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Cosmic Microsphere: a sem study

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Abstract. We have collected, with traditional and less traditional methods, a number of glassy and ferrous micro-spherules (MS). The recovery of the samples was made from many different places inside and outside Italy. Unusual and sometimes astonishing pictures and analytical results strongly indicate a common source for all MSs we checked. Similar synthetic spherules, we was able to produce starting from material of guaranteed cosmic origin, suggest that also a meteoric source could be taken in serious account.

Key words. Meteorites, micrometeorites – Cosmic Dust – Microspherules

1. Introduction

The influx of extraterrestrial material to the Earth at present has been estimated as 40.000 ± 20.000 10^3 kg/yr (Love & Brownlee 1993). When the size is > 1 mm the term meteorite is preferred; when the size is < 1 mm the preferred term is cosmic dust (CD). The CD, of which amount strongly prevails over the meteorites, is composed of Interplanetary Dust particles (IPD), micrometeorites (MM) and Micro-Spherules (MF in general and CF, Cosmic Spherules, in particular). The IPDs are irregular particles of about 10 micron and are gathered since 30 years in the stratosphere at a high of about 60 km, by special aircrafts equipped with adhesive panels (Brownlee et al. 1973) : being of small size and having not passed through the atmosphere, they cant undergo heating processes, so they are normally not differentiated.

The MMs, of which size ranges between some tens and some hundreds of microns, are gathered in terrestrial environments such as deserts or polar regions where they can easily be identified. The MSs are surely the more puzzling particles: their sizes range from 50 to 400 micron and they show a characteristic shape (spherical or oblate), that (when the origin is cosmic) can be explained only as ablation products by aerodynamic melting of meteoroids as they enter the atmosphere. Typical ablation spheres are produced by melting of submillimeter asteroidal and cometary fragments that enter the atmosphere at velocities ranging from 11 to 72 km/s.. The spheres are formed near 80 km altitude, where deceleration, intense frictional heating, melting up to 1500°C, partial vaporization, and solidification all occur within a few seconds. So the CSs are probably the main components of the CD (Brownlee et al. 1998) and it is not surprising that their composition is mainly stony with a small amount of metallic fraction (Iron + traces of Nichel, partially oxidized on the surface by the contact with atmospheric oxygen). The research of CSs started during the second half of IXX century. Spherules of presumed extrater-

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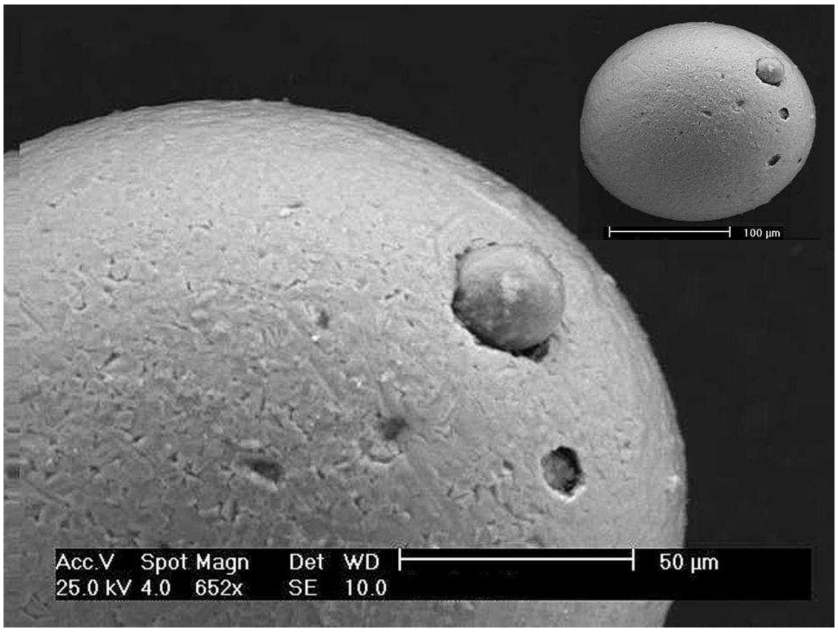

Fig. 1. A *compact* metallic MS found in rain water at Tradate.

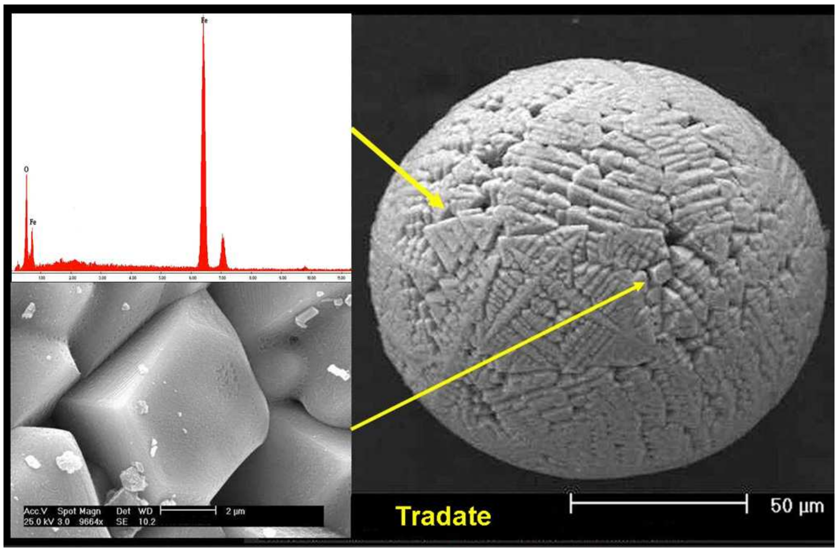

Fig. 2. A *crystalline* metallic MS found in rain water at Tradate.

restrial origin were first discovered more than a century ago, in snow samples by Swedish geologist A.E. Nordenskjold (Nordenskjold 1874) and in deep-sea sediments of the south Pacific during the Challanger Expeditions by Sir John Murrey (Murrey, & Renard 1891). Since the first half of 90s years, the main source of CSs is the Antartica, thanks to a brilliant idea of the so called CRRL (Corps' Cold Regions Research and Engineering), a scientists team

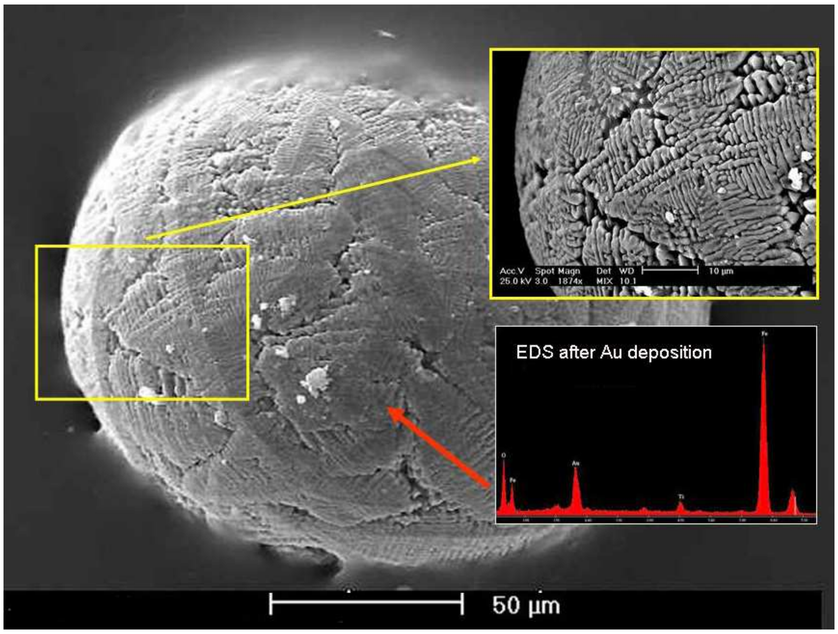

Fig. 3. A *crystalline* metallic MS found in the Arizona desert, near the town of Seligman.

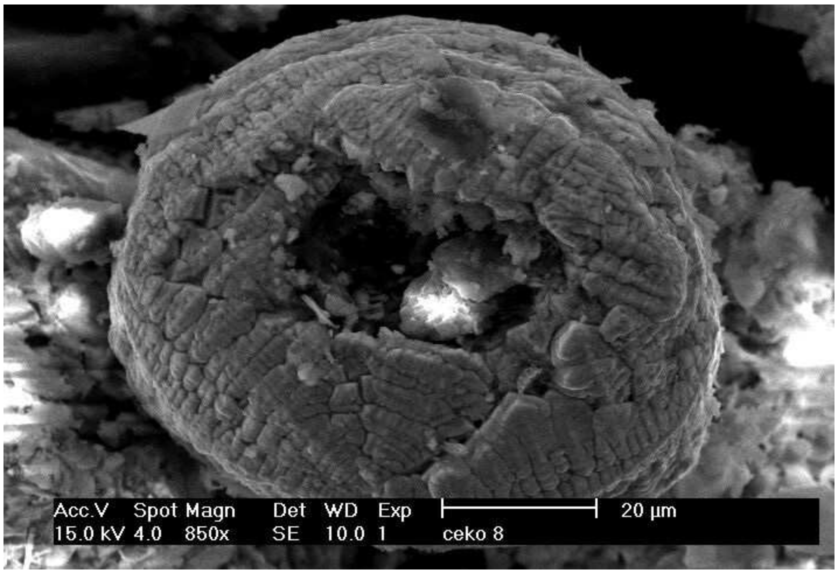

Fig. 4. A *crystalline* metallic MS found at Tunguska (courtesy Romano Serra).

of the New Hampshire University led by Susan Taylor (Taylor et al. 1998). In 1993 the CRRL built, near the antartic base of Amundsen-Scott, a giant 5000 m3 sub-surface water well named SPWW (South Pole Water Well), to be used as supply of drinking water for the station. The drinking water is produced introducing into the well tons of external ice, that

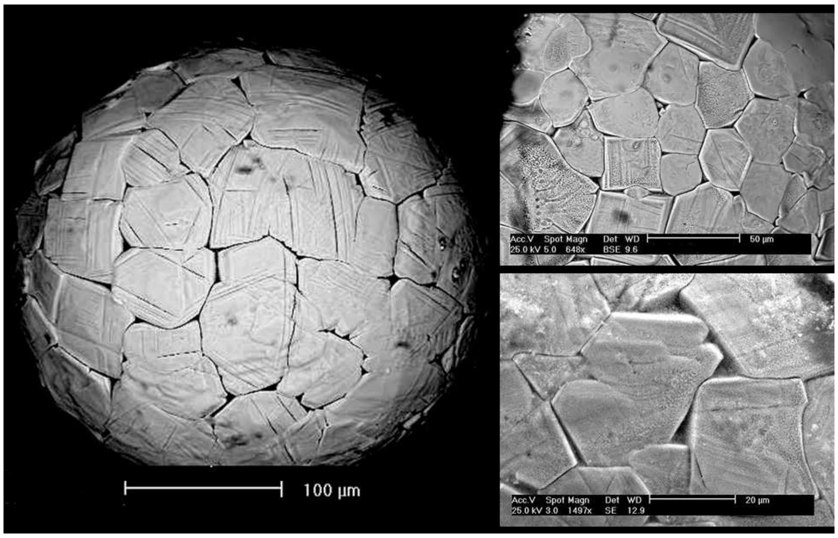

Fig. 5. A *polygonal* metallic MS found in rain water at Tradate.

is melted by using the waste heat generated by the station. Because the antartic ice is the best recovery terrain for MMs and CSs, as the well melts downwards, micrometeorites are released from the ice and remain on the bottom of the water-filled cavity. Here S. Taylor takes periodic drawings and carefully studies their composition and morphology. As a result, thousands of CSs have been collected with size between 20 and 400 μm. The composition is consistent with a cosmic origin (Taylor et al. 2000). The largest part of the antartic CSs shows a stony composition (CS of class S, part amorphous and part crystalline) and only about 1-2% shows a ferrous composition (CS of class I): this is in compliance with the composition of the ordinary chondrites, if we suppose that these MSs are formed from the intense frictional heating, vaporization and melting of the same chondrites when they enter the atmosphere (Greshake et al. 1998).

A strong evidence of the cosmic origin of the CSs is their regular presence inside many ancient geological sediments, even if glassy spherules tend to disappear because of their easy ambient degradation. For example, CSs (1% of class I) were recovered in a 3000 years old ice sheets of Greenlad (Mauriette, 1987). In general, the % of ferrous CSs increase up to 25% in 0,5 million year old marine sediments (Blanchard et al. 1978) and can reach also the 98% in some giurassic rocks (age of 190 million of years), recovered on the Austrian Alpes (Czajkowsky et al. 1987). A further proof of the cosmic origin of the CSs is their tendency to increase in connection with important cosmic impacts. An example is the Permian-Triassic boundary (age of 250 million years). In connection with the so called 'mother of all extinctions', high concentrations of CSs have been found on the following occurrence areas: Bukk Mounts, in Hungary (Detre et al. 1997), Sasayama, Tamba Belt, in Japan (Miono et al. 1996), Guizhou Province, in South Cine (Zhang 1997). In any case, if each year nearly 40.000 tons of cosmic dust fall the Earth from the outer space, the 'rain' of CSs has to be continuous and present everywhere. So we decided to think about some suitable recovery method, in order to collect enough material to make a morphological investigation with the SEM (a Philips XL30 Scanning Electron Microscope) and a composition analysis with the EDS probe (coupled with SEM).

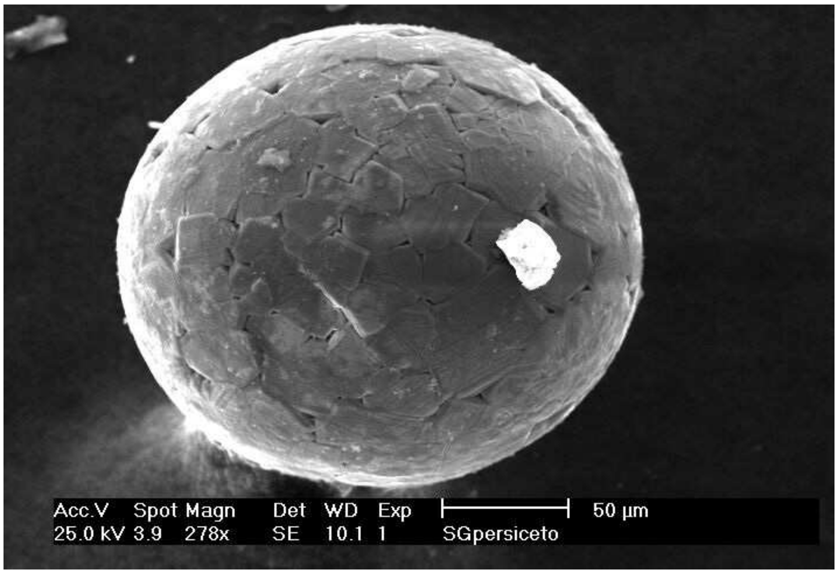

Fig. 6. A *polygonal* metallic MS found in the Arizona desert, neat the town of Seligman.

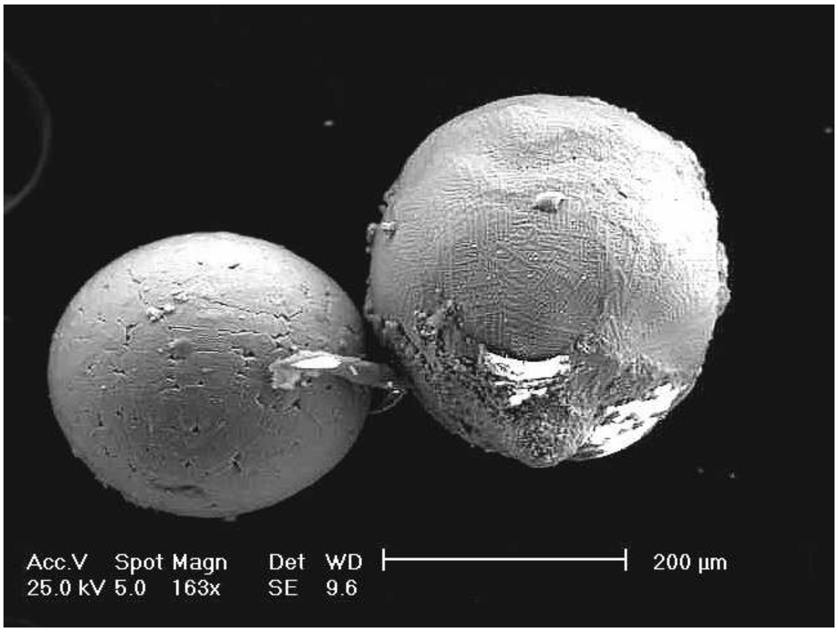

Fig. 7. A *filigreed* (right) + a polygonal (left) metallic MS found in rain water at Tradate.

2. Experimental part

The recovery of the samples was the first and fundamental problem to be solved. Being the samples micrometric in size and very diluted in concentration, we decided to start with a classical method (Stevenson 2003): collection of a large amounts of water from the home roof, after a very strong thunderstone, wait-

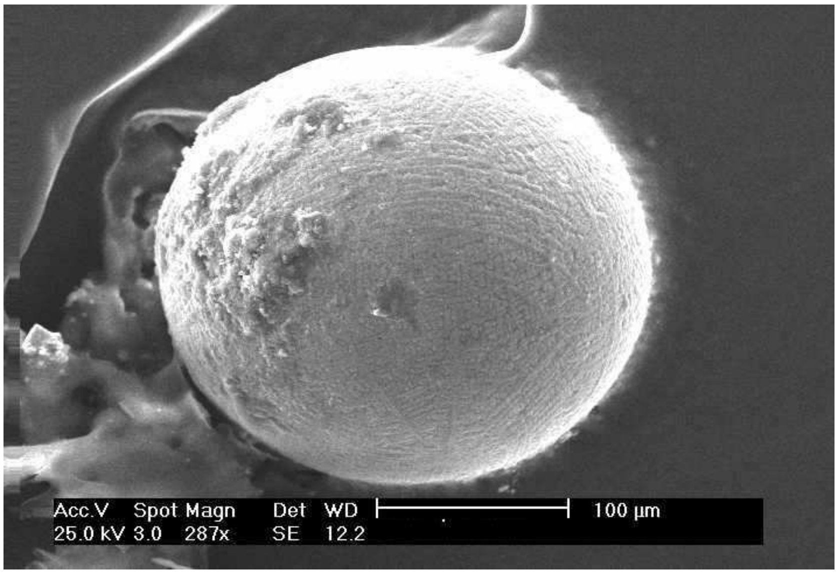

Fig. 8. A *filigreed* metallic MS found on March 31 06, near the Keope Pyramid (Egypt) after a strong rain.

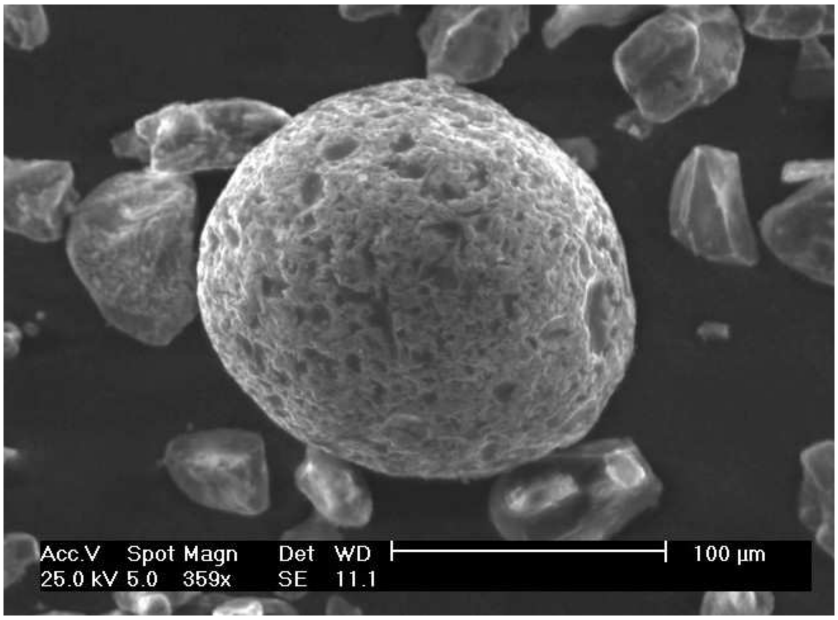

Fig. 9. A *pitted* metallic MS found in Lybia, near the Marzuq dunes (from stuff supplied by R. Serra).

ing some time for a good sedimentation and final recovery of the sediment on the bottom of the water container (slowly discharging the water from the top). A small residue (some mg) is always present, composed of dirt but also of CD, in the form of MMs and of CSs. As a matter of fact, because it is quite impossible to optically distinguish between the

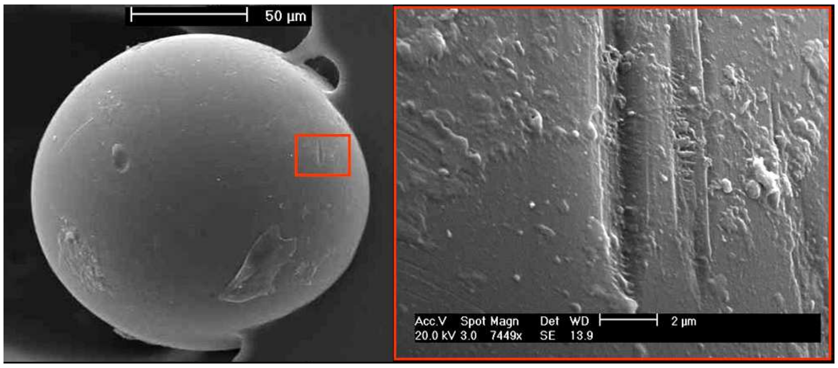

Fig. 10. A glassy MS found in a puddle at Tradate.

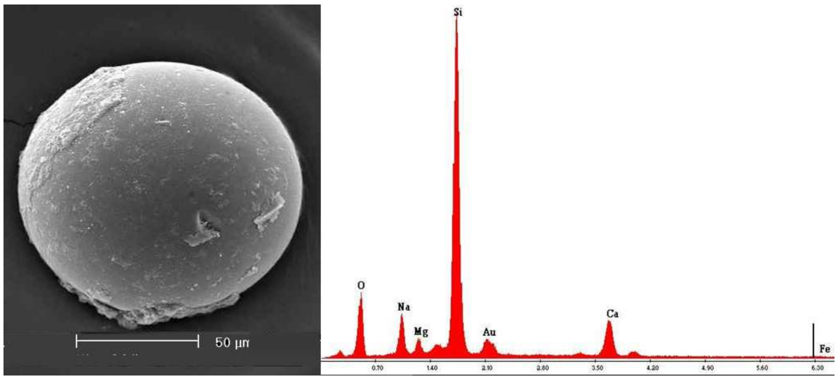

Fig. 11. EDS analysis on a glassy MS found in a puddle at Tradate.

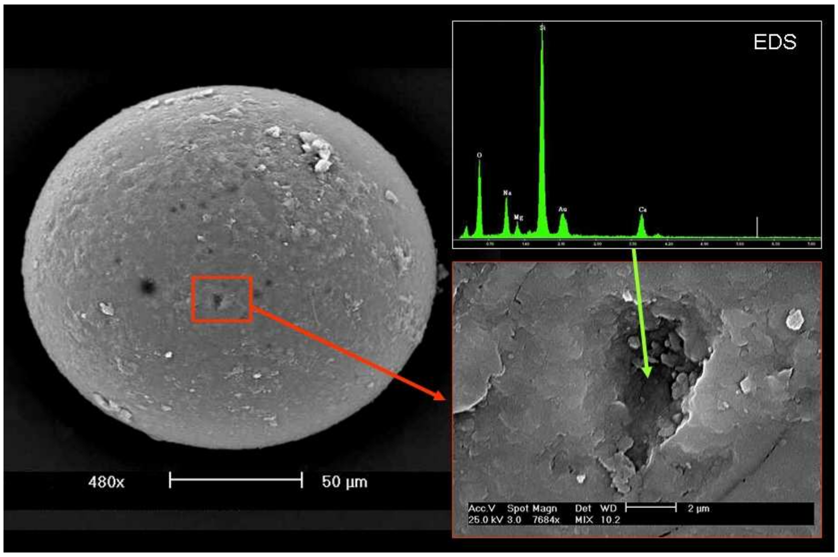

Fig. 12. EDS analysis on a glassy MS found in the Arizona desert.

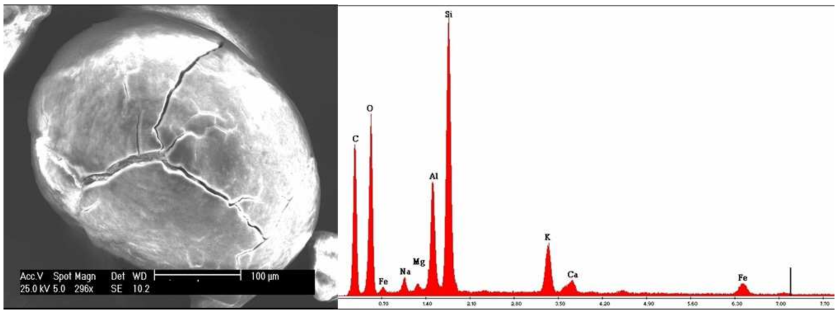

Fig. 13. A glassy CS found in the Numidia desert (from stuff supplied by R. Serra).

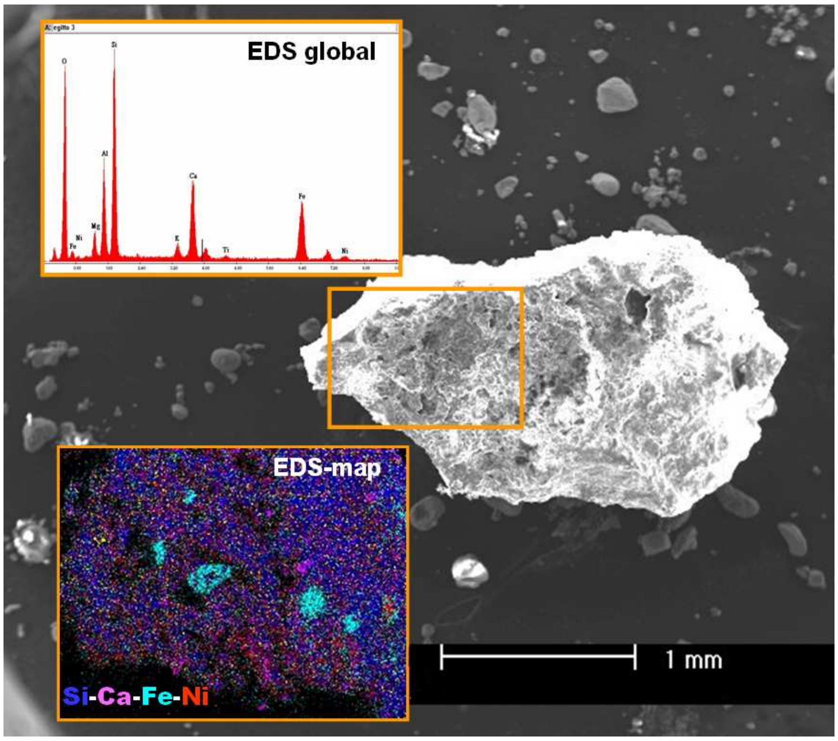

Fig. 14. An MM found in the Egypt desert (from stuff supplied by R. Serra).

MMs and similar terrestrial stuff, it is convenient to direct the attention only on MSs: their rounded shape make them already well visible under a small optical microscope at 20-30x. In this case, a magnet can give a further aid, because it allow an easier separation of the possible CSs of class I. First attempts of recovery made at Tradate (Va, Italy) by one of us (F. Martegani) on May 2005 gave interesting but also suspicious results: the residue from the rain water was always formed by tens of dark and 'heavy' MSs, with size ranging from 20 to 300 μm. The small spherules was easily extracted by a magnet, so their ferrous nature (class I) was evident. On the contrary, no trace was found of MSs of class S. The search of MSs of class S inside the sediment of rain water continued during many months without any

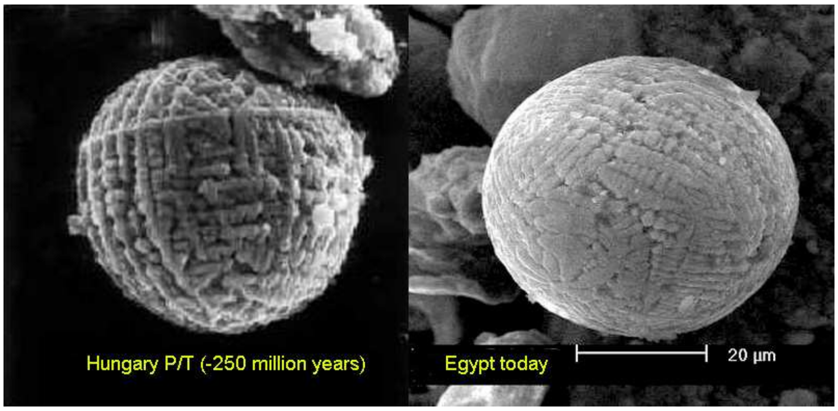

Fig. 15. A comparison between an MS found in the P/T boundary (Bukk Mts, Hungary) and an MS we found near the Keope Pyramid.

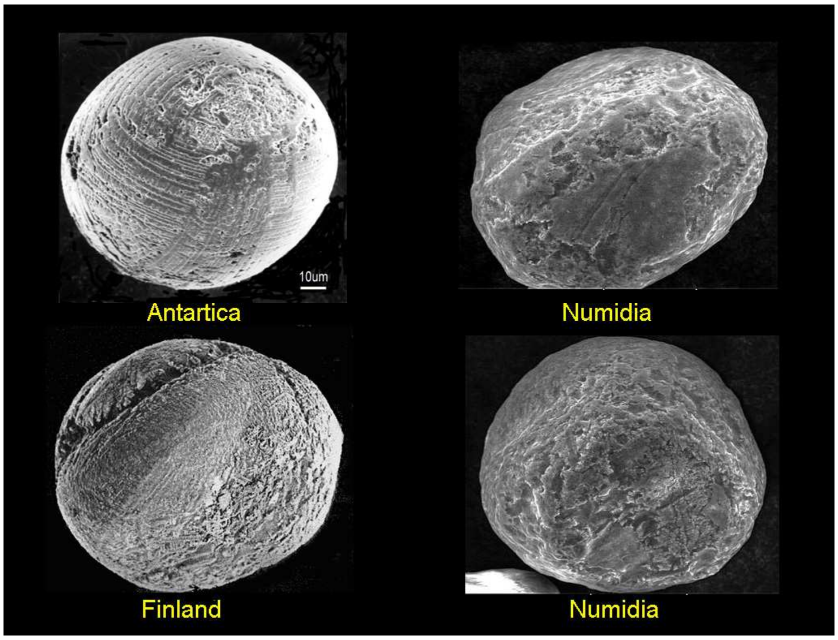

Fig. 16. A comparison between MSs of sure cosmic origin (Antartica, a 1,4 billion years old Finnish sandstone) and MSs found in the Numidia desert (from stuff supplied by R. Serra).

success, for an obvious reason: these microspherules are so light in weight (compared to ferrous s pherules) that their tendency to make sediment from large volumes of rain water is poor or null. Because of a clear selection effect, only the MSs of class I tend to deposit on the bottom of the water well. So, to avoid the loss of possible CSs of class S, we decided to check for them in sandy places, wet or dry. Wet suitable recovery sources are terrains where rain water first piles up and after slowly diminishes by evaporation or penetration (such as puddle, gully-hole). Dry suitable recovery sources are desert terrains where, being absent the selection effect of rain, CSs of class I could be present together with CSs of class S (obviously without any specific tendency to some concentration). We found that a PVC film, electrified by rubbing, is a good collecting tool for the glassy CSs: in fact they are very light and so they tend to stick to the film for electrostatic effect. In general, to be sure that the source of the possible MSs was not linked to some local (and so anthropogenic) process, we checked for MSs both in Northern Italy (Tradate, Besozzo, Aosta Valley) both far away (San Giovanni in Persiceto, Tunguska, Stonhenge, Canary Island of Lanzarote, Egypt deserts , Arizona desert near Seligman town, Lybian desert near Marzuq dunes, Numidian desert). It is very important to underline that we found MSs (above all of class I) everywhere we checked for them.

3. Results and discussion

For the SEM investigation of the surface morphology of MSs of class I , the SE (Secondary Electrons) detector was used, because it 'sees' the electrons released from the more superficial layer of the sample. To avoid misunderstandings in the compositional analyses, the EDS probe was normally applied to original samples (that's NOT covered with a sheet of gold or carbon). We singlet out almost five different kinds of surface morphology, possibly (but not only!) linked to the MS size: 1) compact, 2) crystalline, 3) polygonal, 4) filigreed, 5) pitted:

1): MSs with size range of 50-150 micron, that show a compact but rippled surface, without any clear discontinuity (Fig. 1)

2): MSs with size range of 150-200 micron, that show a spectacular crystalline surface, made up of regular magnetite crystals, that tend to form lozenges of great visual appearance (Fig. 2, Fig. 3, Fig. 4).

3): MSs with size range of 200-300 micron, that show a polygonal surface (similar to a soccer ball), formed by fragments of crust perfectly joined without empty space in between. Enlarged pictures of these polygonal segments are impressive (Fig. 5, Fig. 6)

4): MSs with size >300 μm, that show a filigreed surface similar to a coarse fabric formed by filaments of crossed crystals (Fig. 7, Fig. 8)

5): MSs found inside the sand of Libya and Namidia desert. The surface of these MSs is normally pitted by voids and fissures, possibly created by the action of the irregular and sharpened shape of the sand particles (Fig. 9)

It is important to add that the external geometry of a MS of class I is linked to a surface crust 10-20 micron thick, while the inner bulk is normally made up of a compact sinterized matrix. The EDS composition is always the same: metallic Fe in the inner part and partially oxidized Fe (magnetite) in the crystalline (but very compact!) external skin. In the case of cosmic origin, this is a clear indication of how the MS could be formed. First step is the incineration of a meteorite that enter the atmosphere, with the production of seared microparticles. All metal part contained in the meteoric stuff melts acquiring rounded form. These melted micro-drops quickly solidify in the cold atmosphere, gaining a tension in the surface proportional to the size and/or to the solidification rate (possibly the size of the magnetite crystal increases when the condensation rate decrease). The SEM morphological analysis of the MSs of class S was performed again with the SE probe. But the SEM pictures of these transparent glassy spherules were very sharp only if a thin layer of gold was deposited on the surface (Fig. 10, Fig. 11, Fig. 12).

The size of the glassy MSs is quite smaller as compared with the metallic MSs, ranging from 50 to 150 μm. The external morphology is typical of a glass, smooth and free of intrinsic details. So, we think that only external actions or degradation processes are able to make some surface modification. From the EDS analysis, the composition of all the MSs of class S is always typical of a silicate of Ca, Mg and Na (with presence of Al and absence of Na only in some pitted spherules from Lybia and Numidia deserts). This may be an important starting point for every conjecture about their origin.

4. Conclusions

Surface morphology, size and composition of all MSs of class I (metallic) and of all MSs of

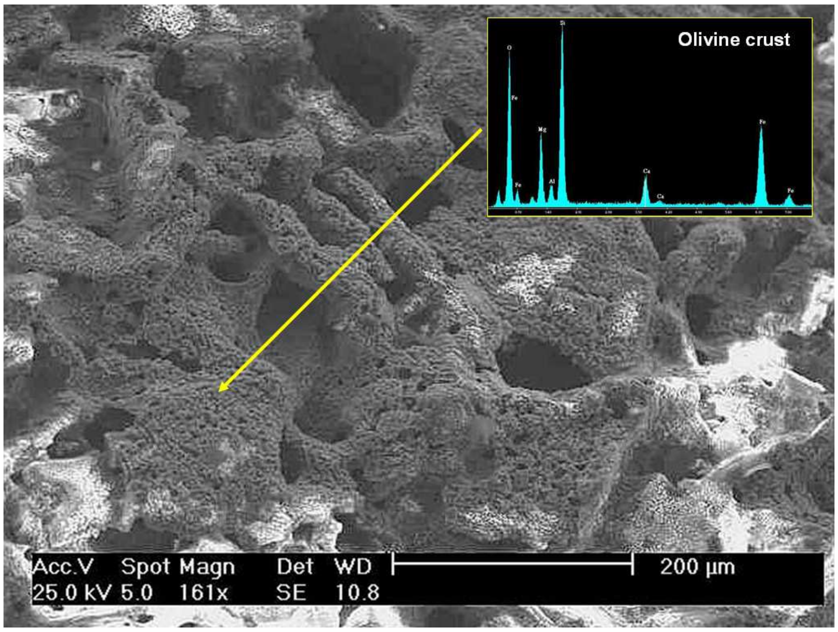

Fig. 17. The ablation surface of a normal chondrite (SEM picture + EDS analysis showing an olivine composition + presence of Fe/Ni).

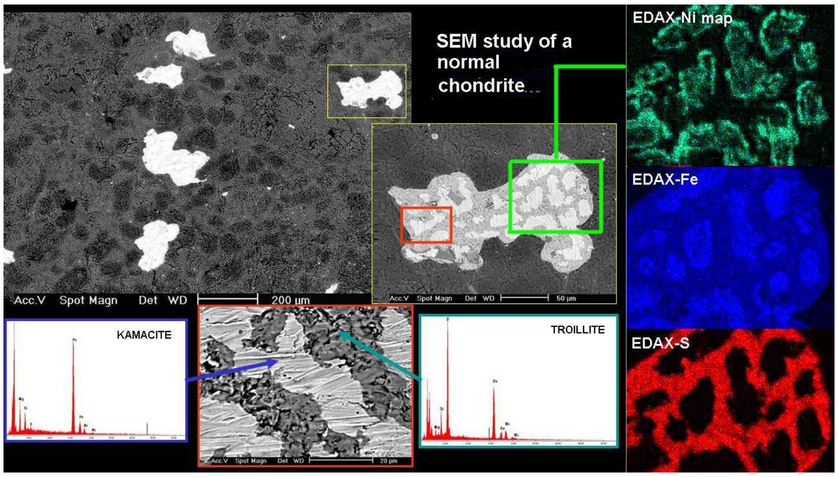

Fig. 18. The internal structure of the same chondrite of (Fig. 17), showing an olivine matrix containing isles of FeS + Fe-Ni inclusions.

class S (stony) were surprisingly always similar, no matter how and where they were found: this is a strong argument to a common origin, enclosed a cosmic source. The real source of the MSs of class S is probably the most difficult to be singled out because it need a composition analysis very careful and impossible to be performed only by the EDS probe of the SEM. In any case glassy spherules can be industrially produced (for a number of applications) by melting and vaporization of recycled glass based on Ca and Na Silicate (Marini

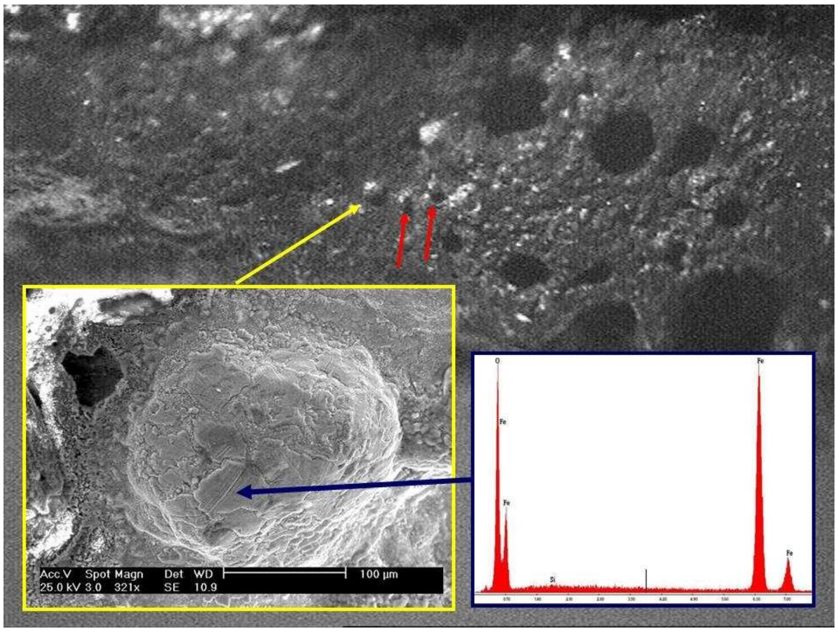

Fig. 19. 'Synthetic' ferrous MS created on the chondritic surface of (Fig. 17), by a strong heating with an oxyhydrogen flame (remarkable the sinterized internal structure, the external polygonal crust and the pure Fe composition) .

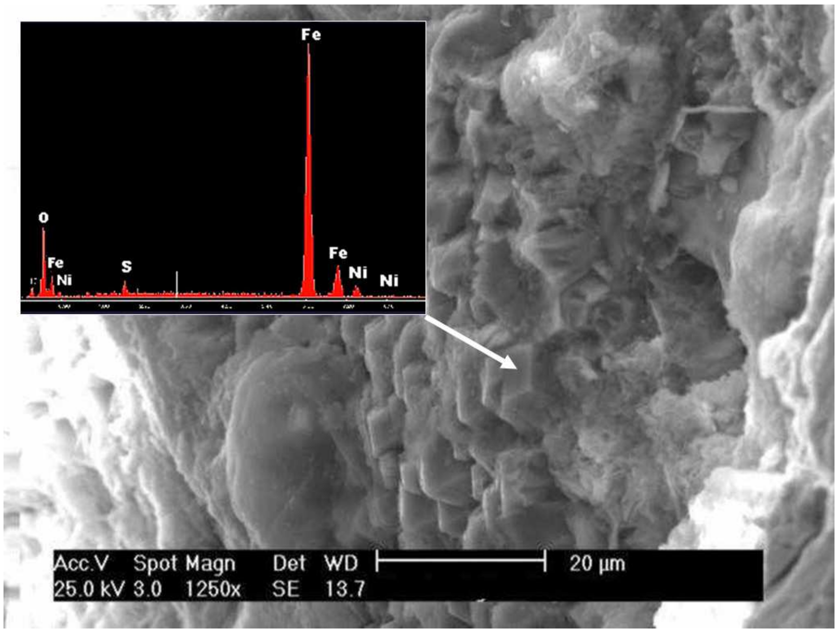

Fig. 20. The internal crystalline matrix of a siderite (SEM picture + EDS analysis).

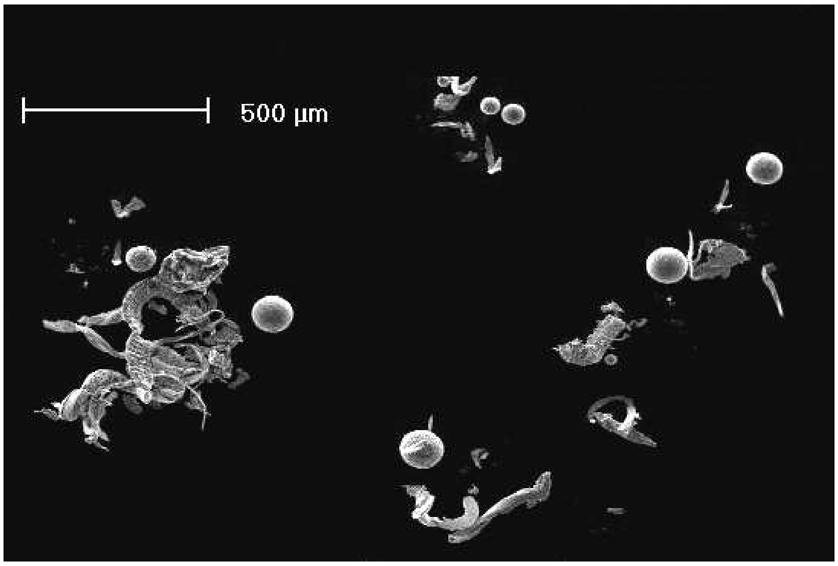

Fig. 21. 'Synthetic' metallic MSs found inside the fillings produced on the siderite of Fig. 20 by the action of a grinding wheel.

2003). So they are rich in Na and poor in Al and Fe. On the contrary CSs, that' s cosmic MS, are normally very poor in Na. In the case of glassy MSs we found in Lombardia and in Arizona desert, they contains a (small) amount of Na and so the anthropogenic origin could be not excluded. In the case of MSs recovered in Namidia desert (by Romano Serra) we found sometime high content of Si, Al, Mg and Fe: this could be a clear indication of cosmic origin (Fig. 13). Also because this composition looks like a very rare case of MM (micro-meteorite) of irregular form (and of composition enriched in Si, Al, Mg and Fe), we found by chance inside some stuff recovered (by R. Serra) in the Egyptian desert (Fig. 14). Also in the case of our MS of class I, the source could be terrestrial or cosmic. What we was able to demonstrate is that the cosmic origin has to be taken in serious account, almost in some circumstances. First of all, the same surface morphologies we discovered by SEM is often present in metallic MSs found inside geological sediments, with age ranging from thousands to million years. For example, it is impressive the resemblance (Fig. 15) between some metallic MSs we found in March 2006 near the Keope Pyramid in Egypt and some micro-spherules found on Bukk Mounts (Hungary) in a 250 million years old geological sample (boundary P-T, Permiano-Trissic) (Detre et al. 1997). Also impressive (Fig. 16) is the morphological likeness between some MSs found in Numidia desert (from stuff supplied by R. Serra) and some MSs from Antartica and from the 1,4 billion years old Satakunta sediment (Finland) (Deutsch et al. 1998). Above all, we experimentally tried to built metallic MSs from basic material of absolutely guaranteed cosmic origin; in a few word, from a stony and from a ferrous meteorite (an ordinary chondrite and a siderite). We performed two kinds of experiments.

1) *Heating at* 1600°*C of the ablation surface of an ordinary chondrite.*

The ablation surface of a normal chondrite shows, when explored by optical microscope at 30-50x, the presence of some rare micro-drops of sphere-like shape. We decided to exalt experimentally this effect by heating at 1600°C for few seconds, by oxyhydrogen flame, a fragment of the external crust of a rock (Fig. 17), of which the cosmic origin was tested in ad-

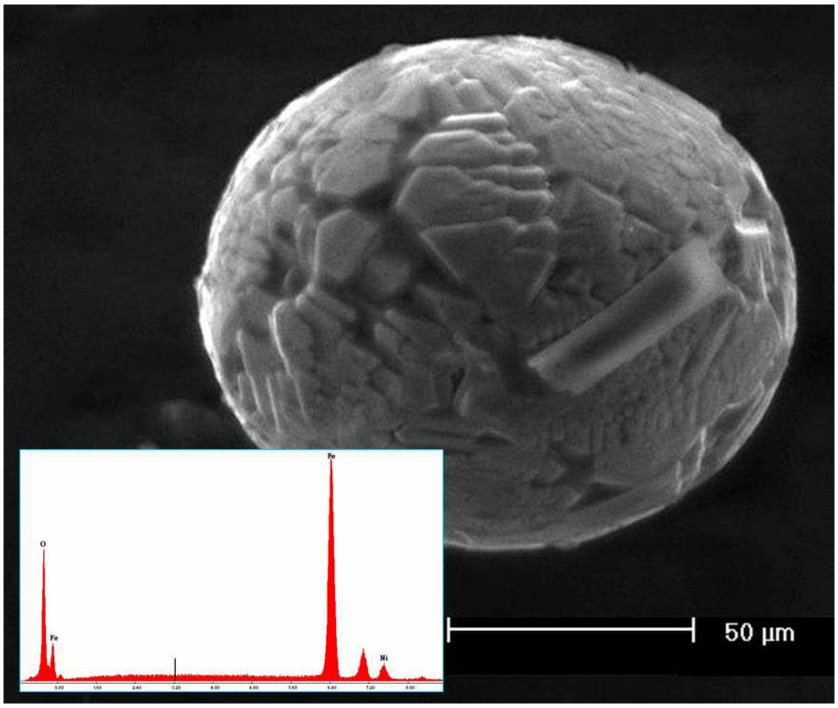

Fig. 22. A 'synthetic' *crystalline* metallic MS, created by grinding a siderite.

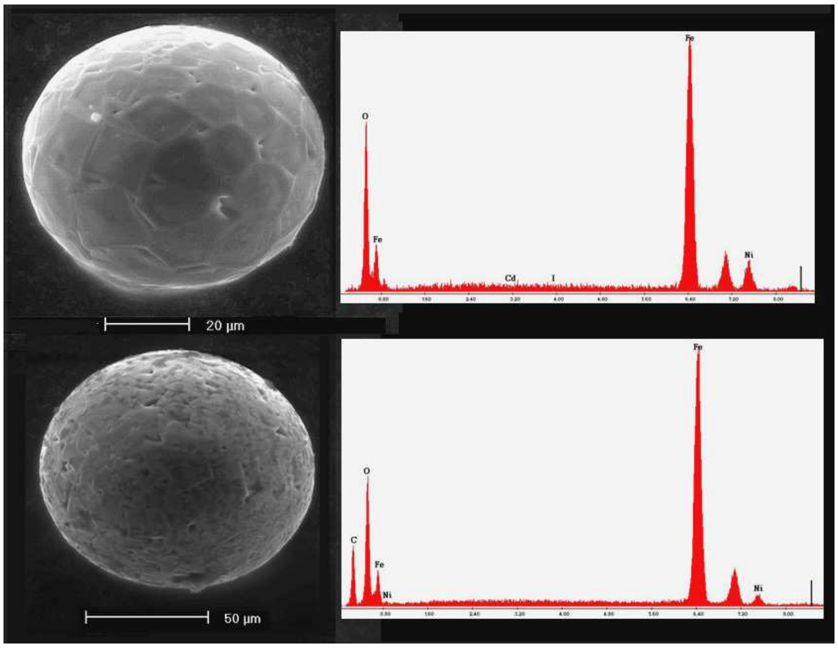

Fig. 23. 'Synthetic' *polygonal* and *compact* metallic MSs, created by grinding a siderite.

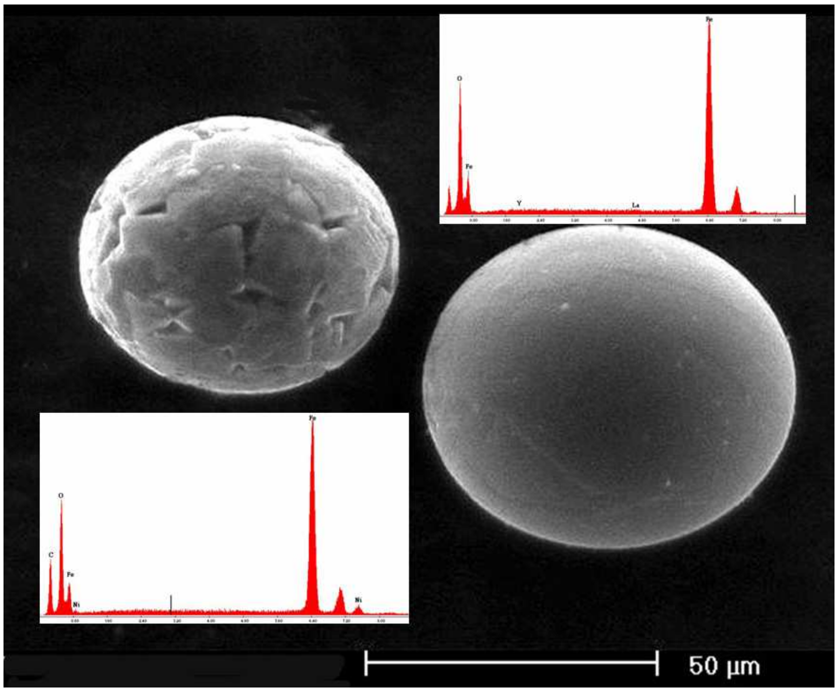

Fig. 24. Other two 'synthetic' *polygonal* and *compact* metallic MSs, created by grinding a siderite.

vance (matrix of olivine and pyroxene with inside irregular micrometric isles of troillite (FeS), containing inclusions of kamacite (Fe-Ni)) (Fig. 18).

The result was very interesting. On the surface of the chondrite a number of micro-spherules were born that, under SEM scrutiny, showed the same external morphology (soccer ball) and the same internal structure (sinterized small particles) of a large part of MSs of class I studied by us (Fig. 19). Furthermore, even if the EDS composition of the original crust was (as expected) stony enriched in Iron, the Iron was the only component of the crystalline surface of our 'synthetic' MSs. This was an important experimental demonstration that MSs of class I (and of class S?) could be the result of disintegration and melting of chondritic material that fall to Earth from outer space.

2)*Disintegration under high temperature of a siderite*.

To verify if a metallic meteorite (siderite) could give rise to MSs with a crystalline external surface, we subjected a sample of siderite (Fe+7% Ni) (Fig. 20) to the action of a grinding wheel (Al based to exclude a spurious iron source). Inside a large amount of fillings produced by this treatment we checked, under an optical microscope, for possible presence of MSs. The result was positive! A little amount of the grinded material (1-2%) was transformed in MSs with a SEM surface morphology exactly alike that one of the metallic MSs we recovered everywhere in the ambient. The surface composition, under EDS scrutiny (Fig. 21, Fig. 22, Fig. 23, Fig. 24),showed now the presence of Fe + trace of Ni (more frequent case), now the presence of pure Fe (case less frequent and possibly linked to the local temperature conditions). So we demonstrate that a metallic meteorite that vaporizes and melts due to heating during its entry into the atmosphere, can surely produce MSs. But, because also the human activity could produce metallic micro-spherules, we conclude that the cosmic source of our MSs is only one between many possible sources: in any case, the more uninhabited is the place of recovery, the more probable is the cosmic origin. Obviously the cosmic source is obliged, when the recovery is made inside sediments older than the beginning of the human activity.

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