# Reanalysis of porous chondritic cosmic dust particles

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**Abstract.** The particles reanalysed in this study were obtained from the NASA Johnson Space Center (JSC) Cosmic Dust Collection. The reanalysis of the particle L2008 P9 indicates typical assemblage of olivine - pyroxene. This sample can be classified as a chondritic porous IDP with the metallic phase grain containing essential amount of nickel and copper (the latter element is most probably due to instrumental artefact). The chemical composition of the particle L2011 S5 corresponds mostly to an assemblage of pyroxene phase - (Mg,Fe,Ni)$SiO_3$ roughly 75 wt.% and a sulphide phase - probably pyrrhotite (Fe,Ni)S about 25 wt.%.

**Key words:** cosmic/interplanetary dust, chemistry, analytical electron microscope, olivine, pyroxene, porous chondritic micrometeorites

## 1. Introduction

Interplanetary dust particles (IDPs) are predominantly debris from impact erosion of asteroids in a belt between Mars and Jupiter and icy-bodies in the Edgeworth-Kuiper belt beyond the Neptune orbit and cometary dust released during perihelion passage when ice sublimation releases embedded dust from the nucleus. IDPs are therefore the best samples available for the study of dust that accreated in the early solar system to form protoplanets at 4.56 Ga ago.

As in this paper, the analysis of cosmic samples are the first step to gaining the more reliable input data which is necessary for further theoretical and modelling research in the field of the dust dynamics. A more precise EDS (X-ray energy-dispersive spectrometry) spectra, chemical composition, porosity, etc. of the examined particles help us to obtain more precise crucial factors needed in evaluating the evolution of the dust orbits, e.g. the complex refractive index m($\lambda$), the efficiency factor Q$pr$, the dimensionless dynamical parameter $\beta$, the mean bulk density, the packing factor and many other derived optical-physical properties of the examined particle. Thus this paper deals with the chemical-analytical part only so far as are needed for the dynamical reasons mentioned above. These results have already been used and we tend to use the critical evaluation of several nongravitational effects which play an important role in the dynamics of cosmic dust in the interplanetary space (Kapišinský, 1984). Application of consequences is significant not only in the re-evaluation of classical Poynting-Robertson effect but also in other effects (see e.g. Kocifaj et al., 1999, 2000, etc.).

A workable first-order classification scheme made a chemical subdivision into chondritic and iron-chondritic IDPs. A particle is "chondritic" when the elements Mg, Al, Si, S, Ca, Ti, Cr, Mn, Fe and Ni occur in relative proportions similar (within a factor 2) to their cosmic abundance, represented by the CI, carboneous chondrite composition (Brownlee et al. 1976). So, according to results of our reanalysis of both our chondritic IDPs we can depict then as CI and CM carboneous chondrites, which are very fine-grained, have carbon and sulphur contents greater than 4 wt. % and contain pyrrhotite, Fe-poor olivines and pyroxenes and magnetite. In this conclusion the chondrite classification is used (see. e.g. F. Heide and F. Wlotzka, 1995), where there are the most primitive, in chemical sense, CI chondrites, named after a type of specimen by Ivuna. They consist of up to 99 % of a fine-grained mixture of hydrated phyllosilicates . Unfortunately, only five representatives of these CI chondrites are known (the largest is Orgueil).

CM chondrites (after the specimen type Mighei) consist of about 50 % of a hydrous, fine-grained groundmass similar to CI chondrites (for details see F. Heide and F. Wlotzka, 1995).

## 2. History of analysed particles

The original aim when choosing the suitable particles for the reanalysis was to gain the greatest and the most compact particles of cosmic origin. Our margin of choice was however restricted by the List of Available Interplanetary Dust Samples published in Dust Courier, N12 issued in February 1997 (see pp. 15-18). With respect to this restriction and with respect to the aim of our research in the theoretical field it was therefore decided to choose four particles of cosmic origin gathered at the collection areas L2008, L2009 and L2011, respectively. From these particles only two were chosen for the reanalysis in the paper: L2008 P9 and L2011 S5 with respect to their optical and physical features.

The fourteenth volume of Cosmic Dust Catalog was published in June 1994 by the NASA JSC, (Warren et al., 1994), compiled as usual by the Cosmic Dust Preliminary Examination Team - CDPET. It is summary of the preliminary analysis of 558 particles. They were retrieved from collection surfaces L2008

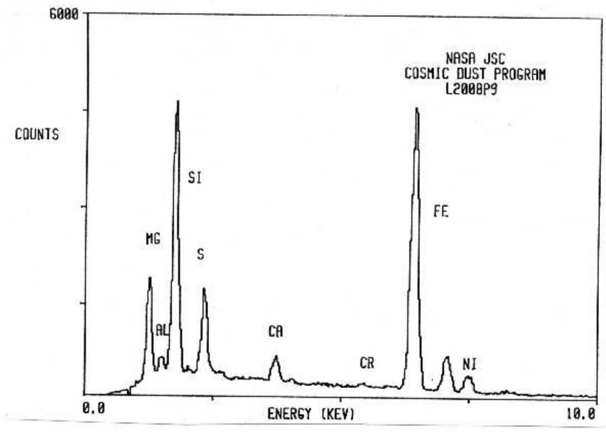


**Figure 1.** The NASA EDS preliminary spectrum of the particle L2008 P9

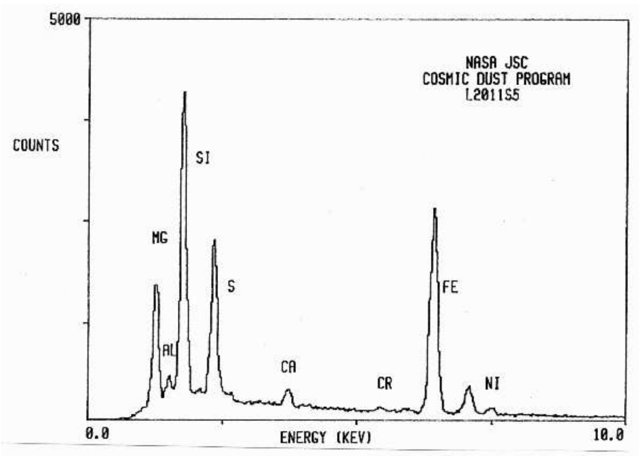


**Figure 2.** Original EDS spectrum of the sample L2011 S5

and L2009. Among the samples on the L2008 surface, there was also cosmic particle P9.

PARTICLE L2008 P9 was classified by the CDPET in NASA as cosmic dust (type "C") and published in CDC quoted above (see page 135). The particle is irregularly shaped, 30 × 22 micrometers in size, yellow to black coloured, opaque, with a dull luster. In the NASA original EDS spectrum peaks of Si and Fe elements dominated, but the small peaks of Mg and S are visible too, accompanied by little paths of Al, Ca, Ni. This sample was collected during a series of flights made within west-central North America in a standard manner with a total 40 hours of stratospheric exposure (time) in November 1989. The collection surface L2008 had a 300 $cm^2$ surface area, known as LAC - Large Area Collector.

The EDS preliminary spectrum of the particle L2008 P9 made by CDPET in NASA is shown in Fig. 1.

PARTICLE L2011 S5 was one of the cosmic samples retrieved from collection surface designated L2011 that 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. CDC V13 (Barrett et al., 1992) summarizes preliminary analyses of 328 particles of all types. Among the cosmic dust (classified as type "C" by the CDPET) we decided to reanalyse the equidimensional shaped, opaque particle L2011 S5, $32 \times 15$ micrometers in size, with brown to black colour and a resinous luster. The original NASA analysis shows the highest peak for Si and relatively lower peaks for the Mg, S and Fe elements in EDX spectrum as we can see in CDC V13 quoted above (see page 136). The original EDS spectrum of examined of chondritic aggregate IDP L2011 S5 made in NASA is in Fig. 2. The main results of our EDS reanalysis follow in the next section.

## 3. Experimental results

Our analysis was carried out by means of an analytical electron microscope JEM 100C with scanning attachment ASID-4D and EDX spectrometer KEVEX DELTA 4 equipped with a QUANTUM window and an electron-hardened Si(Li) detector. X-ray mappings representing composition over the entire particle were also performed. The spectra were processed with the XPP (eXtended Phi-rho-z Procedure) - program modified for light elements analysis. Point (quantitative) analyses in 20 and 30 points, respectively of both examined samples were also carried out. The results of analysis of particle L2008 P9 are presented in Table 1. Used technical microscope output data includes:

- Accelerating voltage 20.0 KeV
- Beam - sample incidence angle 60.0 degrees
- X-ray emergence angle 20.7 degrees
- X-ray - window incidence angle 0.0 degrees

For illustration in Fig. 3 there are the positions of surface points A1 up to A6 in which point analysis was made. These point analyses depict how the chemical composition of particle changes from point to point. To save space we only present a graph of the approximate chemical composition at points A1 and A3 (see Figs. 4 and 5). It must be noted that for better graphical illustration these figures were made on a microscope which was not equipped with an oxygen detector and therefore the percentage of oxygen was not registered there.

**Table 1.** Standardless EDS Analysis (XPP Quantification)

| Element & Line | Weight Percent | Atomic Percent* | Precision 2 Sigma | K-Ratio** |
|---|---|---|---|---|
| O KA | 25.06 | 41.19 | 0.81 | 0.0661 |
| Mg KA | 15.92 | 17.22 | 0.26 | 0.0581 |
| Al KA | 3.65 | 3.56 | 0.13 | 0.0137 |
| Si KA | 20.96 | 19.62 | 0.20 | 0.1016 |
| S KA | 4.66 | 3.82 | 0.10 | 0.0266 |
| Cl KA | 1.99 | 1.48 | 0.08 | 0.0122 |
| Ca KA | 1.22 | 0.80 | 0.05 | 0.0102 |
| Cr KA | 0.13 | 0.06 | 0.02 | 0.0011 |
| Fe KA | 22.22 | 10.46 | 0.20 | 0.1959 |
| Ni KA | 1.76 | 0.79 | 0.09 | 0.0150 |
| Cu KA | 2.44 | 1.01 | 0.12 | 0.0201 |

*Note: Atomic percent is normalized to 100
**Note: K-Ratio = K-Ratio × R
where R = reference(standard)/reference(sample)
Normalisation factor: 1.000

Concerning particle L2011 S5 our analysis is presented in the following Tab. 2 with the same technical conditions of microscope data as for particle L2008 P9.

Along a line crossing the examined particle L2011 S5 point analysis at 20 points (see Fig. 6) was also made. These point analyses demonstrates a very heterogeneous composition on a micrometer scale, concerning seven basic elements, despite the fact that the percentage of three of the elements is not of good visibility at the bottom of the graph (see Fig. 7).

## 4. Discussion

Concerning the particle L2008 P9 our analysis indicates typical assemblage of olivine - pyroxene (see Tab. 1).

This particle is certainly of natural extraterrestrial origin and can be classified as chondritic porous IDP (Reitmeijer, 1992).

Due to the dimensions involved it is not possible to analyse individual mineral grains but only sub-assemblies consisting of approximately 10 to 100 grains.

All characteristics and estimation of chemical composition clearly points to the high particles' heterogeneity in the order of $10^{-7}$ to $10^{-5}$ m.

Reanalysis of several predominant olivine-pyroxene particles showed a certain amount of sulphur. In some particles multipoint analysis indicates correlation of iron and sulphur content, but due to the size of primary grains (mostly

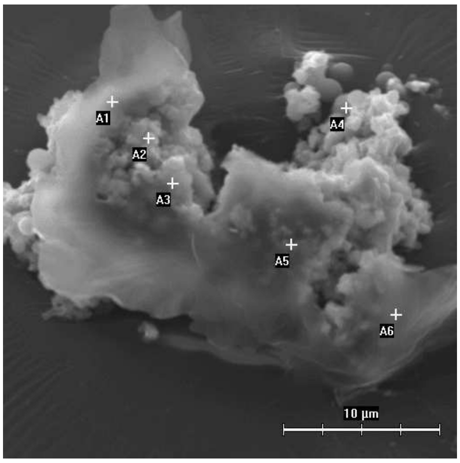


**Figure 3.** The positions of surface points A1 up to A6 on the particle L2008 P9

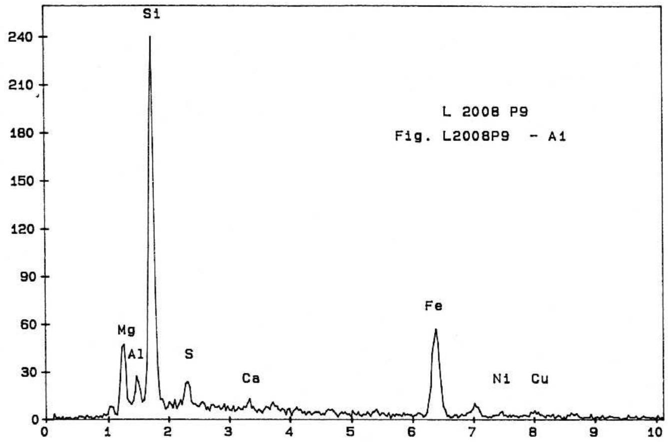


**Figure 4.** The approximate chemical composition at point A1, without oxygen detector

several hundreds nanometers), it is not possible to identify individual sulphide grains.

The measurement revealed that this particle can also be classified as a chondritic porous IDP showing characteristics of a polyphase unit (Rietmeijer, 1992). In our analysis at a single point a metallic phase grain containing essential amount of nickel and copper was found.

The surprisingly high wt. % (and at. % also) of copper is not present in the original NASA analysis. It is open question whether the presence of a copper peak is an instrumental artefact due to spurious X-rays generated in the

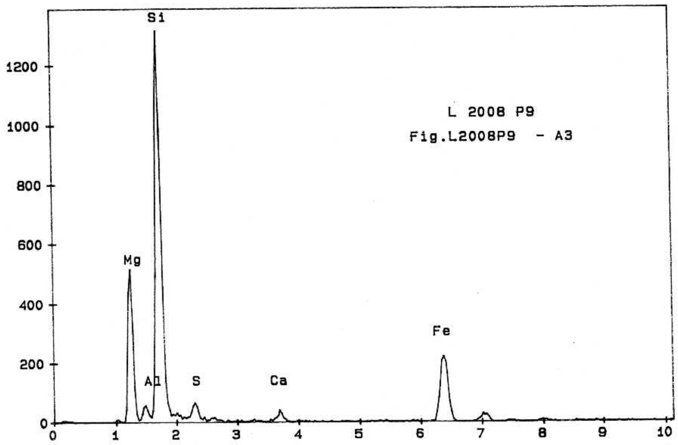


**Figure 5.** The approximate chemical composition at point A3, without oxygen detector

**Table 2.** Standardless EDS Analysis (XPP Quantification)

| Element & Line | Weight Percent | Atomic Percent* | Precision 2 Sigma | K-Ratio** |
|---|---|---|---|---|
| O KA | 30.38 | 48.73 | 0.57 | 0.0881 |
| Mg KA | 12.12 | 12.79 | 0.15 | 0.0414 |
| Al KA | 1.23 | 1.17 | 0.06 | 0.0046 |
| Si KA | 19.77 | 18.06 | 0.13 | 0.1000 |
| S KA | 7.20 | 5.76 | 0.07 | 0.0426 |
| Ca KA | 0.52 | 0.33 | 0.02 | 0.0044 |
| Cr KA | 0.13 | 0.07 | 0.02 | 0.0012 |
| Fe KA | 25.02 | 11.50 | 0.15 | 0.2207 |
| Ni KA | 3.63 | 1.59 | 0.08 | 0.0308 |

Total 100.00
Iterations 11
*Note: Atomic percent is normalised to 100
** Note: K-Ratio = K-Ratio × R
where R = reference(standard)/reference(sample)
Normalisation factor: 1.000

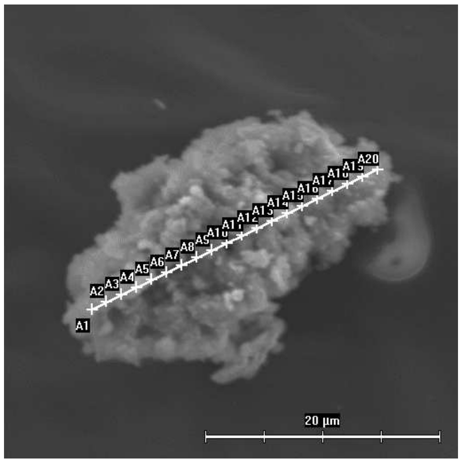


**Figure 6.** The line crossing the examined particle L2011 S5 with 20 points

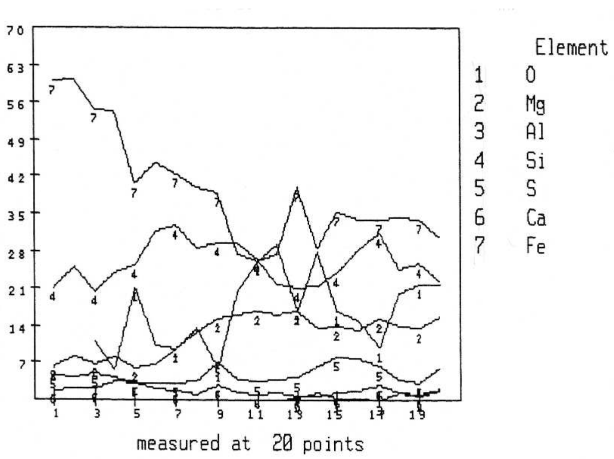


**Figure 7.** The point analysis, concerning seven basic elements. The percentage of other elements is not of good visibility at the bottom of the graph

electron microscope (as was published several times in similar analyses (see e.g. Rietmeijer, 1998).

The results show that the chemical composition of the particle L2011 S5 corresponds mostly to an assamblage of pyroxene phase - (Mg, Fe, Ni)$SiO_3$ approximately 75 wt. % and a sulphide phase – most probably pyrrhotite (Fe, Ni)S about 25 wt. %. The distribution of the analysed amount of 1,59 at. % of nickel can not be resolved from these results. The ratio of Mg/(Mg+Fe) in pyroxene phase can be estimated roughly to 0,65, i.e. about 2/3 positions for divalent atoms are occupied by magnesium atoms.

The Fe/Ni atomic ratio in the reanalysed particles ranges mostly from 5 to 30, which is a lower value than the average value of 29,4 observed in porous chondritic IDPs by Schramm et al., 1989. The atomic and also weight Fe/Ni ratio in particle L2008 P9 was evaluated for three different point measurements. The results are presented in the following three tables:

**Table 3.** Analysis of iron and nickel percentage at six selected points in particle L2008 P9

| Analysis Point | Fe [at. %] | Ni [at. %] | Fe/Ni |
|---|---|---|---|
| A1 | 22.85 | 2.49 | 9.2 |
| A2 | 14.89 | 0.92 | 16.2 |
| A3 | 15.30 | 0.37 | 41.4 |
| A4 | 6.36 | 1.68 | 3.8 |
| A5 | 28.19 | 5.14 | 5.5 |
| A6 | 21.16 | 2.25 | 9.4 |

**Table 4.** Analysis of iron and nickel percentage in particle L2008 P9 along line with 20 points (data in weight per cent were inferred from graph

| Analysis Point | Fe [wt. %] | Ni [wt. %] | Fe/Ni |
|---|---|---|---|
| 1 | 2.0 | | |
| 2 | 18.0 | | |
| 3 | 16.0 | | |
| 4 | 12.0 | | |
| 5 | 10.5 | | |
| 6 | 10.8 | | |
| 7 | 11.5 | 1.3 | 8.9 |
| 8 | 21.0 | 0.7 | 30.0 |
| 9 | 14.0 | 1.2 | 11.7 |
| 10 | 18.5 | 1.3 | 14.2 |
| 11 | 17.0 | 1.0 | 17.0 |
| 12 | 17.0 | 1.2 | 14.2 |
| 13 | 9.0 | 2.1 | 4.3 |
| 14 | 19.0 | 0.6 | 31.7 |
| 15 | 31.0 | 1.5 | 20.7 |
| 16 | 25.0 | 0.6 | 41.7 |
| 17 | 21.5 | 0.6 | 35.8 |
| 18 | 29.5 | | |
| 19 | 35.0 | | |
| 20 | 34.0 | | |

**Table 5.** Analysis of iron and nickel percentage in particle L2008 P9 along another line with 30 points (data in weight per cent were inferred from graph)

| Analysis Point | Fe [wt. %] | Ni [wt. %] | Fe/Ni |
|---|---|---|---|
| 1 | 37.0 | 3.5 | 10.6 |
| 2 | 25.5 | 2.3 | 11.1 |
| 3 | 31.0 | 2.3 | 13.5 |
| 4 | 24.0 | 1.7 | 14.1 |
| 5 | 22.5 | 1.5 | 15.0 |
| 6 | 23.0 | 3.5 | 6.6 |
| 7 | 27.0 | 1.0 | 27.0 |
| 8 | 24.0 | 3.2 | 7.5 |
| 9 | 25.5 | 3.2 | 8.0 |
| 10 | 20.0 | 1.2 | 16.7 |
| 11 | 24.0 | 0.4 | 60.0 |
| 12 | 18.5 | 2.0 | 9.3 |
| 13 | 20.0 | 1.4 | 14.3 |
| 14 | 23.0 | 3.3 | 7.0 |
| 15 | 20.0 | 0.8 | 25.0 |
| 16 | 19.0 | 0.0 | |
| 17 | 20.0 | 0.0 | |
| 18 | 17.0 | 0.0 | |
| 19 | 17.5 | 0.0 | |
| 20 | 20.0 | 0.0 | |
| 21 | 29.0 | 0.0 | |
| 22 | 13.0 | 0.0 | |
| 23 | 13.5 | 0.0 | |
| 24 | 10.0 | 0.0 | |
| 25 | 16.0 | 0.0 | |
| 26 | 7.0 | 0.0 | |
| 27 | 3.5 | 0.0 | |
| 28 | 18.5 | 0.0 | |
| 29 | 18.5 | 0.0 | |
| 30 | 18.5 | 0.0 | |

The observed differences in local chemical composition are undoubtedly related to chemical heterogeneity but the effects due to surface morphology of the analysed particle have to be taken seriously into account.

Finally we would like to mention an ambition to thin both individual reanalysed particles using the ion milling method to make possible pioneer observations by transmission electron microscopy.

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