

Chondrule-like object from the Indian Ocean cosmic spherules

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Five hundred and eighteen cosmic spherules were identified among the 672 spherules handpicked from deep sea sediments by using Scanning Electron Microscope-Energy Dispersive Spectrometry (SEM-EDS). One of the spherules is found to enclose a spherical chondrule-like object that can be distinguished from the rest of the spherule by its shape, texture and composition and whose petrographic features, size and chemical composition are similar to chondrules from a chondritic meteorite, probably of carbonaceous chondritic nature. The present finding suggests that a small fraction of the particulate extraterrestrial matter enters the earth as fragments of larger meteorites.

1. Introduction

Nearly 30000 ± 20000 tons of extraterrestrial material enter the earth's atmosphere every year (Love and Brownlee 1993a, b; Ravizza and McMurtry 1993; Peuker-Ehrenbrink 1996; Engrand and Maurette 1998; Esser and Turekian 1998; Peuker-Ehrenbrink and Ravizza 2000); micrometeorites constitute a major part of this material. Micrometeorites are collected from different domains: polar ices by melting the ice and subsequent examinations and handpicking of the filtrates collected from the molten ice (Thiel and Schimidt 1961; Maurette *et al.* 1986; Genge and Grady 1988; Koeberl and Hagen 1989; Harvey and Maurette 1991; Kurat *et al.* 1994; Engrand and Maurette 1998; Taylor *et al.* 1998, 2000; Yada *et al.* 2005; Suavet *et al.* 2010; Ginneken *et al.* 2011), deep-sea sediments using magnetic techniques (Brunn *et al.* 1955; Brownlee *et al.* 1979; Parashar *et al.* 2010; Rudraswami *et al.* 2011) and by filtering large quantities of sediment (Millard and Finkelman 1953; Blanchard *et al.* 1980), from

the stratosphere using different panels (Love and Brownlee 1993a, b); using other collection devices such as balloon born collector (Brownlee *et al.* 1973; Wlochowiaks *et al.* 1976) and space collector (Brownlee *et al.* 1977, 2003) and from the sedimentary rocks (Fredriksson and Gowdy 1963; Marvin and Einaudi 1967; Taylor and Brownlee 1991). In terms of quantity, the polar and deep sea collections enable large collections, whereas the stratospheric collections although enable smaller numbers of particles, some of them are highly friable, pristine and in an excellent state of preservation (Brownlee 1985; Lal and Jull 2002).

Most micrometeorites of size $>50 \mu\text{m}$ undergo melting, oxidation and mass loss during entry (Brownlee 1985; Love and Brownlee 1993a, b; Taylor *et al.* 2000), which is proven by the presence of magnetite rims around the spherules and presence of Fe-Ni bead and Pt group nuggets (Brownlee 1985; Bonte *et al.* 1987; Toppani *et al.* 2001; Genge 2006; Parashar *et al.* 2010; Rudraswami *et al.* 2011). Magnetite rims will be absent in the less heated and are present

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in more heated and oxidized cosmic spherules (Toppani *et al.* 2001), Sometimes large micrometeorites ($>50\ \mu\text{m}$) survive atmospheric entry without melting if they have low velocities and low incident angles (Brownlee 1985). The degree of melting and mass loss of micrometeorites during atmospheric entry depends on the size, velocity, entry angle and the composition of the material (Flynn 1989; Love and Brownlee 1991; Greshake *et al.* 1997). Micrometeorites and cosmic spherules are assigned/classified into different categories based on their mineralogy, textures and chemical compositions in a more or less direct manner. Whereas, one of the main constraints experienced in micrometeorite investigations is the identity of the parent bodies from which they are derived. This difficulty is compounded by the changes that the micrometeorites undergo (heating) during atmospheric entry. Micrometeorites are expected to have been derived from parent bodies which are conventional meteorites or material that have compositions similar to that of known meteorites; the dominant parent bodies being carbonaceous chondrites CI, CM or CR chondrites (Brownlee 1985; Kurat *et al.* 1994; Brownlee *et al.* 1997; Genge *et al.* 1997; Engrand and Maurette 1998; Alexander *et al.* 2002; Taylor *et al.* 2005; Parashar *et al.* 2010; Ginneken *et al.* 2011) and a few are from ordinary chondrites (Beckerling and Bischoff 1994; Genge *et al.* 2008; Parashar *et al.* 2010; Suavet *et al.* 2011; Taylor *et al.* 2011), iron meteorite type parent bodies (Blanchard *et al.* 1980; Herzog *et al.* 1999) and a few rare ones are from achondrites (Taylor *et al.* 2006, 2011; Cordier *et al.* 2012). The parent bodies of micrometeorites are determined indirectly with the help of oxygen isotopes, relict mineral grains, chemical compositions (elemental or atomic ratios) which are then compared with known meteorite types. The meteorites (especially chondritic meteorites) comprise of a mix of chondrules, matrix, metal, CAIs (Calcium Aluminum rich Inclusions), AOs (Amoeboid olivine aggregates), etc. However, one rarely recovers chondrules, CAIs or AOs among the tens of thousands of micrometeorites that have been recovered so far. There are a few rare exceptions, for example, Kurat *et al.* (1996) found the fragment of radiating pyroxene chondrule with a diameter of $120\ \mu\text{m}$ in micrometeorites; Taylor *et al.* (2008, 2011) reported on a CH type-barred olivine chondrule from the Antarctic collection. Genge *et al.* (2004) discovered chondritic igneous objects and matrices that constitute $\sim 1\%$ of their collection, which in turn suggested a chondrule bearing asteroid as the parent body. Recently, Taylor *et al.* (2011) reported on a spherule that contained chondrule/fragments of chondrule and that constituted nearly $<0.05\%$ out of 5682 spherules from South Pole Water

Well (SPWW) collection. Micrometeorites enclosing CAIs have been reported previously by Taylor *et al.* (2008, 2010a, b, 2011), Greshake *et al.* 1995 and Hoppe (1995).

We have isolated a large number of cosmic spherules from the deep sea sediments of the Indian Ocean. For the present study, cosmic spherules from $\sim 164\ \text{kg}$ of sediment from five different locations are examined, from which we report here the discovery of a spherule which encloses a chondrule-like object providing direct evidence of being derived from a carbonaceous chondritic body, more specifically a CH chondrite. This is perhaps the second time that a CH type chondrule has been discovered inside a micrometeorite and gives a direct indication of the parent bodies/parts of parent bodies that eventually end up as micrometeorites.

2. Sampling and analytical procedure

Samples were collected from close-spaced locations in the Central Indian Ocean Basin (CIOB) at depths $>5000\ \text{m}$ by using a van veen grab onboard *AA Sidorenko*, a research vessel hired by Govt. of India in 2003, during the cruise AAS-62 (figure 1a–d). Each grab sample represents an area of $50\ \text{cm}^2$ and a seafloor penetration of up to $15\ \text{cm}$; the total area sampled for the present study is $1.25\ \text{m}^2$. For the $15\ \text{cm}$ maximum seafloor penetration of the grab sampler, it is estimated that the terrestrial age of the spherules would have a range of $0\text{--}50,000$ years (Prasad *et al.* 2013). The sediments were washed, sieved in a mesh size of $\sim 200\ \mu\text{m}$ on board and dried (figure 1e–g). The spherules were magnetically separated from the $>200\ \mu\text{m}$ fractions of the sieved sediments. In this study, the chondrule-like object bearing spherule is a part of 672 spherules that are hand-picked from the magnetic fraction separated from the five different sediment samples (total weight of sediment sieved – $164\ \text{kg}$ wet weight) using the binocular microscope. All the spherules were mounted in plastic and were polished. The spherules were observed in JEOL JSM5800LV Scanning Electron Microscope (SEM) and images were taken using the back scattered electron mode. Primary composition of the spherules was obtained by the OXFORD INCA Energy Dispersive Spectrometer (EDS) attached with the SEM. Cosmic spherules ($n = 518$) were identified among all the magnetically separated spherules ($n = 672$) and are characterized based on their composition and textures. Chemical composition of spherule having the chondrule is determined by CAMECA SX-5 Electron Probe Micro Analyzer (EPMA) at NIO with a beam diameter of



Figure 1. Sample collection by using van veen grab from the Indian Ocean basin: (a) van veen grab, (b) lowering the grab, (c) lifting up the grab from water column with the sediments, (d–e) collecting sediments from grab, (f) sediments samples collected by using grab sampler, and (g) sieving of the grab samples on board.

~1–2 μm , sample current of 12 μA and 15 kV accelerating voltage. Matrix correction is done using an online program with PAP correction (Pouchou and Pichoir 1991). Different standards were used for each element; for Na→Albite, K→Orthoclase, Mg→Diopside, Si→Olivine, Mn→Willemite, Fe→Andradite, Co→Skutterudite, Ni→Nickel Silicide, P→Apatite, S→Pendlantite, Ca→Diopside, Cr→Crocoite and for Ti→Benitotite. For each element, peak time was 10 s and the detection limit for each element was (wt%): P_2O_5 – 0.04, Mg_2O , Al_2O_3 – 0.05, SO_2 , K_2O , Ca_2O , SiO_2 – 0.06, MnO_2 , TiO_2 – 0.07, Na_2O , Cr_2O_3 – 0.08, FeO – 0.09, NiO – 0.17 and CoO – 0.13. The spherule under investigation is found to be partially etched; therefore small unetched portions on the spherule and chondrule were chosen under high magnification for the analysis. Analysis with a defocused beam having a diameter of 10 μm and also 25 μm was tried, however, in view of the pitted nature of the spherule, the totals are found to be low. Therefore, more than 10 spots were analyzed both on the chondrule and material surrounding the chondrule (clasts). Average of these spot analyses is taken as the bulk composition of the spherule. X-ray elemental maps were acquired for the spherule with a beam current of 12 μA and accelerating voltage of 15 kV. Other parameters are: dwell time – 0.1 s, points per line – 512 and step in μm – 0.441.

3. Results and discussions

The spherule under investigation has an actual diameter of 204.1 μm measured with the help of binocular microscope and is partially etched and contains many voids. The spherical object at the center of the spherule can be distinguished from the rest of the spherule by its barred structure (figure 2a). This spherical object may be a chondrule. The spherule under investigation must have undergone less heating as it lacks magnetite rim around the spherule and preserves the chondrule-like object. Diameter of the chondrule-like object is 72 μm . The chondrule-like object contains bars of ~1–2 μm (figure 2b) composed of Ca-poor pyroxene (En 89.9%, Fe 10.01 and Wo 0.05). The clasts surrounding chondrule have pyroxene normative mineralogy; contain pyroxene (~8–15 μm) and magnetite (~1–7 μm). Rounded and irregularly shaped voids are present within the clasts (figure 2c–e). The rounded voids could be formed by degassing of volatile material or either by the separation of chondrule or metal from the spherule during atmospheric deceleration. Irregular voids in the clasts could be due to the sea water interaction in the terrestrial environment. Microprobe analysis of the chondrule-like object and the

clasts surrounding the chondrule-like object in the present investigation are given in table 1. EPMA result shows that compositionally there is not much difference between chondrule-like object and clasts; both are having pyroxene normative mineralogy. X-ray mapping (figure 3) was done for the elements Mg, Fe, Si, Al, Cr, Ca and Mn with a beam current of 12 μA and a voltage of 15 kV. The X-ray image for the elements Mg and Fe show clear cut boundary between the Mg rich, Fe-poor chondrule-like object and the clasts surrounding it; which are enriched in Fe and depleted in Mg. Si is distributed uniformly throughout the spherule. Si and CI normalized composition of the chondrule shows that the chondrule is depleted in moderately volatile element such as Mn, and refractory elements like Ca, Al and Ti with respect to CI chondrites (figure 4). When compared to the chondrule-like object, the clasts are depleted in Mg and enriched in refractory and moderately volatile elements (table 1, figure 3). Comparison of the chondrule value with the cryptocrystalline chondrules collected from SaU290, PAT91564 and PCA91328 CH chondrites (Krot et al. 2000; Nakashima et al. 2011) shows a close similarity (figure 4). However, when we compare the bulk elemental ratios with the other meteorites this spherule shows a proximity to Enstatite meteorites composition (table 2). One reason for this similarity could be due to depletion of moderately volatile and refractory element in the spherule (both in the chondrule and the clasts) or this particular micrometeorite must have been derived from a type of parent body which is not yet known.

Size of the chondrule is one of the keys to identify the parent body, each chondritic meteorite has chondrules of specific sizes except for CI (CI chondrite is matrix dominated). Diameter of the chondrule in different chondrites is given in table 3. Size of the chondrule-like object found in the present study is similar to the chondrules in a CH chondrite, which has the smallest of chondrules (0.02–0.09 mm) compared to other carbonaceous chondrites. CH meteorites comprise 70% chondrules and chondrule fragments (Scott and Krot 2003). Most of the chondrules in CH chondrites are cryptocrystalline including radial pyroxene and barred Olivine (80%) and Porphyritic chondrules comprise the remaining 10% (Scott 1988), whereas the matrix is absent in CH chondrites except in Acfer 214 (Scott and Krot 2003). CH type chondrule is rare among micrometeorite collections. Micrometeorite enclosing CH chondrite has been first reported by Taylor et al. (2008, 2011) from Antarctic collections. They found a barred olivine chondrule having a diameter which is similar to chondrules of CH chondrites. In the present study, based on the result obtained by EPMA and SEM

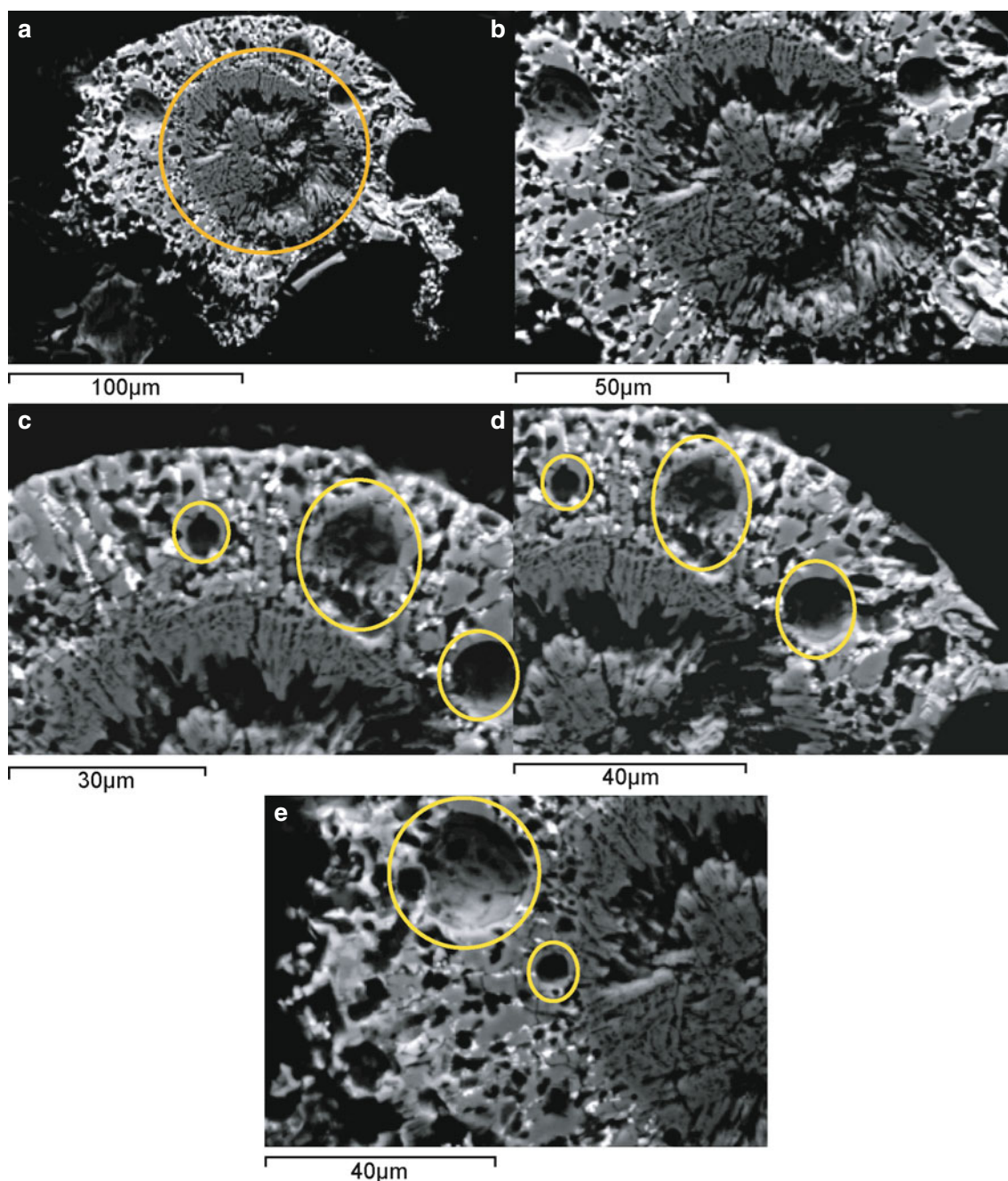


Figure 2. Back scattered images of the micrometeorite enclosing chondrule-like object (a) micrometeorite with the chondrule-like object at the center (inside the circle), (b) magnified image of the chondrule-like object showing laths of Mg-rich Ca-poor pyroxene, and (c–e) magnified images of the clasts surrounding the chondrule-like object. Clasts are composed of pyroxene and magnetite grains. Rounded voids (inside the yellow circle) in the clasts could be the result of removal of chondrule, Fe-Ni bead or volatile material during atmospheric entry.

analysis, the chondrule-like object is classified as a Ca-poor barred pyroxene chondrule. The voids present within the chondrule must have formed due to the loss of volatile elements during atmospheric entry.

Krot *et al.* (2000) suggest that the Mg-rich cryptocrystalline chondrules in CH chondrites are formed by direct condensation from the solar nebula rather than from the dust cloud formed by the

impact of large CH body asteroids and the prolonged heating of the precursor chondrule material. Absence of Fe-Ni and depletion of moderately volatile elements in the chondrule indicates that this chondrule is formed before the condensation of metal and moderately volatile elements at higher temperature (above 1200 K) in the inner part of solar nebula and is transported from the hot solar nebula to low temperature place (Asteroid belt)

Table 1. Major elemental composition of (wt%) micrometeorite enclosing chondrule-like object analysed by EPMA.

Oxides	Chondrule	Lithic clasts	Bulk
SiO ₂	57.73	53.33	55.92
TiO ₂	0.03	0.05	0.04
Al ₂ O ₃	0.96	1.75	1.29
Cr ₂ O ₃	0.55	0.77	0.64
FeO(t)	6.69	14.70	9.99
MnO	0.17	0.35	0.24
MgO	33.73	27.03	30.97
CaO	0.18	0.55	0.33
Total	100.11	98.59	99.48

B.D.: below detection limit; FeO(t): total Iron; and the analytical errors for all the major elements are <1%.

where the condensation of parent body took place by solar winds and has escaped from further low temperature alteration (Krot *et al.* 2000, 2001; Hezel *et al.* 2002). Other reason for the depletion of Fe-Ni in the chondrule could be removal of these metals from the silicate rich chondrule melt (Krot *et al.* 2000). Whereas depletion of refractory elements in the chondrule is mainly due to the fractional condensation in hot solar nebula; by this process refractory elements have condensed and are removed during early stages of condensation (Krot *et al.* 2000, 2001; Nakashima *et al.* 2011). In addition, the presence of 0.6% Cr₂O₃ and 7% FeO indicates that this chondrule formed under oxidizing conditions (Krot *et al.* 2001). Absence of matrix around the chondrule indicates that chondrule formed in a dust free environment. The lithic clasts around the chondrule must have been added later to the chondrule in the asteroid belt (Krot *et al.* 2001). Lithic clasts of CH chondrite consists mainly phyllosilicates, sulphides, magnetite and carbonates and are chondritic (CM2, CI and CR) in composition (Scott 1988; Weisberg *et al.* 1998; Greshake *et al.* 2001; Ivanova *et al.* 2009). The lithic clasts in the spherule under investigation are mainly composed of pyroxene and magnetite, which could be formed by dehydration and melting of phyllosilicates and other minerals. Comparison with the matrix of carbonaceous chondrites (figure 5) shows that the clasts are depleted in Fe, Ni and in moderately volatile elements like Na, K, P and S. This could be due to degassing of volatile elements and separation of Fe Ni metal from the clasts during high velocity entry to the earth's atmosphere.

Micrometeorites have been suggested to be the ablation products of meteorites (Blanchard *et al.* 1980; Nishiizumi 1983). Alternatively, the presence of cosmogenic radionuclides in individual micrometeorites suggests that the majority of micrometeorites were exposed to the cosmic rays as small

bodies in the space for >1 million years and are entitled to the title micrometeorites (i.e., meteorites but of smaller size) (Raisbeck *et al.* 1983; Raisbeck and Yiou 1987; Nishiizumi *et al.* 1991, 1992, 1995, 2007; Herzog *et al.* 1999; Jull *et al.* 2007). In addition, enrichment of volatile elements in ablation spherules compared to the micrometeorites; which lost their volatility during the atmospheric entry supports the above view (Genge *et al.* 2008). Lal and Jull (2002) suggested that micrometeorites are the fragments/ablation products of large meteorites of size 1 m, i.e., 1 m diameter during atmospheric entry. These particles are absent in the stratospheric collections because stratospheric collections are biased towards the primary particles that are entering as small micrometeoroids and the frequency of meteorite fall is low compared to micrometeorites. The fragmented meteoritic particles would be sampled efficiently from the terrestrial samples which represent large area and time such as the deep sea sediment samples, ice samples, etc. For the present study, large quantities of samples have been collected from the deep sea region that represents an age of up to 50,000 yrs and in an area of 1.25 m² of the seafloor. However, chondrules/chondrule fragments, CAIs, and AOs are found in meteorites and are rare in micrometeorites (Kurat *et al.* 1996; Taylor *et al.* 2011). A few investigators reported the presence of chondrule/chondrule fragments, CAIs and AOs in micrometeorites, examples are: Kurat *et al.* (1996) found the fragment of radial pyroxene chondrule with a diameter of 120 µm in Antarctic micrometeorites. Genge *et al.* (2004) discovered chondritic igneous objects and matrix which constitute 1% of their collection, and suggested a chondrule bearing asteroid as the parent body. Micrometeorites enclosing CAIs have been reported by Greshake *et al.* (1995), Hoppe (1995), Taylor *et al.* (2008, 2010a, b, 2011). Taylor *et al.* (2008, 2010a, b, 2011) reported on spherules containing CAIs and chondrule/chondrule fragments of CV and CH type chondrite respectively. Chondrules and CAIs constitute less than 1% of the Antarctic micrometeorites collection (Engrand and Maurette 1998; Taylor *et al.* 2008, 2010a, b, 2011). Greshake *et al.* (1995) analyzed trace elements in the CAIs whose composition was similar to CM and CH chondrites.

The spherule enclosing the chondrule-like object in the present investigation may be a fragment of a meteorite or a meteorite ablation spherule which entered the earth as a small body and has not experienced much heating. The preservation of a chondrule and the lack of magnetite rim also suggests that this particle entered the earth at low zenith angles and has undergone less atmospheric heating. Formation of a magnetite rim depends

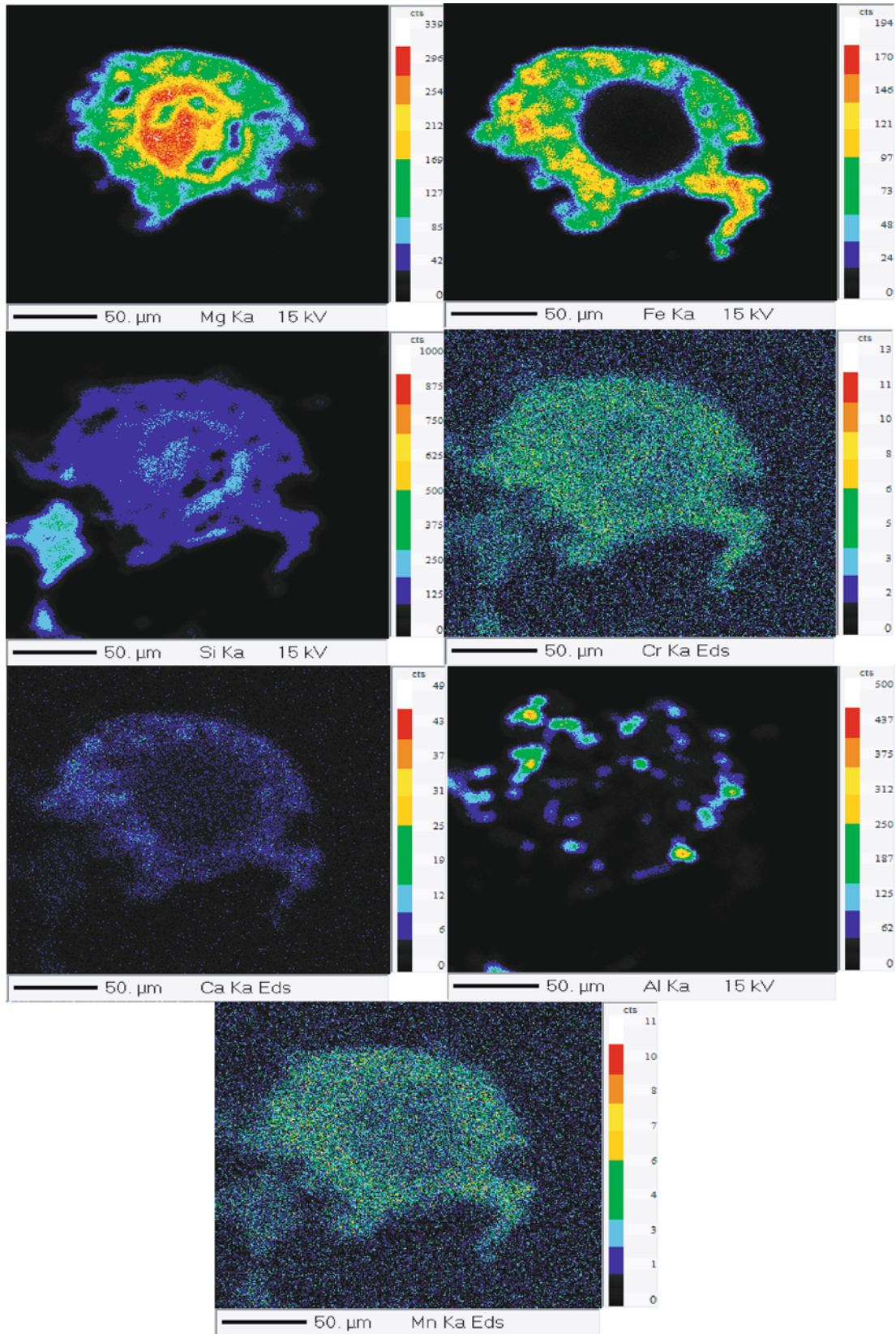


Figure 3. X-ray images for Mg, Fe and Si, Al, Cr, Ca and Mn. X-ray image for the element Mg and Fe shows the boundary of the chondrule-like object clearly, which is rich in Mg and depleted in Fe compared to the clasts surrounding it. Si is distributed uniformly throughout the spherule. Al, Ca, Cr and Mn elements are depleted in chondrule-like object compared to the clasts.

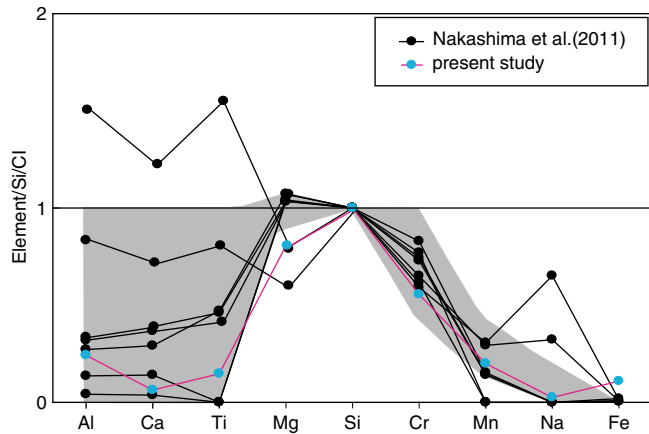


Figure 4. Element to Si ratio normalized to CI (Wasson and Kallemeyn 1988) for chondrule-like object in the present study (coloured line). Black line represents the Si and CI normalized chemical composition of the chondrule from CH chondrite SaU290 (Nakashima *et al.* 2011) and the grey patch shown in the figure represents the composition of Mg-rich cryptocrystalline chondrule from CH chondrites (Krot *et al.* 2000). Composition of chondrule-like object shows a similar trend with the SaU 290 and falls in the field of Mg-rich cryptocrystalline chondrule from CH chondrite.

Table 2. Comparison of elemental ratios of spherule, chondrule and lithic clasts with the chondritic meteorites.

	Mg/Si	Al/Si	Ca/Si	Fe/Si	Ca/Al
Chondrule	0.90	0.02	0.00	0.05	0.17
Lithic clasts	0.80	0.02	0.01	0.20	0.20
Bulk	0.83	0.03	0.01	0.15	0.24
CI	1.09	0.08	0.09	1.73	1.07
CM	0.91	0.09	0.1	1.62	1.08
CO	0.91	0.09	0.1	1.56	1.10
CV	0.93	0.11	0.12	1.51	1.09
CH ¹	1.06	0.08	0.06	1.52	0.72
E	0.96	0.07	0.05	0.82	0.74
H	0.93	0.07	0.05	0.58	0.72
L	0.94	0.07	0.05	0.49	0.74
EH	0.73	0.05	0.04	0.87	0.71
EL	0.88	0.06	0.04	0.59	0.65
CI fine grained matrix ¹	0.92	0.09	0.01	0.54	
CM fine grained matrix ²	0.96	0.12	0.03	0.94	

¹Wasson and Kallemeyn (1990), ²McSween and Richardson (1977), and other chondrite values were taken from Wasson and Kallemeyn (1988).

on the temperature, duration and the oxygen fugacity (Toppani *et al.* in 2001; Toppani and Libourel 2003). According to Greshake *et al.* (1997), magnetite crystals are formed between the temperatures 600° and 1200°C depending on parameters named above, and their presence is seen as an indicator of the changes due to heating and oxidation experienced by the incoming particle. As in

Table 3. Chondrule diameter in different chondrites (Scott and Krot 2003).

Chondrite	Group	Avg. diameter of chondrule (mm)
Carbonaceous	CI	
Carbonaceous	CM	0.3
Carbonaceous	CO	0.15
Carbonaceous	CV	1
Carbonaceous	CR	0.7
Carbonaceous	CH	0.02–0.09
Carbonaceous	CB _a	~5
Carbonaceous	CB _b	~0.5
Carbonaceous	CK	0.8
Ordinary	H	0.3
Ordinary	L	0.5
Ordinary	LL	0.6
Enstatite	EH	0.2
Enstatite	EL	0.6
Other	K	0.6
Other	R	0.4

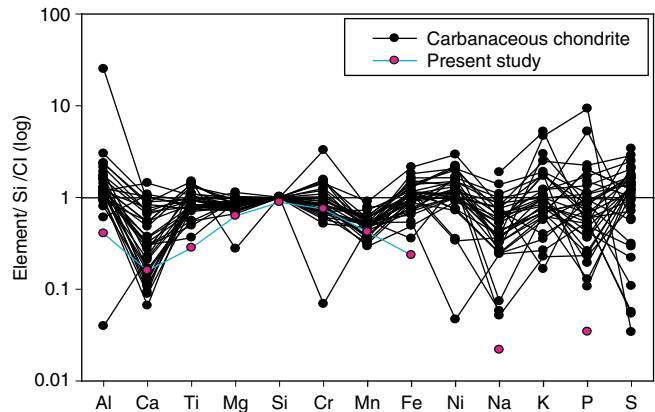


Figure 5. Element to Si ratio normalized to CI (Wasson and Kallemeyn 1988) for clasts (coloured lines) compared with the matrix of different carbonaceous chondrites (Zolensky *et al.* 1993). The composition of clasts show a close similarity except for the elements Fe, Ni, Na, K, P and S, which are depleted in the clasts compared to composition of carbonaceous chondrite matrix.

all other findings, the present discovery of a single chondrule in one spherule constitutes an extremely small percentage (0.2%) of the bulk sample (n = 518) collected from a large area. This could however be misleading; there could be a larger percentage of such meteoritic materials entering the atmosphere. The reason for the less abundance of meteoritic material among the cosmic spherules could be due to a large percentage of micrometeorites had undergone sufficient heating to have changed their original texture resulting in textures such as a barred, cryptocrystalline, glass and CAT

(Taylor and Brownlee 1991; Engrand and Maurette 1998; Taylor *et al.* 2000, 2011; Yada *et al.* 2005; Genge *et al.* 2008; Rochette *et al.* 2008; Parashar *et al.* 2010). For example, in unbiased collections, barred, cryptocrystalline, glassy and CAT spherules constitute nearly 80% and the remaining 20% covers the least melted micrometeorites such as scoriaceous, relict-grain-bearing and porphyritic (Taylor and Brownlee 1991; Taylor *et al.* 2000). The present finding suggests that micrometeorites may be from either source – ablation products of larger meteorites or individual particles released from the asteroid belt that enter the earth's atmosphere.

4. Conclusion

Six hundred and seventy two spherules were separated from material sieved from 164 kg of surface sediment sample. The spherule enclosing chondrule-like object is a part of the above sample. The chemical composition and petrographic features of the chondrule-like object agree with the chondrules of CH chondrite. This cosmic spherule must have landed on the earth's surface under the conditions of low entry velocity and low zenith angle without much atmospheric heating as the chondrule boundary and the chemical composition of the chondrule-like object are well preserved. The spherule has a pyroxene normative chemical composition. X-ray images show a clear cut boundary between the Mg-rich Fe-poor chondrule-like object and the Fe-rich Mg-poor clasts surrounding it. The chondrule-like object is Ca-poor in composition and shows a best match with the Mg-rich chondrules collected from CH chondrites. The depletion of Fe-Ni, moderately volatile elements and refractory elements compared to CI meteorite in the chondrule-like body may be due to the fractional condensation in the solar nebula. The pyroxene normative clasts surrounding the chondrule have compositions similar to carbonaceous chondrite matrix. Compared to carbonaceous chondrite matrix, the clasts are depleted in Fe-Ni and moderately volatile elements; this could be due to the removal of these elements during atmospheric deceleration. The samples in the present investigation represent a large quantum of time and space: they have a terrestrial age of 0–50,000 years and are spread over an area of 1.25 m². The present spherule could be a fragment of a meteorite. Although such findings are rare ($\leq 1\%$) in major unbiased collections, the present finding represents only a small fraction of the bulk sample. More importantly, it leads us to suggest that the micrometeorites may enter the earth as small dust-sized particles from the interplanetary medium

or as meteorite ablation spherules/fragments of a larger body.

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