SOLUBLE AMINES IN ANOMALOUS CR CHONDRITE MILLER RANGE (MIL) 090001. J. C. Aponte[1,2], N. M. Abreu[3], L. P. Keller[4], J. E. Elsila[2], and J. P. Dworkin[2]. [1]Catholic University of America, Washington, DC 20064, USA, e-mail: jose.c.aponte@nasa.gov. [2]Solar System Exploration Division, Code 691, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA. [3]Earth Science, Penn State University – DuBois, DuBois, PA, 15801, USA, e-mail: abreu@psu.edu. [4]ARES, Code XI3, NASA Johnson Space Center, Houston, TX 77058, USA.

Introduction: Carbonaceous chondrites (CCs) are unique natural samples that provide information about the available chemical inventory at the birth of the solar system and through its evolution in time. Among the most primitive samples studied to date are Renazzo-type (CR) CCs [e.g. 1-6]. CRs are generally richer in soluble organic compounds such as amino acids and amines than other CC groups [7, 8]. CRs record a range of asteroidal aqueous alteration features [e.g., 1-6]. Most CRs are classified as type 2, with moderate aqueous alteration. The least altered CRs have been argued to be to petrologic type 3 [5], whereas the CRs that record most extensive signs of aqueous alteration are type 1 [6]. However, except for impact-driven heating, CRs record minimal signs of thermal metamorphism [9].

Table 1. Abundance (nmol/g of meteorite) and $\delta^{13}C$ (‰VPDB) values of aliphatic amines in MIL 090001.

Aliphatic amine[a]	MIL 090001	
	[C]	$\delta^{13}C$
1- *tert*-Butylamine	1.1 ± 0.1	n.d.
2- Isopropylamine	24 ± 4	–19 ± 3
3- Methylamine	24 ± 3	–8 ± 6
4- Dimethylamine	< 0.01	–46 ± 9
5- Ethylamine	12 ± 1	–16 ± 9
6- *tert*-Pentylamine	0.5 ± 0.1	n.d.
7- Ethylmethylamine	2.2 ± 0.3	n.d.
8- (*R*)-*sec*-Butylamine	0.9 ± 0.1	n.d.
9- Diethylamine	0.13 ± 0.02	n.d.
10- (*S*)-*sec*-Butylamine	0.9 ± 0.1	n.d.
11- *n*-Propylamine	< 0.01	–31 ± 3
12- (*R*)-3-Methyl-2-butylamine	< 0.01	n.d.
13- Methylpropylamine	< 0.01	n.d.
14- Isobutylamine	< 0.01	n.d.
15- (*R*)-*sec*-Pentylamine	n.d.	n.d.
16- (*S*)-3-Methyl-2-butylamine	n.d.	n.d.
17- Ethylpropylamine	n.d.	n.d.
18- 3-Pentylamine	n.d.	n.d.
19- (*S*)-*sec*-Pentylamine	< 0.01	n.d.
20- *n*-Butylamine	0.8 ± 0.1	n.d.
21- (*R*,*S*)-2-Methylbutylamine	0.33 ± 0.03	n.d.
22- Isopentylamine	0.2 ± 0.1	n.d.
23- *n*-Pentylamine	0.18 ± 0.03	n.d.
24- Pyrrolidine	0.45 ± 0.05	n.d.
25- *n*-Hexylamine	0.05 ± 0.01	n.d.
Total Abundance	*67.8*	-

[a]Compounds were identified by comparison with elution time and mass spectra of standards. Values are the average of three measurements; errors shown are standard deviations.
n.d: Value could not be determined due to coelution or limited amount of sample.

The chemical and isotopic characteristics of Miller Range (MIL) 090001 have resulted in an evolving classification. MIL 090001 was initially classified as a reduced CV (CV_{red}) [10]. MIL 090001's classification was later revised to CV2, based on its: (1) high abundance of refractory inclusions (higher than for other CC groups, including the CRs) and (2) higher degree of aqueous alteration compared with other CVs [11]. Whole-rock O-isotope analyses however, showed that this meteorite belongs to the CR group [12]. The bulk composition of MIL 090001, including its Zn/Mn v. Sc/Mn ratios are consistent with classification as a CR [13]. The characteristics of MIL 090001 matrix are consistent with CR classification; namely, matrix contains amorphous Fe-Mg silicates, Fe(Ni)-sulfides, and secondary Fe-Mg phyllosilicates, tochilinite, and Ca-carbonates [2, 11]. However, this matrix mineral assemblage is not unique to CR matrices and has been identified in other primitive CCs, including CMs, COs, and ungrouped CC Acfer 094. Further, the textural characteristics of chondrules in MIL 090001 are unusual for both CV and CR groups. CR chondrites display a broad range of chondrule sizes extending from tens of microns to millimeters and show signs of deformation. In contrast, chondrules with large diameters (>1mm) are extremely rare in MIL 090001, which do not show signs of deformation. Chondrules in MIL 090001 are smaller than chondrules in CV or CRs, with diameters generally below 0.7 mm [2]. Therefore, we refer to MIL 090001 as an anomalous CR chondrite. In this study, we measure the abundance of aliphatic amines (Table 1) and place these observations in the context of the petrologic classification of MIL 090001 within the CR group.

Methodology: MIL 090001 (CR2, specific 41, parent 4; 5.717 g) was obtained from the Antarctic meteorite collection at the NASA Johnson Space Center. The sample, which did not show any visual evidence of fusion crust, was analyzed by gas chromatography mass-spectrometry after extraction, acid hydrolysis, and derivatization for chiral analysis using previously published methods [14].

Results and Discussion: We investigated a range of aliphatic amines in MIL 090001 (Table 1), finding lower concentrations and more depleted $\delta^{13}C$ values of amines with relation to those found in other CR2 chondrites [9] (Figure 1). The abundance and isotopic composition of amines that we found in MIL 090001, resonate with those previously found for aliphatic ami-

no acids [15]. The lower abundance and distinctive isotopic composition of amines and amino acids in MIL 090001 is not surprising, since these organic compounds may be synthetically related [8, 14], and thus, they both may have similarly been affected by processes occurred in the parent body.

It is unclear if the depletion of amines and their lower ^{13}C-content in MIL 090001 may be related to its unusual petrologic characteristics. TEM observations of MIL 090001 chondrules and matrix show that its asteroidal history is similar to that of other weakly altered CR chondrites, such GRA 95229 and LAP 02342 [3]. Compared with GRA 95229 and LAP 02342, MIL 090001 shows more aqueous alteration, as evidenced by the higher abundance of secondary matrix phases such as Fe-Mg phyllosilicates, tochilinite, and Ca-carbonates [2]. The distribution of Ni and Co in Fe-Ni metal showed that the thermal metamorphism of MIL 090001 is like that of weakly altered CRs [16]. Additionally, MIL 090001 shows no signs of shock or shock-related metamorphism, such as plastic deformation or the presence of high-pressure minerals. These observations may suggest that secondary processes were not responsible for amine depletions.

Conclusions: We investigated the abundance, molecular distribution, and ^{13}C-isotopic composition of aliphatic amines in MIL 090001. Our results show the presence of indigenous amines in concentrations that are about 30 times lower than those found for other CR2 meteorites, and isotopic compositions that seem unique for this CC. Further studies of these and other meteoritic organic compounds in this and other meteorites are needed to assess the relation between their organic content, mineralogy and processing histories.

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Figure 1. Total abundance of amines in acid-hydrolyzed hot water extracts of CI1, CM1/2, CM2, CR2, CO3, CV3, CK4, and CK5 carbonaceous chondrites (values taken from [17]). Meteorites are arranged according to their aqueous and thermal alteration [1, 9].