POTENTIAL DISCOVERY OF AMPHIBOLE IN MILLER RANGE (MIL) 090292 VIA RAMAN SPECTROSCOPY. M. G. Queener[1,2,3], N. G. Lunning[2], M. D. Fries[2], R. S. Jakubek[2,4], and A. H. Peslier[2,4]. [1]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907, USA, [2]Astromaterials Research and Exploration Science, NASA Johnson Space Center, 2101 NASA Pkwy, Houston, TX 77058, USA, [3]Universities Space Research Association, 7178 Columbia Gateway Dr, Columbia, MD 21046, USA, [4]Jacobs/JETS/UTC Aerospace Systems, 2101 NASA Pkwy, Houston, TX 77058,USA

Introduction: Ungrouped carbonaceous chondrites have the potential to provide insights into processes on their parent bodies that may not be accessible through studying established groups. Miller Range (MIL) 090292 is an extensively aqueously altered ungrouped carbonaceous chondrite [1], which provides the potential to reveal new information about alteration processes on carbonaceous chondrite-like asteroids.

The meteorite MIL 090292 was initially classified as a CR1 chondrite [2-3]. It experienced heavy aqueous alteration [2-4] and, texturally, the meteorite is highly brecciated [4]. MIL 090292 was reclassified as a C1 ungrouped chondrite [3] after it was found that the $\Delta^{17}O$ values of its magnetite grains do not plot along the CR mixing line [2-4]. Furthermore, there is a lack of calcium carbonate grains in the sample, which are common in aqueously altered CRs – calcium is found in andradite and hedenbergite (which are not found in CRs) and phosphates [4]. However, beyond this basic mineralogical information, there is a lack of knowledge about the petrogenetic history of the meteorite or its parent body.

Materials and Methods: The focus of this study is the thin section MIL 090292,17. This thin section was made from two separate small pieces from different parts of the meteorite (Figure 1).

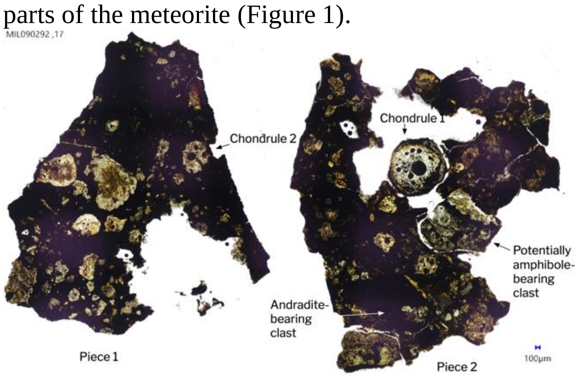

Figure 1. MIL 090292,17 under plane polarized light with features of interest annotated.

Raman spectrometry. UV resonance Raman spectroscopy was carried out on MIL 090292,17 in the WITec α300 R Raman spectrometer (XMB3000-3003) located at NASA Johnson Space Center. A 488 nm blue laser (WITec XSL3100-1155) and the mercury-argon lamp emission line method of calibration for long collection times [5] were used.

Electron microprobe analysis. Major and minor element composition data was collected for mineral grains in MIL 090292,17 using the CAMECA SX100 electron microprobe (EMP) at NASA Johnson Space Center.

Results: Several features of interest that are found in Piece 2 of MIL 090292,17 are Chondrule 1, which contains olivine, pyroxene, magnetite and Fe-Ni spherules (this is the only place that metal is found in MIL 090292,17), an andradite-bearing clast, and a potentially amphibole-bearing clast. Located in Piece 1 is Chondrule 2, which is primarily composed of pyroxene. Macromolecular carbon (MMC) content and Raman D-to-G band ratios, which show the degree of graphitization of the MMC associated with thermal alteration, are highly variable between clasts in Piece 2; while there are still some preserved MMC textures in Piece 1, its D-to-G band ratios are much more homogenized.

Matching the Raman data to the spectra in the CrystalSleuth software indicated that there was andradite in the sample, a fact which was confirmed with the EMP analysis. It also indicated that the matrix material might be lizardite and phillipsite, and that there was a piece of gypsum in Piece 1 of the sample, agreeing with a previous finding [4].

In Chondrule 1, there were two main types of pyroxene that were sampled – a low-Mn variety and a high-Mn variety, plus several pyroxene grains with anomalous compositions. The low-Mn pyroxene, as determined by EMP cation totals, has composition $En_{39}Wo_{49}$ and MnO content below the detection limit; the high-Mn pyroxene has composition $En_{39}Wo_{51}$ and MnO weight percent equal to 4.66%. Chondrule 2's pyroxene composition was found to be $En_{63}Wo_{36}$. The pyroxene in the andradite-bearing clast in Piece 2 has the composition $En_{47}Wo_{48}$, indicating that it is diopside (Figure 2). Note that these compositions are different from that of the hedenbergite previously described in the literature [4].

The andradite composition in Piece 2 was $Ca_{3.166}Fe_{2.290}Si_{3.305}O_{12}$; regarding the olivine in Piece 2, the average composition of that in Chondrule 1 was $Fo_{99.4}$. A grain in the potentially amphibole-bearing clast had composition $Fo_{99.5}$, meaning that both are forsterite.

Additionally, amphibole may have been found in one of the clasts in Piece 2. The CrystalSleuth spectra that fit its spectrum the best are gedrite, hastingsite, and arfvedsonite (Figure 3).

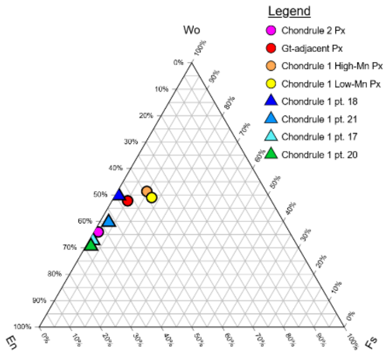

Figure 2. Ternary plot of selected pyroxene compositions in MIL 090292,17. Entire ternary plot included because the high-Mn pyroxene plots outside of the standard pyroxene quadrilateral.

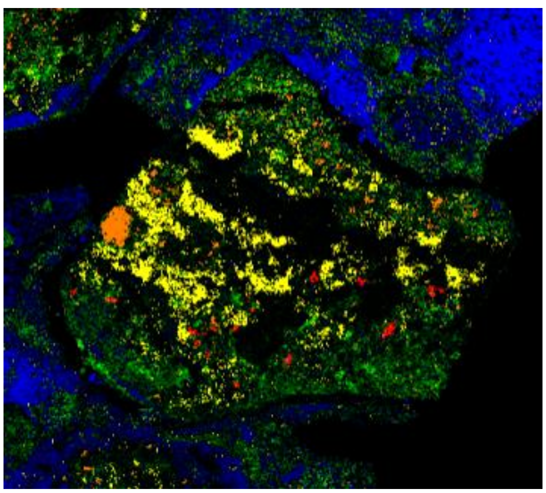

Figure 3. False-color mineral map of the potentially amphibole-bearing clast located in Piece 2 of MIL 090292,17 from Raman data. R = amphibole, G = phyllosilicate, B = carbon, O = olivine, Y = pyroxene.

Discussion: Piece 1 is characterized by homogenous D-to-G band ratios and MMC distribution, plus a lower abundance of phyllosilicates, which are primarily located in some of the chondrules, not in the matrix. Piece 2, on the other hand, is characterized by a variety of D-to-G band ratios (Figure 4) and MMC concentrations, an abundance of phyllosilicates in the matrix, and clasts containing relatively high-temperature secondary minerals (andradite and potentially amphibole). The distinct clast boundaries visible in the MMC Raman maps further support that this meteorite is brecciated, and the variation between the two pieces indicate that scale of breccia may be coarser than the areas of the two pieces sampled in MIL 090292,17. These two pieces exhibit different history and suggest the parent body underwent variable thermal and aqueous alteration conditions.

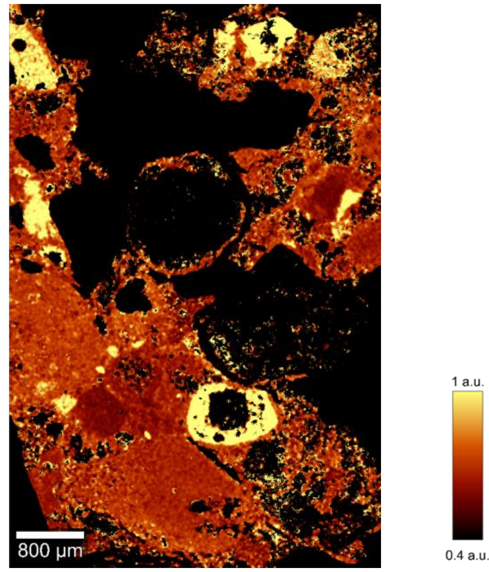

Figure 4. Raman D-to-G band intensity ratios in Piece 2 of MIL 090292,17.

The variability in the D-to-G band ratios visible in Figure 4 plus the presence of phyllosilicates in Piece 2's matrix indicate that this chip did not experience significant thermal alteration after lithification, since the D-to-G band ratios would have been homogenized and the phyllosilicates would be broken down if that were the case. However, the D-to-G band ratios and the homogenized distribution of MMC content in Piece 1 indicate that that fragment had been consistently heated.

Amphibole is a hydrous mineral and is extremely rare in carbonaceous chondrites [e.g., 6-7]. The fact that it may be in a single clast in MIL 090292 (Figure 3) suggests that the source parent body(ies) experienced a large range of aqueous and thermal alteration.

Conclusion: The D-to-G band and MMC variation between the individual clasts and the two pieces suggest that the components in MIL 090292 came from different parent bodies or a single asteroid which experienced a range of alteration environments. The occurrence of andradite and possibly amphibole in isolated clasts provide further evidence that MIL 090292 preserves a broad range of parent body alteration conditions.

References: [1] Righter K. et al. (2021) *8th ISAS Symposium of the Solar System Materials*, Abstract #S4-9. [2] Harju E. R. et al. (2014) *GCA*, 139, 267-292. [3] Schrader D. L. et al. (2014) *EPSL*, 407, 48-60. [4] Jilly-Rehak C. E. (2018) *GCA*, 222, 230-252. [5] Jakubek R. S., and Fries M. D. (2020) *J. Raman Spectrosc.*, 51, 1172-1185. [6] Hamilton V. E. et al. (2021) *Nat. Astron.*, 5, 350-355. [7] Abreu N. M. (2013) *GCA*, 105, 56-72.