FERRICRETES OF THE BAHARIYA OASIS, WESTERN DESERT, EGYPT: A KEY TO UNDERSTANDING IRON OXIDE FORMATION MECHANISMS ON MARS. M. Salvatore[1], C. S. Edwards[1], and L. Tanner[2], [1]Northern Arizona University, Flagstaff, AZ, mark.salvatore@nau.edu, [2]Le Moyne College, Syracuse, NY.

Introduction: Orbital and landed spacecraft have identified widespread occurrences of crystalline ferric (Fe^{3+}) iron oxide phases on Mars, indicating the existence of oxidizing environments [1]. Some of the more notable examples are the hematite-bearing plains of Meridiani Planum [2,3] and the hematite-bearing Vera Rubin Ridge in Gale crater [4]. Alone, the presence of oxide phases cannot be used to understand formation mechanisms or paleoenvironmental conditions, as iron oxides can form in a variety of primary and secondary environments. Thus, it is necessary to investigate the bulk mineralogy, geochemistry, and physical properties of these geologic units to fully understand the conditions present when such mineral phases formed.

In this study, we explore an analog environment in which numerous Fe^{3+}-bearing oxide phases are thought to have formed under several different environmental conditions. We describe these different formation hypotheses and predict the mineralogical, geochemical, and physical characteristics that would correspond to each mode of formation. Lastly, we report on our preliminary results and future work that is designed to better understand these linkages on both Earth and Mars.

Background: The Bahariya Oasis in central Egypt is home to the Bahariya Formation, an Upper Cretaceous- (Cenomanian-) age sequence of fluvial, estuarine to intertidal, and shallow marine deposits dominated by mudstones and sandstones containing abundant silica and carbonates [5]. Embedded within the Bahariya Formation are numerous Fe^{3+}-rich ferricrete units (**Fig. 1**) that were originally interpreted to have formed in relation to changing sea level, although additional work has identified several additional formation mechanisms [5-10]. These additional mechanisms include the contemporaneous subaerial weathering (laterization) of Fe-bearing sedimentary phases [5], the subsurface mobilization and reprecipitation of iron through groundwater mobilization [6], and iron mineralization through bacterial mediation [7,8]. In addition to the ferricretes within the Bahariya Formation, other studies have identified modern lateritic weathering within the Bahariya Oasis [9]. In total, at least four different modes of Fe^{3+}-enrichment have been identified throughout the Bahariya Oasis, allowing for each mechanism to be assessed for their potential relevance to Fe-oxide-bearing regions identified on Mars.

Ancient paleosol environments. Pedogenesis results in the weathering of unstable mineral phases and the top-down leaching of soluble ions, combined with any biological activity that may be occurring at or near the surface. Fe-oxides and oxyhydroxides are typically present throughout the soil sequence, as they are insoluble phases that are resistant to leaching as well as the products of precipitation when Fe^{2+}-bearing phases are dissolved, transported to depth, and oxidized. Buried pedogenic sequences can be identified based on these unique patterns of leaching and precipitation.

Concentration via groundwater. Where evidence of pedogenesis is lacking, it has been proposed that ferricretes are the result of the mobilization and concentration of Fe-oxides via groundwater. The proposed source of iron is glauconite, which is common throughout the sandstones in the Bahariya Formation and is susceptible to leaching. Once the dissolved Fe^{2+}-rich groundwater experiences oxidizing conditions, the iron is able to oxidize and precipitate in well-defined stratigraphic layers controlled by permeability.

Bacterially mediated iron mineralization. Studies have identified concentric Fe-oxyhydroxide laminae in ferricretes throughout the Bahariya Formation that are morphologically consistent with microstromatolites. Organic materials including proteins, lipids, carotenoids, and carbohydrates have also been identified in these structures, supporting a biological origin. It is hypothesized that bacteria oxidized Fe^{2+}-rich groundwater under both neutral and acidic conditions, forming the observed morphologies.

Modern lateritic weathering. Capping many cone hills and small plateaus throughout the Bahariya Oasis are ferricrete deposits associated with more recent episodes of lateritic weathering. These formations shield the underlying sedimentary deposits from erosion.

Preliminary Spectral Analyses: In conjunction with previous geochemical and mineralogical analyses of ferricretes throughout the Bahariya Oasis, we have acquired visible/near-infrared (VNIR) reflectance and thermal infrared (TIR) emission spectra of ferricrete samples from the Gebel El-Dist type locality within the Bahariya Oasis [6]. These methods are helpful for identifying spectrally significant mineral phases and for comparisons to martian surface and orbital datasets. VNIR spectra (0.35 - 2.50 μm) were acquired at Northern Arizona University using an ASD FieldSpec4 spectroradiometer under controlled illumination with an emergence angle of 30º and an illumination angle of 0º. These data reveal the dominance of crystalline Fe-oxides (hematite and goethite, **Fig. 2a**) at wavelengths less than 1.0 µm, consistent with orbital measurements of Vera Rubin Ridge in Gale crater. TIR spectra (2000 - 200 cm^{-1}) were acquired at Arizona State University's Thermal Emission Spectroscopy Laboratory using a Nicolet Nexus 670 spectrometer using the methods of [11] and unmixed using the non-negative least squares model from [12] (**Fig. 2b**). Unmixing of a ferruginous sandstone indicates ~50% phyllosilicates (dominated by Fe-smectites), ~11% carbonate, ~11% quartz, and ~10% Fe-oxides (combination of hematite and goethite), consistent with x-ray diffraction studies [6]. This is consistent with the glauconite-dominated Bahariya sandstones. When unmixed using a more extensive rock-mineral library, the most abundant phases were modeled to be glauconitic sandstone, smectite clays, and synthetic goethite, closely matching the actual lithologic composition. These results suggest that both VNIR and TIR analyses are valuable additions to the study of Fe-oxide-bearing lithologies from the Bahariya Oasis.

Future Work: While this preliminary investigation of the ferruginous lithologies throughout the Bahariya Oasis suggests that these are compelling analogs for Fe-oxide-bearing landscapes on Mars, additional work is necessary to more accurately characterize their spectral, geochemical, and mineralogical diversity. Specifically, there is a need to identify, collect, and analyze ferricrete samples derived from the different formation environments mentioned above to be able to differentiate between formation mechanisms based on their compositional and spectral characteristics. If possible, this work would significantly improve our ability to understand the paleoenvironmental conditions present during the formation of Fe-oxide-bearing lithologies observed on Mars.

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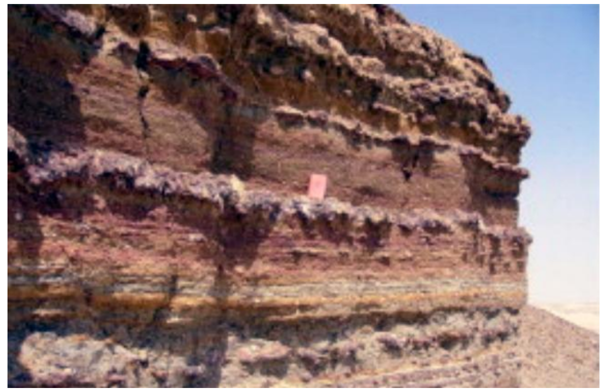

Fig. 1. A sequence of finely interbedded claystones, mudstones, and ferruginous sandstones at Gebel El-Dist in the Bahariya Oasis. Field notebook for scale. From [6].

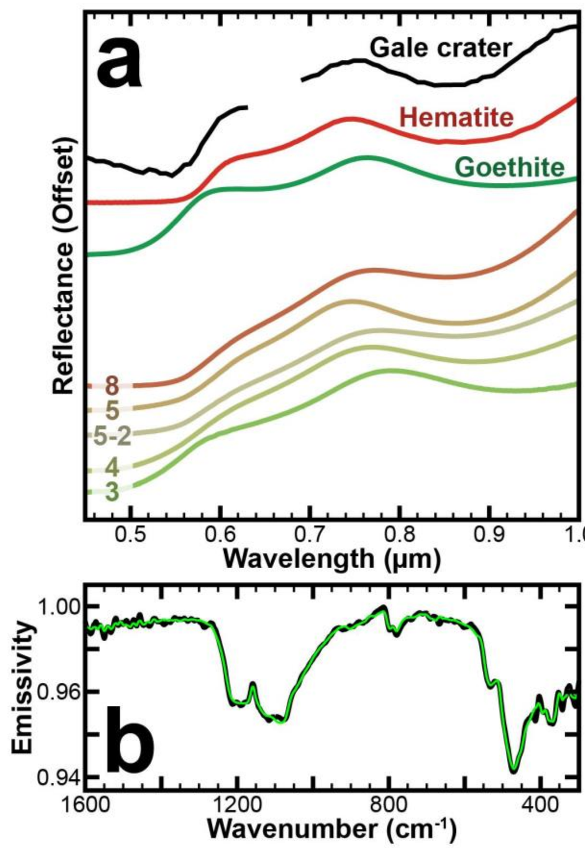

Fig. 2. (a) A comparison of VNIR spectra from Gale crater [4] and the Bahariya Formation (bottom), with pure hematite and goethite for comparison [13]. The color of the Bahariya spectra reflect the relative spectral similarity to hematite (red) and goethite (green). Numbers next to each Bahariya spectrum correspond to sample numbers. (b) A TIR spectrum of a ferruginous sandstone from the Bahariya Formation (black) with the result of a linear unmixing analysis overlain (green).