THE CLASSIFICATION OF CM AND CR CHONDRITES USING BULK H ABUNDANCES AND ISOTOPES. C. M. O'D. Alexander[1], R. Bowden[2], M.L. Fogel[2], K.T. Howard[3] and R.C. Greenwood[4]. [1]DTM, Carnegie Institution of Washington, Washington, DC 20015, USA (alexander@dtm.ciw.edu). [2]GL, Carnegie Institution of Washington, Washington, DC 20015, USA. [3]Mineralogy Dept., The Natural History Museum, London, SW7 5BD, UK. [4]PSSRI, Open University, Milton Keynes MK7 6AA, UK.

Introduction: The CM and CR chondrites exhibit wide ranges in the extent of aqueous alteration they experienced. Classification schemes for the CM and CR chondrites are primarily based on petrologic assessments of the extent of aqueous alteration. If the degree of aqueous alteration is the main determinant of petrologic type, there should be a simple relationship between bulk water/OH content and petrologic type. The phyllosilicates are not the only H-bearing components in these chondrites, the other being the organic material. The organics only contribute modestly to the bulk H budgets, but being very D-rich they are potentially much more important contributors to the bulk D. Thus, if the organic contents of CM or CR chondrites are fairly constant and the H isotopic compositions of the water and organics are quite different, one would expect correlated variations in H abundances and isotopes with degree of alteration. Here we explore whether bulk H abundances and isotopic compositions can be used to classify the petrologic types of CM and CR chondrites.

Experimental methods: To ensure representative sampling, where possible samples of ~1g were acquired. These included some falls and a large number of Antarctic finds. The bulk meteorite samples were crushed to <150 μm. Aliquots were stored in desiccators for days to weeks at room temperature to minimize adsorbed water contents. Prior to analysis, the samples were quickly transferred to an autosampler and flushed with dry He for 1-2 hours, again to minimize adsorbed water. The samples were analyzed by mass spectrometry as described in [1].

Results: As can be seen in Fig. 1, for most CMs there is an inverse correlation between H abundance and isotopic composition. This includes both falls and finds, suggesting that weathering has not significantly modified the bulk H abundances and isotopic compositions of the Antarctic finds. However, some meteorites scatter to lower H abundances. These include a few meteorites for which petrologic evidence for their having been heated, possibly by shocks, has been reported. Those that fall far from the main trend or have been reported to be heated are indicated by the "Heated" symbols. Those that lie between the heated samples and the main trend are indicated by the "Heated?" symbols.

Figs. 2 compares the bulk H isotopic compositions with the petrologic classification scale of [2] – from 2 for complete alteration to 3 for no alteration. There is a general positive correlation between classification number and H abundance, but the scatter is considerable. There is a much clearer negative correlation between classification number and bulk δD value. Similar behavior is seen if phyllosilicate abundance [3] rather than classification number is used.

Fig. 3 shows the bulk H abundances and isotopic compositions for a number of CR chondrites and two potentially related meteorites. With the exception of Al Rais, there is an overall inverse correlation between bulk H abundance and isotopic composition, just as in the CMs, although the number of more altered samples is very sparse. Included in the CRs are two shocked meteorites - GRA 06100 and GRO 03116. Unlike the heated CMs, these two meteorites are displaced to much lower δD values than the unshocked samples. Despite such low δD values, their petrology and high bulk δ^{15}N compositions (66 ‰ and 136 ‰, respectively) indicate that they are probably CRs. Two other meteorites, MIL 090001 and LEW 85332, are also included in Fig. 3. Both have high bulk δ^{15}N compositions (244‰ and 208‰, respectively), suggesting that they may be related to the CRs. For MIL 090001, a CR classification was confirmed by O isotope measurements of a sample washed in EATG to remove weathering products (δ^{17}O=-0.61±0.04‰ and δ^{18}O=2.03±0.08‰). However, if they are CRs their low δD values suggest that they have been heated/shocked.

Discussion: The CM results suggest that for these meteorites, bulk H abundances and isotopic compositions may be a quick and effective means of classifying them, both for extent of alteration and of heating. Somewhat surprisingly, H isotopes rather than abundances may be better for petrologic classification purposes. The reason for this may be illustrated by the results for two separate stones from the Bells fall. Generally, for paired samples and multiple samples of the same meteorite from different institutions, the H abundances and isotopic compositions are similar. However, for the two Bells stones there is a considerable difference between their H abundances, while their H isotopic compositions are very similar. It seems likely that the abundance of phyllosilicates can be heterogeneous even at the scales sampled here (typically ~1g), but that the H isotopes of the phyllosilicates are more or less equilibrated throughout.

In Fig. 2, there is an essentially linear correlation between classification number and bulk δD value. This means that it is straightforward to assign classification numbers to samples with bulk δD values that fall between those of the already petrologically classified samples. It also means that one can possibly extrapolate the classification somewhat to samples with more D-rich isotopic compositions. Based on our measurements, Bells and Essebi are the least altered CMs we have sampled. This is contrary to the classification scheme of [4], but both meteorites are highly brecciated and were altered under different conditions to other CMs [5], making their classification based on petrology more difficult.

For the CRs, there is no classification scheme similar to that for the CMs. Our results suggest that bulk H abundances and isotopes may be useful for their classification. However, sample heterogeneity may be even more problematic than for the CMs. [1] and [6] reported roughly a factor of two difference in insoluble organic matter (IOM) abundances between two quite large samples of GRO 95577. The compositions of the IOM from the two samples were very similar. The range of IOM abundances was attributed to differences in the abundances of matrix and dark inclusions between the two samples. Our Al Rais sample was relatively small and has about a factor of two more C than the other CRs measured here, including GRO 95577. It seems likely that the reason our Al Rais sample falls off the general unshocked CR trend is because it contained more matrix and/or dark inclusions than is typical for bulk CRs.

The CR results in particular point out that it is important to also measure bulk C contents when try to use bulk compositions for classification purposes. Plots of bulk C/H vs. δD [7] seem to be better behaved than H vs. δD. Ultimately, C/H ratios, rather than H abundances, in conjunction with δD may prove to be better tools for classification purposes.

Whether one uses H abundances, C/H ratios or δD values, most CRs exhibit a quite limited range of compositions. It has been suggested on petrologic grounds that QUE 99177 and MET 00426 have much less alteration than other CRs. Based on our results, these two meteorites are fairly typical CRs. It is possible that these meteorites are heterogeneous at the scale of a thin section and that the sections examined by [8] experienced anomalously little alteration. [9] have found evidence for phyllosilicates in other section of these meteorites. Alternatively, CRs generally contain similar amounts of water, but differ in the degree of crystallinity of the alteration products with the least crystalline samples appearing less altered.

References: [1] Alexander C. M. O'D. *et al.*, (2010) *GCA* **74**, 4417. [2] Rubin A. E. *et al.*, (2007) *GCA* **71**, 2361. [3] Howard K. T. *et al.*, (2011) *GCA* **75**, 2735. [4] Browning L. B. *et al.*, (1996) *GCA* **60**, 2621. [5] Brearley A. J., (1995) *GCA* **59**, 2291. [6] Alexander C. M. O'D. *et al.*, (2007) *GCA* **71**, 4380. [7] Alexander C. M. O'D. *et al.*, (2012) *Lunar Planet. Sci.* **43**, #1929. [8] Abreu N. M., Brearley A. J., (2010) *GCA* **74**, 1146. [9] Bonal L. *et al.*, (2011) *Lunar Planet. Sci.* **42**, #1287.

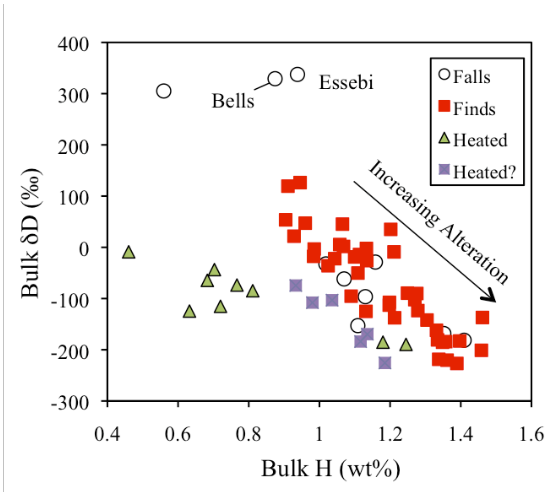

Figure 1. The bulk compositions of CMs.

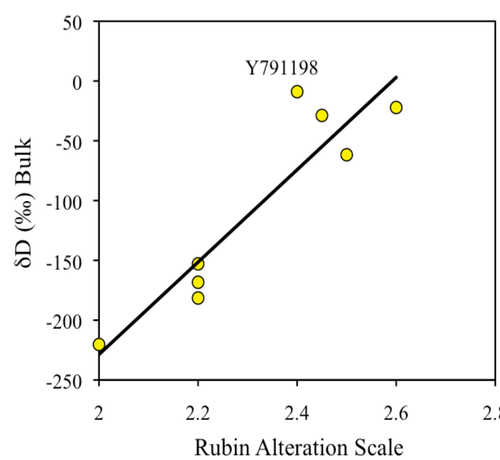

Figure 2. Bulk δD values vs. alteration scale of [2].

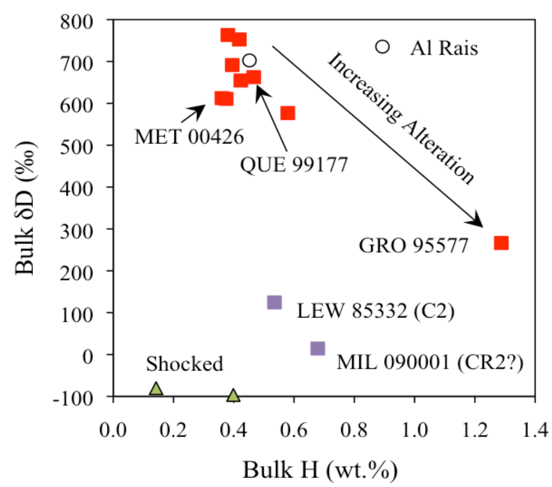

Figure 3. The bulk compositions of CRs.