Imaging Magnetofossils in Situ

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(I) Introduction

Background

- Magnetotactic bacteria (MTB) biomineralize magnetic nanominerals (~20-120 nm), which can be preserved in the geologic record as “conventional” magnetofossils. More enigmatic, “giant” magnetofossils are much larger (1-3 µm) and are produced by unknown organisms. In this study, we aim to image magnetofossils in situ (without extracting them from the sediment), in contrast to previous research, to characterize them in their unperturbed depositional environment, and assess their style of preservation.

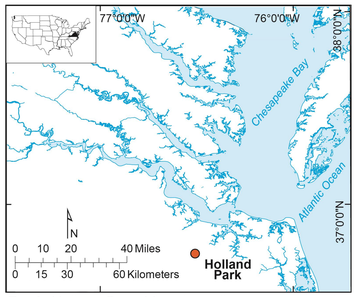


Fig 1: Holland Park, Virginia sediment core sample location; red dot indicates drilling site (Wagner et al., 2024).

- Modern MTB have been researched extensively, cultured in laboratories, and utilized for industrial practices. Magnetofossils have been found throughout the Cenozoic, but only sparsely in the Mesozoic.

- The sediment samples utilized in this study were retrieved from a sediment core drilled in Holland Park, Virginia, which was part of the continental shelf in the Cretaceous (Lowery et al., 2021) **(Fig 1).** We focus on the Cenomanian-Turonian transition (~97-93 Ma), which is associated with the thermal maximum known as Oceanic Anoxic Event 2 (OAE2). OAE2 was a mass extinction event characterized by a sharp decline in ocean biodiversity, including a notable decrease in magnetofossils (Wagner et al., 2024)**,** in contrast to the preceding period, which contains a wide variety of both giant and conventional magnetofossils.

Methods

- Magnetofossils have distinct magnetic signals that can be fingerprinted using magnetic first-order reversal curve (FORC) measurements. This was done using a vibrating sample magnetometer (VSM) **(Fig 3)** on small sediment chips (~0.1-2 mg). FORC diagrams were created in IGOR with FORCinel (Harrison and Feinberg, 2008).
- Sediment samples containing magnetofossils were made into thin sections to be viewed in a petrographic microscope to identify mineral assemblages. Samples were embedded in epoxy and carbon-coated for scanning electron microscope (SEM) observations and geochemical analysis using energy-dispersive X-ray spectroscopy. This technique allows us to image magnetofossils in situ and determine their chemical composition.
- An SEM with a focused ion beam was used to serially image through a magnetofossil-rich sediment sample in increments of 10 nm creating image stacks that were used for preliminary 3D modeling experiments with Dragonfly ORS software (Comet Technologies Canada Inc, 2022).

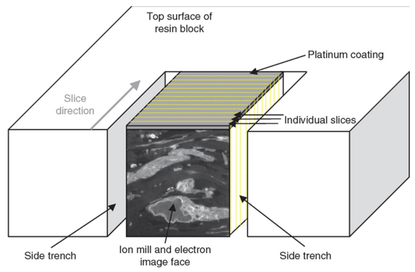
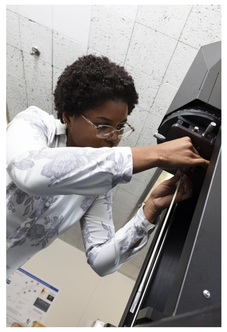


Fig 2: Schematic representation of FIB experiment technique (Bushby et al., 2011).

We detect magnetofossils through fingerprinting with FORC diagrams for imaging. This allows us to image magnetofossils in situ for the first time.

Fig 3: Ie'Jana Woodley attaching sample rod to VSM for magnetic measurements NMNH Photo, 2024



(II) Results

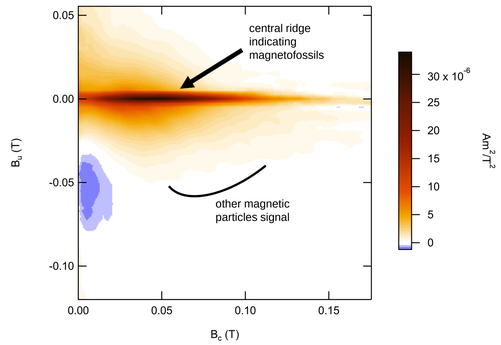


Fig 4: First-order reversal curve diagram used for magnetic measurements for magnetofossil detection. Magnetofossils are single domain non-interacting nanoparticles, coercivity varies (~0.15 - 0.2 T), and magnetic measurements show a sharp ridge. Bulk sediment samples display an ambient signal of coarser materials.

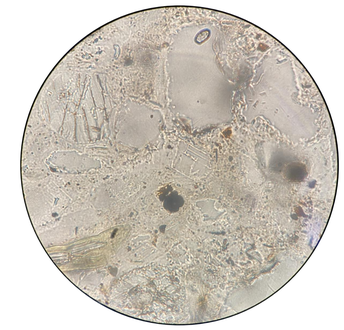


Fig 5: Magnetofossils-rich sediment in thin section with plane transmitted light: 100 magnification; field of view 0.21 mm.
Talk about lithology

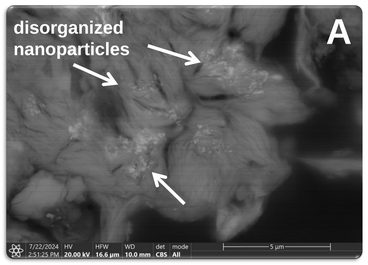


Fig 6: Exploratory SEM and EDS session of disorganized nanoparticles. **A**; SEM image of iron oxide nanoparticles. **B**; EDS of A displaying abundance of Fe_3O_4.

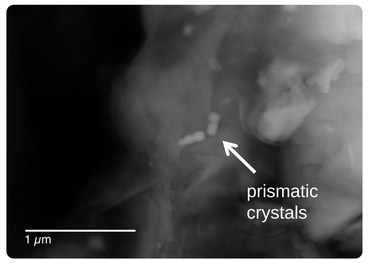


Fig 7: SEM image of prismatic crystals in situ.

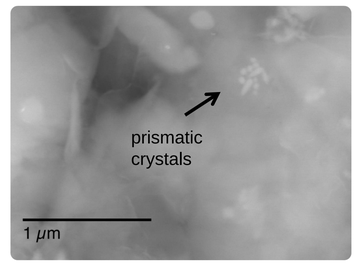


Fig 8: SEM image of conventional cuboctahedra and small bullets.

(III) Summary and Next Steps

Summary

- Magnetofossils have a distinct magnetic signature that can be detected in bulk sediment measurements allowing researchers to image them in situ rather than extracting them creating new avenues for magnetofossil exploration.
- We observed magnetofossils preserved in various assemblages; well preserved chains, small (<1 µm) and large (>1 µm) disorganized collections of fossils. These preliminary observations of magnetofossil assemblages' preservation offer insights to their unknown deposition.

Next Steps...

- We plan to utilize light microscopy on a thin section containing magnetofossils to analyze sediment characteristics and view the fossils before SEM and EDS analysis.
- Utilizing the methods developed in this study we plan to 3D model magnetofossils from high-resolution image slices acquired from a FIB slice dataset.

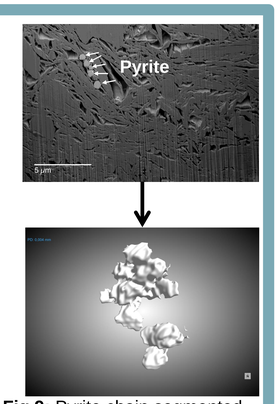


Fig 9: Pyrite chain segmented from image slice dataset.

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Additional Information: