A NEW SUBGROUP OF AMPHIBOLE-BEARING R-CHONDRITES: EVIDENCE FROM THE NEW R-CHONDRITE MIL 11207. J. Gross[1], A.H. Treiman[2], H.C Connolly Jr.[1,3,4,5]; [1]American Museum of Natural History, New York, NY 10024; [2]Lunar and Planetary Institute, Houston TX 77058; [3]Dept. Phys. Sci., Kingsborough Community College CUNY, Brooklyn, NY 11235, USA. [4]Earth and Envi. Sci., CUNY Graduate Center, New York, NY 10016, USA. [5]Lunar and Planetary Laboratory, University of Arizona, 1629 E. University Ave., Tucson, AZ 85721, USA; (jgross@amnh.org).

Introduction: The newly recovered Miller Range 11207 (MIL 11207) meteorite is a shocked R-6 chondrite [1]. It is of significantly important because it contains ~10-15 volume% amphibole (edenite) and biotite – both water bearing minerals. This is the second R-chondrite reported to contain water-bearing minerals, the other being LAP 04840 [2]. However, MIL 11207 is petrologically distinct from the LAP 04840 pairing group [1], and thus elevates LAP 04840 from a unique oddball to the first find of a distinct sub-class or grouplet of chondrites. The importance of this grouplet lies in the elevated pressure of water vapor required to stabilize its amphibole and biotite [2]. For LAP 04840 calculated equilibrium water pressure is 250-600 bars [2]. This much lithostatic pressure suggests that the meteorite's parent body was large, more than a hundred km in radius [3]. Maintaining the vapor pressure at the above level requires that the parent body did not loose abundant gas to the surrounding ambient nebular gas, thus the surface was sealed against interplanetary space, most reasonably by a shell of ice or ice-filled regolith [3]. This has been suggested for Ceres and other ice-bearing asteroid [4].

Here we report mineralogy and petrography of MIL 11207 and discuss the implications of our results for the geological history of its parent body.

Method: MIL 11207 was studied by optical petrography, BSE and elemental mapping imagery, and by EMPA. Element maps were optained by the field emission SEM (7600F; NASA JSC). Mineral analyses were obtained using the electron microprobe (Cameca SX100) at the American Museum of Natural History, NY. Operating conditions were: 15kV accelerating voltage, 20nA beam current, focused beam for olivine, pyroxene, sulfides, and spinel, defocused beam (10 micron) for amphibole, biotite, and apatite. Apatite was analyzed using the protocol of [11]. Measurement times were 10-20s per element. Standards included well characterized natural and sythetic materials.

Sample: Compared to LAP 04840, MIL 11207 is finer grained and more altered (Fig. 1) as it contains more shock-melted sulfides, most of which are anoxidized intergrowths of pyrrhotite and pentlandite. MIL 11207 contains no metal, indicative of relatively high oxidation state similar to LAP 04840 [5]. Accessory chromite is present.

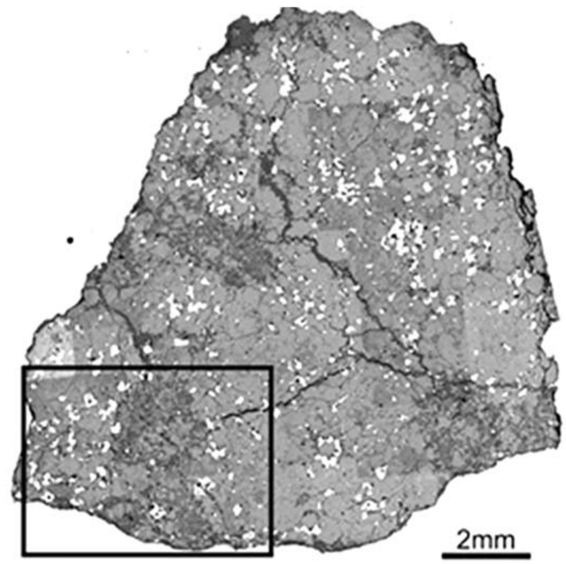

Fig. 1: Backscattered (BSE) mosaic of MIL11207,14. Black box shows the location of Figure 2. Most of the section is olivine; brighter grains are sulfides; darkest areas are mostly albite.

Mineralogy: The main mineral phases in MIL 11207 are (in decreasing order): olivine, sulfides, feldspar, augite, amphibole, apatite, biotite, and oxide.

Olivine: Olivine is the most abundant mineral and is homogeneous at Fo_{58-61}, with NiO ranging from 0.3-0.6wt%. Parts of the meteorite are dunitic, i.e. nearly all olivine (+ sulfides). The olivine grains are anhedral with straight boundaries and grain edge angles approximately 120º that suggests textural equilibrium.

Sulfides: Sulfides are present as pyrrhotite and pentlandite, as discrete grains and as intergrowths/exolutions. Some sulfide masses are spherical, suggesting they were once molten.

Feldspar: The feldspar in MIL 11207 is albitic in composition ($Or_{4-6}Ab_{83-87}An_{7-12}$) and chemically homogeneous. It contains rounded grains of all other minerals in a poikilitic texture (Fig. 2). In some areas, albite contains round or spherical void spaces like bubbles.

Pyroxene: MIL 11207 contains only clinopyroxene (augite to diopside) and it is homogeneous throughout the meteorite, $Wo_{46}En_{42-43}Fs_{11-12}$. The grains are poikilitic in texture and contain rounded grains of all other minerals except feldspar (Fig. 2).

Amphibole: The amphibole grains are brown and strongly pleochroic in polarized light. The amphibole is magnesian edenite [6,7] with average composition of $(Na_{0.6}K_{0.1})(Ca_{1.7}Na_{0.3})(Cr_{0.2}Ti_{0.2}Mg_{3.3}Fe_{1.3}Mn_{0.01})(Si_{6.6}Al_{1.4}Fe_{0.03})O_{22}(F_{0.01}Cl_{0.02}OH_{1.97})$. The grains are homogeneous in composition throughout the sample. The amphibole is hydroxyl rich with up to 0.02sfu F, 0.02sfu Cl, and 1.98sfu OH (by difference).

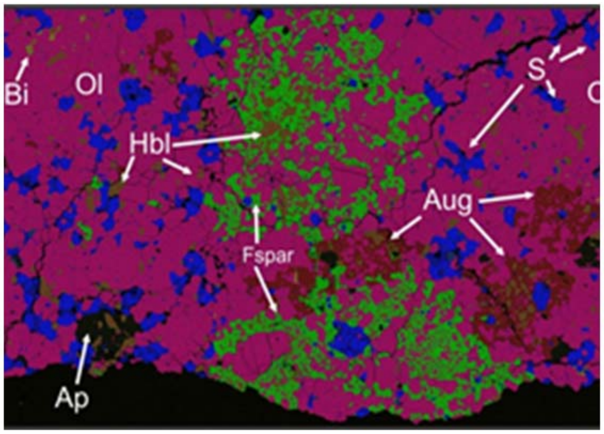

Fig. 2: X-ray element map of a portion of MIL11207,14 (see Fig. 1). Red=MgKα; green=AlKα; blue=FeKα. Ol=olivine (purple); S=sulfide (blue); Fspar=feldspar (bright green); Aug=augite (dark red); Hbl=hornblende (brown-green); Ap=apatite (black); Bi=biotite (olive-green).

Apatite: Apatite is abundant and forms large grains. It contains little substitution of S, Si, REE, etc. Water content of the apatite was determined indirectly from our EMP analyses of F and Cl, and the assumption of stoichiometry that F + Cl + OH = 1.00 structural formula unit (sfu) (see [8]). Apatite in MIL 11207 contains up to 0.14sfu F, 0.35sfu Cl, and up to 0.72sfu OH component.

Biotite: The biotite in MIL 11207 is phlogopite and is hydroxyl rich with 0.07sfu F, 0.02sfu Cl, and 3.91sfu OH (by difference). The calculated formula is $(K_{1.35}Na_{0.42})(Mg_{3.56}Fe_{1.7}Al_{0.4}Cr_{0.19}Ti_{0.25})(Al_{2.2}Si_{5.77})O_{20}(OH_{3.92}Cl_{0.02}F_{0.06})$. In most areas, material identified in x-ray maps as biotite is a symplectic intergrowth of olivine and feldspars (Fig. 3), though most of the symplectites are too small to be analysed.

Oxide: MIL 11207 contains chromite, $Chr_{73-77}Mt_{5-7}Sp_{11-12}Usp_{6-8}$. It is most commonly associated with Fe-Ni sulfides.

Discussion and Implications: MIL 11207 is distinct from LAP 04840, because it contains cpx but no opx, while LAP contains opx but no cpx. That means in general, the rocks must have had different opx:cpx ratios with respect to amphibole formation, as by 2diopside + 5enstatite +H_2O = tremolite + olivine.

However, MIL 11207 is similar to LAP 04840 in containing amphibole and biotite. The presence of these hydrous minerals makes MIL 11207 important as the second R-chondrite that contains water bearing minerals (besides apatite). These hydrous phases appear to have formed during a metamorphic episode whose conditions can be constrained via standard metamorphic facies analyses [9]. The temperature and partial pressure of water during equilibration are restricted by the absence of anothopyllite and the presence of phlogopite and feldspar (see [9]). MIL 11207 most likely was hydrated while hot, otherwise its original olivine and pyroxene would have been altered to serpentine, chloride, smectite etc. [e.g. 10].

However, the symplectic nature of the biotite-composition areas (Fig. 3) suggests decomposition via biotite ←→ olivine +Kspar + oxide + water. Similarly, amphibole shows alteration/reaction at grain boundaries with olivine, pyroxene, and feldspar, suggesting that both reactions happened in a secondary metamorphic event. Possible scenarios could include: 1) a catastrophic disruption and reaccreation of the parental body, retaining both heat but allowing dehydrogen, or 2) heating during the primary metamorphic event that overstepped the biotite stability field and possibly reached the limits of amphibole stability as well. Pressure and temperature calculations will shed light into the formation history of this interesting meteorite.

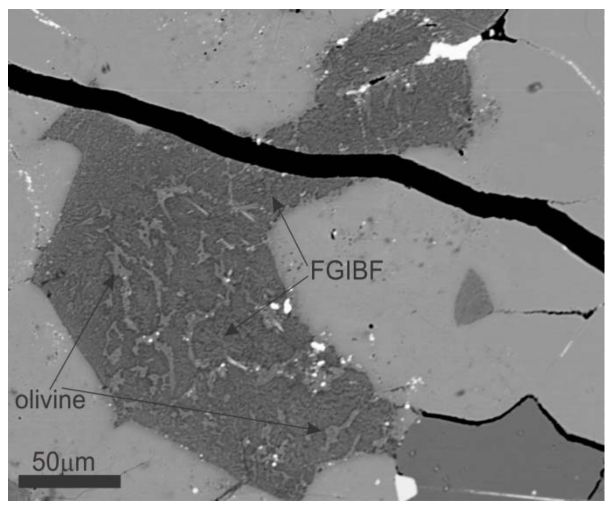

Fig. 3: BSE image of biotite, which seems to breakdown into olivine and a Fine Grained Intergrowth of Biotite and Feldspar (FGIBF).

References: [1] Antarctic meteorite Newsletter 35, No.2 (2012) http://curator.jsc.nasa.gov/antmet/; [2] McCanta et al. (2008) *GCA,* **72**; [3] Treiman & McCanta (2008) *73rd MetSoc meeting MAPS #5389*; [4] DuFresne & Anders (1962) *GCA* **26**; [5] McCanta et al. (2007), 38th *LPSC,* **2149**; [6] Leake et al. (1997) *Eur. J. Mineral*, **9**. [7] Hawthorne & Oberti (2007) *Rev. Min. Geochem*., **67**. [8] McCubbin et al. (2011), *GCA*, **75**. [9] Treiman et al. (2007) 38th *LPSC,* **1309**. [10] Brearley & Jones (1998) *Rev. Mineral.,* **36**, p191ff. [11] Goldoff et al. (2012) *Am. Min.,* **97**, 1103-1115.