CARBON ISOTOPIC HETEROGENEITY OF GRAPHITE IN THE SAN JUAN MASS OF THE CAMPO DEL CIELO IAB IRON METEORITE.

T. Maruoka[1], G. Kurat[2], E. Zinner[1], M. E. Varela[3] and S. J. Ametrano[4], [1]Laboratory for Space Sciences, Physics Department, Washington University, St. Louis, MO, 63130, USA (teruyuki@wuphys.wustl.edu), [2]Naturhistorisches Museum, Postfach 417, A-1014 Vienna, Austria, [3]CONICET-UNS, Dpto. de Geologia, San Juan 670, 8000 B. Blanca, Argentina, [4]Museo de La Plata, B1900FWA, La Plata, Argentina.

Introduction: The origin of IAB iron meteorites is still a matter of debate [e.g., 1]. It is generally believed that iron meteorites originated from molten cores in small planetesimals because the fractionation trend of trace elements (e.g., Ir, Ge, Ga, etc. vs. Ni) for most iron meteorites can be more or less explained by fractional crystallization from metal melts. However, this process cannot produce trace element characteristics of the IAB (and other) iron meteorites [2, 3]. To explain these trace element abundance patterns, several models have been proposed [e.g., 4-6]. Although most of these models require a high temperature, clear evidence has recently been obtained for a sub-solidus formation of IAB iron meteorites from noble gas analyses [1]. Moreover, heterogeneous distributions of some trace elements in metal and other phases also suggest a low temperature origin of at least some IAB iron meteorites [e.g., 7, 8]. Here we use the carbon isotopic compositions of graphite to constrain the origin of IAB iron meteorites. Our data confirm a possible low temperature origin of IAB iron meteorites.

Sample and Methods: The San Juan A mass of Campo del Cielo [8] was cut and a polished section of a silicate inclusion was made for this study. The silicate inclusion is angular and consists of olivine, graphite, orthopyroxene, plagioclase, clinopyroxene and small amounts of metal and sulfide. Graphite occurs as inclusions in silicates, fills intergranular space between silicates, and covers the inclusion's surface. In addition, graphite intergrowths are present in kamacite of the octahedrite metal. We have made carbon isotope measurements on graphite located inside the silicate inclusion, between the inclusion and the metal, and inside the metal, using the Cameca ims3f ion microprobe of Washington University.

Results and Discussion: Fig. 1 shows $\delta^{13}C$ (relative to PDB) values for the three types of graphite. The graphites in the silicate inclusion have relatively constant $\delta^{13}C$ values (-3.7 ± 4.3 ‰ for 14 spots). This range of $\delta^{13}C$ is similar to that of graphites in silicate inclusions in several IAB iron meteorites [9-11]. The graphite rims between the inclusion and metal have a lower $\delta^{13}C$ values (-13.2 ± 5.6 ‰ for 10 spots) than the graphite inside the silicate inclusion. The $\delta^{13}C$ values

of the graphites embedded in the metal (-17.3 ± 6.7 ‰ for 19 spots) are more variable and generally lower than those of the graphite inside the inclusion.

Carbon isotopic heterogeneity of graphite nodules in the El Taco mass of Campo del Cielo has previously been reported [10]. This heterogeneity has been interpreted as being possibly due to mixing between carbon originating from the inclusion and carbon exsolved from taenite. This interpretation was based on the observation that taenite separates from octahedrites have $\delta^{13}C$ values (between -19.7 and -22.1 ‰) that are lower than those of graphite nodules [10]. This mixing process requires a high temperature to dissolve carbon into the metal. If graphite formed by exsolution from the metal, its isotopic composition in the metal should have been homogenized and this mixing process could not have resulted in a heterogeneous isotopic distribution of carbon. Consequently, this process cannot explain the isotopic compositions of the graphites in our sample because $\delta^{13}C$ values inside the metal vary on a sub-mm scale (Fig. 2). This sub-mm heterogeneity of graphite $\delta^{13}C$ implies that these graphite inclusions never have experienced high temperature.

Based on the heterogeneous distribution of trace elements in schreibersite in the same sample mount used for this study, Kurat et al. [8] concluded that the schreibersite could not have been formed by exsolution from the metal. Its heterogeneous chemical composition apparently reflects strongly changing conditions of the formation environment, possibly nebular. Because the trace element abundances in the schreibersite roughly are anticorrelated with the decomposition temperature of the respective metal carbonyls, these authors also suggested that the formation of San Juan schreibersite might be related to precipitation of metal and graphite from carbonyls. Carbonyls as the source for iron meteorites have been originally proposed by Bloch and Müller [12] and have been invoked for the formation of metal and graphite in graphite-metal rocks of the Canyon Diablo IAB iron meteorite [7]. A typical carbonyl decomposition reaction can be given as follows:

$$Fe(CO)_5 \rightarrow Fe + 5CO$$
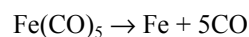
Carbon isotopic heterogeneity of graphite in San Juan: T. Maruoka et al.

$$2CO \rightarrow C + CO_2$$
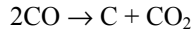
The second reaction should be accompanied by isotopic fractionation of carbon between graphite and carbon dioxide [e.g., 13, 14]. Graphite produced by this reaction should have a $\delta^{13}C$ value lower than that of the initial CO. The difference should increase with decreasing reaction temperature. Moreover, some CO molecules liberated by the first reaction might have been converted to CH_4 by a process such as the Fischer-Tropsch reaction before the second reaction occurred. The CO molecules might have been mixed with surrounding nebular CO. Both of these processes also affect the isotopic compositions of CO and, therefore, those of graphite condensates. Furthermore, the carbon isotopic composition of the carbonyls might not have been constant in time. Because the decomposition reaction is expected to also be accompanied by C isotopic fractionation between the carbonyls and CO, $\delta^{13}C$ values of the residual carbonyls might also have varied in time. Therefore, there are many possible factors that can induce $\delta^{13}C$ variations of graphite resulting from the carbonyl decomposition reaction. This reaction can easily give rise to the $\delta^{13}C$ values reported here for the graphite embedded in the metal. The strongly changing physicochemical conditions, which are required to maintain heterogeneity of trace element abundances in the schreibersite [8], can also cause the sub-mm-scale $\delta^{13}C$ variation of graphites through carbonyl decomposition. We conclude that the carbonyl decomposition model can explain $\delta^{13}C$ variations of graphites from the San Juan mass of Campo del Cielo.

References: [1] Maruoka T. et al. (2001) *MAPS, 36,* 597-609. [2] Scott E. R. D. and Wasson J. T. (1975) *Rev. Geophys. Space. Phys. 13,* 527-546. [3] Wasson J. T. and Wang J. (1986) *GCA, 50,* 725-732. [4] Choi B. et al. (1995) *GCA, 59,* 593-612. [5] Wasson J. T. and Kallemeyn G. W. (2002) *GCA, 66,* 2445-2473. [6] Rubin A.E. et al. (2002) *GCA, 66,* 3657-3671. [7] Kurat G. et al. (2000) *LPS XXXI,* #1666. [8] Kurat G. et al. (2002) *LPS XXXIII,* #1781. [9] Deines P. and Wickman F. E. (1973) *GCA, 37,* 1295-1319. [10] Deines P. and Wickman, F. E., (1975) *GCA, 39,* 547-557. [11] Sugiura N. (1998) *MAPS, 33,* 393-409. [12] Bloch M. R. and Müller (1971) *EPSL, 12,* 134-136 [13] Deines P. (1980) *GCA, 44,* 943-961. [14] Scheele N. and Hoefs J. (1992) *Contrib. Mineral. Petrol., 112,* 35-45.
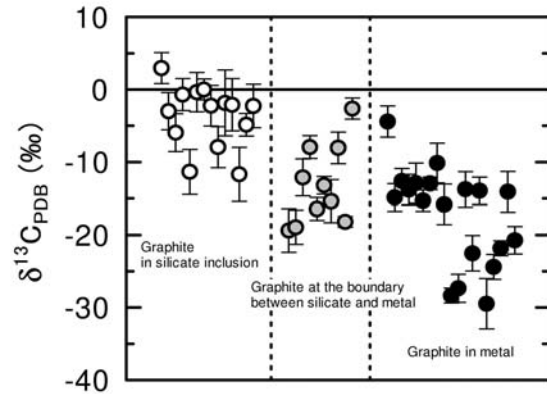

Fig. 1 Carbon isotopic ratios of graphite in silicate, at the silicate-metal boundary, and in metal from the San Juan mass of Campo del Cielo (IAB).
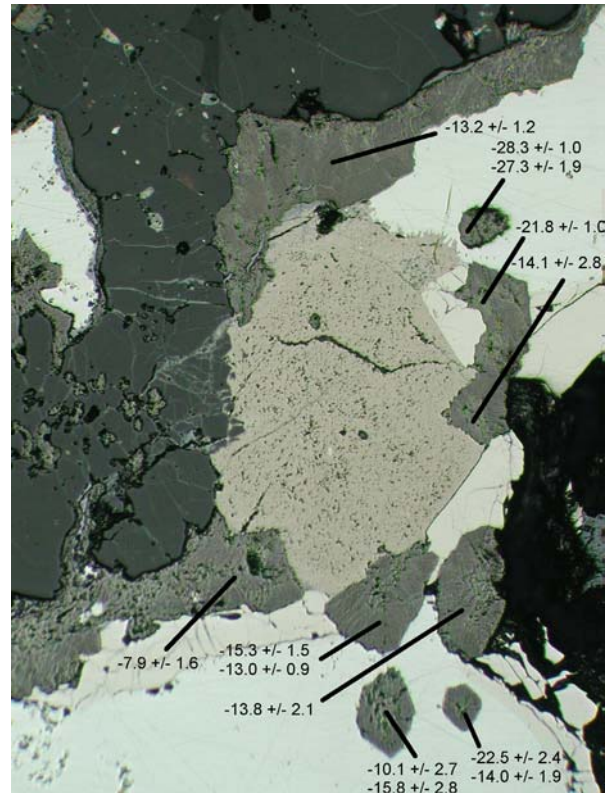

Fig.2 Optical image of metal-silicate boundary in a polished section from the San Juan A mass of Campo del Cielo (IAB). Numbers represent $\delta^{13}C$ values (relative to PDB; ‰). Two values for a single spot represent results from repeated analyses. The width of the image is 930 μm.