ASUKA 12236, THE MOST PRISTINE CM CHONDRITE TO DATE.

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Introduction: Carbonaceous chondrites accreted in the protoplanetary disk and provide a record of the earliest planet-formation processes. It is desirable to identify meteorites with the least amount of parent-body modification (e.g., aqueous alteration, thermal metamorphism) as these provide a largely unmodified sample of presolar and nebular materials. The most abundant CCs, the CMs, show a wide range of parent-body modification, but all have been altered to some extent. Moreover, with the impending return of samples from asteroids Ryugu and Bennu by the Hayabusa2 and OSIRIS-REx spacecraft, respectively, CMs have come under increasing scrutiny, since spectroscopic evidence suggests both bodies may be related to this class of meteorites. Kimura et al. [1] recently reported evidence that three Antarctic CMs may be even more pristine than the Paris meteorite, heretofore considered the least-altered CM [2]. We report a multi-technique study of one of these, Asuka (A) 12236, that confirms that this is indeed a highly primitive meteorite.

Samples and Methods: We obtained a 0.5 g chip and a polished thin section (PTS) of A12236 from the Japanese National Institute of Polar Research. The chip was used to determine bulk H, C, and N abundances and isotopic composition, following the method of [3]. The PTS was analyzed for mineralogy and chemistry by EMPA point-counting and SEM-EDS, followed by NanoSIMS mapping for C-rich and O-rich grains [4, 5].

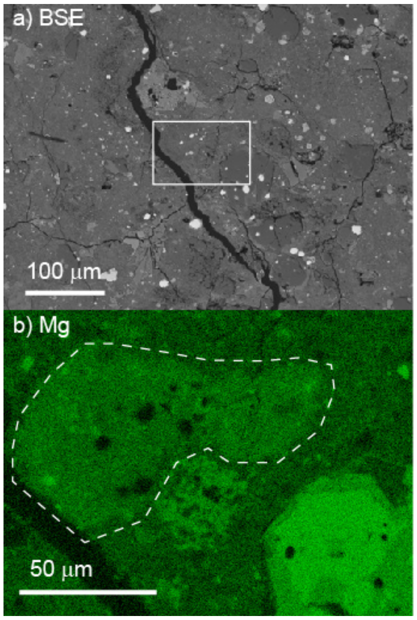

Fig. 1. a) BSE image of a portion of A12236; b) Mg EDS map of small fine-grained Mg-rich area (dashed line) with the highest presolar silicate abundance of 90 ppm.

Results and Discussion:

Petrography. SEM and EMPA analysis confirmed A12663 to have a typical CM texture and mineralogy (Fig. 1), with ~60% matrix, 33% chondrules, 3.7% refractory inclusions, and the remainder isolated (>10-µm) silicate, metal, and sulfide grains. Rare calcite grains are present in the matrix, but no tochilinite-cronstedtite intergrowths, and a few (≈150-µm) CI-/CM-like clasts were also seen. Compositional analysis is ongoing. Several regions of matrix with varying textures and chemistry as indicated by EDS mapping were identified for NanoSIMS searches for presolar grains and organic matter.

Presolar Grains: We obtained C- and O-isotopic maps, with ~150-nm resolution, for a total of ~16,000 μm^2 across 6 different regions of A12236 matrix. We identified 18 presolar O-rich grains (mostly silicates, but including at least 1 Al-rich oxide) and 8 presolar SiC grains, ranging in diameter from ~150 nm to 400 nm. The isotopic compositions of the grains are within previously observed ranges [6] and most likely originated in earlier generations of asymptotic giant branch stars and supernovae.

Presolar grain abundances have been shown to be highly sensitive tracers of parent-body processing [7-9], with silicates being particularly sensitive to aqueous alteration. The matrix-normalized abundance of presolar O-rich grains varied between the areas from 30 ppm to 90 ppm, with an average value of 63 (+18, -15, 1σ) ppm (Fig.2). The highest abundance was found in an unusual fine-grained, slightly Mg-rich region (Fig. 1b). The average SiC abundance is 25 (+15, -9) ppm, similar to many other CCs [8]. The presolar silicate+oxide abundance is lower than that seen in the least altered CO and CR chondrites and C-ungrouped Acfer 094, but is higher than all other reported CM chondrites [10], and the ungrouped CC NWA 5958 [11], which has some affinities to CMs. However, it overlaps within errors with the recently revised abundance estimated for the metal-rich lithology of Paris [5] indicating that A12236 is no more altered than the least altered portion of that meteorite.

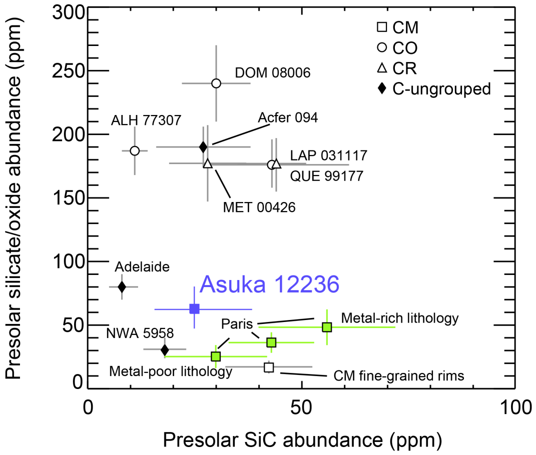

Fig. 2. Presolar grain abundances in various CCs [5, 10, 11].

Bulk H, C, N: We determined bulk H, C, and N contents of A12236 to be 0.71 wt.%, 1.94 wt.%, and 0.12 wt.%, respectively, with $\delta D=141\pm2$‰, $\delta^{13}C=0.9\pm0.3$‰, and $\delta^{15}N=58.3\pm0.2$‰. The C abundance and isotopic composition is typical of CMs, but these are the highest δD and $\delta^{15}N$ values observed for any bulk CM, other than Bells (CM-anom). On a plot of bulk δD versus bulk H contents (Fig. 3), unheated and heated CMs form distinct arrays [12]. A12236 lies at the least altered end of the unheated array, providing further evidence it is a very pristine meteorite. Paris, in contrast, has only a slightly lower bulk δD value, but considerably lower H contents [13], suggesting that it has seen more heating than A12236. On the petrologic scale of [12], based on bulk H contents, we estimate the petrologic type of A12236 to be 3.0. Using the δD and $\delta^{15}N$ values, calibrated to the scale of [14], the meteorite is classified as type 3.0 and 2.7, respectively.

Preliminary NanoSIMS mapping of N isotopes in the A12236 PTS has also revealed substantial isotopic heterogeneity at the micron scale, as commonly seen in the most primitive meteorites [15]. Figure 4 shows a cluster of carbonaceous nanoglobules with large excesses of ^{15}N, similar to those seen in Tagish Lake and other CCs [16, 17].

Conclusions: The mineralogy, including a lack of phyllosilicates [1], the relatively high abundances of presolar grains, and the bulk H, C and N abundances and isotopic compositions all support A12236 being among the most pristine, unaltered CM chondrites. This will be explored further with XRD and NanoSIMS H and N isotopic mapping, as well as targeted FIB-TEM analysis.

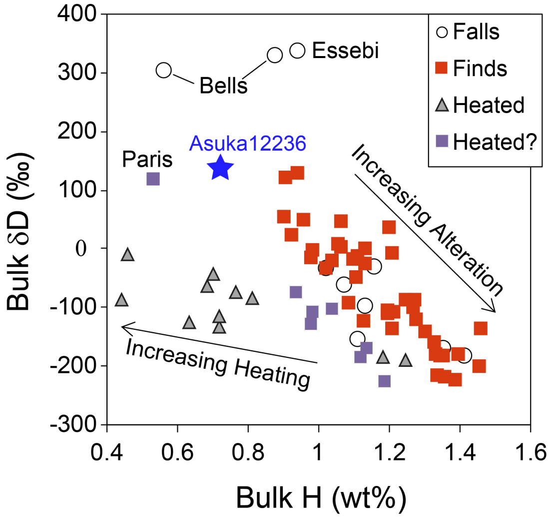

Fig. 3. Bulk δD versus H for CM chondrites and anomalous CMs Bells and Essebi [12, 13].

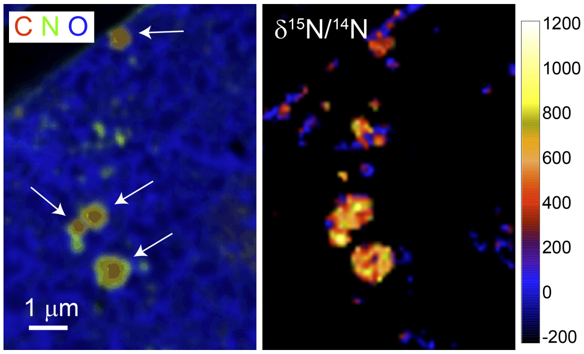

Fig. 4. ^{15}N-rich nanoglobules in A12236.

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References: [1] Kimura M., et al., (2019) *82nd Annual Meeting of The Meteoritical Society*, Abstract 6042. [2] Hewins R. H., et al. (2014) *GCA, 124,* 190-222. [3] Alexander C. M. O'D., et al. (2012) *Science, 337,* 721–723. [4] Nittler L. R., et al. (2018) *GCA, 226,* 107-131. [5] Verdier-Paoletti M. J., et al. (2020), this conference. [6] Nittler L. R. and Ciesla F. (2016) *ARAA, 54,* 53–93. [7] Huss G. R. and Lewis R. S. (1995) *GCA, 59,* 115–160. [8] Davidson J., et al. (2014) GCA, *139,* 248–266. [9] Floss C. and Haenecour P. (2016) *Geochem. J., 50,* 3-25. [10] Leitner J., et al. (2020) *Meteoritics & Planet. Sci.,* in press. [11] Nittler L. R., et al. (2019) *Meteoritics and Planet. Sci.,* in press. [12] Alexander C. M. O'D., et al. (2013) *GCA, 123,* 244–260. [13] Vacher L. G., et al. (2016) *ApJ, 827,* L1. [14] Rubin A. E., et al. (2007) *GCA, 71,* 2361-2382. [15] Alexander C. M. O'D., et al. (2017) *Chemie der Erde, 77,* 227-256. [16] Nakamura-Messenger K., et al. (2006) *Science, 314,* 1439–1442. [17] De Gregorio B. T., et al. (2013) *Meteoritics & Planet. Sci., 48,* 804–828.