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Reanalysis of the cosmic dust L 2011 S2 and L 2009 I14 NASA samples

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Abstract: In this study the cosmic dust samples L 2011 S2 and L 2009 I14 have been reanalysed. Particles were obtained from the NASA Johnson Space Center(JSC) Cosmic Dust Collection. The reanalysis of the particle L 2009 I14 near the equilibrium state shows the 6.7 mass % of SiO_2, and 60; 16.7; 5.4 and 11.2 mass % of pyroxene, cordierite pentlandite and iron silicide Fe_2Si, respectively.

In the case far from equilibrium state there can not be excluded a presence of other phases as bronzite or hypersthene or klinoferrosilite as well as troilite and pyrrhotite and sluggish crystallised pyroxene.

For particle L 2011 S2 it was not possible to make any reliable qualitative conclusions due to problems mentioned in the paper.

Key words: cosmic/interplanetary dust – chemistry – analytical electron microscope – porous chondritic micrometeorites

1. Introduction

A complex analysis (or reanalysis) of stratospheric NASA dust samples is important from several points of view. One of them is the **origin** of

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collected dust samples, which often include ultrafine - grained chondritic interplanetary dust particles (IDPs), that mostly may be debris from:

- the impact erosion of asteroids in the main belt between Mars and Jupiter;
- icy–bodies in the Edgeworth – Kuiper belt beyond the Neptune orbit;
- cometary dust released during perihelion passage (when ice sublimation release embedded dust from the nucleus);
- extinct and dormant comets;
- carbonaceous chondrite parent bodies, including the (infared) C and K classes of asteroids;
- C-rich (infared) asteroidal class P and D;
- carbon-bearing chondritic IDPs include predominantly anhydrous CP (chondritic porous) IDPs, but also hydrated, generally CS (chondritic smooth) IDPs, etc. *(Rietmeijer, 1996; Bradley et al., 1988).*

It is also to be emphasized, that contribution of the present population of active comets (of all periods of revolution), is not only inadequate to explain the abundance of small interplanetary particles, but also inconsistent with the distribution of their orbits *(Kresák, 1980).*

So IDPs are the best samples available for a study of dust that accreated at 4,56 Ga ago, when the early solar system was formed. Therefore our reanalysis of L 2011 S2 and L 2009 I14 particles can also contribute to finding a solution for their origin.

Another important aspect is **dynamics** of dust particles. It is well-known, that crucial dynamical factors, which are necessary in evaluating the evolution of the dust orbits (e.g. the efficiency factor Q_{pr}, the complex refractive index $m(\lambda)$, the mean bulk density, the dimensionless dynamical parameter β, the packing factor and other derived optical-physical properties) depend also on chemical composition of examined microparticles. Therefore a more precise EDS spectra together with surface texture, porosity and other physical properties help us to obtain more reliable input data

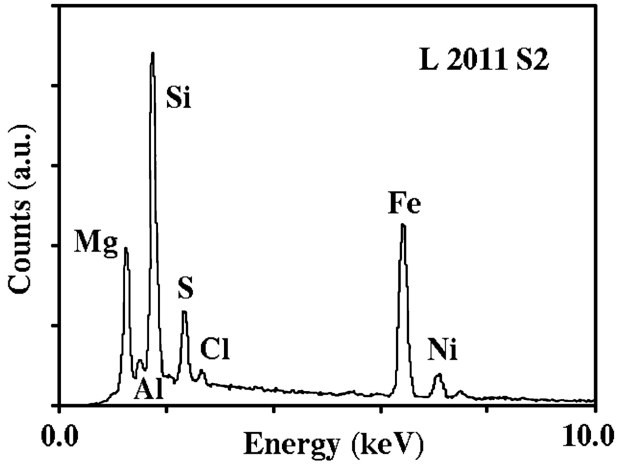

Fig. 1. The original NASA preliminary analysis of L 2011 S2 sample with dominating peak for Si and smaller peaks for Mg, S and Fe elements in EDS X-ray spectrometry.

necessary for further theoretical study in the field of the cosmic dust dynamics and joined astronomical interpretation. It was also one of the main reason to continue and finish a more detailed chemical analysis of the last set of NASA samples in the presented paper.

2. A brief history of L 2011 S2 and L 2009 I14 samples

With respect to the restriction by the List of Available Interplanetary Dust Samples published in Dust Courier N12 issued in February 1997 (see pp. 15–18), and also with respect to the aim of our research in the theoretical field it was decided to choose other two particles of cosmic origin gathered at the collection areas L 20011 and L 2009, respectively.

Particle L 20011 S2, similarly to particle L 20011 S5 which we reanalysed two years ago *(Kapišinský et al., 2001)* was one of the cosmic samples retrieved from collection surface designated L 20011. That surface had been exposed during a series of flights also made within west central North America flown aboard a NASA ER-2 aircraft in the fall of 1989. *Barrett et al.*

(1992) in the thirteenth volume of Cosmic Dust Catalogue (CDC) published in September 1992, summarized preliminary analyses of 328 particles of all different types. Among the type "C" - cosmic dust - as it was classified by the Cosmic Dust Preliminary Examination Team (CDPET), we decided to reanalyse the equidimensionally shaped, opaque particle L 20011 S2, 26 × 22 micrometers in size, with black colour and submetallic luster. The original NASA preliminary analysis has shown the highest peak for Si and relatively lower peaks for Mg, S and Fe elements in X-ray energy - dispersive spectrometry (EDS) as we can see in CDC V13 quoted above on the page 134 (Fig. 1). Second particle L 2009 I14, was classified by the CDPET in NASA as cosmic dust (type "C") and published in June 1994 in the fourteenth volume CDC *(Warren et al., 1994)* on page 212. This volume is a summary of the preliminary analyses of 558 particles, which were retrieved from collection surfaces L 2008 and L 2009. These surfaces were flat plates LAC (Large Area Collectors), each with a 300 cm^2 surface area, which were coated with dimethyl siloxane (silicon oil). Among the samples on L 2009 surface was also the cosmic particle I14.

The particle L 2009 I14 is irregularly shaped, 33×22 micrometers in size, black coloured, opaque with dust luster. In the NASA original EDS spectrum of Si and Fe elements dominated, but small peaks of Mg, S and Ni were visible too, accompanied by little paths of Al and Cr. This sample was collected also during a series of flights that were made within west-central North America in a standard manner, i.e., flown aboard a NASA ER-2 aircraft. Collectors were installed in a specially constructed wing pylon, which ensured the necessary level of cleanliness between periods of active sampling. In the case of L 2009 surface it means, the successive periods of high altitude (20 km) cruise and 36 hours of exposure accumulated time in June-July 1991, when the collector was exposed in the stratosphere by barometric controls and then retracted into sealed storage containers prior to descent.

All necessary original information about L 2009 I14 sample can be seen in CDC V14 quoted above on page 212 (Fig. 2). The main results of our EDS reanalysis are summarized in the next sections.

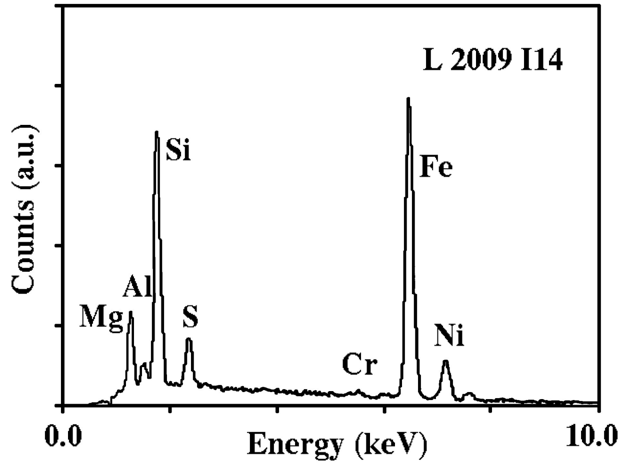

Fig. 2. The NASA EDS spectrum of L 2009 I14 particle with the highest peaks of Si and Fe elements, but small peaks of Mg, S and Ni are visible, too.

3. Technical equipment

Analytical electron microscope JEM 100 C operated at the accelerating voltage of 20 kV with scanning attachment ASID-4D and EDX spectrometer KEVEX DELTA 4 equipped with a QUANTUM window (L 2011 S2) and JEOL JSM - 5310 scanning electron microscope operated at the accelerating voltage of 15 kV with an EUMEX detector with beryllium window (L 2009 I14) were used for dust particle analysis. Secondary electron micrographs and energy dispersive X-ray spectra were obtained. Point analysis as well as X-ray mappings representing composition over the entire particle were performed. The obtained spectra were processed with the XPP (eXtended Phi-rho-z Procedure) - program modified for light element analysis.

4. Experimental results

The results of our EDXS analysis of particle L 2011 S2 are summarized together with the technical conditions of microscope data described above in

Table 1. Unfortunately, with respect to technical and processing problems (microscope which was not equipped with an oxygen detector, and therefore, the percentage of oxygen was not registered there) it was not possible to make such qualitative conclusions about this particle as it was done in the case of particle L 2009 I14. Therefore besides of Table 1 we present only a graph of approximate chemical composition (see Fig. 3) without a more comprehensive discussion.

Table 1. Standardless EDS analysis (XPP Quantification) of the NASA L 2011 S2 sample

Element & Line		Weight Percent	Atomic Percent*	Precision 2 Sigma	K-Ratio**
Mg	Ka	16.51	21.87	0.00	0.0996
Al	Ka	17.05	20.34	0.00	0.0996
Si	Ka	16.26	18.64	0.00	0.0996
S	Ka	13.72	13.77	0.00	0.0996
Cl	Ka	14.10	12.80	0.00	0.0996
Fe	Ka	11.11	6.40	0.00	0.0996
Ni	Ka	11.26	6.17	0.00	0.0996

* Note: Atomic percent is normalized to 100
** Note: K-Ratio = K-Ratio x R
where R = reference (standard)/reference (sample)
Normalisation factor: 1.00
Iterations 8

Regarding particle L 2009 I14, the situation was more suitable. The results of this analysis are presented in Table 2 and graphically shown in Fig. 4.

The EDXS analysis of L 2009 I14 sample was recalculated taking into account the standard free energy of formation of all possible compounds. However, there is a crucial problem, because nothing is known about the state of the system concerning equilibrium. Suppose the system had enough time to be near the equilibrium state, than the phase composition would be as follows:

– 6.7 mass% of SiO_2
– 60 mass % of pyroxene (enstatite)
– 16.7 mass % of cordierite
– 5.4 mass % of "pentlandite" which composition is $(Fe_{0.65}Ni_{0.35})_9S_8$

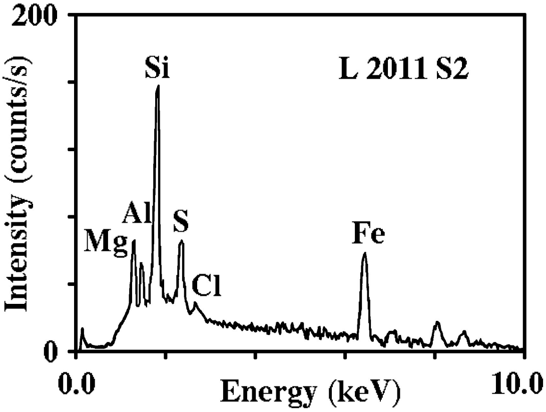

Fig. 3. EDXS analysis of L 2011 S2 particle with the highest peak of Si element and smaller secondary peaks of Mg, Al, S and Fe elements.

Table 2. Standardless EDS analysis (XPP Quantification) of the NASA L 2009 I14 sample

Element & Line		Weight Percent	Atomic Percent*	Precision 2 Sigma	K-Ratio**
O	Ka	28.74	46.99	1.15	0.0871
Mg	Ka	10.96	11.79	0.32	0.0368
Al	Ka	2.50	2.43	0.15	0.0095
Si	Ka	22.21	20.68	0.29	0.1109
S	Ka	4.35	3.55	0.13	0.0250
Fe	Ka	28.19	13.20	0.33	0.2499
Ni	Ka	3.05	1.36	0.14	0.0258

* Note: Atomic percent is normalized to 100
** Note: K-Ratio = K-Ratio x R
where R = reference (standard)/reference (sample)
Normalisation factor: 1.00
Iterations 11

– 11.2 mass % of iron silicide Fe_2Si.

A more complicated situation arises if the system is far from equilibrium. In the porous system the presence of iron oxide cannot be excluded. In this case other phases as bronzite or hypersthene ((MgO, FeO)SiO_2) or klino-

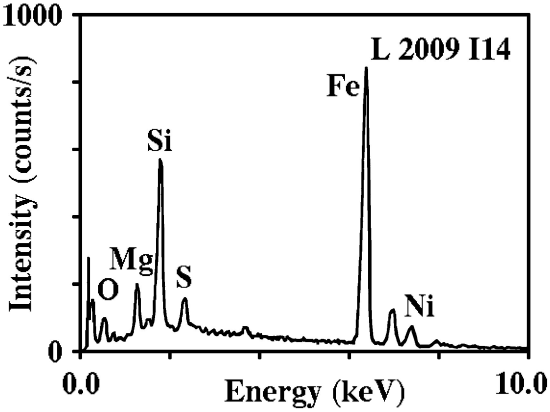

Fig. 4. The EDXS analysis of L 2009 I14 particle with the highest peak of Si element and smaller secondary peaks of Mg, Al, S and Fe elements.

ferrosilite ($FeO.SiO_2$) as well as the troilite (FeS) and pyrrhotite ($Fe_{1-x}S$), beside the sluggish crystallised pyroxene, may be present.

5. Discussion

In spite of the technical problems concerning the analysis of L 2011 S2 sample, one cannot expect any substantiated differences (except of oxygen containing compounds) in its basic chemical composition to be derived from new measurement.

Finally we would like to mention, that sulphur is a volatile element that will evaporate from sulphides during the atmospheric entry flash heating. This means that variable sulphur content that can go all the way from the S/Fe ratios in sulphide minerals to pure Fe-oxides may occur in the IDPs. The most common sulphide in IDPs is pyrrhotite (S/Fe close to unity). Pyrrhotite occurs both as Ni-free and Ni-bearing grains, while some IDPs also contain pentlandite, and Fe, Ni-sulfide. A complete review of the mineralogy in IDPs was published in (Reviews in Mineralogy vol. 36., Mineralogical Society of America). As some fraction of iron is also associated with olivine, pyroxene and amorphous ferromagnesiosilica materials in

IDPs, particularly in aggregate IDPs, one has to be careful with an estimation of sulphide phase content or compositions of sulfides in IDPs (personal communication, February 04, 2000, Rietmeijer, F.J.M. – V. Figusch)

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