

IRON AND CHROMIUM VALENCES OF PYROXENES IN THE LUNAR BASALTIC METEORITE ELEPHANT MORAINÉ 96008: IMPLICATIONS FOR REDOX CONDITIONS AND MAGMATIC PROCESSES ON THE MOON.

M. Wadhwa¹, S. R. Sutton^{2,3}, A. Lanzirotti³, A. G. Distel¹, and J. Davidson^{1,4}, ¹School of Earth and Space Exploration (SESE), Arizona State University (ASU), 781 E. Terrace Rd, Tempe AZ 85287-6004, USA, ²Department of the Geophysical Sciences and ³Center for Advanced Radiation Sources (CARS), University of Chicago, Chicago, IL 60637, USA, ⁴Buseck Center for Meteorite Studies, SESE, ASU, Tempe AZ 85287, USA.

Introduction: It has long been recognized that the valence systematics of multivalent elements such as Fe, Cr, V, and Ti in pyroxenes can be utilized as tracers of magmatic processes and the redox conditions involved in the petrogenesis of planetary basalts from the Earth, Moon, and Mars [1,2]. Nonetheless, it is only within the last decade or so that micro-X-ray Absorption Near Edge Structure (micro-XANES) spectroscopy methods have provided a powerful means of quantifying the valences of such elements in individual mineral grains such as pyroxenes and olivines in planetary materials (e.g., [3,4]). As such, there have only been a few such micro-XANES studies of lunar basaltic samples thus far. Specifically, the valence systematics of Cr, V, and Ti were recently reported for pyroxenes and olivines in two Apollo 14 aluminous basalts [5] and several Apollo 17 high-Ti and very low-Ti (VLT) basalts [6]. Here we report the Fe and Cr valences in pyroxenes from the Elephant Moraine (EET) 96008 meteorite. This lunar meteorite is a fragmental breccia composed mainly of basaltic clasts, and is characterized by bulk rock geochemical characteristics similar to those of VLT basalts that have experienced extreme fractional crystallization [7].

Analytical Methods: Based on initial characterization of a thin section of EET 96008 using optical microscopy, six pyroxene grains (PX1–6, ranging in size from ~0.5 to ~2 mm across) were selected for micro-XANES analyses. It is noted that since this meteorite is a fragmental breccia, these pyroxenes may be fragments of originally larger grains.

The Fe and Cr valences were determined using methods described in [3,4] and briefly summarized here. The Fe and Cr K-edge XANES spectra were collected at 4 orientations on multiple spots on each pyroxene using station 13-ID-E at the GSECARS X-ray microprobe at the Advanced Photon Source at Argonne National Lab. We merged the 4 orientation spectra for each spot we analyzed and determined the valences from the merged spectrum. For Fe, the valence was determined using the “Lasso” (least absolute shrinkage and selection operator) method described in [8]. The Fe valence is reported as “ $2 + (\text{Fe}^{3+}/\Sigma\text{Fe})$ ”; precision of the reported Fe valence values is estimated to be ± 0.0075 (1σ) based on the average intragrain standard deviation for homogeneous grains. The Cr valence method used the normalized intensity of the derivative spectrum peak produced by a $1s \rightarrow 4s$ electronic transition [9]. The Cr valence is reported as “ $2 + (\text{Cr}^{3+}/\Sigma\text{Cr})$ ”; precision of the reported Cr valence values is estimated to be ± 0.01 (1σ).

Results: The Fe valence in EET 96008 pyroxenes analyzed here ranges from 2.001 to 2.097, while the Cr valence ranges from 2.60 to 2.75. Not only is there significant variation between pyroxene grains (e.g., Fe and Cr valences in PX3 lie towards the lower end of the ranges indicated here, whereas these lie towards the higher end of the ranges in PX4), but there is also quite significant intragrain variation (e.g., the ranges of Fe and Cr valences in PX2 are 2.028–2.082 and 2.65–2.74, respectively). Overall, there appears to be a good correlation between the Fe and Cr valences in the EET 96008 pyroxenes.

Discussion: It has previously been assumed that the fraction of ferric iron ($\text{Fe}^{3+}/\Sigma\text{Fe}$) in lunar pyroxenes is negligible [1]. However, this study shows that in fact the fraction of ferric iron in pyroxenes of the EET 96008 lunar basaltic meteorite ranges from negligible ($0.1 \pm 0.6\%$) up to 9.7%. It is possible that the inter- and intragrain variation in Fe valence and the fraction of ferric iron (up to nearly 10%) in the EET 96008 pyroxenes could have resulted from weathering and oxidation in the terrestrial environment (given that this meteorite is estimated to have a residence time in Antarctica of 80 ± 30 ka [10]). However, this seems unlikely given 1) the good correlation observed in this study between the Fe and Cr valences in the EET 96008 pyroxenes, and 2) the range of Cr valence in the EET 96008 pyroxenes falls well within the range observed in pyroxenes of Apollo 17 VLT basalts (Fig. 4 of [6]) that are not affected by terrestrial weathering. Future investigations correlating the Fe and Cr valences with hydrogen isotope compositions and water contents of these pyroxenes will provide further insights into whether the inter- and intragrain variations in Fe and Cr valences in EET 96008 may have resulted from terrestrial weathering and/or lunar magmatic processes such as degassing and dehydrogenation.

References: [1] Papike J.J. et al. (2005) *Am. Mineral.* 90:277–290. [2] Papike J.J. et al. (2016) *Am. Mineral.* 101:907–918. [3] Sutton S.R. et al. (2017) *GCA* 204:313–330. [4] Sutton S.R. et al. (2020) *Chem. Geol.* 531:119305. [5] Simon S.B. and Sutton S.R. (2017) *MAPS* 52:2051–2066. [6] Simon S.B. and Sutton S.R. (2018) *MAPS* 53:2138–2154. [7] Anand M. et al. (2003) *GCA* 67:3499–3518. [8] Dyar D. et al. (2016) *Am. Mineral.* 101: 1171–1189. [9] Berry A.J. and O’Neill H.St.C. (2004) *Am. Mineral.* 89:790–798. [10] Nishiizumi K. et al. (1999) *LPS* 30:1980.