

THE MOSS (CO3) METEORITE: AN INTEGRATED ISOTOPIC, ORGANIC AND MINERALOGICAL

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Introduction: Following a bright fireball and a loud explosion the Moss meteorite fell on 14 July 2006 at approximately 10:20am in the Moss-Rygge area on the east side of Oslofjord [1]. 5 stones were subsequently recovered with a total mass of nearly 4 kg [1]. Petrography, mineralogy and oxygen isotope analysis confirm that Moss is a carbonaceous chondrite of the Ornans group (CO3) [1].

Ornans-type chondrites are a distinct group with a characteristic texture consisting of a high density of small (0.2 – 0.5 mm) chondrules, inclusions and lithic fragments enclosed by a dark matrix. They also have a significantly lower matrix to chondrule ratio than other carbonaceous chondrites [2, 3]. As a consequence of this textural coherence, CO3 chondrites are thought to represent samples from a single asteroid. Unique among the carbonaceous chondrites, the Ornans group show textural, mineralogical and isotopic evidence for a metamorphic series analogous to that seen in the ordinary chondrites [4, 5, 6, 7]. In discussing the metamorphic grade of CO3 chondrites the scheme of [5] is used throughout.

Moss is only the sixth fall in the CO3 group and the first since Kainsaz in 1937. In view of the importance of the Ornans group in understanding early Solar System processes, an integrated study of Moss has been undertaken to investigate further the metamorphic conditions that prevailed on the CO3 parent asteroid.

Analytical techniques: Mineral analyses were undertaken using a Quanta 200 FIB-SEM and a Cameca SX-50 WDS microprobe operated at 20kV and 2nA. Oxygen isotope analyses were performed by infrared laser-assisted fluorination [7]. C, N, and Ar isotopes were analyzed by stepped combustion using the Finesse fully automated mass spectrometer [8]. Organic analysis was undertaken using a Pegasus 4D (GCxGC) TOFMS (LECO Corporation) fitted with a Pyrola 2000 (Pyrolab, Sweden) for pyrolysis under the conditions described in [9].

Results: Petrography and mineral analysis: The results of petrographic studies confirm the classification of Moss as 3.4/3.5 [5]. Fe-Mg zoning profiles in type 1A chondrule olivines suggest that Moss is closest to 3.5 in grade.

Oxygen isotopes: Analysis of two replicates gave the following whole-rock oxygen isotope composition for Moss: $\delta^{17}\text{O} = -5.90\text{‰} \pm 0.08$, $\delta^{18}\text{O} = -2.21\text{‰} \pm 0.07$, $\Delta^{17}\text{O} = -4.75\text{‰} \pm 0.04$ (errors = 1σ). On an

oxygen three-isotope diagram (Fig.1) previously analyzed CO3 falls plot as a tight central cluster with CO3 finds on either side [7]. The oxygen isotope analysis for Moss plots within this central cluster and hence confirms it as being a CO3 chondrite.

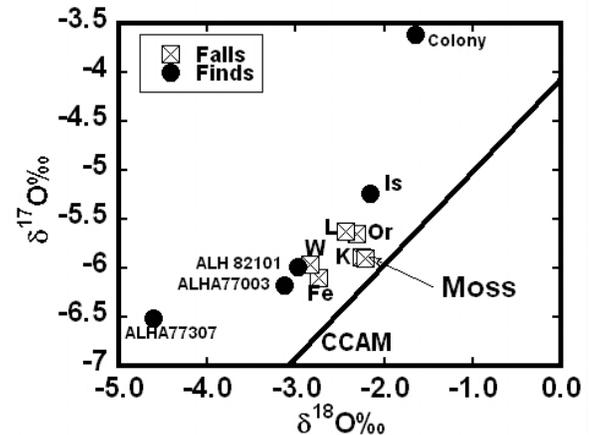


Fig. 1 Oxygen three isotope plot for CO3 chondrites. CCAM = carbonaceous chondrite anhydrous mineral line of [10]. Symbols: Is: Isna; Or: Ornans; L: Lancé; K: Kainsaz; W: Warrenton; Fe: Felix

The trend of increasing $\Delta^{17}\text{O}$ values with increasing metamorphic grade seen in the data of [10] is not consistent with the more recent data for Warrenton (3.6) [7] and the analysis of Moss presented here (Fig. 2).

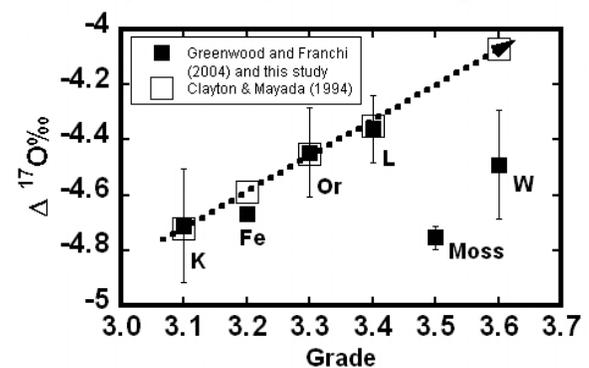


Fig.2 Metamorphic grade against $\Delta^{17}\text{O}$. (errors 1σ)

Carbon, Nitrogen and Argon: C, N and Ar data were obtained by simultaneous stepped combustion. The total integrated concentration of C in Moss is 0.25 wt% with a bulk $\delta^{13}\text{C}$ value of -7.7‰ . In comparison with the other CO3 falls [7, 11, 12] Moss has a low C content and in this respect resembles Ornans. The

bulk $\delta^{13}\text{C}$ value of Moss is anomalously heavy compared to other CO3s and further work is in progress to investigate this feature. The total integrated N is 10 ppm with a bulk $\delta^{15}\text{N}$ of -46.6‰. Nitrogen generally has a light isotopic signature with two $\delta^{15}\text{N}$ minima at 800°C and 1100°C (-90 and -150‰ respectively). These exactly correspond to the peaks of ^{36}Ar release (Fig. 3), which also has a bimodal release profile. Additionally, Fig. 3 indicates that most carbon is decoupled from N and ^{36}Ar . The nitrogen isotope profiles have been observed before for other CO meteorites [12] and attributed to the presence of nanodiamonds. However, the amounts of ^{36}Ar associated with the release of light nitrogen are too high to be related to nanodiamonds. Therefore, most of the ^{36}Ar appears to represent the planetary component associated with Q. If the N is largely from nanodiamond, then interesting questions arise: why are Q and nanodiamonds released at the same time and why does this happen in two distinct temperature intervals? Obviously such behavior characterizes Q as a separate phase and sheds light on its chemical nature.

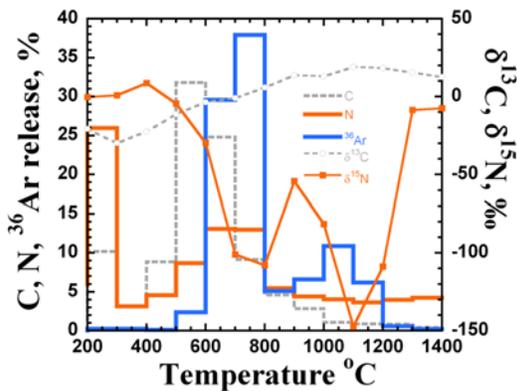


Fig. 3. Stepped combustion results of the Moss whole rock sample.

Organic analysis: Several powdered samples of Moss were analysed, yet only one yielded any appreciable organic components, suggesting that organic materials are either heterogeneously distributed throughout the sample, or that Moss contains a highly condensed organic structure not readily amenable to pyrolytic breakdown. The 2-ring aromatic compound naphthalene is the highest molecular weight component detected and alkylated species are rare. Such a condensed organic network is not unexpected in light of the CO3 group's metamorphic history. However, when considering the defined metamorphic sequence [5] and Moss' classification as a CO3.4/5 [1], when compared with other CO3 chondrites of similar or greater metamorphic grade, Moss presents an unusual

organic inventory akin to the geochemically anomalous Ornans. Detailed organic analysis of the Moss meteorite compared with other CO3 falls is presented in a companion paper to this [9].

Discussion: On the basis of its petrology and oxygen isotope composition Moss is clearly a relatively high grade (3.4/3.5) member of the CO3 chondrites. However, its bulk $\delta^{13}\text{C}$ is significantly heavier than any other member of the CO3 group and it does not fit into the previously defined group trend of increasing $\Delta^{17}\text{O}$ with increasing metamorphic grade [10]. This suggests such a trend is an oversimplification [7] and Moss' relationship within the CO3 group is more complex.

Moss' bulk C content and organic inventory resemble that of Ornans [7, 11, 12] rather than Lancé (CO3.4), which is similar in grade. Significantly, Ornans' anomalous geochemistry when compared with other CO3 chondrites has resulted in the definition of the "Ornans paradox" [2]. The results of this study suggest that this paradox no longer exists in that the similarities between Moss and Ornans indicate either variable initial compositions within the CO3 source region or heterogeneous, post-accretionary metamorphism on the CO3 parent body.

Conclusions: The Moss meteorite fall has presented an important opportunity to reassess our understanding of the processes that operated on the CO3 parent body. The results of this study indicate that alteration on the CO3 parent body was significantly more complex than previously envisaged.

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References: [1] Met. Bull. (2007) MAPS 42. [2] McSween H. Y. (1977) *Geochim. Cosmochim. Acta*, 41, 477-491. [3] Brearley A.J. and Jones R.H. (1998) *Reviews in Mineralogy* 36,(3) 1-398. [4] Keck B.D. and Sears D. W.G. (1987). *Geochim. Cosmochim. Acta*, 51, 3013-3021. [5] Scott E. R. D. and Jones R.H. (1990) *Geochim. Cosmochim. Acta*, 54, 2485-2502. [6] Chizmadia L. J., Rubin A. E. and Wasson J. T. (2002) *Meteoritics & Planet. Sci* 37, 1781-1796. [7] Greenwood R. C. and Franchi I. A. (2004) *Meteoritics & Planet. Sci.* 11, 1823-1838. [8] Verchovsky, A. B., Fisenko, A. V., Semjonova, L. F., and Pillinger, C. T. (1997), *Meteoritics & Planet. Sci.*, 32, A131. [9] Pearson V.K. et al (2007) LPSC XXXVIII [10] Clayton R. N. and Mayeda T. K. (1999) *Geochim. Cosmochim. Acta*, 63, 2089-2104, [11] Pearson, V. K. (2006) MAPS, 41 1891-1918. [12] Newton J. (1994) PhD Thesis, Open University.