CHEMICAL ABUNDANCES OF ROCK-FORMING ELEMENTS OF COMETARY STREAMS OBTAINED FROM METEOR SPECTROSCOPY. J. Llorca[1,2], J.M. Trigo-Rodríguez[3], J. Borovicka[4] and J. Fabregat[5], [1]Dept. Química Inorgànica, Univ. Barcelona, Spain (jordi.llorca@qi.ub.es), [2]Institut d'Estudis Espacials de Catalunya, Spain, [3]Dept. Ciències Experimentals, Univ. Jaume I, Spain (trigo@exp.uji.es), [4]Ondrejov Observatory, Czech Republic, [5]Dept. Astronomia i Astrofísica, Univ. València, Spain.

Introduction: Up to now, only cometary dust from comet 1P/Halley has been analyzed *in situ* by mass spectrometry techniques. In contrast, numerous studies have been performed in the laboratory over interplanetary dust particles (IDPs) thought to be related to comets. Another discipline that addresses the study of the chemical composition of small meteoroids is meteor spectroscopy, which focuses on the light emitted upon the process of ablation and fragmentation of these particles into the atmosphere due to the high velocity encounter with the Earth. We have derived the relative chemical abundances of Si, Mg, Fe and Ca of eight fireballs belonging to well-known cometary streams (5 Perseids, 1 κ Cignid, 1 Andromedid and 1 Leonid) and compared them to the chemical composition of 1P/Halley dust as well as IDPs.

Methods: All spectral records were obtained with fixed cameras (focal length 360 mm, focal ratio 1:4.5) equipped with prisms (resolution 130 Å mm^{-1} at 4000 Å to 550 Å mm^{-1} at 6000 Å) or diffraction gratings (resolution 50 Å mm^{-1}) and registered on 18x24 cm plates (Agfa 100 and Orwo NP27) at the Ondrejov Observatory. As a representative example, figure 1 shows the spectrum recorded for a meteor belonging to the Perseid stream. Each spectrum was corrected from the spectral sensitivity of the spectrograph and plate sensitivity. Data reduction and relative chemical composition of meteoroids were obtained following the procedure developed by Borovicka [1].

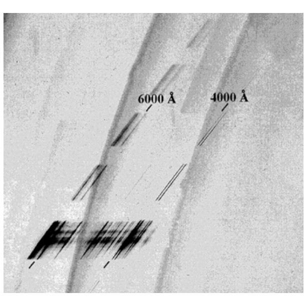

Figure 1. A Perseid spectrum recorded in August 12, 1970 with a prism dispersion element. The fireball was photographed from three stations, then the orbital parameters could be accurately determined and the fireball unambiguously associated to comet 109P/Swift-Tuttle. The photometric mass for this meteoroid was ca. 6±4 grams as deduced from Verniani formula [2].

Relative chemical abundances: We have obtained relative chemical abundances of Na, Mg, Ca, Si, Ti, Cr, Mn, Fe, Co and Ni for each fireball [3]. We focus here our attention on the distribution of the main rock-forming elements Mg, Si, Fe and Ca, which may serve as a distinctive feature of interplanetary materials. The relative abundances of Mg, Fe and Ca have been obtained directly from meteor spectra in all cases. In the spectra produced by high geocentric velocity meteors (Perseids at 59.9-61.1 km s^{-1} and Leonid at 71.9 km s^{-1}) we have obtained directly the silicon abundance from the second component of the spectra, where Si II lines are very prominent. Unfortunately, for slow meteors (κ Cignid at 26 km s^{-1} and Andromedid at 24.3 km s^{-1}) it has been not possible to determine the Si abundance from the spectra since the second component is very faint and Si II lines are almost missing. On the other hand, spectra with a much larger resolution would be needed in order to separate the contribution of the Si I line (multiplet 3 at 3905.5 Å), which is located in a spectral region where Fe I and Ca II lines are very prominent. In these cases we have adopted a Si/Fe ratio of 1.16. Figure 2 shows the location of the four meteoroid streams associated to comets that we have analyzed through associated meteor spectra in the ternary diagrams Si-Mg-Fe and Mg-Fe-Ca. We give for each cometary stream the averaged values obtained from the respective fireballs along their trajectory. The composition of the fireballs was measured in several segments according to the characteristics of each fireball. The total number of segments averaged for each cometary stream was: 45 for Perseid, 6 for κ Cignid, 16 for Andromedid and 9 for Leonid. From the values obtained for individual segments a dispersion error of major constituents was evaluated at ±30%. In addition, we have also included in figure 2 the location of 1P/Halley dust, IDPs, and CI carbonaceous chondrites [4].

In the ternary diagram Si-Mg-Fe all the fireballs corresponding to the different cometary streams cluster in the same region. They are located in between the values corresponding to IDPs and CI chondrites, but far from 1P/Halley dust value. Taking into account that 1P/Halley dust analyzed by spacecraft was below 10^{-12} g, IDPs are typically below 10^{-9} g, and meteor spectroscopy is usually performed over gram-sized particles, the position of the fireballs along an ideal line connecting the different solar system materials plotted in the Si-

Mg-Fe ternary diagram is in accordance to the hierarchical dust accretion model developed by Rietmeijer [4]. As accretion procedeed, the compositions of increasingly larger particles became more chondritic, as hierarchical accretion lowers the Mg/Fe and Mg/Ca ratios. In the ternary diagram Mg-Fe-Ca the fireball data is distributed close to the CI value. However, it should be recalled that there is a clear dependence between Ca relative abundance and the geocentric velocity of the meteoroids. In particular, we have observed incomplete calcium evaporation in the slowest meteoroids κ Cignid and Andromedid, which in turn plot at the bottom of the ternary Mg-Fe-Ca diagram. Calcium suffers from incomplete evaporation since it is present in refractory mineral phases that have an especial resistance to volatilization. When the geocentric velocity increases, the main temperature reached in the meteoric column also increases and calcium evaporation is more efficient.

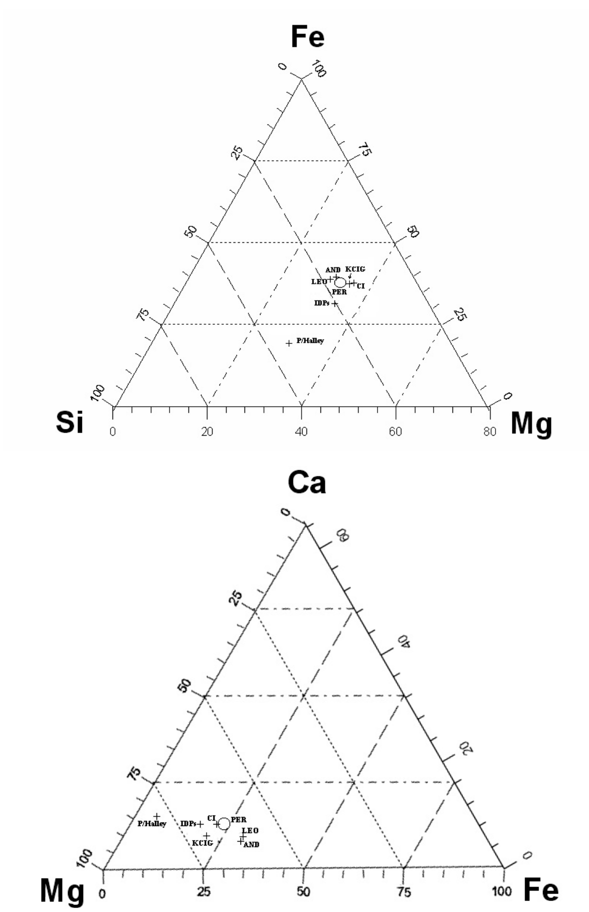

Figure 2. Si-Mg-Fe and Mg-Fe-Ca ternary diagrams (atomic ratios) showing the location of cometary meteoroids as deduced from meteor spectroscopy of associated fireballs in comparison to other solar system minor bodies.

The location of our data concerning cometary streams with respect to 1P/Halley dust deserves additional discussion. From data gathered by VEGA 1 and 2 spacecraft it was concluded that most of the comet 1P/Halley dust particles had chondritic composition with mixtures of various primary silicate phases [5]. There was evidence also for minor populations of Mg-rich as well as Fe-rich particles, which possibly had a secondary origin such as aqueous alteration. Interestingly, the smallest rock particles (10^{-13}-10^{-16} g) were highly enriched in Mg, whereas the other particles investigated (10^{-12}-10^{-13} g) exhibited a solar Mg/Si ratio. Spacecraft spectrometers analyzed mainly only very small 1P/Halley particles that had their mass equivalent to the called *principal components* (PCs) that are inside the matrix of IDPs and may represent the first dust particles to accrete in the solar system. But neither PCs nor any other constituent (e.g. mineral grains) have chondritic relative abundances. In addition, it has also claimed that the apparent Fe deficiency and Si overabundance of 1P/Halley rock particles from CI chondrites could be due to the insufficiently well known ion yields in both the PIA (Giotto) and PUMA (VEGA) mass spectrometers used to measure the elemental composition of dust particles emitted from the comet rather than to reality [6].

Taking into account that the spectra of meteors are obtained over gram-sized meteoroids, the comparison between the elemental composition of 1P/Halley dust obtained *in situ* may thus not be directly comparable to that of fireballs. From our results we believe that 1P/Halley dust data obtained *in situ* from spacecraft can not be used as type sample for cometary dust. The question about what standard is more adequate to appreciate the chemistry of incoming cometary matter remains unsolved, keeping in mind that there are similarities but surely also differences among individual comets. A quantitative mass-dependent model combined to the hierarchical dust accretion principle may be thus required.

References: [1] Borovicka J. (1993) *A&A, 279,* 627-645. [2] Verniani F. (1973) *JGR, 78,* 8429-8462. [3] Trigo-Rodríguez J.M. (2002) Ph.D. thesis. [4] Rietmeijer F.J.M. (2000) *Meteoritics & Planet. Science, 35,* 1025-1041. [5] Fomenkova M.N., Kerridge, J.F., Marti, K., McFadden L.-A. (1992) *Science, 258,* 266-269. [6] Jessberger E.K., Christoforidis, A, Kissel, J. (1988) *Nature, 332,* 691-695.