

AN INVESTIGATION OF PYROXENES WITHIN DIFFERENT LITHOLOGIC DOMAINS IN MARTIAN METEORITE NWA 7034. A. R. Santos¹, C. B. Agee¹, F. M. McCubbin¹, C. K. Shearer¹, ¹Institute of Meteoritics, 1 University of New Mexico, MSC03-2050, Albuquerque, NM 87131 (asantos5@unm.edu).

Introduction: The martian meteorite NWA 7034, a breccia, contains various clasts of igneous rocks and minerals, impact generated melts, and possible sedimentary clasts all set in a fine grained matrix. Several interpretations regarding the relationship of these clasts, lithic, and mineral fragments have been proposed. The initial study by [1] suggested they originated from the same volcanic event, while a study by [2] proposed some materials were plutonic in origin while others formed by fractional crystallization of an impact melt sheet. Based on compositions of the different igneous clasts, [3] suggested either a fractional crystallization relationship or assimilation. Specific minerals can be used to investigate the relationship of these materials, and pyroxene has proven to be effective for this purpose [e.g. 4, 5]. A detailed study of pyroxene from the different domains within this meteorite (e.g. igneous clasts, isolated matrix minerals) was conducted to elucidate the relationships between the different materials composing NWA 7034.

Methods: Classification of Materials: Pyroxenes within different domains of the meteorite were included in this study, and domains are defined after [6]. This study included pyroxenes within igneous clasts (basaltic clasts, trachyandesite clasts, basaltic andesite clasts, Feldspar, Fe,Ti-oxide, Phosphate clasts (FFTP clasts)) and isolated single crystal pyroxene fragments surrounded by bulk rock matrix (“pyroxene fragments”).

Electron Microprobe Analysis: Major and minor element data as well as BSE images were collected using the JEOL 8200 Electron Microprobe at UNM using a 15 kV accelerating voltage, 20 nA beam current, and 5 μm spot size. BSE images were used to assess mineral textures. Fe^{3+} was calculated using the methods of [7], and only analyses having good stoichiometry were used (after [8]). Equilibration temperatures were determined using the QUILF program of [9].

Results: Most basaltic, trachyandesite, and basaltic andesite clasts contain a granulite texture with rounded pyroxene-plagioclase boundaries, though some were observed to contain a more basaltic texture (i.e. subhedral grain boundaries). Pyroxene in these clasts contain variable textures including fine lamellae (Fig. 1A) and patchy zoning (i.e. irregular shaped zones of differing Fe content). Some grains appear homogenous in BSE images but may contain fine lamellae only observable using techniques such as TEM. Pyroxene fragments contain greater textural diversity including

normal igneous zoning (Fig. 1B), lamellae (typically coarser than that in the igneous clasts, 1-5 μm), or are homogenous. Pyroxene fragments have equilibrated at temperatures within $\sim 900\text{-}960^\circ\text{C}$, while some of the pyroxenes in clasts equilibrated at temperatures between $840\text{-}1000^\circ\text{C}$.

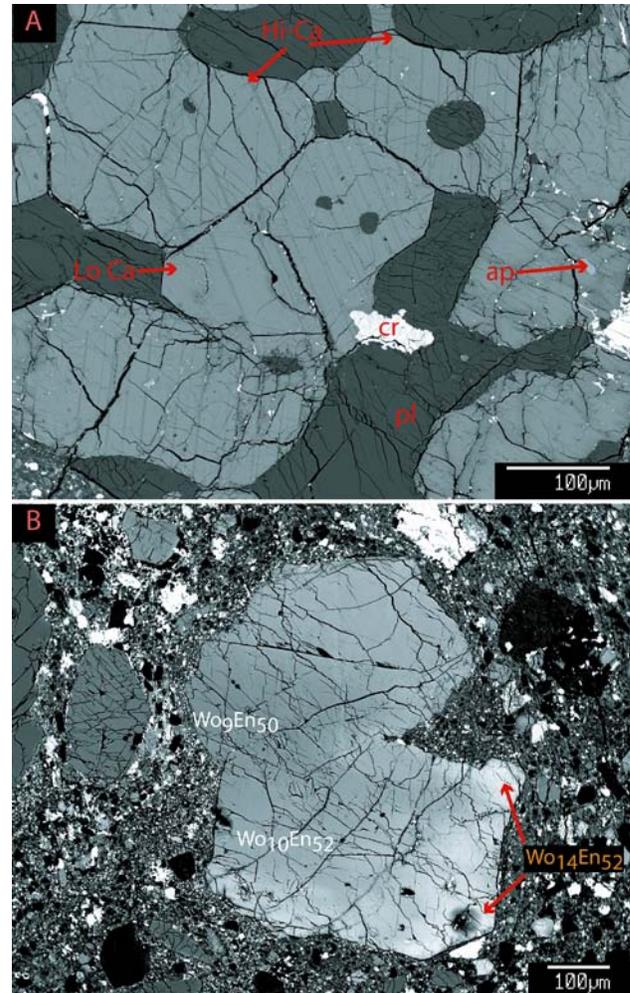


Figure 1: A) Thin high Ca lamellae in a basaltic andesite clast, B) Diffuse boundary igneous zoning in a pyroxene fragment. Ap-apatite, pl-plagioclase, cr-chromite.

Major element components are represented by the quadrilateral shown in Fig. 2. Significant compositional deviation is not present between the pyroxene groups, with the majority of pyroxenes containing less than 6 mol% Wo and the second most numerous group containing between 6-11 mol% Wo. Few igneous clasts contain high Ca pyroxene as a separate phase. Trends among all pyroxene types show Fe enrichment, and

also an Fe,Ca “enrichment” for the 6-11 mol%Wo group.

Minor elements such as Cr, Ti, Al, and Na exhibit substantial variation within and among pyroxenes. For example, a plot of Ti vs. Al for pyroxenes with $Wo \leq 5$ mol% is shown in Fig. 3. Basaltic clasts overlap in Ti/Al with both the trachyandesite clasts and pyroxene fragments, though most high Ca pyroxene fragments do not overlap with clast pyroxene values.

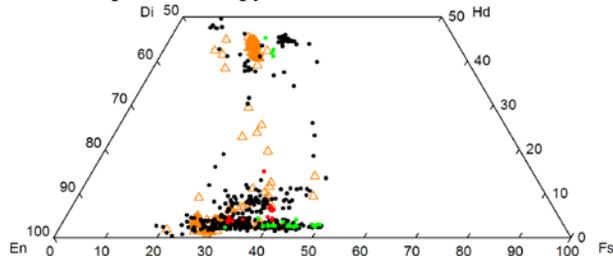


Figure 2: Pyroxene quadrilateral showing compositions from basaltic clasts (black circle), trachyandesite clasts (green circle), basaltic andesite clasts (red circle), and pyroxene fragments (orange triangles). Note the Fe trend and Fe-Ca trend.

Cr content in pyroxene grains does not correlate with Mg or Fe, and Cr is relatively constant among grains with similar Ca values. Despite relatively constant Cr, Ti and Al do vary to the same degree among pyroxenes from all domains. Changes in Al/Si with changing Fe/Mg are small, but pyroxene grains do show higher Al/Si at higher Fe/Mg.

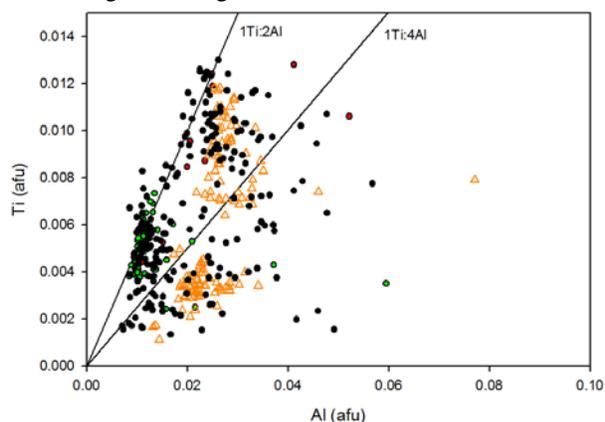


Figure 3: Al vs. Ti (afu) for the four pyroxene groups considered for this study with the same symbols in Fig. 2. Trachyandesite clasts tend to fall on the 1:2 line, while basaltic clasts and pyroxene fragments range from below the 1:4 line to above the 1:2 line. Grains plotting on the 1:2 line indicate Ti-2Al is the dominant substitution pair, grains on the 1:4 line indicate a 50/50 mix of Ti-2Al and Al-Al, and grains below the 1:4 line are likely to have more Cr-Al substitution.

Discussion: Pyroxene data suggest at least two groups of materials with different cooling histories within this meteorite. One group is represented by the

matrix grains that preserve remnant igneous zoning (fast cooling), and the other is represented by fragments and clast grains containing exsolution lamellae (slow cooling) [4]. These groups could have formed as products of different igneous events or as different parts of the same igneous event (i.e. exterior and interior of a shallow intrusion). Slow cooled/reheated grains have lost much of their original igneous chemical information due to equilibration, however some of the equilibrated grains have likely retained their original bulk chemistry as pyroxenes have not lost all of their Al to surrounding plagioclase [4]. This implies equilibrated grains are likely not useful for magmatic interpretations, however comparison of grain bulk chemistries can still yield information about relationships of materials.

Perhaps the most striking feature of pyroxenes from the different domains is their similar chemistries. Major and minor elements cannot be used to distinguish pyroxene from one domain over another, and also do not provide strong insights into the crystallization sequence of their parent magmas. One group, the trachyandesite clasts, does suggest a co-crystallization of feldspar and pyroxene (or a post crystallization equilibration) based on the prevalence of the Ti-2Al substitution pair (Fig. 3). Several clasts and some pyroxene fragments likely come from a magma that did not crystallize high calcium pyroxene, as they have little Wo component and do not coexist with a high Ca pyroxene phase.

Pyroxene chemistries do not support a fractional crystallization relationship for either the clasts or matrix pyroxenes based on Cr abundances and major element contents. The similarities between the basaltic clast and trachyandesite clast pyroxenes suggest they originated from magmas with the same composition, possibly the same magma. A similar conclusion can be drawn for the basaltic clasts and a portion of the pyroxene fragments. Further study of trace elements within these different groups will improve the understanding of the relationships of these materials.

References: [1] Agee C.B. et al. (2013) *Science*, 339, 780-785. [2] Humayun M. et al. (2013) *Nature*, 503, 513-516. [3] Santos A.R. et al. (2013) *Meteoritics & Planetary Sci.*, 48, A306. [4] Pun A. and Papike J.J. (1996) *Am. Min.*, 81, 1438-1451. [5] Papike J.J., Fowler G.W., and Shearer C.K. (1994) *Am. Min.*, 79, 796-800. [6] Santos A.R. et al. (2013) *LPSC XLIV*, Abstract #2533. [7] Droop G.T.R. (1987) *Mineralogical Magazine*, 51, 431-435. [8] Papike J.J. et al. (2009) *GCA*, 73, 7443-7485. [9] Andersen D.J., Lindsley D.H., and Davidson P.M. (1993) *Computers & Geosciences*, 19, 1333-1350.