MONAZITE, CHEVKINITE-PERRIERITE AND XENOTIME 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: Martian breccias NWA 7034 and its pairings (NWA 7475, 7533, 7906, 7907, 8114) are peculiar in many aspects. They consist mainly of Na- and K-rich feldspars and pyroxenes with minor magnetite (+ maghemite + rutile exsolution), pyrite, zircon and phosphates [1-6]. The U-Pb dates from zircon and apatite suggest a formation age of 4.428 Ga and a resetting age of ~1 Ga [2, 4]. Moreover, the bulk analysis of NWA 7034 also suggested that this sample is water rich (up to 6000 ppm) and the step-heating released water at low temperature contains oxygen isotope compositions similar to Martian meteorites [1, 6].

In the 8th International Mars Conference, we reported finding of monazite in NWA 7034, representing the first of such rare-earth minerals in a Martian rock [7]. In order to examine the textural association of monazite in NWA 7034, we examined 3 additional sections, 2 of which are from different pieces. During this search, we recognize the presence of xenotime, and chevkinite-perrierite group minerals in NWA 7034, in addition to the common occurrence of monazite in apatite. These first findings of rare-earth minerals in NWA 7034 suggest the presence of these minerals in Martian crust, either by formation in alkali-rich igneous systems or by hydrothermal activities. Both formational mechanisms on Earth involve water-rich fluids.

Results: Owing to the small sizes, the compositions reported here were estimated based on SEM-EDS measurements using Oxford internal standards and the XPP matrix correction procedure. Electron microprobe analysis of these minerals is on-going.

Monazite-(Ce), monazite-(Nd) and chevkinite-perrierite-(Nd)-bearing lithic clast (Fig. 1). This clast consists of feldspar minerals, including plagioclase series of variable Na contents, which inter-grow 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 and pyrite (with alterations), and zircon. The bulk SiO_2 content estimated from constituent minerals places this clast near the andesitic-dacitic boundary.

The monazite and chevkinite-perrierite grains occur in a small region (~10 µm by 10 µm), which consists of a few subhedral monazite and chevkinite-perrierite grains in a fine mixture of silicates and tiny P-rich and REE-rich minerals (also monazite?). The monazite contains 3-4 wt% Y_2O_3, 3-4 wt% La_2O_3, ~22 wt% Ce_2O_3, ~29 wt% Nd_2O_3, and 2 wt% Sm_2O_3 with no detectable Th. The chevkinite-perrierite grains are with ~4 wt% La_2O_3, >18 wt% Ce_2O_3, and >20 wt% Nd_2O_3.

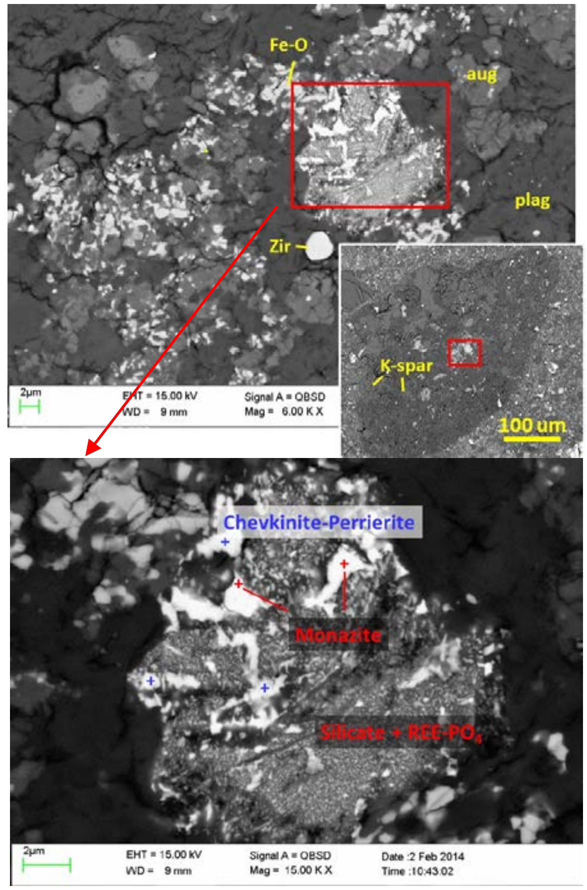

Figure 1. *A lithic clast in NWA 7034 with monazite-(Ce) & -(Nd) and chevkinite-perrierite-(Nd) grains. Aug: augite; plag: plagioclase; K-spar: alkali feldspar; FeO: magnetite.*

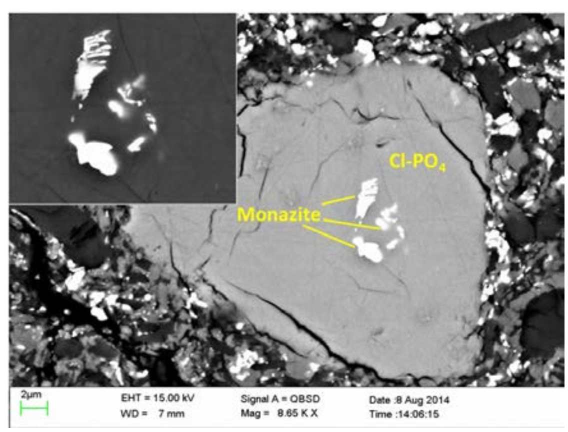

Figure 2. *Monazite-(Ce) inside a chlorapatite in NWA 7034.*

Monazite-(Ce) in apatite (Fig. 2). Monazite occurs as inclusions in chlorapatite grains (mono-mineralic clasts) in three sections investigated. Compared to monazite in **Fig. 1**, these monazite are more rich in Ce than Nd, and also contains more Y and La with Y_2O_3 (6-10 wt%) and La_2O_3 (7-11 wt%).

Xenotime(Y)-bearing lithic clast (Fig. 3). A few xenotime grains were observed in a clast that mainly consists of ilmenite and pyrite, which show significant alteration. The clast also contains abundant zircon grains. Xenotime was found along grain boundaries, and contains ~4 wt% of Gd_2O_3 and 5 wt% Dy_2O_3.

Previous occurrences in lunar rocks and meteorites: Combining with our report in the 8th International Mars conference [7], ***we present the first report of multiple rare earth minerals*** (monazite, xenotime, and chevkinite-perrierite) ***in a martian rock*** (NWA 7034). To date, monazite has only been observed in three occurrences: inclusion in hedenbergite in Apollo 11 basalt 10047 [8], intergrown with whitlockite in Apollo 17 melt breccia 76503 [9], and in a howardite Yamato 7308 [10]. Monazite composition in Yamato 7308 was not reported. 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%). Chevkinite-perrierite in NWA 7034 is the second such finding in addition to the report of Ce-rich ones in a lunar basalt [11]. However, xenotime in NWA 7034 is the first occurrence in extraterrestrial samples.

Implications: Monazite in NWA 7034 differs from terrestrial metamorphic ones in their lower La and higher Nd [12]. The higher Y and La contents in monazite inclusions in apatites are consistent with igneous monazite on Earth. However, a detailed compilation of terrestrial monazite chemistry, particularly those in more mafic rocks, is lacking [12-14].

The lithic clast with monazite-(Ce), monazite-(Nd) and chevkinite-perrierite-(Nd) in NWA 7034 differs from those in lunar samples. In lunar case, these minerals are the very-late-stage phases after the rock went through extreme crystallization. They are typically found in mesostasis with Fe-silicates, silica phases, and apatite. The lithic clast in NWA 7034 has at best a dacitic bulk composition, and does not contain silica phases or Fe-silicates as in lunar samples. Thus, the texture and composition of this clast suggests a possible fluid-induced formation.

The chemistry of xenotime in NWA 7034 is similar to metamorphic ones on Earth [12]. The appearance of xenotime and many small zircons in the ilmenite-pyrite-rich clast is also the most intriguing. This type of lithology is atypical for an igneous origin, but is possibly similar to hydrothermal deposits on Earth [13, 14].

In conclusion, NWA 7034 is a breccia representing martian crust [1-2], and the different textural associations of rare-earth minerals suggest diverse crustal environments on Mars, some of which may require a hydrothermal environment. As suggested by Herd et al. [15], finding monazite in a crustal sample offers a possible explanation for LREE depletion in shergottites.

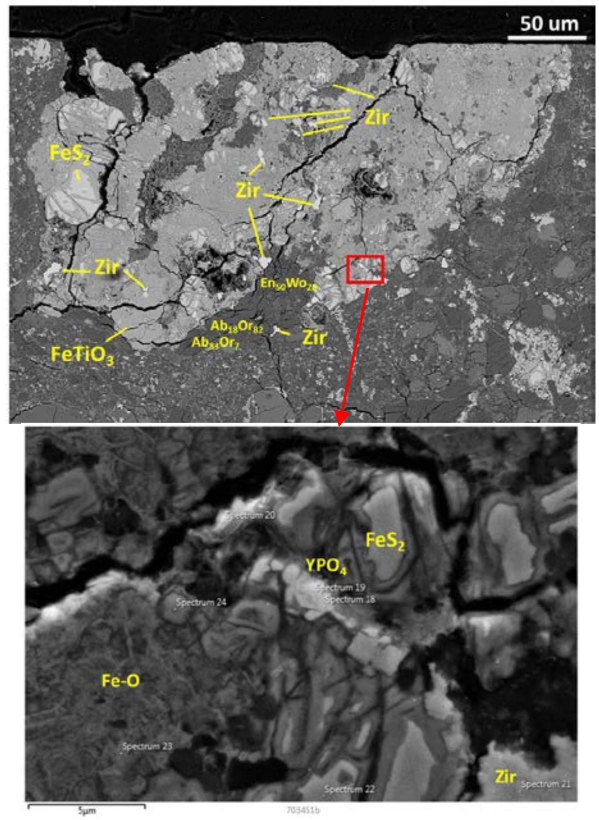

Figure 3. *Xenotime-(Y) in a clast in NWA 7034, consisting mainly of ilmenite and pyrite with extensive alteration to ferric oxide hydroxide. The clast also contains many small zircon (Zir) grains.*

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