

SODIUM OVERABUNDANCE IN METEOROIDS FROM METEOR SPECTROSCOPY. J.M. Trigo-Rodríguez¹ and J. Llorca^{2,3}. ¹Institute of Geophysics & Planetary Physics, University of California Los Angeles (UCLA), Los Angeles CA 90095-1567, USA (jtrigor@ucla.edu); ²Dept. Química Inorgánica, Universitat de Barcelona, Spain (jordi.llerca@qi.ub.es); ³Institut d'Estudis Espacials de Catalunya, Spain.

Introduction: The relative abundances of Na in meteoroids have been estimated by averaging the composition of the radiating gas along the fireball path produced during their atmospheric entry. We used the method of thermal equilibrium for thirteen fireballs produced by meteoroids mainly of cometary origin. The results show greater sodium abundances than those expected for IDPs and chondritic meteorites, and interesting differences with the sodium abundance of 1P/Halley comet dust has been found.

Methods: We analyzed fifteen fireball spectra obtained with fixed cameras (focal length 360 mm, focal ratio 1:4.5) equipped with prism (resolution 130 Å mm⁻¹ at 4000 Å to 550 Å mm⁻¹ at 6000 Å) or diffraction grating (resolution 50 Å mm⁻¹) and registered on 18×24 cm plates (Agfa 100 and Orwo NP27) at the Ondřejov Observatory, Czech Republic. Data reduction and relative chemical composition of meteoroids were obtained using the procedure developed by Borovicka [1]. Basically, to deduce the relative chemical composition of meteoroids, we considered the radiating volume as a prism with square base and elongated in the direction of the meteor flight. The prism length is b and the width is a . The ratio b/a of the meteor radiating head could not be determined from photographic observations due to a low resolution and to the fact that the meteor spectra moved too quickly along the plate in the exposure interval. Only an upper limit for a could be obtained from the width of the meteor trail on the photograph. Assuming thermal equilibrium, the brightness of the spectral lines were computed by adjusting four parameters: temperature (T), the column density of atoms (N), the damping constant (Γ) and the surface area (P) [1]. The surface area registered by the spectrograph is:

$$P = a \cdot b \cdot \sin \theta \quad (1)$$

We assumed the same value of $b/a=2$ for all spectra. The procedure consisted of the reconstruction of a synthetic spectrum that allowed the determination of these four parameters from the observed brightness of lines. This was done by the least squares method. As most lines in the spectrum are of neutral iron, Fe I is taken as a reference element to adjust the intensity of lines and temperature. To obtain chemical abundances, the degree of ionization of different elements have been considered taking into account the ratio of neu-

tral, singly and doubly ionized atoms given by the Saha equation explained in [1].

Results and discussion: We have obtained relative chemical abundances of Na, Mg, Ca, Si, Ti, Cr, Mn, Fe, Co and Ni [2-4]. We focus here our attention on the relative chemical abundance of sodium in these meteoroids. Sodium lines are omnipresent in meteor spectra. Their low excitation potential (2.1 eV) makes it possible to observe easily the Na I doublet (multiplet 1) at 5,893 Å. The intensity of the lines of the sodium doublet, in general terms, fully agrees with the computed synthetic spectra showing that the assumed physical parameters of the model are realistic. However, to rule out the presence of artificial effects in the determined relative sodium abundances in meteor spectra we must consider the influence of two important factors. The first is the influence of the assumed geometrical b/a ratio of the radiating volume, bearing in mind that this ratio is variable and unknown along the fireball trajectory. The second factor is related to the presence of a sodium layer in the region of meteor ablation in the atmosphere [5].

In order to evaluate the influence of the b/a ratio on the derived sodium abundance we recomputed in [3] the Na abundance in the brightest segment of several spectra with representative geocentric velocities, taking into account different b/a ratios. The results clearly show that the differences in Na abundance are smaller than the relative dispersion errors. We concluded that the geometry assumed for the radiating volume affects only slightly the determination of relative chemical abundances. On the other hand, we may consider if the relative abundance of Na is related to the presence of metal layers in the upper atmosphere [5]. We demonstrated in [3] that the sodium relative abundance in the meteoric column was more than seven orders of magnitude larger than that deduced from lidar techniques in the Na mesospheric layer. An important consequence of this result is that the sodium abundance detected in fireballs must be real and not an artifact related to its presence in the upper terrestrial atmosphere.

The study of the sodium abundance, relative to silicon, in cometary meteoroids is particularly valuable since in recent years important differences have been reported in the sodium content in comets. For example,

the sodium abundance measured in the dust of comet 1P/Halley was ca. 5 times larger than the cosmic value [6]. In contrast to this, the observations of comet Hale-Bopp's sodium tail showed that the amount of sodium causing this tail is less than ca. 0.1% of the cosmic abundance [7]. From meteor spectroscopy we have analyzed the sodium content in meteoroids coming from different comets. The abundance of sodium was obtained in several segments of each fireball and averaged as explained in [2]. The errors were estimated from the dispersion of the abundance in all segments analyzed. In this work we decided to avoid the faintest segments where the sodium values have larger dispersion errors. In Figure 1 we have arranged fireball sodium relative abundance as a function of the photometric mass of the incoming meteoroid determined from [8]. For the sake of comparison, the cut-off of the x-axis allows us to show the measured abundance in IDPs, 1P/Halley dust [6] and CI and CM carbonaceous chondrites [9]. Clearly the estimated sodium abundances in meteor spectra are larger than the values of the other samples of interplanetary matter. It is quite significant that particles coming from periodic comets, such as 109P/Swift-Tuttle comet (PER1 to PER5) and 55P/Tempel Tuttle (LEO), display sodium abundances that are twice those of comet 1P/Halley dust measured from the Giotto spacecraft, although a silicon anomaly in Halley dust could also contribute to the low abundance ratio of Na/Si taking into account the unusually high Si/Mg and low Fe/Mg ratios shown by this comet. Other meteoroids of our sample show similar values although on some occasions the typical values for interplanetary samples are inside the error bars.

It is interesting to note for the Perseid family of this study, constituted by five meteoroids (PER1 to PER5), a trend between the sodium relative abundance and the mass of the corresponding meteoroids. The larger the mass of the incoming meteoroid, the higher the relative sodium abundance. This may correspond to an erosion effect in the interplanetary medium. If this is the case, then the sodium content of the Perseid parent body, comet 109P/Swift-Tuttle, should probably be even higher. We also note that the long-lasting characteristic trains and the differences observed in the photometric curves of young meteoroid material in comparison to annual meteoroids of the same shower [10] could also be associated with the differences in Na content. As was proposed by Baggaley [11], long-lived luminosity of meteor trains can involve the store of recombination energy of free atmospheric oxygen with sodium atoms continuously catalyzing the transformation of atomic oxygen to molecular oxygen by NaO formation, so that the dissociation energy of O₂ is converted into sodium light with the aid of the atmos-

pheric species O₃ and O₂. Determination of a possible relationship between exposure times in the interplanetary medium for young Leonid meteoroids based on orbital modeling [12, 13] and the relative sodium abundances of young members of the stream as well as those characteristic of annual Leonid members is in progress.

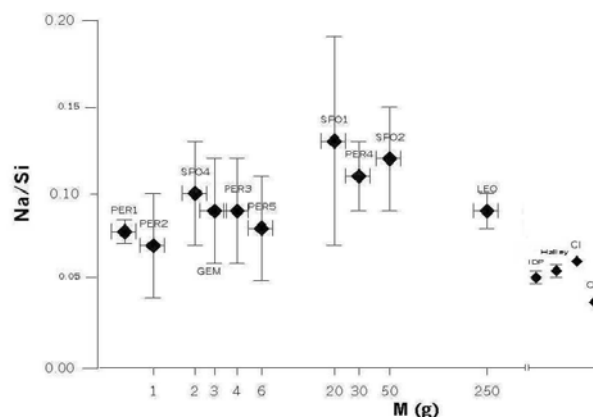


Figure 1. Relative sodium abundances for the spectra as function of the mass of the incoming meteoroid. We plot particles less than 250 grams in mass.

Finally, it is remarkable that the GEM meteoroid, associated with the Phaeton asteroid, has a high Na content compared to chondritic meteorites (that may be considered representative of asteroid samples). It supports the suggested cometary origin of Phaeton as previously suggested [14, 15].

References:

- [1] Borovicka J. (1993) *A&A*, 279, 627-645.
- [2] Trigo-Rodríguez J.M., Llorca, J., Borovicka, J., Fabregat, J. (2003) *Meteoritics & Planet. Sci.*, 38, 1283-1294.
- [3] Trigo-Rodríguez J.M., Llorca, J., Fabregat, J. (2004) *MNRAS*, in press.
- [4] Llorca J., Trigo-Rodríguez J.M., Borovicka, J., Fabregat, J. (2003) *LPSC XXXIV*, Abstract #1029.
- [5] Plane J.M. (1991) *Intern. Rev. Physical Chemistry* 10, p.55.
- [6] Jessberger E.K., Christoforidis A. and Kissel A. (1988) *Nature* 322, p.691.
- [7] Cremonese G., Fulle M. (1997) *EM&P* 79, p.209-220.
- [8] Verniani F. (1973) *JGR* 78, 8429-8462.
- [9] Rietmeijer F.J.M. and Jenniskens P. (2000) *EM&P* 82/83, p.505-524
- [10] Trigo-Rodríguez J.M. (1992) *WGN* 20, p.105-106.
- [11] Baggaley W.J. (1975) *Nature* 257, p.567-568.
- [12] Betlem H., Jenniskens P., Spurny P., Van Leeuwen G.D., Miskotte K., Ter Kuile C.R., Zarubin P. and Angelos C. (2000) *EM&P* 82-83, p.277-284.
- [13] Trigo-Rodríguez J.M., Llorca J. and Fabregat J. (2002) *EM&P* 91, p.107-119.
- [14] Gustafson B.A.S (1989), *A&A* 225, p.533-540.
- [15] Halliday I. (1988) *Icarus* 76, p.279-294.