MONAZITE IN MARTIAN BRECCIA METEORITE NWA 7034. Yang Liu[1] and Chi Ma[2]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA. [2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA. (Email: yang.liu@jpl.nasa.gov)

Introduction: A new group of Martian meteorites reported recently consists of polymict breccias NWA 7034 and its pairings (NWA 7475, 7533, 7906, 7907, 8114) [1-2]. This new type contains Na- and K-rich feldspars [1-2], old zircons (4.428 Ga, [2]), and has mineral components that yield Amazonian ages [1-4]. Moreover, the bulk analysis of NWA 7034 also suggested that this sample is water rich (up to 6000 ppm). The step-heating released water at low T contains oxygen isotope compositions ($\Delta^{18}O$) similar to Martian meteorites [1, 5].

A section of NWA 7034 was kindly allocated by the Institute of Meteoritics, University of New Mexico. The preliminary results of D/H signatures of alteration products are reported in [6] and briefly summarized here. This abstract reports the first observation of monazite [(Y, REE)PO_4] in a lithic clast in NWA 7034.

Results:

Summary of Liu et al. [6]. The section studied contains impact melt, rock and mineral clasts as well as spherules. The spherules consist of pyroxene and Fe-Ti oxide (possibly ilmenite) in the interior, and a feldspar-like glass rim. Zoning in pyroxene within lithic clasts is not common, but was observed in two cases. A normal zoning from Mg-rich low-Ca pyroxene, to Fe--rich low-Ca pyroxene and then to high-Ca pyroxene at the rim, but the rim appears to be altered (Fig. 1). In another lithic clast, homogenous hedenburgite core was rimed by a diopside-rich pyroxene. Pyroxene fragments often contain exsolution lamellae of enstatite and augite compositions.

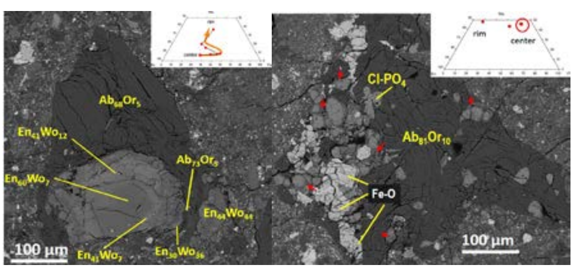

Figure 1. *BSE images of alteration and rims of pyroxene grains in two lithic clasts. Inset shows the zonation of pyroxene plotted in the pyroxene quadrilateral.*

Weathering features are widely dispersed in the section, in the form of weathering rinds around sulfides, alteration of oxides, around pyroxenes, near or inside spherules (Fig. 1-4). Preliminary results from the NanoSIMS imaging of these alteration products suggest they are depleted in D, unlike those measured in aeolian deposits in the in Gale crater that equilibrated with Martian atmosphere signatures (i.e., D/H = 5-7 × VSMOW [7]).

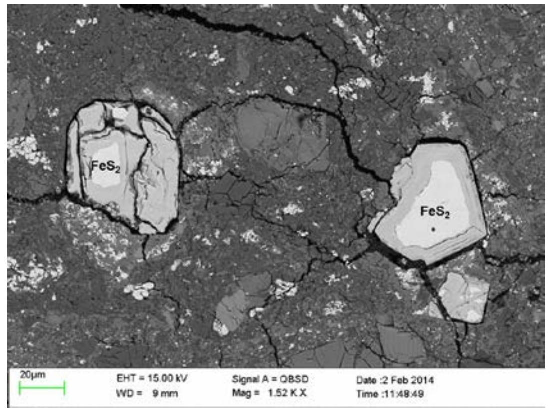

Figure 2. *BSE image of ferrihydrite mantling pyrite grains in the matrix of NWA 7034.*

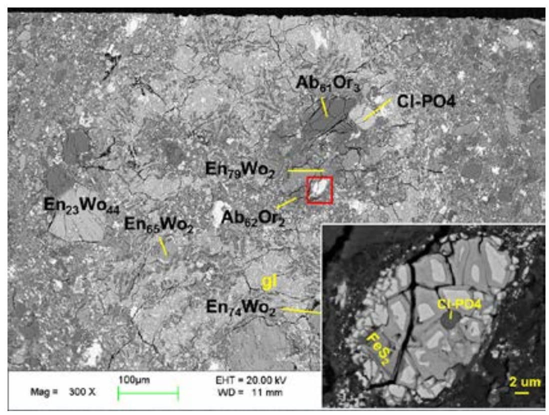

Figure 3. *BSE images of alteration of pyrite sitting in a lithic clast. Red square marks the position of the inset.*

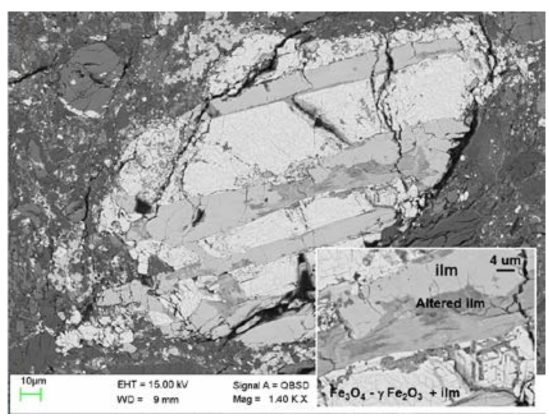

Figure 4. *BSE images of alteration of oxides in NWA 7034. The magnetite (Fe_3O_4) contains a minor amount of maghemite (γ-Fe_2O_3), and abundant ilmenite (ilm) exsolution.*

Monazite-bearing clast. NWA 7034 and pairs contain abundant zircon and baddelyite grains. In addition, in our section, we observed monazite grains in a lithic clast (Fig. 5). Owing to the small sizes, the compositions reported here were estimated based on SEM-EDS using factory internal standards and the XPP matrix correction procedure.

This clast dominantly consists of feldspar minerals, including plagioclase series of variable Na and K contents, which were intergrown with alkali-feldspar of compositions up to ~$Or_{75}Ab_{25}$. Augite (~$En_{50}Wo_{45}$) is next abundant mineral. Minor to trace minerals include apatite, magnetite (with ferrihydrite alteration), sulfide, and zircon. Major minerals suggest that the bulk SiO_2 composition of this clast would place it near the andesitic-dacitic boundary.

The monazite grain is located in a small region of ~30 μm by 30 μm. The larger grains are sitting in a fine mixture of silicate and tiny P-rich and REE rich minerals (also monazite?). The matrix near monazite sometime contains up to 1.3 wt% F. The mixture may be formed by immiscible liquids between a REE and P-rich liquid and a silicate-rich one, or by reaction of larger monazite with a silicate-rich fluid. EDS analysis of the monazite shows that its chemistry as: 3-4 wt% Y_2O_3, 3-4 wt% La_2O_3, ~24 wt% Ce_2O_3, 28-30 wt% Nd_2O_3, 2 wt% Sm_2O_3 with no detectable Th.

Implications: *This is the first report of monazite in Martian rocks*, and the 4th occurrence in lunar samples and meteorites. The three previous reports include: an inclusion in hedenburgite in Apollo 11 basalt 10047 [8], intergrown with whitlockite in Apollo 17 melt breccia 76503 [9], and in a howardite Yamato 7308 [10]. Compared to the monazite grains in NWA 7034, those in lunar rocks are higher in La_2O_3 (13-16.5 wt%) and Ce_2O_3 (27-30 wt%), but lower in Nd_2O_3 (12-15 wt%).

Monazite is generally found in granitic rocks or metapelites on Earth as an accessory mineral. The clast hosting this monazite in NWA 7034 is not highly silicic. The formation of monazite could resemble that in lunar rocks, as a very-late-stage mineral after extreme fractional crystallization [8-9, 11]. As suggested by Herd et al. [11], finding monazite offers a possible explanation for LREE depletion in shergottite. Or perhaps, the clast comes from a rock experienced metamorphism that induced monazite and the silicate-rich matrix.

References: [1] Agee C. B. et al. (2013) *Science*, *339*, 780-785. [2] Humayun M. et al. (2013) *Nature*, *503*, 513-516. [3] Yin, Q-Z. et al. (2014) 45th LPSC, #1320. [4] Tartese, R. et al. (2014) 45th LPSC, #2020. [5] Ziegler, K. et al. (2013) 44th LPSC, Abstract # 2639. [6] Liu, Y. et al. (2014) 45th LPSC, #2368. [7] Leshin L. A. et al. (2013) *Science*, 341, 1238937. [8] Lovering et al. (1974) EPSL 21, 164-168. [9] Jolliff, B. L. (1993), LPSC 24th, 72-726. [10] Yagi, K. et al. (1978) Meteoritics, 13, 23-45. [11] Herd, C. D. K. et al. (2004) AGU Spring meeting #P53A-07.

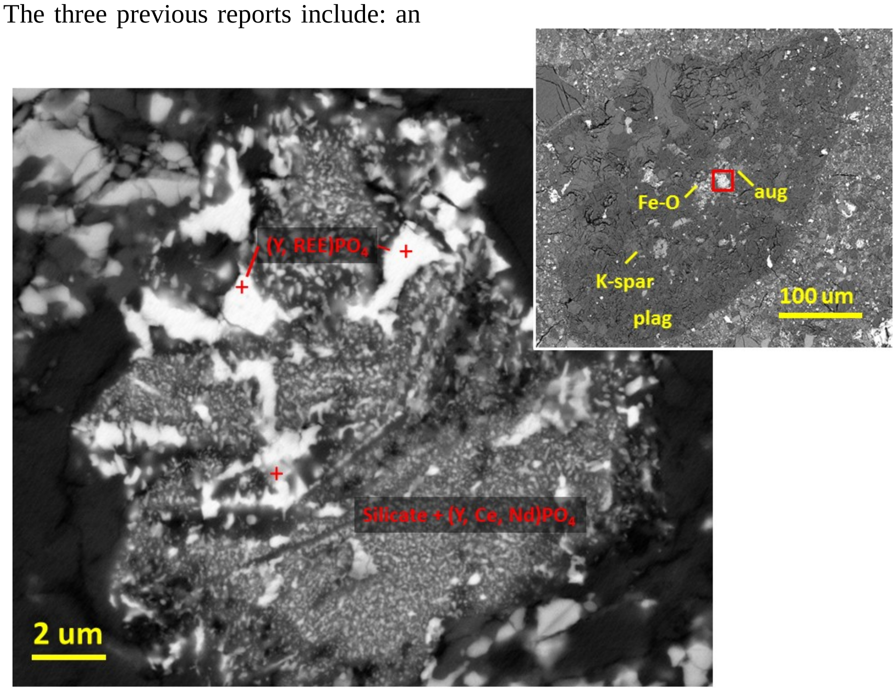

Figure 5. *BSE images of monazite-bearing clast in in NWA 7034. The inset shows the clast, and the red box marks the area containing monazite. Aug: augite; plag: plagioclase; K-spar: alkali feldspar; Fe-O: magnetite.*