COMPOSITIONAL HETEROGENEITY WITHIN COMETARY BODIES.

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Introduction: Comets have been found to contain a highly diverse mixture of grains from different regions of the solar system, and beyond [1]. It has also been learned from space missions that unlike the classical view that the population of tiny grains (sub-mm to sub-micron), are emitted directly from the surface as the ices surrounding them are sublimated away by the thermal input from solar insolation, but are instead initially in cm to meter-sized aggregates released from the nucleus which then quickly disintegrate into semi-localized of clouds composed of the small grains [2, 3]. As analyzed by the time-of-flight Particle Impact Analyzer (PIA instrument) on the Giotto mission to comet 1P/Halley, the compositions of grains were variable and could be divided into three broad classifications, one class of which contained no signature of Si but were composed of organic indicator elements such as C, N, O and H. These "CHON" particles [4] were ubiquitous, albeit generally smaller than the grains of silicates and particles which were of "mixed" composition, containing both silicates and organics. We have further examined the PIA data set to define additional sub-classifications according to the scheme shown in Figure 1.

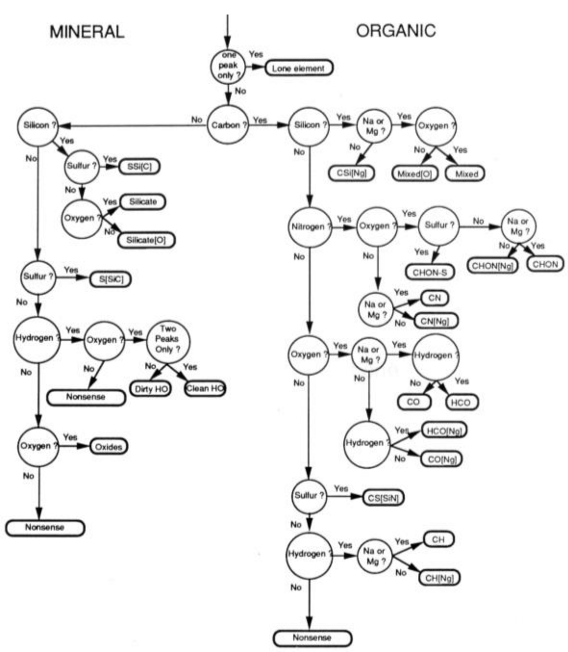

Fig. 1. Classification Scheme for Particulates

Classes of Particulates: Our primary approach was to sub-classify the particles containing C and no Si (various versions of CHON's). [note that the use of element symbols here does not imply exact stoichiometry, but rather simply the presence of these elements]. The CHON subdivides into groups which are missing either O or N. Similar analyses have been conducted by Fomenkova et al. [5, 6] on the PUMA instruments' results from the VEGA flyby missions to Halley. It has also been found that particles which contain O often exhibit an additional peak we now assign to Na [7]. CHON's which contain N but are deficient in O do not exhibit this peak. Based on average relative mass, the hierarchy seems to be (HCN)-rich particles which associate with (HCO) and (HCO-Na) particles to produce CHON-Na particles. Similarly, the PIA data also imply that (FeS) particles combine with silicate particles (SiMgFeCa), and that these are more often than not also organic-rich, presumably by containing CHON materials of various classifications.

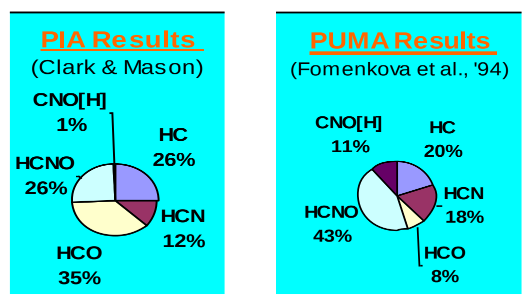

Fig. 2. Cumulative Results for CHON Particles

Chemical Heterogeneity: Most importantly, the PIA and PUMA data indicate variations in which different compositions predominant during the coma flythrough's [4, 5]. Presumably, flythroughs at other times and relative locations would produce different results, as evidenced by the significant differences in relative populations of compositional species between the time of the Vega-1 and Giotto flyby, some 10 days later and exposed to different portions of the Halley nucleus, Fig. 2. Significant changes in predominant compositions were also noted as a function of time for the Giotto flythrough, and hence location within the coma of comet Halley.

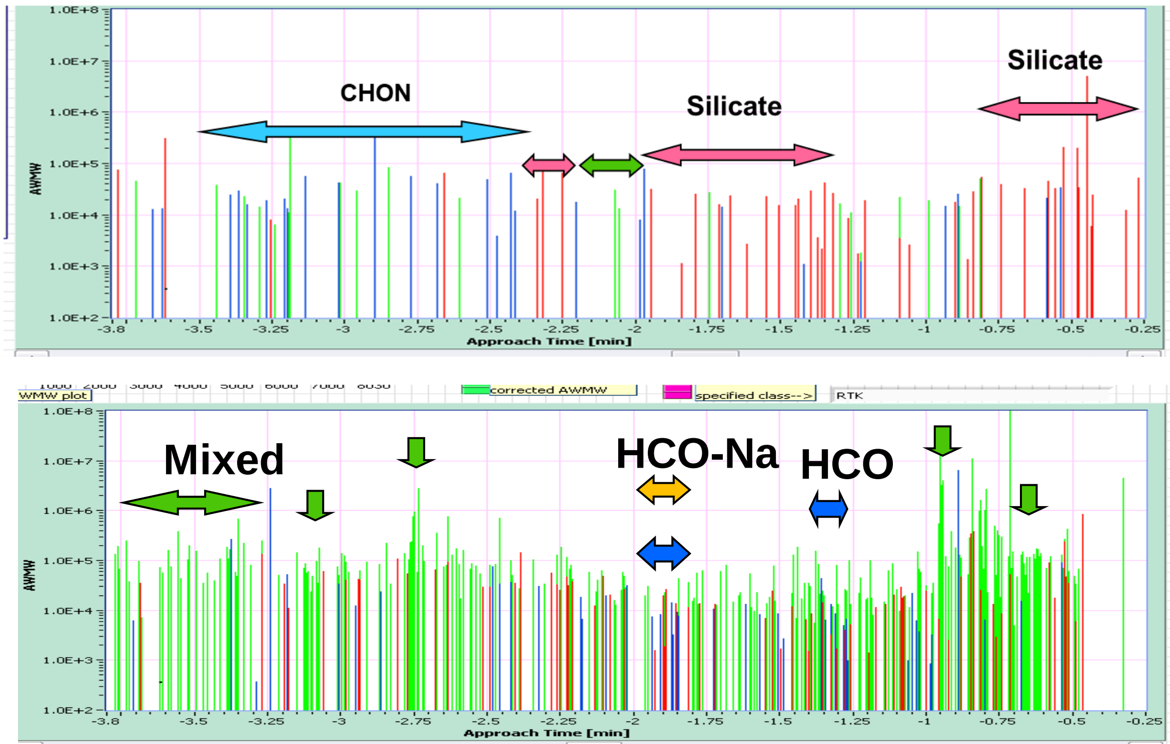

Figure 3. Particle-type occurrences as a function of time of the flythrough of the coma of Comet Halley (E-3.8 to E-0.25 min.)

Observed Compositional Variations during Flyby: In Figure 3, we show some examples of different particle classes which were observed during the incoming path to the point of closest approach (E = Encounter). At the flyby speed of 69 km/sec and closest approach distance for Giotto of only 600 km, the dust "clouds" produced by individual disintegrating aggregates are still apparent in the data, making possible the identification of the biases in composition of different aggregates (primordial cometesimals?). As seen in Figure 4, the preponderance of larger particles are surrounded by nearby smaller particles (highlighted by green arrows), with gaps between these clusters.

Figure 4. Particle clusters from aggregates

This type of clustering is indicative of one larger particle shedding multiple smaller particles in arbitrary directions, resulting in a quasi-spherical "cloud" through which a spacecraft passage will detect smaller particulates on the outer portions of the cloud (analogous to starburst fireworks) and gaps between former parent aggregates.

Summary: Indications for variable compositional regimes were detected in the coma of comet Halley. Subsequent analysis of particle event stochastics reveals the type of clustering of events that occurred during the coma flythrough measurements at comets Wild 2 [4] and Tempel 1, indicating similar characteristics as Halley and by extension, most other comets. The variations in composition of particular constituents may reflect the primordial compositions of numerous components of independent origin in a rubble pile model of the make-up of cometary nuclei.

References: [1] Brownlee, D. (2014) *Annu. Rev. Earth Planet. Sci.*. 42:179–205. [2] Clark, B.C. et al., *JGR*, *109*, E12S03. [3] Green, S. F. et al. (2004) *JGR*, *109*, E12S06.. [4] Clark, B.C. et al. (1987) *Astron. Astrophys.* 187: 779-794. [5] Fomenkova, M. N. et al. (1994) *Geochim. Cosmochem. Acta*, *58*, 4503-4512. [6] Fomenkova et al. (1992) *Science*, *258*, 266-2269. [7] Clark, B.C. (2018), *MAPS*, *53*, Abs. #6167.