TEXTURAL, GEOCHEMICAL, AND THERMODYNAMIC CONSTRAINTS ON THE EVOLUTION OF EUCRITE EET 90020. J. S. Gorce1,2, D. W. Mittlefehldt2, J. I. Simon2, 1Lunar and Planetary Institute, USRA, 3600 Bay Area Blvd., Houston TX 77058, USA (jgorce@lpi.usra.edu). 2Astromaterials Research and Exploration Sciences, NASA Johnson Space Center, Houston, TX 77058, USA.

Introduction: Basaltic eucrites, which are possibly parts of the Vesta crust, formed as either lava flows or intrusions [1-2], and can offer insights into early crust formation. However, most eucrites have experienced thermal metamorphism [1], which exacerbates the challenges of understanding these samples. A variety of petrogenetic models such as partial melting of a primitive source [3], fractional crystallization of magmas emplaced in a primitive crust [4-6], and/or partial melting of an eucritic source coupled with melt mixing and assimilation [7-9], have been proposed in order to explain observed petrologic and chemical characteristics of eucrites.

Elephant Moraine (EET) 90020 is an unbrecciated eucrite that has experienced significant thermal metamorphism, with temperatures of metamorphic equilibration calculated to be ~840-1040°C [8,11]. Its petrologic history remains contentious, in part due to differences in trace element analyses [10,17, this work], which has led to multiple metamorphic interpretations [8,10-11]. Here, we combined petrologic observations, chemical analyses, and thermodynamic modeling, to interpret micro-domain textures identified in EET 90020 and better constrain its petrologic history. Ultimately, the development of such textures is a direct result of the geologic processes operating on a young Vesta or similar asteroid.

Sample description: We identified three textural domains in EET 90020 (Fig. 1); (I) A coarse grain domain with granoblastic plagioclase and pyroxene, (II) a medium grain domain with curved grain boundaries between plagioclase and pyroxene, and (III) a fine grain domain containing tridymite that fills in interstitial space between plagioclase.

Geochemical results: Major element chemistry, acquired by electron microprobe analysis (EMPA) at NASA JSC, is consistent among phases across domains. Pyroxene have distinctive high-Ca lamellae (Wo40.92En28.1Fs31.0) that formed from the low-Ca pigeonite host (Wo3.3En33.3Fs62.8). There are small amounts of fayalitic olivine along pyroxene/oxide grain boundaries, where pyroxenes appear to have reacted with ilmenite/chromite clasts. Plagioclase is anorthitic (Avg ~An45), with little variation (An45-92).

Bulk rock trace element analyses were collected via ICP-MS and individual mineral analyses with LA-ICP-MS at NASA JSC (Fig. 2). Domain concentrations were calculated using modal mineralogy and mineral compositions. Variations in domain and bulk rare earth element concentrations [10,17, this work] are influenced by the presence of phosphates [10].

Thermodynamic modeling: The software package, Perple_X, was used to calculate mineral phase equilibria over a range of conditions using a Gibbs free energy minimization approach [12]. Models used all major/minor elements except P₂O₅. Thermodynamic properties from [13] were used to constrain endmember phase stabilities. Activity models were used to describe mixing in phases with solid solution.

Isochemical Pressure-Temperature (P-T) phase diagrams were constructed for the bulk thin section and the coarse, medium and fine grain domain compositions. Domain compositions were determined using EMPA analyses of phases identified in each domain and observed modal mineral abundances.

Figure 1: False color element map of EET 90020. Red = Si, blue = Al, and green = Ca. Domain boundaries are marked with dashed yellow lines.

Figure 2: Rare Earth Element concentrations normalized to CI chondrite measured for minerals and computed for coarse, medium, and fine grain textural domains, each reconstructed via their measured mineral compositions and modal mineralogy.
namically stable pyroxene compositions were extracted from model results and compared to pyroxene compositions collected via EMPA, allowing us to calculate temperatures for metamorphic equilibrium.

**Model output:** Results that use the coarse domain composition (Fig. 3a) demonstrate overlap at T ~ 840°C indicating a high T of equilibration. There was no overlap using the medium or fine grain domain compositions, or the bulk composition of all three domains (e.g., Fig. 3b), indicating either that these are not equilibrium assemblages or domain/rock compositions are not representative. These results were replicated using data from [8, 17].

**Discussion:** The disequilibrium results from the bulk rock, fine grain, and medium grain models imply that EET 90020 might have been modified during and/or after peak metamorphism (i.e., it experienced open system behavior). However, this is in contrast to the coarse domain where it appears as if equilibrium was maintained. We suggest that this difference is explained by highly localized equilibrium occurring at millimeter length-scales, which has been observed in terrestrial metamorphism where aqueous fluid infiltrate [14] or melt loss occurs [15]. Preliminary results from LA-ICP-MS analyses suggest that Hf, Zn, P, and V in pyroxene are influenced by those location within the sample and therefore might be influenced by processes such as differential melt loss and/or element mobility. If phases such as phosphates and oxides control the distribution of these elements, it would result in only a trivial change in bulk rock major elements. While major elements are consistent between domains for a given phase, calculated major element abundancies for domain composition vary, implying that heterogeneous modal mineralogy controls major element distributions between domains.

Modeling results of the coarse grain domain, where equilibrium was maintained, can provide useful insights into the geologic evolution of EET 90020, whereas bulk rock compositions that represent a mixture of domains do not. We approximate maximum metamorphic temperatures, using the Ca component in pyroxene, at ~1040°C (Fig. 3), which is consistent with previous two-pyroxene thermometry [8,11]. At this temperature, models calculate that up to 10 vol % melt can be produced in the coarse grain domain, which is greater than the minimum melt needed in order to segregate and form a melt network [16]. Tridymite and plagioclase would be the first minerals to completely melt during heating starting ~990°C. Melting processes might explain the heterogeneous modal mineralogy and is texturally supported by an abundance of curved grain boundaries and spherical grain morphologies in the medium and fine grain domains. This contrasts with the coarse domain, where grain boundaries are angular.

We suggest that a partial melting model best explains the textural development of EET 90020. Upon heating, melt generated was either trapped, resulting in no net change in the localized rock composition, or migrated, resulting in disequilibrium between pyroxene and the surrounding matrix. This is consistent with previous studies suggesting that EET 90020 experienced partial melting [8]. However, a better understanding of the bulk rock trace element contents is required as initial results (i.e. consistent REE concentration between textural domains) appear inconsistent with the hypothesis that EET 90020 is a residual eucrite. Ongoing work focuses on inter-domain, trace element changes with respect to phosphate and oxide grain proximity in order to test the extent of element mobility and partial melting. Future work will study other heterogeneous samples to see if EET 90020 presents a unique circumstance or whether crustal partial melting was ubiquitous on the eucrite asteroid.