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ANATOMY OF A CLUSTER IDP (II): NOBLE GAS ABUNDANCES, TRACE ELEMENT GEOCHEMISTRY, ISOTOPIC ABUNDANCES, AND TRACE ORGANIC CHEMISTRY OF SEVERAL FRAGMENTS FROM L2008#5;

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In Part I, we described the bulk chemistry and mineralogy of large fragments and fines (<5 μm) from a cluster IDP originally ~ 40-50 μm in diameter [1]. Here we report results from several types of analyses: noble gas measurements (Nier), Synchrotron X-Ray Fluorescence (SXRF) for trace element abundances (Flynn and Sutton), ion probe studies (Messenger and Walker), and trace organic chemistry (Clemett and Zare). The same fragments were analyzed for isotopic abundances and organic compounds.

Noble Gas Content and Release Temperatures He content and the He release temperatures for four samples were determined by step-heating experiments [2]. The average ^{4}He abundance is ~4.1 (cc x 10^{11}) and extraction temperatures for removal of 50% of the He range from 750-1040 °C, with an average at 928 °C (Table 1). The low He content and high release temperatures indicate that all fragments from L2008#5 have experienced heating during atmospheric entry. He measurements have been used to distinguish asteroidal from cometary IDPs in individual, small-sized particles (< 10 μm in diameter) [3]; however these measurements cannot be used to determine sources of cluster particles because higher deceleration heating occurs in large-size particles.

Trace Element Abundances SXRF was used to determine trace element abundances in four fragments from L2008#5 [technique described in 4]. Two fragments show marked depletions in Zn (Zn/Fe < 0.1) indicating they have experienced heating during atmospheric entry (Table 2). Zn/Fe ratios range from 0.2-0.5 for the remaining fragments. All four fragments show deviations by more than a factor of 2 from CI for 3 or more elements (Table 2). The only consistent trends are enrichments in Cu, Se, and Br, and a depletion in Zn relative to CI.

Heating Summary of Cluster Fragments He content and release temperatures of fines suggest they experienced atmospheric entry heating. The large range in 50% He release temperatures suggests that fragments have not been heated equally. Low Zn/Fe ratios show that 2 of 4 fragments were heated during atmospheric entry. Previous TEM studies have shown that the presence of magnetite rims on IDP surfaces is an indication of atmospheric entry heating [e.g., 5]. Magnetite rims were observed in 13 of 20 fragments and fines from this cluster[1]. The He measurements indicate that cluster L2008#5 has not been uniformly heated; trace element abundances and magnetite rims are evidence that heating is seen in selected fragments, probably those located on the exterior surfaces of the cluster.

Isotopic Measurements D/H ratios of eight fragments were measured using an ion microprobe [technique described in 6]. Deuterium enrichments (δD) were observed in all four of the C-rich fragments and range from +322- +822 per mil. Four fragments from Clu37, which had a chondritic C abundance, showed no D enrichment (Table 3). The D enrichments in the C-rich fragments are far in excess of values for terrestrial samples and are another indication that the fragments are extraterrestrial [6]. There is an apparent positive correlation of D enrichment with the abundance of carbonaceous material in our fragments. A larger group of IDPs should be examined to confirm this result.

Trace Organic Chemistry The signatures of polycyclic aromatic hydrocarbons (PAHs) in IDPs have been observed with a microprobe two-step laser mass spectrometer (μL^{2}MS) [7]. All cluster fragments which had been analyzed previously for isotopic abundances were examined for the presence of PAHs (Table 3).

All PAH signatures observed show significant variability between different particles. In fact, intensities of PAH signatures varied in pieces from the same fragments (e.g., Clu19 and Clu37, Table 3). For example, a strong PAH signature was observed in Clu19(β), while essentially no signal was found in Clu19(α) (Table 3). The PAH spectra from all fragments are very different from those of two other unrelated IDPs, Aurelian or Florianus [7]: the range of aromatic species observed is reduced (limited from 1 to 6 ring species) although individual peak intensitites (e.g., naphthalene and the alkyl-phrenathrenes) are in some cases more intense than the most intense peak observed from Aurelian. The spectra are dominated by even mass PAHs with little evidence for odd mass peaks, suggestive of nitrogen substituted aromatic species. Although the distribution of PAHs may be affected by previous exposure to the ion probe (10kev Cs^+ ions), strong PAHs signatures have only been observed in D-rich particles [this work & 7]. PAHs and elemental carbon coexist in some fragments of this cluster; however, there is a lack of correlation in the abundance of C and the presence of PAHs. Considering the mass of the entire cluster, PAHs and elemental carbon are not homogeneously distributed.

In summary, analyses of fragments from one cluster IDP show large variations in He content, He release temperatures, trace element and isotopic abundances, and the presence of organic components.

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Table 1. He measurements of fines from cluster L2008#5.

Sample #	^4He (cc x 10^{11})	50% He Release Temp (°C)	$^3He/^4He$ ($x10^{-4}$)	$^{20}Ne/^{22}Ne$	$^4He/^{20}Ne$
1	4.5	750	3.3 +/- 0.7	13.3 +/- 1.6	9.9 +/- 0.4
2	6.1	1040	4.7 +/- 0.5	11.5 +/- 1.3	14.3 +/- 1.0
3	3.4	1010	7.2 +/- 1.2	7.2 +/- 1.0	12.0 +/- 3.0
4	2.2	910	5.9 +/- 1.4	10.5 +/- 1.7	6.8 +/- 1.0

Table 2. SXRF trace element abundances normalized to CI of 4 large fragments from L2008#5.

Sample #	Cr	Mn	Fe*	Ni	Cu	Zn	Ga	Ge	Se	Br	Zn/Fe
Clu16	0.2	0.4	1.4	2.0	3.5	0.06	0.4	0.2	6.1	2.0	0.04
Clu18	1.3	1.8	1.3	0.5	1.7	0.06	7.1	0.3	1.8	7.3	0.05
Clu21	0.4	3.1	2.1	2.0	7.4	0.44	1.4	0.6	3.4	7.3	0.2
Clu319	3.5	0.2	1.1	0.9	2.6	0.52	10.0	2.8	5.4	24.8	0.5

*Values from EDS

Table 3. Carbon abundance (Wt.%), Deuterium enrichments (δD), and the presence of PAHs signatures in several large fragments from cluster L2008#5.

Sample	Wt.% Carbon (EDS)	δD (per mil)*	μL^2MS (%) **
Clu19(α)‡	a+b=14	+664 +/- 84	>5
Clu19(β)‡	"	+424 +/- 71	100
Clu110	10	+822 +/- 91	43
Clu313†	15	+322 +/- 67	Not measured
Clu37(α)§	a+b+c+d=3	-24 +/- 17	20
Clu37(β)§	"	+25 +/- 22	7
Clu37(χ)§	"	-14 +/- 36	32
Clu37(δ)§	"	+12 +/- 29	13

*Terrestrial range is -200 - +50 per mil **Integrated signal intensity from 80-450 amu normalized relative to Clu19(β) ‡ Clu19 broke into 2 separate pieces (α & β) †3 μm fragment, possibly too small for PAHs analysis § Clu37 fractured into 4 pieces (α, β, χ, δ)