THE OXYGEN ISOTOPIC COMPOSITION OF MIL 090001: A CR2 CHONDRITE WITH ABUNDANT REFRACTORY INCLUSIONS. L. P. Keller[1], K. D. McKeegan[2] and Z. D. Sharp[3]. [1]Robert M. Walker Laboratory for Space Science, Code KR, ARES, NASA/JSC, Houston, TX 77058 [2]IGPP, Dept. of Earth and Spce Sciences, UCLA, Los Angeles, CA 90095. [3]Dept. of Earth and Planetary Sciences, UNM, Albuquerque, NM 87131 (Lindsay.P.Keller@nasa.gov).

Introduction. MIL 090001 is a large (>6 kg) carbonaceous chondrite that was classified as a member of the CV reduced subgroup (CV_{red}) that was recovered during the 2009-2010 ANSMET field season [1]. Based on the abundance of refractory inclusions and the extent of aqueous alteration, Keller [2] suggested a CV2 classification. Here we report additional mineralogical and petrographic data for MIL 090001, its whole-rock oxygen isotopic composition and ion microprobe analyses of individual phases. The whole rock oxygen isotopic analyses show that MIL 090001 should be classified as a CR chondrite.

Methods and Samples. Two double polished thin sections (MIL 090001,10 and ,11) from two different chips (,7 and ,8) were examined using optical and electron microscopy. Backscattered electron imaging and elemental mapping were performed using a JEOL 7600F field-emission scanning electron microscope (SEM) equipped with a Noran Si drift detector. Quantitative analyses were obtained using a Cameca SX-100 electron microprobe operated at 15kV with a beam current of 12 nA and a 10 µm defocussed incident probe. We extracted FIB sections from one of the CAIs and from chondrule mesostasis. We obtained imaging, diffraction and chemical data from the microtome thin sections using the JSC JEOL 2500 field-emission STEM equipped with a Noran thin window energy-dispersive X-ray (EDX) spectrometer.

The whole rock oxygen isotope composition of the bulk chondrite was determined by a laser ablation technique using a Finnigan Mat Delta Plus XL mass spectrometer at UNM. Two separate fragments of the chondrite that each weighed approximately 2 mg were placed in nickel sample holders and oxygen was extracted by laser ablation in a BrF_5 atmosphere. Errors on individual measurements are ± 0.1 ‰ for $\delta^{17}O$, ± 0.1 ‰ for $\delta^{18}O$ and <0.05 ‰ for $\Delta^{17}O$.

Oxygen isotopes were measured on the UCLA Cameca ims-1270 ion microprobe using a primary Cs+ beam and negative secondary ions. Samples were sputtered with a primary beam of about 0.6 nA intensity and 20 keV impact energy focused to a 10-µm spot. A normal incident electron gun was used to compensate for sample charging. Oxygen isotopes were simultaneously measured on a multicollector using a Faraday cup (FC, ^{16}O) and an electron multiplier (EM, ^{17}O, ^{18}O) at a mass resolving power >5000 to resolve interference of ^{16}OH at mass 17. Instrumental mass fractionation was determined from San Carlos olivine, LP204 magnetite, Burma spinel, and NBS18 carbonatite. With these conditions, the precision on an individual measurement was in the range 0.2-0.5‰ and the reproducibility on $\delta^{18}O$ and $\delta^{17}O$ was around 1.3‰ and 1.5‰ (at 1σ), respectively.

Results and Discussion. The mineralogy and petrography of MIL 090001 were reported in [2]. Ca- and Al-rich inclusions (CAIs) are common and highly altered in MIL 090001, with residual spinel and perovskite surrounded by Al-rich chlorite and $CaCO_3$. This contrasts with other CR chondrites where CAIs are rare and unaltered [3]. The $CaCO_3$ occurs in aggregates with individual crystal sizes ranging from 5-30 µm. Electron diffraction data confirm that at least some of the carbonate is aragonite. We have not detected any dolomite or Mg-Fe carbonates to date. Amoeboid olivine aggregates (AOAs) are also common but not as heavily altered as the CAIs. The forsterite and spinel in AOAs have resisted alteration, but other phases have been replaced by aluminous phyllosilicates and $CaCO_3$. Chondrule mesostasis is also largely replaced with fibrous green to reddish-brown phyllosilicates and $CaCO_3$ grains with only a few remnant high Ca-pyroxene grains surviving. Aluminous chlorite predominates in altered chondrule mesostases and in CAIs and is more magnesian than the matrix phyllosilicates. Matrix phyllosilicates are a mixture of serpentine and chlorite, with serpentine more abundant than chlorite. Overall, the alteration assemblage of serpentine+chlorite+calcite+magnetite is very similar to that observed in other CR chondrites [4, 5] and we infer similar alteration conditions for MIL 090001.

The whole rock oxygen isotopic composition was obtained on two fragments of MIL 090001 (average of $\delta^{17}O$ = 0.65 ‰, $\delta^{18}O$ = 3.78 ‰) and plots on the CR mixing line defined by [6] and distinct from the CV chondrites. The CR chondrite mixing line reflects a trend from the least altered/isotopically light samples (QUE 99177 CR3.0) to the most altered/isotopically heavy rocks (GRO 95577 CR1). The whole-rock oxygen isotopic composition of MIL 090001 is consistent with the observed extent of aqueous alteration effects.

In situ oxygen isotopic analyses were obtained from spinel in CAIs, forsterite in chondrules, magnetite aggregates in matrix, and $CaCO_3$ in CAIs. The spinel and olivine analyses plot on or near the slope ~1 CCAM line (Fig. 1) and are consistent with previous analyses of CAIs and Fe-poor chondrules in CR chondrites [3, 7]. The carbonate compositions plot in two distinct regions (Fig. 2) which implies two episodes of $CaCO_3$ formation from two different fluids, or from one fluid that produced some carbonate and changed its isotopic composition by reaction with the rock and then precipitating a later generation of $CaCO_3$. The high $\delta^{18}O$ group of carbonates likely formed from the least isotopically evolved fluid phase. On the other hand, the lower $\delta^{18}O$ group plot on a common mass dependent fractionation line with the whole rock data and the magnetite analyses. This trend suggests a low formation temperature (~25˚C) for the low $\delta^{18}O$ $CaCO_3$ group from an isotopically evolved fluid similar to that postulated for the CM chondrites [8]. The oxygen isotopic range in the high $\delta^{18}O$ $CaCO_3$ group overlaps with the $CaCO_3$ analyses from the GRO 95577 CR1 chondrite [9] suggesting a common CR parent body fluid that was isotopically heavy.

Conclusions. The whole rock oxygen isotopic composition of MIL 090001 shows that it is a new member of the CR chondrite group. The formation of abundant phyllosilicates and carbonates resulting from low-temperature parent body fluid alteration of matrix and chondrules is consistent with petrographic grade 2. MIL 090001 is anomalous for a CR chondrite because of its high modal abundance of refractory inclusions compared to other members of the CR group.

References. [1] *Ant. Met. News Lett.* (2010) 33(2). [2] Keller, L. P. (2011) *LPSC XVII*, #2409. [3] Aléon, J. *et al.* (2002) *MAPS* 37, 1729. [4] Weisberg, M. K. *et al*. (1993) *GCA* 57, 1567. [5] Weisberg, M. K. and Huber, H. (2007) *MAPS* 42, 1495. [6] Schrader, D. S. *et al.* (2011) *GCA* 75, 308. [7] Krot, A. N. *et al*. (2006) *GCA* 70, 767. [8] Clayton, R. N and Mayeda, T. (1999) *GCA* 63, 2089. [9] Tyra, M. A. et al. (2011) *LPSC XVII*, #1639.

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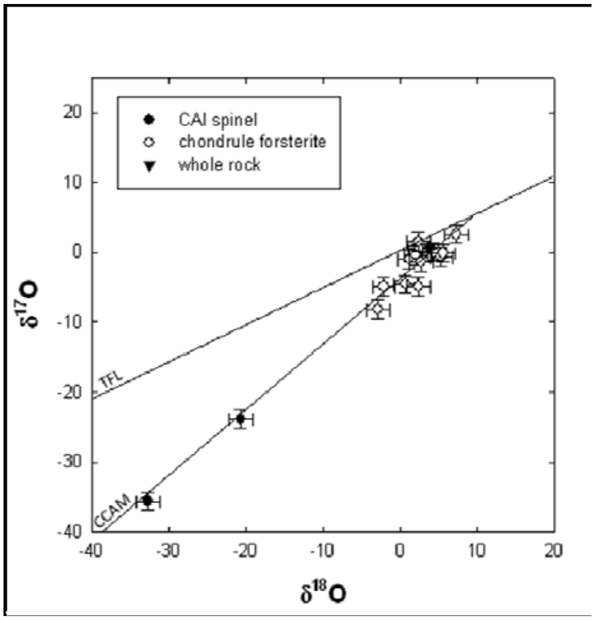

Figure 1. Oxygen isotopic compositions for spinel in CAIs and forsterite in Fe-poor chondrules. The terrestrial fractionation line (TFL) and the carbonaceous chondrite anhydrous minerals (CCAM) lines are from [8].

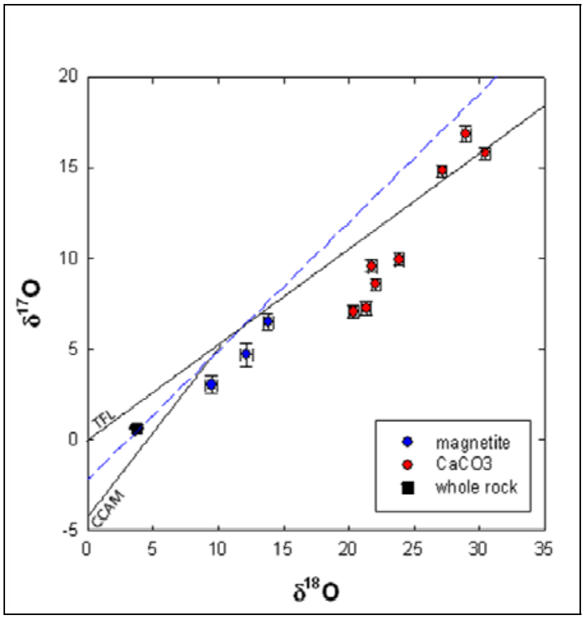

Figure 2. Oxygen isotopic compositions of $CaCO_3$, magnetite and whole rock data for MIL 090001. The blue dashed line is the CR whole rock mixing line from [6].