and Oligocene sediments. Such sediments will allow a better understanding of how ocean ecosystems, as well as ocean circulation and chemistry, responded to the paleoceanographic and paleoclimatic changes leading to the Eocene–Oligocene transition. In this study, we present early Eocene through early Oligocene carbon and oxygen stable isotope data ($\delta^{13}C$ and $\delta^{18}O$) of bulk carbonates from sediment samples collected in Holes U1557B, U1558A, and U1558F. The data show that the western South Atlantic, a relatively understudied region for the Eocene, recorded some global geochemical features, such as the relatively low $\delta^{13}C$ and $\delta^{18}O$ values typical of hyperthermal events characterizing the onset of the Early Eocene Climatic Optimum and the rapid shift toward high $\delta^{18}O$ and $\delta^{13}C$ values at the Eocene/Oligocene boundary.

1. Introduction

The South Atlantic Transect (SAT) comprises a series of sites along the western flank of the southern Mid-Atlantic Ridge (~31°S) cored during International Ocean Discovery Program (IODP) engineering Expeditions 390C and 395E and Expeditions 390 and 393 conducted between October 2020 and August 2022 (Estes et al., 2021; Williams et al., 2021; Coggon et al., 2022; Teagle et al., 2023). This region was previously spot cored between December 1968 and January 1969 during Deep Sea Drilling Project Leg 3 (Maxwell et al., 1970) and had not been revisited since.

Seven sites were drilled along the SAT on crust ranging around 61 Ma. These new cores offer the opportunity to investigate the evolution of a bipolar ocean circulation in connection with the opening of the Drake Passage and the history of the deep western boundary current, changes in carbonate surface productivity and carbonate burial in the western South Atlantic throughout the Cenozoic, and the development of a modern-like subtropical gyre and its impact on planktonic assemblages.

During the Eocene (~56–33.9 Ma), Earth transitioned from a climate characterized by high temperatures and the absence of permanent ice sheets to a climate characterized by cooler temperatures, lower atmospheric CO_2 concentrations, and the build-up of permanent ice sheets on

Antarctica at the Eocene–Oligocene transition, with possible episodic Northern Hemisphere glaciations, as well (i.e., hothouse–coolhouse transition; Westerhold et al., 2020) (e.g., Zachos et al., 2001; Cramer et al., 2011; Anagnostou et al., 2016; Tripati and Darby, 2018; Miller et al., 2020).

Sediments recovered at Site U1557 during engineering Expedition 390C (October–December 2020) and Site U1558 during engineering Expedition 390C and Expedition 393 (June–August 2022) (**Coggon et al.**, 2024a; **Teagle et al.**, 2024) are promising archives of ocean circulation and chemistry changes during the Eocene and Oligocene. Here, we report carbon and oxygen stable isotope data ($\delta^{13}C$ and $\delta^{18}O$) of bulk carbonates from sediment samples collected at these sites. Data were combined to build a stable isotope curve spanning the entire Eocene and early Oligocene. These data can be used to refine the age models at Sites U1557 and U1558 and for chemostratigraphic correlation with sites located in the Atlantic and other ocean basins. This data set could also facilitate further sampling efforts of cores from these sites for high-resolution paleoceanography-relevant Eocene research.

2. Methods and materials

2.1. Site description

Site U1557 (30°56.4547′S, 26°37.7775′W; Figure **F1**) is located in a downthrown fault-bounded basin ~1250 km west of the Mid-Atlantic Ridge, at a water depth of 5012 m (**Coggon et al.**, 2024b). This site is located on oceanic crust of ~61 Ma and, together with Sites U1556 and U1561, is one of the oldest sites drilled along the SAT. For this study, we utilized cores collected from Hole U1557B (Cores 31X–51X; 277.38–469.86 m core depth below seafloor, Method A [CSF-A]). This hole was drilled during engineering Expedition 390C (Estes et al., 2021), but the cores were described during Expedition 390 (**Coggon et al.**, 2024b). The cores analyzed for this study were cored using the extended core barrel (XCB) system, and recovery was 31%–95%. Sediments in the Eocene/early Oligocene study interval are mostly composed of nannofossil and/or calcareous chalk (**Coggon et al.**, 2024a).

Site U1558 (30°53.7814′S, 24°50.4822′W; Figure **F1**) is located ~1067 km west of the Mid-Atlantic Ridge, at a water depth of 4337 m (Estes et al., 2021; **Coggon et al.**, 2024b). It sits on oceanic crust

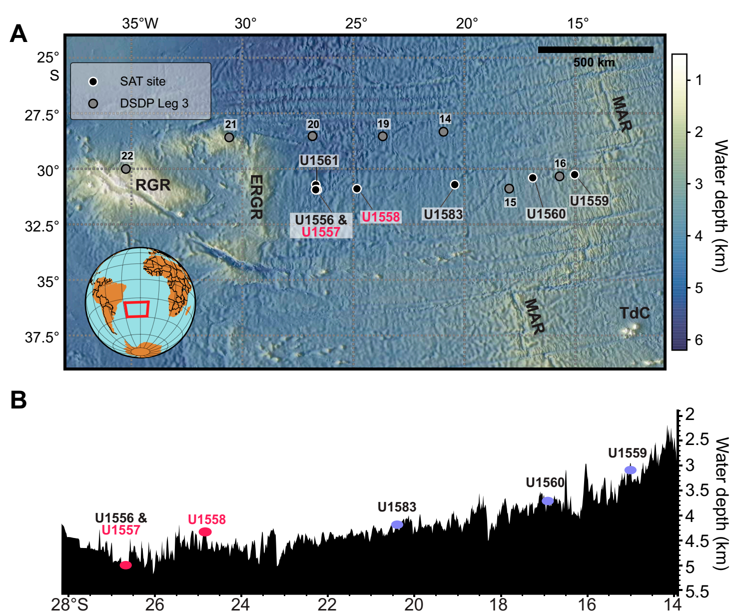

Figure F1. SAT study region, Expeditions 390/393, 390C, and 395C. A. Bathymetry of the South Atlantic Ocean (Ryan et al., 2009). Inset: regional settings. RGR = Rio Grande Rise, ERGR = eastern Rio Grande Rise, MAR = Mid-Atlantic Ridge, TdC = Tristan de Cunha. B. SAT drilled sites shown above seafloor bathymetry measured during CREST cruise (Reece and Estep, 2019). The sites used in this study are in red.

of ~49 Ma. For this study, we measured samples collected from Holes U1558A (Cores 12X–18X; 121.54–190.20 m core composite depth below seafloor [CCSF]) and U1558F (Cores 12F–24X; 120.22–207.10 m CCSF). Hole U1558A was drilled during engineering Expedition 390C; the cores analyzed here were cored with the XCB system and recovery varied between 58% and 80% (Estes et al., 2021). Hole U1558F was drilled during Expedition 393. Cores 12F–19F were cored using the half-length advanced piston corer (HLAPC) system, which resulted in significantly better recovery, whereas Cores 20X–24X were XCB cored. Overall, recovery for the cores used in this study ranged 77%–109% (**Coggon et al.**, 2024b). The sediment analyzed consists of nannofossil ooze/chalk with clay (**Teagle et al.**, 2024).

2.2. Sample preparation and stable isotope analyses

We analyzed a total of 250 sediment samples from Holes U1557B (n = 96), U1558A (n = 57), and U1558F (n = 97). Sampling resolution was driven by the goal to obtain a (relatively) high resolution record for the early Eocene hyperthermals (~54–52 Ma) and the late Eocene through early Oligocene interval (~34.5–32 Ma) and a lower resolution record for the rest of the Eocene. Core sampling was guided by the preliminary age models for these sites (**Coggon et al.**, 2024a; **Teagle et al.**, 2024) and the need to accommodate for core gaps or disturbances. Sampling resolution ranged ~20 cm to several meters.

Samples were prepared for analysis at the University of Rochester (USA). Samples were dried overnight at 50°C and homogenized afterward by grinding a small aliquot of sediment with a mortar and pestle. Bulk $\delta^{13}C$ and $\delta^{18}O$ were measured using a Nu Carb device attached to a Nu Instruments Perspective isotope ratio–mass spectrometer (IR-MS) at the Department of Earth and Planetary Sciences at Rutgers University (USA). Samples were reacted in phosphoric acid at 70°C, and the evolved CO_2 was collected in a liquid nitrogen cold finger. Stable isotope values were reported relative to Vienna Peedee belemnite (VPDB) through the analysis of an in-house laboratory reference material (RGF1). The 1σ standard deviation of RGF1 made during daily runs (typically 8 RGF1 analyses for every 24 samples) was 0.03‰ ($\delta^{13}C$) and 0.06‰ ($\delta^{18}O$). RGF1 is routinely calibrated to NBS-19 to ensure consistency using 1.95‰ for $\delta^{13}C$ and −2.20‰ for $\delta^{18}O$, as reported by Coplen (1994). The internal laboratory reference material differs from NBS-19 by +0.10‰ for $\delta^{13}C$ and +0.04‰ for $\delta^{18}O$. The laboratory analyzes NBS-18 to monitor for changes in source linearity for $\delta^{18}O$ for comparison to the value of 23.01‰ reported by Coplen (1994).

Data are displayed against depth; the CSF-A scale is used for Site U1557, which does not have a splice (Figure **F2**), and the CCSF scale is used for Site U1558 (Figure **F3**). For Site U1558, the CCSF

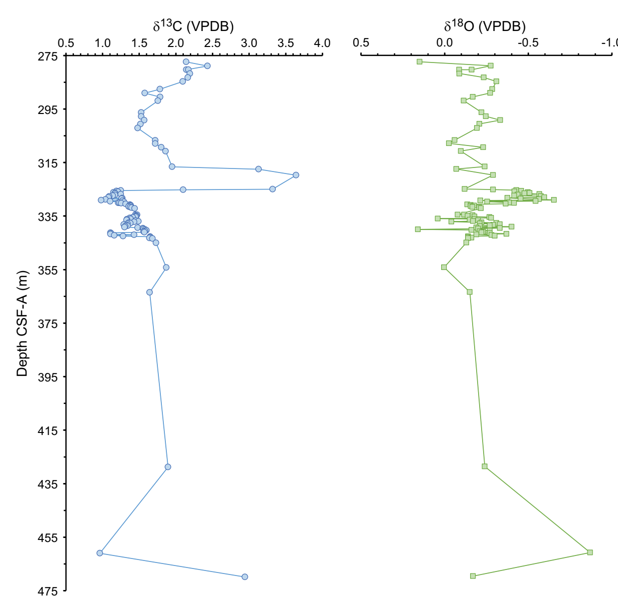

Figure F2. Carbon and oxygen stable isotope ($\delta^{13}C$ and $\delta^{18}O$) bulk carbonate data, Site U1557.

depth scale was calculated using the shipboard correlator's affine table. Data are also displayed against age (Figure **F4**). Sample ages were calculated based on the preliminary age models for these sites (**Coggon et al.**, 2024a; **Teagle et al.**, 2024). For Site U1558, we used the Hole U1558F age model to calculate sample ages along the splice because it is better constrained than the age model for Hole U1558A.

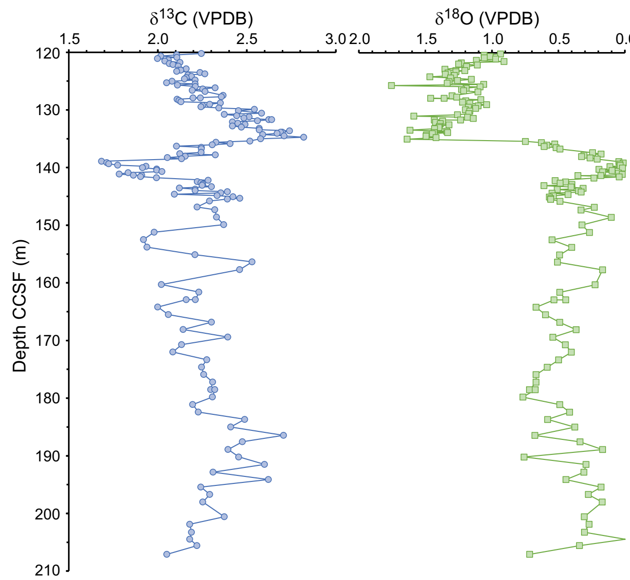

Figure F3. Carbon and oxygen stable isotope ($\delta^{13}C$ and $\delta^{18}O$) bulk carbonate data, Site U1558. The data set was obtained by combining data from Holes U1558A and U1558F.

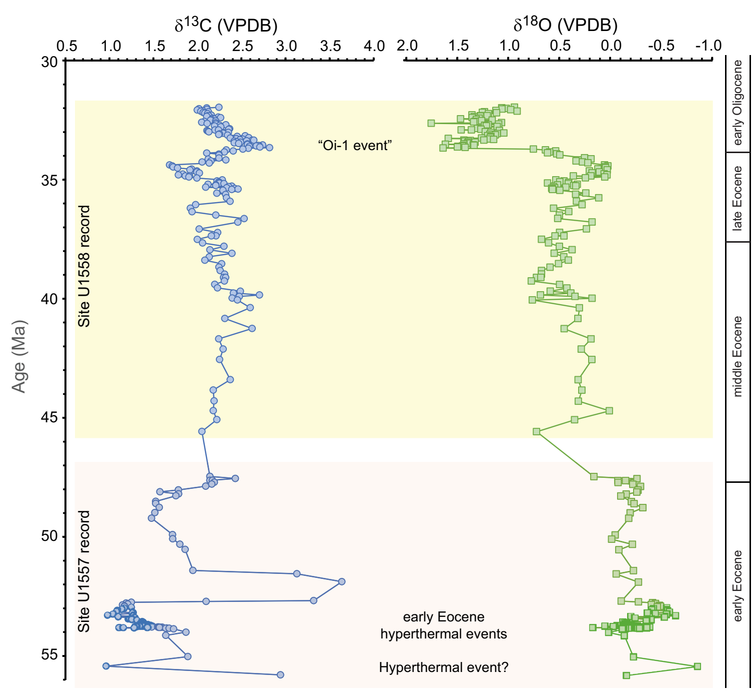

Figure F4. Carbon and oxygen stable isotope ($\delta^{13}C$ and $\delta^{18}O$) bulk carbonate data vs. age, Sites U1557 and U1558. The data set was obtained by combining data from Holes U1557B, U1558A, and U1558F. Ages were calculated according to the shipboard age models for these sites (Coggon et al., 2024a; Teagle et al., 2024) and reported according to *Geologic Time Scale 2020* (Gradstein et al., 2020). Pink shading = the part of the record generated by analyzing samples from Hole U1557B, yellow shading = the part of the record generated by analyzing samples from Holes U1558A and U1558F.

3. Results

3.1. Bulk carbon stable isotopes

At Site U1557, $\delta^{13}C$ values range ~1‰–3.64‰ from the early to early middle Eocene (Figures **F2**, **F4**). The lower part of the record (470–345 m CSF-A) indicates a shift in $\delta^{13}C$ from 2.94‰ to ~1.73‰. In particular, a negative shift from 2.94‰ to 0.96‰ is recorded in two samples between ~470 and 460 m CSF-A and occurs in the earliest Eocene (Figure **F4**). The Paleocene/Eocene Thermal Maximum (PETM) was identified at Site U1557 based on the occurrence of the calcareous nannoplankton excursion taxon *Rhomboaster* spp., one of the classic PETM markers (Bown, 2005), at 461.33 m CSF-A in a ~50 cm thick dark red pelagic clay that was not sampled for this data report (**Coggon et al.**, 2024a). Therefore, this initial negative isotope excursion is likely one of the earliest Eocene hyperthermal events, but more detailed chemostratigraphic and biostratigraphic analyses are required to properly confirm this hypothesis. Average $\delta^{13}C$ values ~1.4‰ characterizes the record from 345 to 325 m CSF-A and are tentatively interpreted as the carbon isotope excursions of the hyperthermal events (Galeotti et al., 2010; Kirtland Turner et al., 2014) characterizing the onset of the Early Eocene Climatic Optimum (~54–48.2 Ma) (Westerhold et al., 2018). This interpretation agrees with the shipboard age model for this site (Figure **F4**) (**Coggon et al.**, 2024a). Between ~325 and 315 m CSF-A, the record shows a well-constrained positive excursion in $\delta^{13}C$ (with values as high as ~3.6‰ and as low as ~2‰), which is followed by values from ~1.7‰ to 2‰ toward the upper part of the section (315–277 m CSF-A).

At Site U1558, $\delta^{13}C$ values range ~1.7‰–2.8‰ (Figure **F3**). In the lower part of the record (207–157 m CCSF), values vary between 2‰ and 2.7‰. A well-constrained $\delta^{13}C$ shift from ~1.9‰ to ~2.6‰ is recorded by samples located between 140 and 135 m CCSF and accompanies the increase in $\delta^{18}O$ values that we interpret as the Eocene/Oligocene boundary (see below). A steady decrease to ~2‰ is shown in the upper analyzed sediments (~134–120 m CCSF). According to the shipboard age model (**Teagle et al.**, 2024), the Site U1558 samples measured are of middle Eocene–early Oligocene age (Figure **F4**).

3.2. Bulk oxygen stable isotopes

At Site U1557, $\delta^{18}O$ values range ~0.2‰ to approximately −0.9‰ (Figures **F2**, **F4**). The lower part of the record (470–460 m CSF-A) shows a negative shift in $\delta^{18}O$ of ~0.7‰, which supports the possibility of this part of the record recording a hyperthermal event. This negative excursion is followed by a partial recovery to approximately −0.2‰. Values ranging ~0.2 to −0.7‰ characterize the rest of the samples analyzed (354–277 m CSF-A). A transient shift of ~0.2‰ toward slightly more negative values (345–325 m CSF-A) supports the preliminary interpretation of this interval capturing some the early Eocene hyperthermals (cf. Kirtland Turner et al., 2014).

At Site U1558, $\delta^{18}O$ values range ~1.8‰–0‰ (Figures **F3**, **F4**). From 207 to 140 m CCSF, $\delta^{18}O$ oscillates between 0‰ and ~0.8‰. A large shift of ~1.6‰ toward more positive values is recorded by samples located between ~140 and ~135 m CCSF. Based on the similarity of this signal with other bulk carbonate $\delta^{18}O$ records (e.g., Shackleton, 1986) and the preliminary age model for this site (**Teagle et al.**, 2024), this shift is interpreted as the global Eocene/Oligocene increase in $\delta^{18}O$ (Oi-1 event; e.g., Miller et al., 1991). Values slowly decrease to ~1‰ in the upper samples analyzed (135–120 m CCSF).

4. Data availability

Stable isotope data are included here in Table **T1** and permanently archived at PANGAEA (**https://doi.pangaea.de/10.1594/PANGAEA.964943** and **https://doi.pangaea.de/10.1594/PANGAEA.965000**).

Table T1. Carbon and oxygen stable isotope ($\delta^{13}C$ and $\delta^{18}O$) bulk carbonate data, Holes U1557B, U1558A, and U1558F. **Download table in CSV format.**

5. Acknowledgments

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