

### ASSESSING DOMAINS OF EQUILIBRATION IN HIGHLY METAMORPHOSED EUCRITES

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**Introduction:** Thermodynamic modeling, combined with petrographic textures, has become a staple tool for determining the *Pressure-Temperature* conditions of metamorphism [1]. Furthermore, the concept of localized metamorphic equilibrium has greatly expanded the utility of equilibrium models, because studies have demonstrated that thermodynamically modeling of microdomains can more precisely infer petrogenetic history [2]. Such methodologies have application to the study of eucrites, many of which have experienced thermal metamorphism. This study assesses how petrographic textures and trace element distributions, combined with thermodynamic models, can act as indicators of metamorphic equilibrium and/or trace element mobility in highly metamorphosed eucrite, Elephant Moraine (EET) 90020.

**Sample description:** EET 90020 is an unbrecciated eucrite recording metamorphic temperatures of ~870-1060°C [3]. Isochemical phase diagrams generated for texturally defined, micro-domains revealed that that highly localized equilibrium likely occurred at millimeter length-scales [4]. However, the dominant driver of open-system behavior remains contentious. Some studies concluded that EET 90020 represents a residual eucrite in which high partial melt volumes were removed during thermal metamorphism [3], while other studies concluded that trace element concentrations are strongly influenced by the distribution of minor and trace mineral phases [5].

**Methods:** Major elemental analyses and mapping were done on an electron microprobe. Bulk rock elemental data were collected on an ICP-MS, and laser ablation ICP-MS analyses were done to characterize minor and trace elements in mineral phases. We constructed four thermodynamic models, where each model used different criteria to define a metamorphically equilibrated area. For model 1, textural observations were used to define the equilibrated area (coarse grain domain from [4]), model 2 used chemical constraints from LA-ICP-MS analyses to define the equilibrated area, model 3 considered both chemical and textural constraints, and model 4 assumed that the entire thin section had equilibrated. The thermodynamic modeling software package, *Perple\_X*, was used to calculate mineral phase equilibria based on the calculated major element composition of the defined equilibrated area. Thermodynamically stable pyroxene compositions were compared to measured pyroxene compositions to test whether metamorphic equilibrium had been achieved and maintained.

**Results:** For models 1, 2, and 3, the measured  $X_{W_0}$  component of pyroxene is stable from ~725-810°C. The measured  $X_{F_s}$  component is stable from ~700-840°C in model 1, ~700-750°C in model 2, and ~700-800°C in model 3; all  $X_{F_s}$  temperature ranges overlap. Similarly, while the magnitude of temperature range over which the  $X_{En}$  component is stable varies between model 1 (~840-1025°C), model 2 (~900-950°C), and model 3 (~860-880°C, 950°C), all  $X_{En}$  isopleths overlap in temperature space. While the  $X_{W_0}$ ,  $X_{F_s}$ , and  $X_{En}$  isopleths overlap for the results of model 1, the remaining models do not exhibit such overlap.

**Conclusions:** Thermodynamic model results for model 1, where the equilibrated area was defined by textural observations, imply that equilibrium was likely achieved and maintained, and thus appropriately defines a region of maintained metamorphic equilibrium. For model 2 (equilibrated area defined by compositional analyses), model 3 (equilibrated area defined by textural and chemical constraints), and model 4 (equilibrated area defined as the entire thin section), lack of overlap in pyroxene isopleths imply disequilibrium, and thus we have not appropriately defined and equilibrated area for these models. We suggest that 1) we underestimated the areas affected by post-metamorphic diffusion of trace elements from phosphate and oxide grains into silicate phases for models 2 and 3 and 2) there is utility in defining micro-domains when attempting to elucidate conditions of metamorphism in eucrites, instead of simply considering a bulk sample.

Model 1 results indicate a maximum temperature of ~1025°C and the generation of up to 10 vol % melt. However, the lack of variation in trace element concentrations for a given mineral phase does not favor large scale segregation and mobilization of melt [3]. Alternatively, we determined that the minimum weight percent of phosphates needed to shift geochemical plots from and apparent LREE depletion [3,5] to an apparent LREE enrichment [4], was <0.2 wt % and we estimated that the bulk powder used in this study contained between 0.3-0.4 wt % phosphate in order to produce measured REE concentrations. Thus, element mobility seems to be primarily controlled by diffusion processes driven by chemical gradients that are established by the location of minor phases within the sample.

**References:** [1] Lanari P. and Duesterhoeft E. (2019) *Journal of Petrology* 60: 19-56 [2] Baldwin J. A. et al., (2005) *Journal of Metamorphic Geology* 23: 511-531 [3] Yamaguchi A. et al., (2001) *Geochimica et Cosmochimica Acta* 65:3577-3599 [4] Gorce J. S. et al., (2021) *52nd Lunar and Planetary Science Conference* No. 2548, id.1656 [5] Mittlefehldt D. W. & Lindstrom M. M. (2003) *Geochimica et Cosmochimica Acta* 67:1911-1934