A NEW CLASSIFICATION SCHEME FOR AQUEOUSLY ALTERED CARBONACEOUS CHONDRITES BASED ON TOTAL PHYLLOSILICATE ABUNDANCE. K. T. Howard[123] & C.M.O.'D Alexander[4] [1]Kingsborough Community College of the City University of New York. [2]American Museum of Natural History. [3]The Natural History Museum, London. 4. Department of Terrestrial Magnetism, Carnegie Institute of Washington. Email: kieren.howard@kbcc.cuny.edu

Introduction: The original classification scheme [1] for carbonaceous chondrites (CCs) assigned type 3 to a sample that is completely unmodified by parent body processes (other than lithification). Decreasing petrologic types from 3 to 1 indicates increasing degrees of aqueous alteration. Conversely, increasing petrologic types from 3 to 6 indicates increasing thermal metamorphism.

The original scheme is relatively coarse in classification of aqueously altered meteorites. Effectively, samples in which chondrules are at least partially preserved are type 2, and samples where chondrules are pervasively altered are type 1. For comparisons with other chemical and isotopic parameters, which are likely to be very sensitive indicators of parent body conditions, it is desirable to have a higher resolution classification scheme. In the largest group of aqueously altered CCs, the CMs, there have been two attempts to provide higher resolution classification schemes [2,3]. Both of these approaches rely on multiple petrographic and geochemical parameters as proxies for relative degrees of alteration. Where the same samples are studied, these two schemes are broadly consistent with each other and this is not surprising since they use similar approaches. A higher resolution classification scheme for CRs is currently lacking. CIs are all type 1 and no further attempts have been made at subdividing this small group that are considered nearly fully hydrated.

The classification of meteorites is usually carried out by optical microscopy and Scanning Electron Microscopy (SEM) - requiring sections. It is hard to distinguish between altered and unaltered fine grained matrices optically, and as a result meteorites may be classified as aqueously altered type 2, despite Transmissin Electron Microscope (TEM) revealing the fine grained materials to be anhydrous (e.g. MET00426 and QUE99177 that were reclassified from 2 to 3 by [4]). Underestimation of hydration also occurs by SEM, where early stage fluid attack is cryptic/topotactic and only evident by TEM [5].

Higher resolution sub-classifications are even more complex and typically use multi-parameter studies, requiring multiple assumptions in selection of proxies for aqueous alteration [2,3]. Irrespective of the validity of assumptions made, the fact that only 14 samples have ever been classified using either of these schemes [2,3] is evidence that their application is difficult. Here we suggest a new scheme that can facilitate rapid classification of larger numbers of samples.

Classification of aqueously altered CCs by total phyllosilicate abundance: The primary manifestation of aqueous alteration is the production of phyllosilicates, predominantly from the serpentine family of minerals. If the rationale for assigning a petrographic subtype is to define the relative degree of hydration, then total phyllosilicate abundance is an assumption-free indicator. In keeping with the traditional 1-6 scheme [1], we propose to rank aqueously altered samples between type 3.0 and 1.0. Classification as type 3.0 is for a completely anhydrous sample (0% phyllosilicate) and type 1.0 a completely hydrous sample (100% phyllosilicate). A sample of type 2.0 contains 50% phyllosilicate (i.e. the subtypes are divided in increments of 5% phyllosilicate). On this scale any CC that has been aqueously altered can be placed, regardless of the group to which it is assigned (and including ungrouped/anomalous samples), meaning inter group comparisons of the degree of hydration are possible. Our classification does not imply a genetic relationship between samples, we are simply measuring the volume of phyllosilicate, so a type 1.4 was not necessarily evolved from a type 1.5 by progressive alteration as implied by other schemes [2,3].

Samples and methods: We determine mineral abundances for phases >1 wt.% by Position Sensitive Detector X-ray Diffraction (PSD-XRD) and a pattern stripping technique [6]. Here we have applied this approach to determine the phyllosilicate abundances and classifications of more than than 40 aqueously altered CCs (finds and falls) from the CR, CM, and CI groups, as well as C2ungrouped samples.

Resulting classifications: In bulk PSD-XRD patterns, the mineralogy of the phyllosilicates observed differ significantly between the CC groups. High intensity diffraction peaks from well-crystalline serpentines dominate CM patterns. In many CRs, diffraction from phyllosilicate is severely limited, but large contributions to PSD-XRD patterns from Fe-rich amorphous materials are evident. In PSD-XRD patterns for CI samples, evidence for decreasing grainsizes, increasing structural complexities in phyllosilicates and increasing saponite contributions are observed. These differences between groups are probably reflecting very different histories of interactions between anhydrous components and H_2O. However, total abundance of phyllosilicate still provides an unambiguous indicator of the degree of bulk hydration of the sample and its parent body.

Based on resolvable phyllosilicate abundances, CRs define a range in petrographic sub-types from 3-1.7 - the type CR Al Rais, is a type 1.9 and much more altered than all other CRs except for GRO95777 which is type 1.7. CMs define a range in relative hydration from petrographic sub-type 1.8 – 1.3. The type member for the group, Mighei, is a type 1.5. CI we have studied are all type 1.2, but note that these still contain anhydrous components (<10%).

Caveats: GRO95777 was classified as a CR1 previously and is regarded as much more altered than Al-rais [7], yet on our scheme they are ranked more closely. GRO95777 contains anomalously abundant Fe-oxide, so we have probably underestimated its degree of hydration when using total phyllosilicate abundances alone. This indicates that caution must be used if applying this approach to very oxidized samples. Similarly, samples that have been subjected to heating must be treated with caution, since thermal processing may have destroyed phyllosilicates and evidence for fluid action. However, it is inherent to 1-6 schemes that samples subjected to both thermal metamorphism and aqueous processes will be hard to classify.

Wider application of our scheme using other analytical approaches: PSD-XRD is an approach that is routinely applied to phase quantification of CCs in only one lab (at The Natural History Museum in London). However, we have shown that our mineral abundance data correlates with multiple independent (destructive and non-destructive) approaches that can be applied to sample powders without the need for time-consuming preparation of sections. For example, phyllosilicate abundances correlate well with bulk OH contents [8]. Infrared (IR) spectra also correlate with PSD-XRD determinations of phyllosilicate contents [9,10]. This means that any of these approaches can be applied independently to classify samples with confidence. Importantly, the spectrographic techniques can be applied remotely to asteroids.

Conclusion: Total phyllosilicate abundance provides an assumption-free way of classifying aqueously altered CCs that can be applied to any powdered sample. This parameter can be quantified by PSD-XRD and estimated by multiple independent parameters. This allows subdivision of the traditional 1-3 scheme, improving its resolution. Between the CC groups studied, the range in petrographic sub-types shows little overlap. CRs are systematically the least aqueously altered CCs.

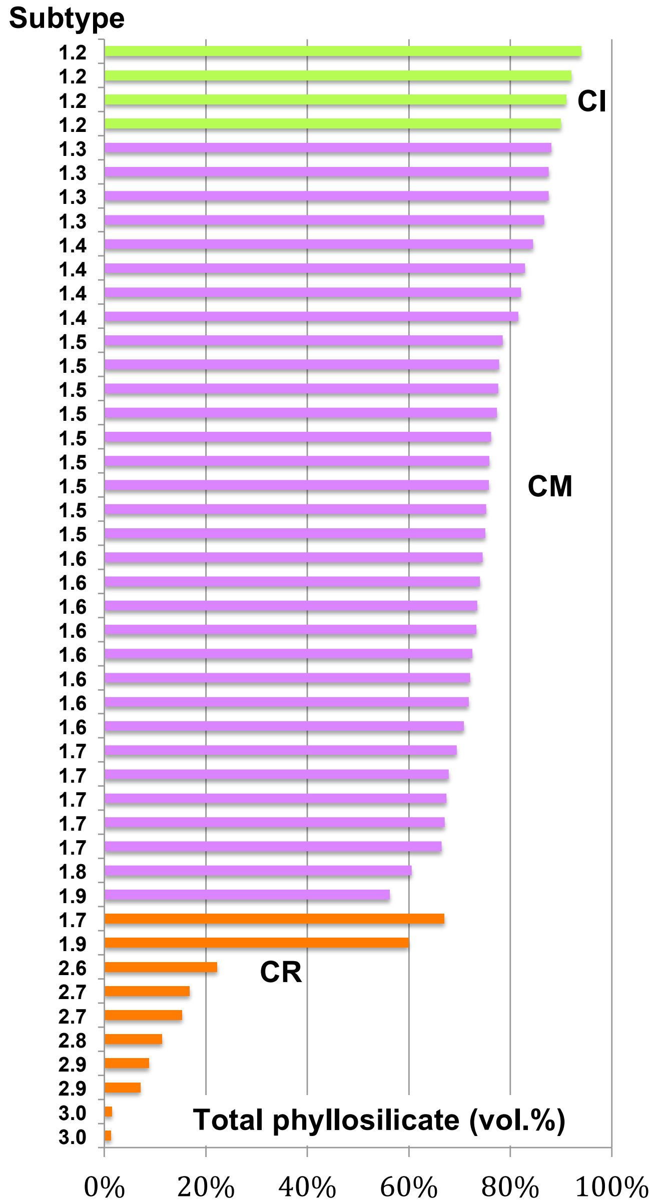

Fig. 1. Classification of CCs using total phyllosilicate abundances. Each step between subtypes corresponds to 5% phyllosilicate.

References: [1] Van Schmus W.R. & Wood J.A. (1967) *GCA*, 31, 747-765. [2] Browning L. et al. (1996) *GCA,* 60, 2621-2633. [3] Rubin A.E. et al. (2007) *GCA,* 71, 2361-2382. [4] Abreau N.M. & Brearley A.J. (2010). *GCA*, 74, 1146-1171. [5] Eggleton R.A. (1984) *Clays Clay Miner*. 32, 1-11. [6] Howard K.T. et al. (2011) *GCA,* 75, 2735-2751. [7] Weisberg M.K. & Huber H. (2007) *MAPS*, 42, 1495-1503. [8] Alexander C. et al. (2012), *submitted.* [9] Beck P. et al. (2010) *GCA,* 74, 4881-4892. [10] McAdam M. et al. (2013) *LPSC 44*, in press.