BROWN AND CLEAR OLIVINE IN CHASSIGNITE NWA 2737: WATER AND DEFORMATION. A.H. Treiman[1], M. McCanta[1], M.D. Dyar[2], C.M. Pieters[3], T. Hiroi[3], M.D. Lane[4], and J.L. Bishop[5]. [1] Lunar & Planetary Institute, Houston TX, treiman@lpi.usra.edu. [2] Dept. Astronomy, Mount Holyoke College, South Hadley, MA. [3] Dept. Geological Sciences, Brown University, Providence, RI. [4] Planetary Science Institute, Tucson, AZ. [5] SETI Institute / NASA-Ames Research Center, Mountain View, CA.

Olivine in the NWA 2737 [1] chassignite is brown, with visually colorless (*vc*) lenses and ribbons of the same composition. *VC* olivine formed by deformation on [100]{021} and recrystallization. The brown color indicates the presence of Fe^{3+}, either in the olivine lattice or as submicron inclusions of magnetite. The Fe^{3+} probably represents loss of H^+ originally dissolved in the olivine, and suggests that NWA 2737 formed from a hydrous magma [2].

Petrography. NWA 2737 contains ~87% olivine (Mg#=78.3±0.4%), ~6% pyroxenes ($Wo_{39}En_{51}Fs_{10}$ (~15% of Fe is Fe^{3+}), $Wo_{06}En_{75}Fs_{19}$), ~3% chromite $(Fe^{2+}_{0.70}Mg_{0.29}Mn_{0.01})(Fe^{2+}_{0.05}Ti_{0.05}Fe^{3+}_{0.10}Al_{0.34}Cr_{1.46})O_4$. and ~4% others [1]. Alteration effects are limited to carbonate material on fractures and limited limonitic staining – there is no evidence that either is Martian.

Olivine in NWA 2737 is primarily brown or tan in thin section, not zoned in composition or color [3], and includes ribbons and lenses of *vc* olivine (Figs. 1,2). The brown color varies slightly in stripes on {010}, which are decorated with micron-scale opaque grains (Fig. 3). Brown and *vc* olivine have the same composition by EMP, but the latter is slightly darker in BSE imagery. Olivine grains with [100] perpendicular to the thin section plane show two sets of *vc* lenses at right angles to each other and symmetric to the grains' optical extinction directions (Fig. 2). This implies that the *vc* lenses follow {021} planes. Olivine grains with [100] near the thin section plane show interfingering bands and flame-shaped patches of *vc* olivine traversing the brown regions. So, *vc* olivine forms anastomosing ribbons with their lengths along [100] and their widths on {021} planes. If an olivine grain has an {021} plane near parallel to that of the thin section, it can appear all colorless or all brown. Micron-scale opaque grains, with reflectances and density consistent with magnetite or chromite, are concentrated at the edges of v-colorless olivine.

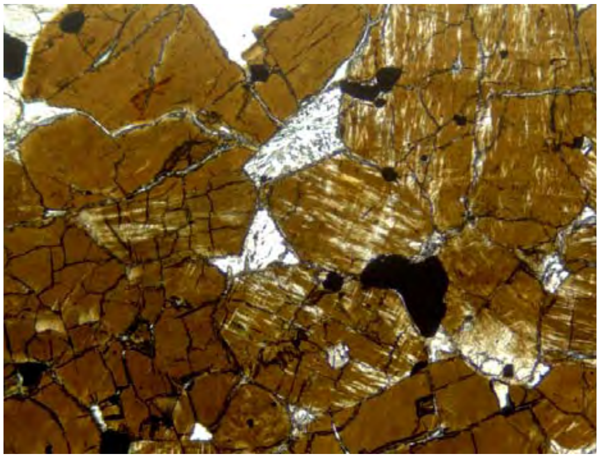
Fig. 1. NWA 2737, plane light, 1.2 mm across. Brown olivine with *vc* bands and stripes. Black is chromite.

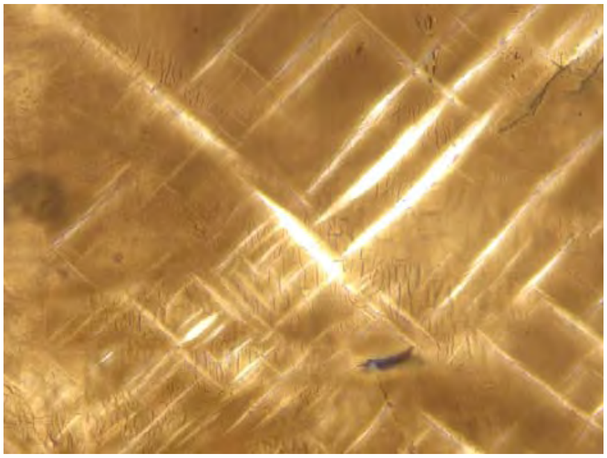
Fig. 2. Olivine viewed down [100], plane light, 0.29 mm across. Lenses of *vc* olivine along {021}. Small cracks, vertical and horizontal, are on {010} and {001}.

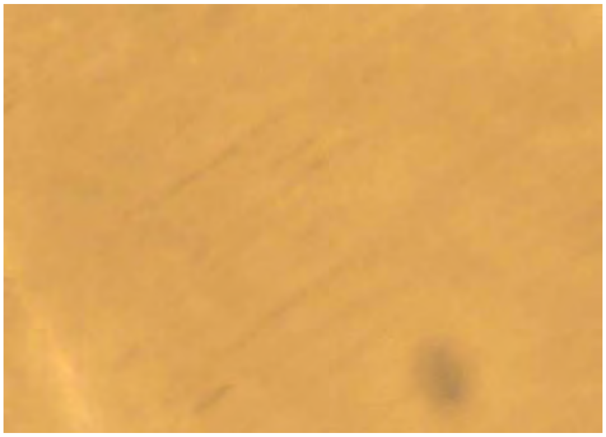
Fig. 3. Olivine viewed down [100], plane light, 0.06 mm across. Opaque dots are on {010} planes.

Equilibration. Two-pyroxene thermometry [4] gives T=~1150°C, similar to that for Chassigny [*5*]. Olivine-spinel Fe^{2+}-Mg exchange equilibria [6] give lower T: ~815°C for NWA 2737 and ~850°C for Chassigny (data of [7]).

Martian meteorites exhibit a range of oxidation states [8-10], which may be important in understanding the origin of the brown olivine. f_{O2} for NWA 2737, calculated from olivine, pyroxene, and chromite compositions, is ~QFM-0.75±0.5 log units [8,9], at the high end of the Martian meteorites' range, and like that of Chassigny (~QFM-1.25). Independently, analyses show the inferred Fe^{3+} content of the NWA 2737 augite and olivine (Mössbauer and EMP data) are similar to those in terrestrial mantle xenoliths equilibrated near or somewhat above the QMF buffer [11,12].

Visually Colorless (*vc*) Olivine. The origin of the *vc* olivine is constrained by its chemical composition and orientations in the host brown olivine. *VC* olivine has the same bulk chemical composition as the brown host olivine, which implies that the former did not arise by exsolution or other bulk chemical transformation. The differences in color and in BSE brightness may imply small chemical differences (e.g. Fe^{3+} content), undetectable by EMP. Thus, a physical transformation is implied. The orientations of the ribbons, on {021} planes and elongated on [100], are consistent with deformation on an easy slip system, [100]{021}, in olivine at high T (~1000°C) and low strain rates [13]. Also, the *vc* olivine consists of multiple subgrains, which is not expected of exsolution but is reasonable for recrystallization of deformed material.

The color stripes parallel to {010} probably also arose by deformation. The stripes' plane is that of the easiest high-temperature slip system in olivine, [100]{010} [13]. This orientation has not been reported for exsolutions or intercalations of other phases, such as laihunite or humite-group minerals.

Brown Olivine. Olivine dominates the EM spectral signatures of NWA 2737 [14], and its low reflectance and brown color (=red-sloped continuum) in visible wavelengths may be important for remote sensing of Mars. Thus, understanding why some olivine is brown and could provide compositional information for Mars and assist in identifying olivine on by remote sensing methods. Olivine in many Martian meteorites is brown or tan (ALHA 77005, LEW 88516, Y-793605, DaG476, NWA 1068, NWA 2046, SaU 005), and that color is attributed to Fe^{3+} in the olivine structure [15,16] or to sub-micron inclusions of magnetite [17-21]. Percent-levels of Fe^{3+} are not required to produce brown color – 10s of ppm may be sufficient [16].

The brown color (Fe^{3+}) of meteorite olivine is commonly attributed to shock [16,22]. Shock cannot be the sole explanation because some heavily shocked meteorites contain colorless olivine and unshocked Earth rocks can contain brown olivine [18-20,23]. Heat in an oxidizing environment is invoked to explain a brown color in terrestrial olivine [18-23]; in meteorite olivine, the heat could also derive from shock [3]. But heat alone does not make olivine brown, because olivine in most heated or metamorphosed rocks is not brown (e.g., [7]). Also, brown olivine in LEW88516 and ALHA77005 is recrystallized to *vc* near pockets of shock melt, which is ascribed to heat [22]. Nor is oxidation state by itself sufficient. Brown olivine is found in Martian meteorites equilibrated at oxidizing (near QFM; NWA 1068 [24]) and at reducing conditions (near IW; Dho 019, SaU 005 [9,25]).

A mechanism that satisfies these constraints is heat-induced loss of hydrogen from olivine, as suggested for brown olivine in mantle nodules [2,26]. Olivine can dissolve significant hydrogen, up to an equivalent of ~0.03 wt% H_2O in the Earth's mantle [27-29]. H^+ diffuses so quickly through olivine that it can be lost in a mild thermal event [29], and each H atom lost implies conversion of one Fe^{2+} to Fe^{3+}: $H^+_{olivine} + Fe^{2+}_{olivine} = \frac{1}{2}[H_2]_{gas} + Fe^{3+}_{olivine}$. For Earth mantle olivine, this yield of Fe^{3+} is ~1% molar of its total iron [2]. The Fe^{3+} in the olivine can remain in the lattice, charge-balanced by defects [2], or migrate to form crystalline inclusions of magnetite or magnesioferrite [19,30].

Conclusions. The brown color of olivine in NWA 2737 reflects the presence of Fe^{3+} that may have arisen from loss of originally dissolved H^+ (<0.03 wt% H_2O) [2,26]. If so, the NWA2737 parent magma was hydrous when the olivine crystallized. The brown colors of olivine in other Martian meteorites may also have formed in this process. It is not known yet if the Fe^{3+} in the NWA 2737 olivine is in the crystal lattice or sits in inclusions of magnetite – TEM studies in progress should answer this question. Understanding the brown color of the olivine is important for utilizing remotely sensed data from Mars [14] and in the search for parent craters for the Martian meteorites [31].

McCanta is a Urey Postdoctoral Fellow at the LPI. AHT's work is funded in part through the NAI-Ames. Supported also by grants NNG04GB53G, NNG04GG12G, and NAG5-12687, NAG5-12271 and NAG5-13279.

References. [1] Beck P. et al., 2006, *GCA* 70, in press. [2] Dyar, 2003, *Meteor. Planet. Sci., 38*, 1733. [3] Bauer, 1979, *Proc. Lunar Planet. Sci. Conf., X*, 2573. [4] Anderson et al., 1993, *Computers & Geosciences, 19*, 1333. [5] Wadhwa & Crozaz, 1995, *GCA 59*, 3629. [6] Sack & Ghiorso, 1991, *Am. Min. 76*, 827. [7] Floran et al., 1978, *GCA 42*, 1213. [8] Herd, 2003, *Met. Planet. Sci. 38*, 1793. [9] Goodrich et al., 2003, *Met. Planet. Sci* 38, 1773. [10] McCanta et al., 2004, *GCA 68*, 1943. [11] Dyar et al., 1989, *Am. Minl*., *74*, 969. [12] Dyar et al. 1992, GCA *56*, 2579 [13] Cordier, 2002, Ch. 6, p. 137-179 in *Plastic Deformation of Minerals and Rocks*, *Rev. Mineral. Geochem*., *51*. [14] Pieters et al. 2006. this volume. [15] Ostertag et al., 1984, E*PSL*, *67*, 162. [16] Burns, 1989, *Reports of Planetary Geology and Geophysics Program, 1988, NASA Technical Memorandum*, 211. [17] Puga et al., 1998, *Lunar Planet. Sci., XXIX*, Abstract #1375. [18] Ruiz-Cruz et al., 1999, *Amer. Mineral., 84*, 1915. [19] Puga et al., 2000, *Canadian Mineralogist, 38*, 1137. [20] Kurat et al., 1993, *Mineral. Petrol*., *48*, 309. [21] Kohlstedt & Vander Sande, 1975, *Contrib. Mineral. Petrol*., *53*, 13. [22] Treiman et al., 1994, *Meteoritics, 29*, 581. [23] Lopez et al., 2005, *Contrib. Mineral. Petrol*., *149*, 627. [24] Herd, 2006, *Amer. Mineral., 91*, in press. [25] Taylor et al., 2002, *Meteorit. Planet. Sci., 37*, 1107. [26] Dyar et al., 1996, p 273 in *Mineral Spectroscopy: A Tribute to Roger G. Burns*, Special Publication #5, The Geochemical Society. [27] Bell & Rossman, 1992, *Science, 255*, 1391. [28] Bai & Kohlstedt, 1992, *Nature, 357*, 672. [29] Mackwell & Kohlstedt, 1990, *JGR 95*, 5079. [30] Khisina et al., 1995, *Phys. Chem. Minerals, 22*, 241. [31] Harvey & Hamilton, 2005, *Meteorit. Planet. Sci., 40*, suppl. A64.