Change in magnetic mineral assemblages as a proxy for weathering and redox conditions around the Cenomanian-Turonian boundary

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Introduction

Cretaceous volcanism caused CO_2 levels to surge around the Cenomanian-Turonian (Ce-Tu) boundary. As a result, there were changes in ocean chemistry, circulation, and temperature that disrupted the biosphere (Kerr, 1998). Marine invertebrate organisms were impacted by a mass extinction in which 26% of all genera were lost (e.g., Sepkoski, 1986; Kerr, 1998). These changes are associated with the hyperthermal event Oceanic Anoxic Event 2 (OAE2) that occurred ~94 Mya.

The Holland Park core in Virginia contains a marine record of the Atlantic Coastal Plain (ACP) over the Cenomanian and Turonian (Figure 1). Preliminary work suggests that the ACP did not reach full anoxia during OAE2. Therefore, the ACP has potential to preserve magnetofossils, the magnetic remains of iron biomineralizing organisms that are sensitive to oxygen levels in aquatic environments.

Magnetofossil assemblages, and other magnetic minerals, can inform us about ocean chemistry and the iron cycle (e.g., Wagner et al., 2021). Changes to the iron cycle can impact coastal processes such as the generation of biomass and eutrophication. Understanding OAE2 may provide an analog for the impacts of anthropogenic climate change despite different timescales and sources of CO_2.

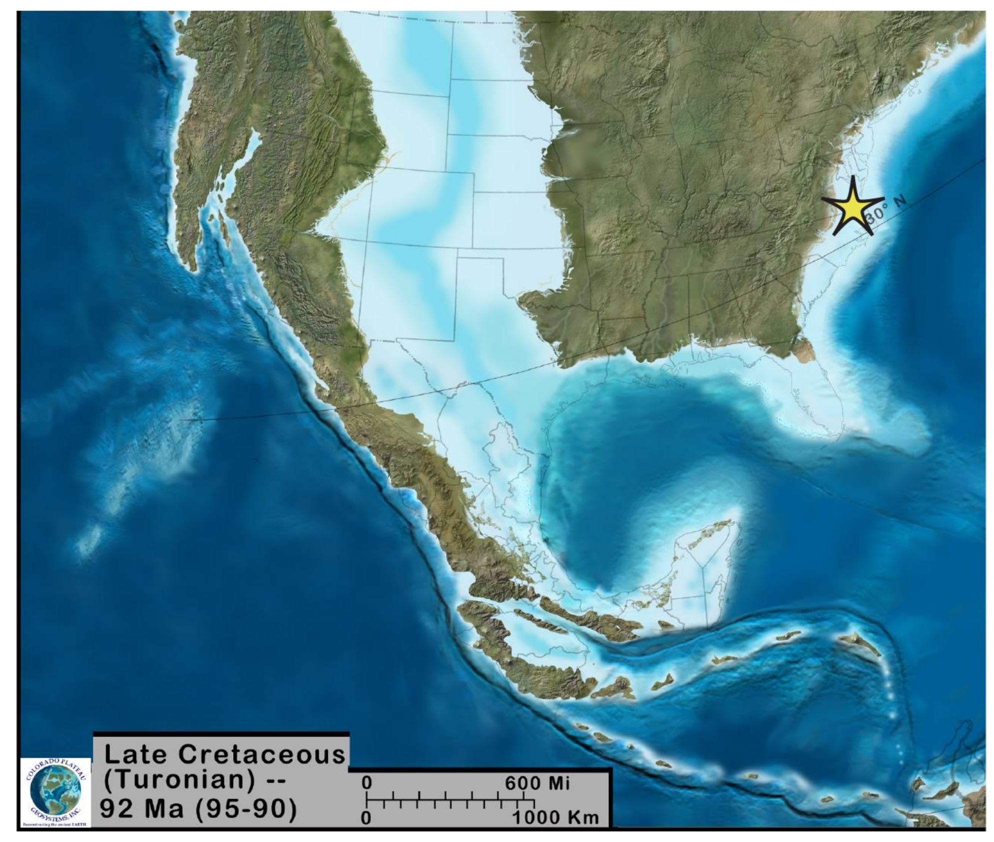


Figure 1. North America during Turonian. The yellow star indicates the location of the Holland Park core on the ACP. Adapted from Blakey, 2013.

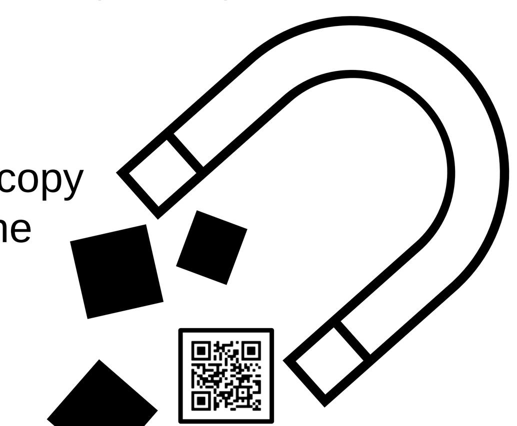
Methods

First Order Reversal Curves (FORC) are a family of magnetization curves that are used for characterizing assemblages of magnetic minerals.

A FORC diagram is a 2D representation of FORC data that allows us to observe the magnetic signatures of different minerals (Figure 2).

FORC-PCA (principal component analysis) is a statistical method for describing changes in magnetic minerals across multiple FORC datasets.

Scanning electron microscopy (SEM) is used to determine crystal composition and morphology, which can help confirm the origin and mineralogy of magnetic minerals.



Scan for citations and methods discussion

Results

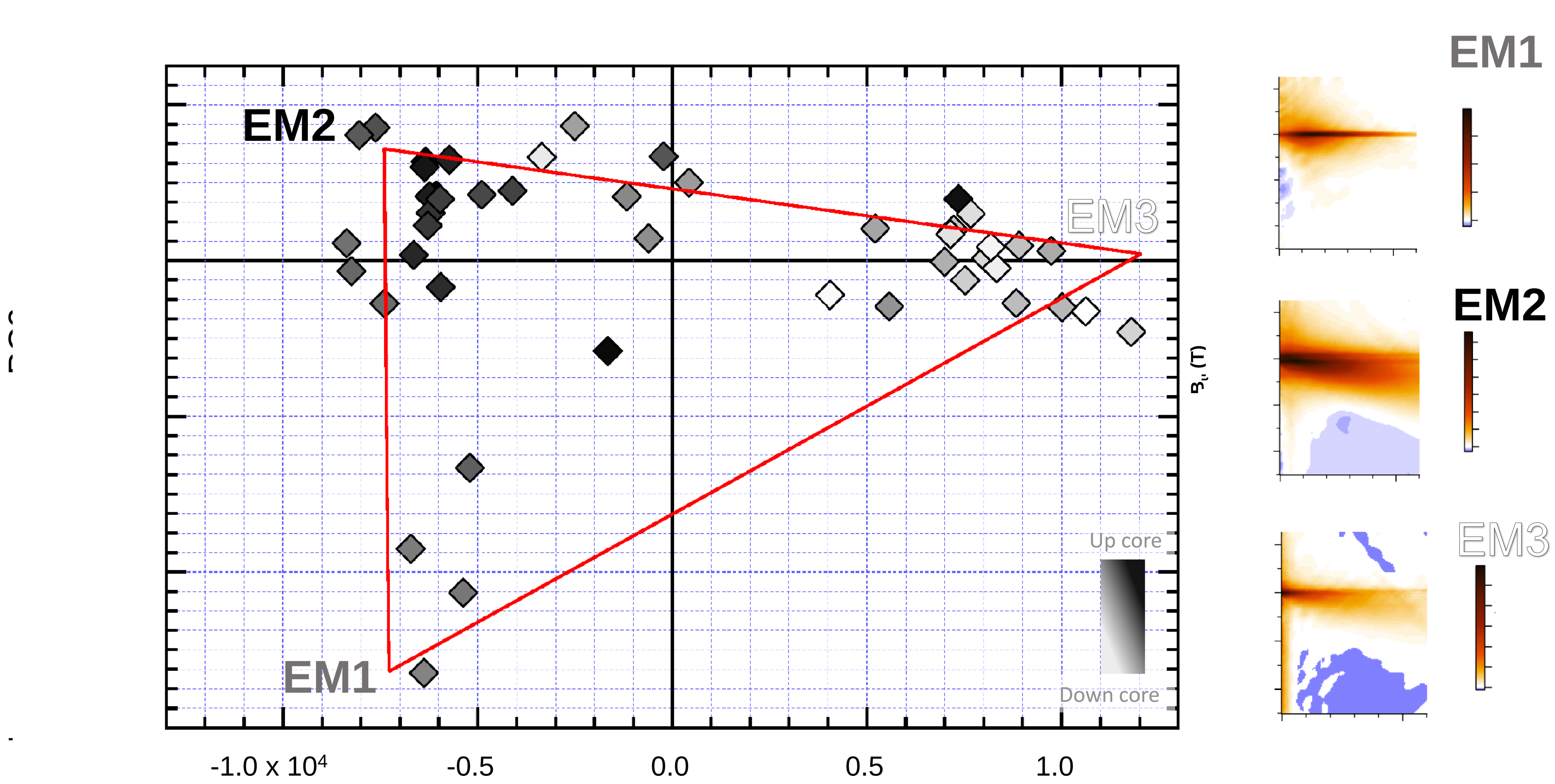


Figure 2. (Left) Results from FORC-PCA of 46 FORC datasets. (Right) Simulated FORC diagrams for the three endmembers identified by FORC-PCA. Further discussion of the PCA can be found at the QR code in methods.

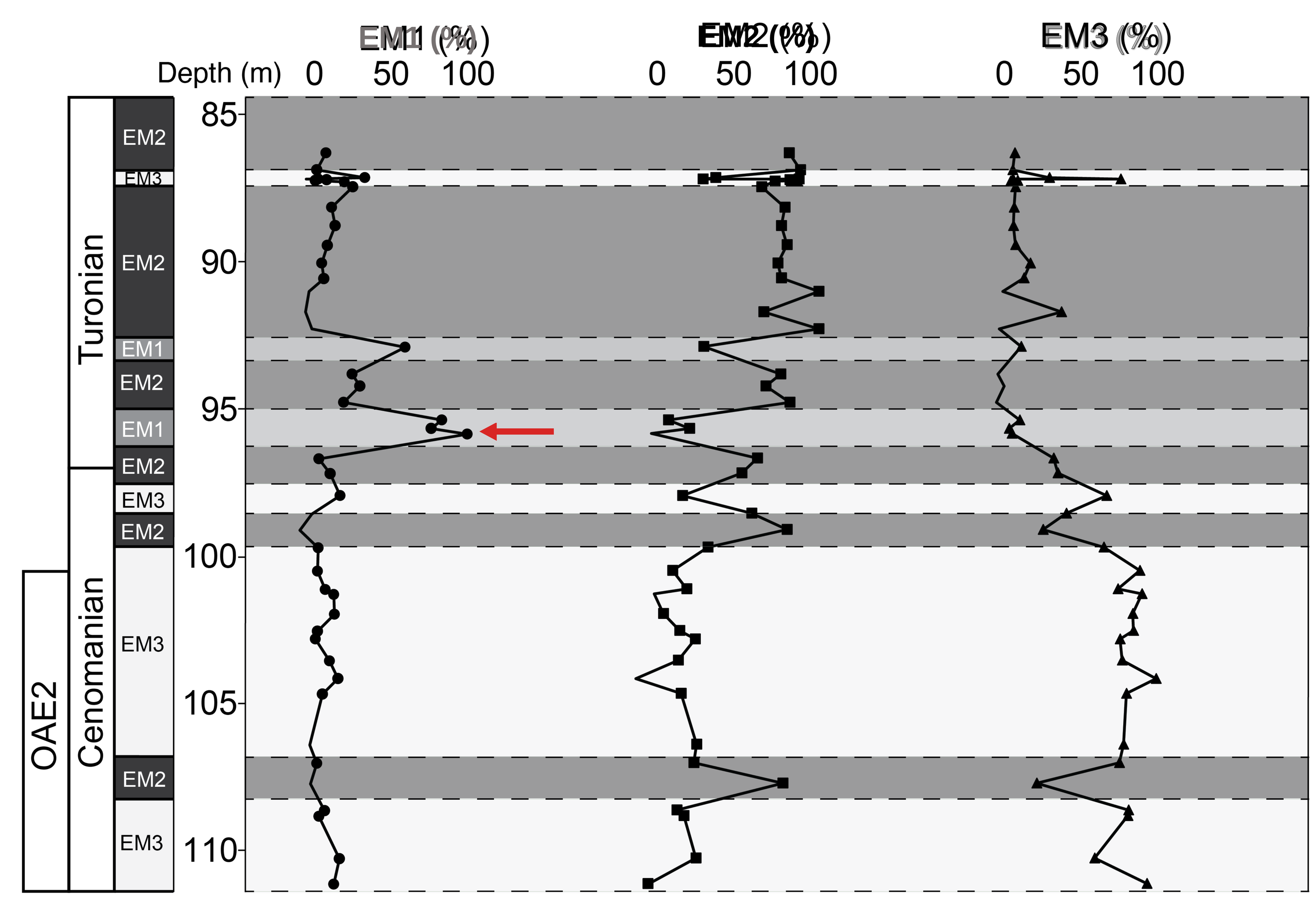


Figure 3. Endmember proportions throughout the Holland Park core. Stratigraphy and core depth are noted on the left. The dominant endmember over each stratigraphic interval is highlighted. The red arrow points to sample HP31435 (95.81 m).

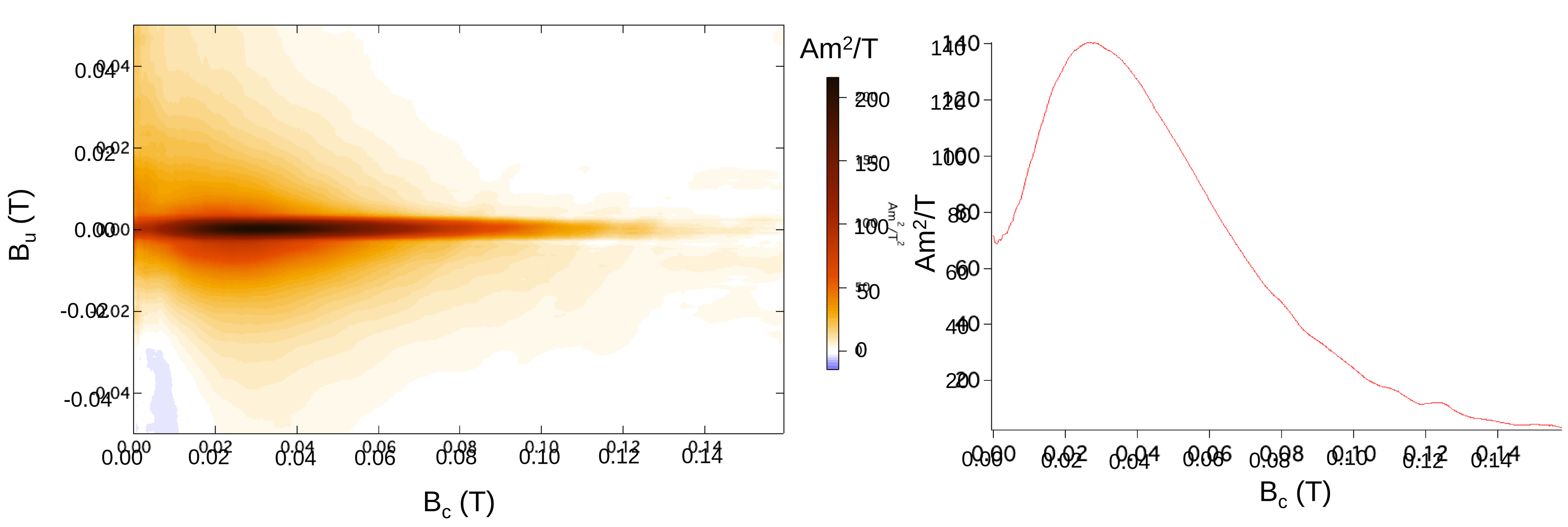


Figure 4. (Left) FORC diagram from sample HP31435 (95.81 m depth) indicated by the red arrow in Figure 3. (Right) Coercivity profile of HP31435 (95.81 m) across where B_u=0.

Figure 5. Representative SEM images from HP31435 (95.81 m) showing ~2 µm spindle-shaped particles in the center of both images. Scale bar is 1 µm.

Discussion

EM1 is defined by a central ridge that peaks at B_c ~0.03 T (Figure 2). These characteristics are consistent with single domain (SD) magnetite (25-100 nm). EM2 has a higher coercivity component that extends below the central ridge in a bean shape, peaking at B_c ~0.02-0.08 T and with more spread along the B_u axis (Figure 2). We interpret EM2 to represent hematite. The simulated FORC diagram for EM3 shows spread along the B_u axis and a low coercivity (B_c <0.015 T) component along the central ridge which represents ultrafine magnetite (<25 nm) (Figure 2).

EM3 characterizes the Cenomanian/OAE2 interval (Figure 3). The presence of ultrafine magnetite may suggest an increased supply of dissolved iron from increased weathering and erosion rates (Liu et al., 2012). OAE2 is characterized by an intensified hydrologic cycle that drove terrestrial run off to the ocean, and therefore increased iron supply, which supports this interpretation (Lowery et al., 2021).

The beginning of the Turonian interval is characterized by EM1 (Figure 3). SEM imaging of the magnetic separate of HP31435 (95.81 m) reveals ~2 µm iron-rich minerals with a spindle morphology which we interpret as giant magnetofossils (Figure 5). Although conventional magnetofossils were not yet imaged, the presence of giant magnetofossils suggests that the SD magnetite signature in our FORC diagrams is from conventional magnetofossils. The preservation of biogenic SD magnetite suggests a shift toward a more hydrologically stable, microaerobic water column.

The rest of the Turonian interval is characterized by EM2 (Figure 3). The higher coercivity signature is interpreted as fine-grained hematite. This suggests a shift toward oxidizing conditions in the water column, signaling another hydrologic shift at this time in which more oxygenated water was delivered to the continental shelf.

In summary, magnetic minerals in the Holland Park core record changes in weathering and redox states on the North American continental margin. Our results have implications toward understanding how continental shelves were affected by OAE2 as well as the role of magnetofossils in hyperthermal events.

Future Work

In our future work we will:

1. Rerun samples to a higher field to correct potential artifacts and better characterize high coercivity components.

2. Complete FORC-PCA with less noisy FORCs and with more datasets for a more complete record of the Cenomanian and Turonian intervals.

3. Capture transmission electron microscopy images of magnetic extracts from representative intervals with high proportions EM2 and EM3 to further investigate the origin of the SD magnetite and putative giant magnetofossils.

Acknowledgements

This research was made possible by funding provided by NSF, REU Site, OCE-1560088.
Thank you to Jean Self-Trail for her help with sample collection.
Thank you to Virginia Power, Vanessa Gonzalez, and Ioan Lascu for their support through the NHRE program.