

Acritarchs in carbonaceous meteorites and terrestrial rocks

Alexei Yu. Rozanov*

Director, Astrobiology Institute,
Joint Institute for Nuclear Research, (RAS)
Dubna, Russian Federation

Richard B. Hoover⁺

Buckingham Centre for Astrobiology, University of Buckingham,
Buckingham, MK18 1EG, United Kingdom
and
Athens State University, Athens, Alabama USA

ABSTRACT

Acritarchs are a group of organic-walled, acid-resistant microfossils of uncertain or unknown origin. Some are thought to represent the cysts or resting stages of unicellular protists (possibly dinoflagellates), chrysophytes (green algae) or other planktonic eukaryotic algae. Acritarchs are found throughout the geologic column extending back as far as 3.2 Ga. The presence of large sphaeromorphs in the Archaean provides evidence that the eukaryotic lineage extends much farther back in time than previously thought possible. Acritarchs are abundant in the Paleoproterozoic shales (1.9-1.6 Ga) of the former Soviet Union and they have been extensively used for the investigation of Proterozoic and Paleozoic biostratigraphy and paleoenvironmental parameters. Scanning Electron Microscope studies have revealed the fossilized remains of organic-walled microfossils of unknown origin and exhibiting characteristics of acritarchs in a variety of carbonaceous meteorites. In many cases, these remains are black or brown in color and have Carbon/Oxygen ratios suggesting they have been diagenetically converted into kerogen. It is not feasible that the fossilized remains of organic-walled microfossils such as acritarchs represent biological contaminant that invaded and became embedded in the rock matrix of carbonaceous meteorites within the short time periods of their residence on Earth. Consequently, these groups of microfossils are considered to provide an additional line for the existence of indigenous extraterrestrial microbial remains in meteorites. This paper presents a brief review of acritarchs in terrestrial rocks and provides images of a number of similar morphotypes of uncertain origin found in freshly fractured samples of carbonaceous meteorites.

Keywords: acritarchs, palynomorphs, organic-walled microfossils, meteorites, Murray, Orgueil, Murchison

1. INTRODUCTION

Acritarchs are a heterogeneous and polyphyletic group of organic-walled, acid-resistant microfossils of uncertain or unknown origin. Acritarchs consist of an organic wall of one or multiple layers enclosing a central cavity. They exhibit a great variety of morphologies and ornamentations. Acritarchs are grouped with the palynomorphs, which includes pollen, spores, dinoflagellate cysts, and chitinozoans. The organic wall of acritarchs is composed of sporopollenine, chitin, kerogen or other matter that is both resistant to decay and to the acid maceration methods used in standard palynological preparation procedures. The term "*Acritarcha*" (derived from the Greek words "*ákritos*"=*uncertain* or *confused* and "*arche*")=*origin* was first proposed in 1963 by Evitt.^{1,2} He considered the Acritarchs to be the group of "small microfossils of unknown and probably varied biological affinities, consisting of a central cavity enclosed by a wall of single or multiple layers and of chiefly organic composition---" Some are considered to represent the cysts or resting stages of dinoflagellates, chrysophytes or other planktonic eukaryotic algae or unicellular protists .

⁺Entogonia@AOL.COM; phone 1-256-337-4082

*Aroza@PALEO.RU

Acritarchs were discovered in 1838 by C. G. Ehrenberg, the great German micropaleontologist and diatomist. Ehrenberg who described "infusoria" including the organic-walled microfossils *Hystrichosphaeridium hirsutum* (Ehrenberg 1838 ex Deflandre 1937 and *Palaeoperidinium pyrophorum* (Ehrenberg 1838 ex. Wetzel 1933).³⁻⁵ In 1862, White⁶ described a group of organic-walled acid resistant microfossils from the Ordovician and Devonian sedimentary rocks from New York State, U.S.A. These are considered the first conclusively acritarch palynomorphs. In addition to acritarchs and hystrichospheres, the palynomorphs also include other groups of acid resistant microfossils such as pollen grains, spores, egg cases, cysts and chitinozoans. In 1933, Wetzel assigned many Mesozoic organic-walled microfossils to acritarchs and dinoflagellate cysts and placed them both in the group Hystrichosphaera.⁵

Many acritarchs possess external spines or processes and they may have a break or opening (Excystment opening) in the wall of the vesicle. The interior wall of the vesicle is designated the endophragm and the exterior wall is called the periphragm. Acritarchs are typically grouped on the basis of the external morphology of the fossil.

External Morphologies of Acritarchs:

- ***Sphaeromorphs* - Simple spherical morphology (Often flattened or wrinkled)**
- ***Polygonomorphs* - Body shape (triangular or square); defined by the number and position of spines**
- ***Acanthomorphs* - Spherical bodies with spines usually opening into body**
- ***Netromorphs* - Fusiform (spindle shaped) body with one or more spines**
- ***Diacromorphs* - Spherical or ellipsoidal bodies with ornament confined to the poles**
- ***Herkomorphs* - Spherical bodies divided into polygonal fields**
- ***Pteromorphs* - Spherical with compressed central zone and flange with radial folds or processes**
- ***Prismatomorphs* - Prismatic to polygonal bodies - the edges may form a flange (possibly serrated)**
- ***Oomorphs* -Egg-shaped morphology with ornamentation confined to one pole**

2. ACRITARCHS IN TERRESTRIAL ROCKS

Acritarchs are found in a wide variety of sedimentary rocks on Earth and they represent many different types of eukaryotic microorganisms, Acritarchs can range in size from ~5 μm to >1000 μm . These microfossils came to be important tools for biostratigraphic correlation that have been very useful for petroleum exploration. Over several decades, Eisenack published a series of papers describing many genera and species of fossil dinoflagellates, hystrichospheres and acritarchs which he came to regard as phytoplanktonic in origin.⁷⁻¹⁷ Extensive work on Pre-Cambrian, Cambrian and Ordovician hystrichospheres and acritarchs was carried out in Leningrad by the Russian palynologist, micropaleontologist and biostratigrapher Boris Vasil'evich Timofeev, who established that acritarchs, hystrichospheres and spores are very abundant in the Paleoproterozoic shales (1.9-1.6 Ga) of former Soviet Union.^{18,19}

Evitt proposed that members of the group Acritarcha should be mainly *organic-walled microfossils of uncertain origin*.² In accordance with Tappan, any acritarch whose biological affinity can be determined should be transferred out of the group Acritarcha and into the proper systematic group.²⁰ For example, after their affinity was recognized, the former acritarchs of the genera *Tasmanites* and *Pterospermella* were transferred out of Acritarcha and into Family Prasinophyceae of the algal Phylum Prasinophyta. The taxonomy of the acritarchs is based entirely on morphological features -- vesicle shape, size, ornamentation and the shape, size and distribution of spines, openings within the cell wall, and presence or absence and distribution of processes. Tappan and Loeblich²¹ described the surface structure of the wall of lower Paleozoic acritarchs. Morphological features can now be better delineated by modern Scanning and Transmission Electron Microscopy (SEM and TEM) techniques and methods. Despite their uncertain biological affinities, acritarchs are all classified under the International Code of Botanical Nomenclature.²² In 1973 and 1976, Eisensack, Cramer, and Diez published their monumental two volume catalog of the Acritarchs.^{23,24}

Due to their widespread distribution, Acritarchs have proven to be very useful in biostratigraphy and paleoenvironmental correlations. Acritarchs from Arctic Russia have been used to establish the Cambrian/Ordovician system boundary.²⁵ In 1996, Strother compiled charts showing the stratigraphic distribution from the Cambrian through the Devonian based on the data given by Downie in his review of British Paleozoic acritarchs.²⁶ It has been proposed that the rapid decrease in acritarchs which occurred at the end of the Devonian led to a "phytoplankton blackout" during the carboniferous and Permian, followed by a replacement of acritarchs by dinoflagellates in the middle of the Triassic.²⁷⁻³⁰

Until recently, it was thought that the oldest eukaryotic life forms on Earth were the 1.65-1.8 billion year (Ga) old Palaeoproterozoic clastic-facies microbiota from the Changzhougou Formation, Changcheng Group found in Jixian, North China.³¹ However, Javaux *et al.*³² reported the detection of large (300 μm diameter) well preserved organic-walled spheroidal microfossils in the 3.2 Ga bedded siltstones and shales of the Mesoarchaeon Moodies Group of the Barberton Greenstone Belt, South Africa. The Moodies Group stones indicate a shallow water marine siliclastic depositional environment. All of the organic-walled microfossils of acritarchs found in the most ancient Archaean rocks were sphaeromorphs and they ranged in size from quite small ($\sim 8 \mu\text{m}$) to very large ($\sim 300 \mu\text{m}$ diameter) eukaryotes. The Moodies Group stones were also found to contain the remains of large cyanobacterial filaments "enveloping small baecocyte cells and oval to sausage-shaped thick walled cysts up to 100 μm long called akinetes." These growth characteristics of cell reproduction by the formation of successively smaller baecocytes (produced of multiple fission followed by successive binary fissions) is known in the large, distinctive and highly recognizable prokaryotic cyanobacteria of the Order Pleurocapsales.^{33,34}

We have previously provided Field Emission Scanning Electron Microscope images and Energy Dispersive X-Ray Spectroscopy (EDS) data on the elemental composition of large filamentous cyanobacteria embedded in a variety of carbonaceous meteorites. These undeniably biological microfossils exhibit the morphological and morphometric characteristics of known representatives of all Orders of cyanobacteria. **Figure 1** provides images of microfossils found embedded in the Orgueil CI1 carbonaceous meteorite. These are well-preserved morphotypes of cyanobacteria of the Order Pleurocapsales. The meteorite filaments are interpreted as large filaments encapsulating polygonal baecocyte cells of diminishing sizes such as characteristic of replication by multiple fission followed by successive binary fissions known in the terrestrial Pleurocapsalean cyanobacteria. These large filaments envelope small baecocyte cells and to be connected to long oval to sausage-shaped thick walled cysts. EDS data reveals that these filaments found in Orgueil are carbonaceous sheaths that have been infilled with magnesium sulfate. EDS data reveals the nitrogen content is below that of the level of detector sensitivity ($<0.5\%$). This clearly demonstrates that these filaments cannot be interpreted as the remains of microorganisms that invaded meteorite stones after they landed. The Orgueil CI1 carbonaceous meteorite was observed to fall on May 14, 1864 near the villages of Orgueil ($43^{\circ} 53' \text{ N}$; $01^{\circ} 23' \text{ E}$), Campsas and Nohic (Tarn-et-Garonne) in the South of France. These morphotypes of Pleurocapsalean cyanobacteria have characteristics similar to the filamentous cyanobacteria reported by Javaux *et al.*³² from the shallow water marine siliclastic depositional environments of the Moodies Group stones.

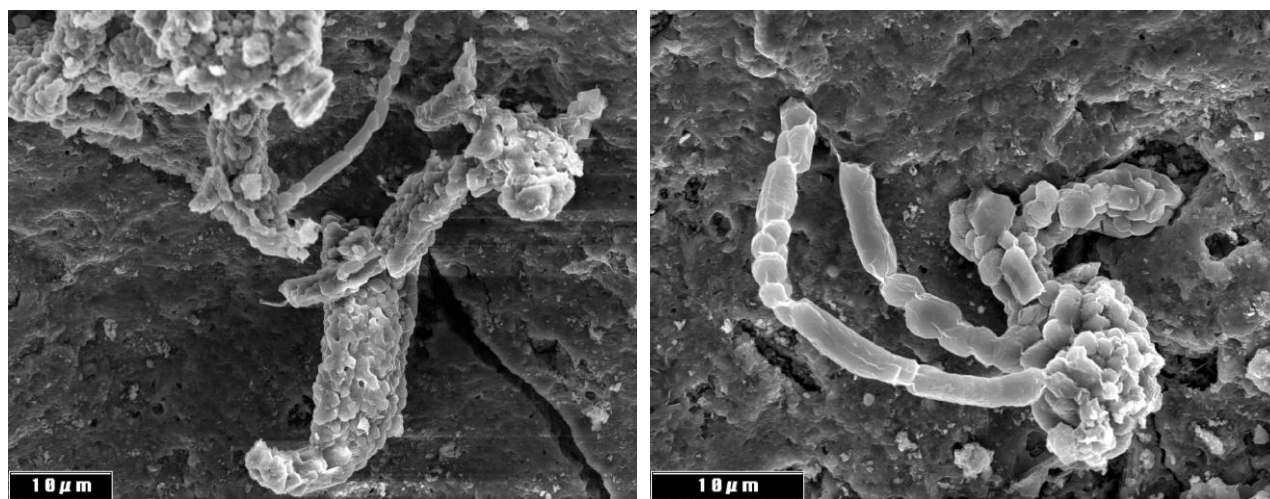


Figure 1. Well-preserved remains of morphotypes of cyanobacteria of the Order Pleurocapsales encapsulating polygonal baecocyte cells and "sausage shaped" akinetes in the Orgueil CI1 meteorite. **Photos:** Gregory Jerman & Richard B. Hoover, NASA/MSFC

3. MICROFOSSILS OF ACRITARCHS IN CARBONACEOUS METEORITES

3.1. Background

The discovery of evidence for acritarchs in carbonaceous meteorites was made in 1963 in Leningrad by Boris Vasil'evich Timofeev, the noted Russian palynologist, paleobotanist, micropaleontologist and biostratigrapher. In the 1950's Timofeev pioneered many techniques for the use of microfossil biomarkers in biostratigraphy while conducting studies for the *All Russia Petroleum Research Institute (VNIGRI)*. He described a number of genera and species of acid-resistant organic-walled microfossils (spores, hystrichospheres, acritarchs and dinoflagellates) and established their stratigraphic distribution in the geological column.^{18,19,35-39}

In 1961, Nagy, Meinschein and Hennessy used mass spectroscopy techniques they had been applying to oil shales and detected evidence for biogenic hydrocarbons in the Orgueil carbonaceous meteorite.⁴⁰ This result led Bartholomew Nagy to initiate a collaboration with the microbiologist George Claus to search for evidence of microfossils in meteorites. They used standard palynological methods to conduct a microbiological examination of the Orgueil and Ivuna CI1 carbonaceous meteorites. They found a large number of spherical organic-walled bodies (some with spines) in these meteorites. They interpreted these forms as evidence for indigenous acid-resistant organic-walled microfossils⁴¹ representing the remains of indigenous extraterrestrial life forms. Many scientists then began to address the problems of applying the Linnaean system to the taxonomy of extraterrestrial microorganisms.^{42,43} Fitch and Anders strongly criticized their results and they adopted the term "Organized Elements" in order to make no implications concerning the biogenicity of the bodies found in the meteorites.⁴⁴⁻⁴⁶ In 1964, Fitch and Anders ultimately won the "Organized Element" when they published a paper in which they claimed to have obtained an "intentionally contaminated" piece of the Orgueil meteorite from the Museum in Montauban, France. They claimed that someone had drilled a hole in the stone (possibly in the 1860's) and inserted bits of coal and reed seeds into the stone which they then re-sealed with glue to simulate a fusion crust.⁴⁷ This one simultaneously solved all the problems scientists had been dealing with concerning these meteorites. Other scientists had previously reported the detection of kerogen, amino acids, porphyrins, long-chain fatty acids and other biomolecules as well as "organized elements" and microfossils of "blue-green algae" (cyanobacteria) in other samples of the Orgueil stones.⁴⁸⁻⁵³ This "contaminated meteorite" paper claimed that these organic molecules and microfossils were the result of an intentional hoax. Consequently, the search for microfossils in meteorites effectively became "taboo" and the search for evidence of biomarkers and microfossils in meteorites remained dormant for almost three decades. It was not revived until 1996 with the McKay et al. announced the detection of evidence for chemical and mineral biomarkers and putative nanofossils in the Allan Hills Meteorite (ALH84001) from Mars.⁵⁴ Images of morphotypes of microfossils of filamentous cyanobacteria embedded in carbonaceous meteorites was published in the following year by scientists working independently in Russia and in the United States.⁵⁵
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3.2. The Mighei CM2 Carbonaceous Meteorite

The Mighei meteorite is the type meteorite for the CM Group of carbonaceous chondrites. It was observed to fall at 8:22 P.M. on June 18, 1889 in the Odessa District, Pervomaisky region near the village of Mighei, Ukraine (48° 4'N, 30° 58'E). In 1890, Yulian Ivanovich Shimashko published a booklet describing the meteorite and reporting that it contained ~4% carbonaceous organic material. Shimashko provided a detailed account from an eyewitnesses who observed the fireball and the fall of the Mighei stone: "*Kostenkova, a peasant, was standing 350 m to the east of the meteorite fall. She witnessed a flying bolide accompanied by a strong whirlwind. According to Kostenkova, the meteorite fell to earth from a height of 20-25 m, and it fell quite vertically... The meteorite seemed a black round rotating sphere like a big watermelon; "smoke and steam like a huge wheel surrounded it". The meteorite buried into the soil for half its diameter...Falling, the meteorite knocked down three sunflowers....All the leaves on the sunflowers around the meteorite hole up to a height of 1.5 m, were covered by a black, marked layer of soot.*"⁵⁸ Subsequent studies have shown that the Mighei meteorite contains aliphatic and aromatic hydrocarbons, extraterrestrial amino acids and other complex organic chemicals and the insoluble polymeric organic matter similar to kerogen that comprises most carbonaceous matter in the meteorite.⁵⁷

3.3. Possible Acritarchs in the Mighei CM2 Carbonaceous Meteorite

In the early 1960's there was intense worldwide interest and debate concerning possible evidence for microfossils in carbonaceous meteorites. Timofeev obtained a 5 gram sample of the Mighei meteorite and began to conduct a microphytological study of the stone. He applied standard palynological techniques to the search for acid-resistant organic-walled microfossils to the Mighei CM2 carbonaceous meteorite.⁵⁹ He described over twenty different types of cells which ranged in size from 10 μm to 60 μm in diameter. The bodies were yellowish-grey to dark grey or brown in color and many had smooth surfaces. Some were wrinkled and covered with small bumps and others had orifices or excystment openings. Timofeev interpreted these organic-walled bodies extracted from the Mighei CM2 carbonaceous meteorite as being biological in nature and representing life forms similar to spores and acritarch microfossils he had found in the Precambrian rocks of the Baltic Shield.⁵⁹

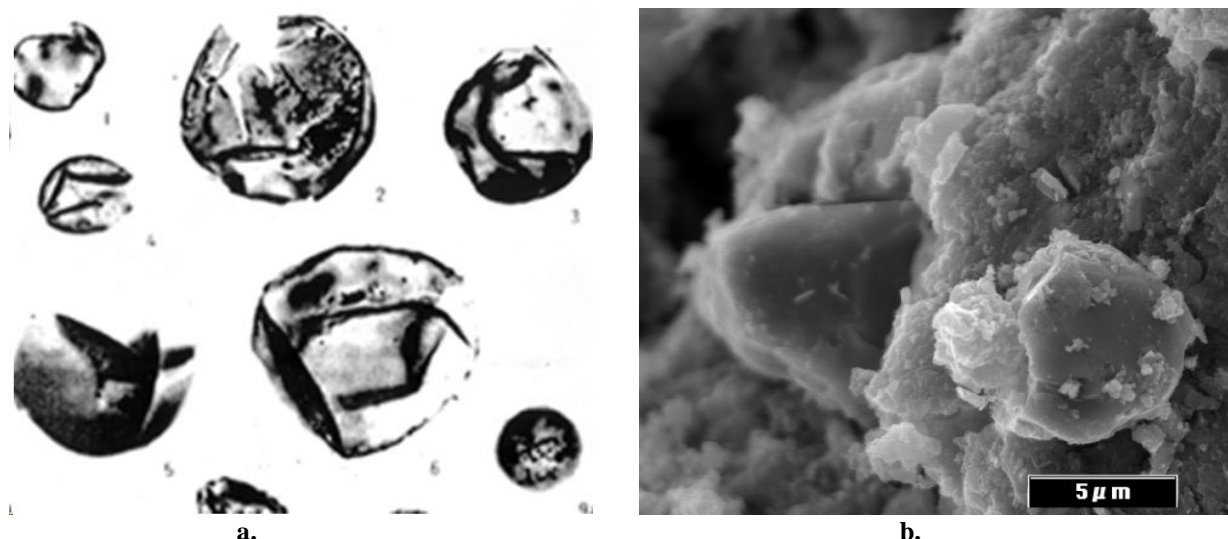


Fig. 2.a. Acid-resistant organic-walled microfossils (~30-60 μm) extracted from the Mighei CM2 carbonaceous meteorite by B. V. Timofeev similar to hystrichospheres and acritarchs he had found in the Precambrian rocks of the Baltic Shield and **b.** FESEM image of 11 μm diameter sphaeromorph with possible excystment opening found in freshly fractured sample of the Mighei meteorite
Photos: **a.** B. V. Timofeev, Leningrad; **b.** Gregory Jerman, Alexei Yu. Rozanov and Richard B. Hoover, NASA/MSFC

Figure 2.a. shows images of acid resistant organic-walled bodies extracted by Timofeev from the Mighei meteorite. The large rounded and wrinkled form (2) at the top has a wedge shaped opening similar to the excystment opening found in many acritarchs. **Figure 2.b.** is an image of acritarch-like forms found at the NASA/Marshall Space Flight Center in a freshly fractured sample of the Mighei meteorite. In the lower right is an 11 μm diameter sphaeromorph with short spines and possible excystment opening.

3.4. Possible Acritarchs in the Murchison CM2 Carbonaceous Meteorite

The Murchison CM2 carbonaceous meteorite was observed as a bright orange fireball with a silvery rim and dull orange conical tail over Victoria, Australia at 11:00 AM on the morning of September 28, 1969.⁶⁰ William Hollyman of Sheparton, Australia saw the meteorite moving almost parallel to the southern horizon and leaving a blue smoke trail.⁶⁰ Another witness saw a tight cluster of three objects of orange to red color with one object tumbling violently and flashing silver. Soon thereafter, several dozen jet-black stones with chondrules fell in a mile wide and ten mile long scatter ellipse around the town of Murchison (36°37'S; 145°14'E) indicating the meteorite trajectory was from the south-east.

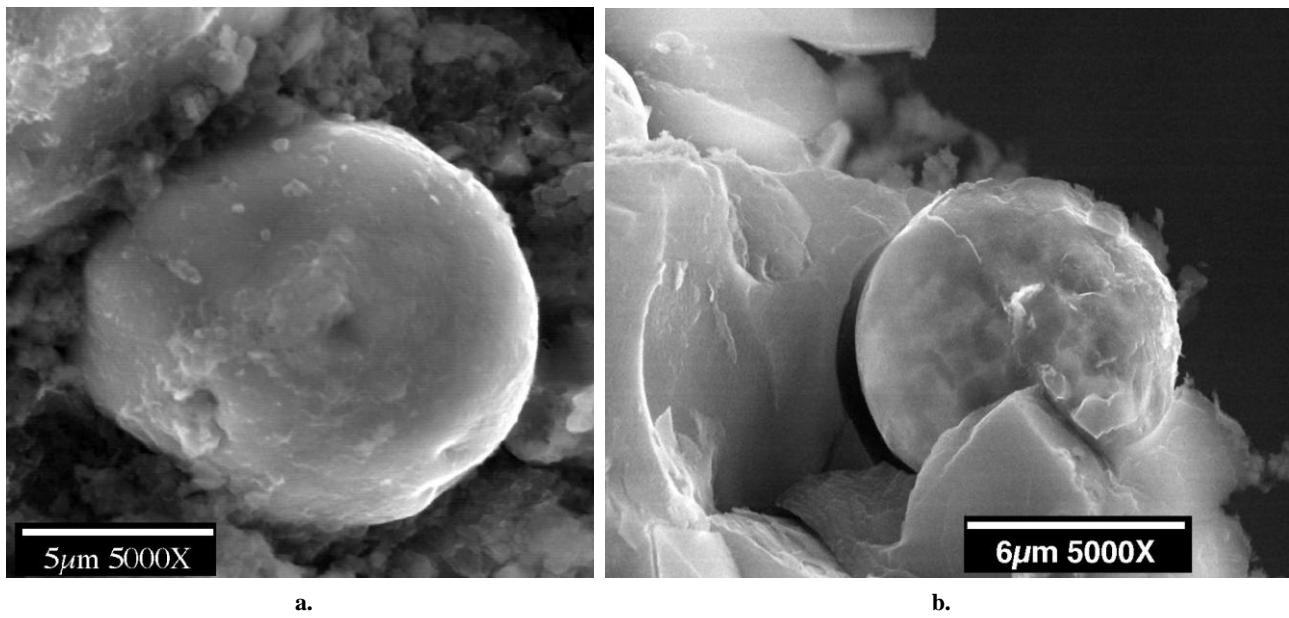


Fig. 3. Environmental Scanning Electron Microscope images of spherical forms in freshly fractured interior surfaces of the Murchison CM2 meteorite **a.** Sphaeromorph (~12 μm diameter) with small dimples and **b.** organic-walled embedded sphaeromorph with thin broken carbon-rich shell. **Photos:** Gregory Jerman, James Coston and Richard B. Hoover, NASA/MSFC

Figure 3 shows Environmental Scanning Electron Microscope (ESEM) images of spherical bodies or possible acritarchs found in freshly fractured interior surfaces of the Murchison CM2 carbonaceous meteorite. Energy Dispersive X-Ray Spectroscopy (EDS) data has shown that these bodies are carbon rich. **Figure 3.a** is a sphaeromorph (~12 μm diameter) with small dimples. **Figure 3.b.** is an ESEM image of organic-walled embedded sphaeromorph with thin broken carbon-rich shell. The shell covers the lower two thirds of the spherical body and is missing from the upper portion of the sphere. EDS data shows significantly higher levels of Carbon (>10%) as compared with the upper region where the shell is missing (C < 1%). If this carbonaceous matter is polymeric in nature (Kerogenous) it would remain behind if the interior mineral matter were removed by acid maceration such as is typically employed for extracting acritarchs and other acid-resistant microfossils from terrestrial rocks.

3.5. Possible Acritarchs in the Orgueil CI1 Carbonaceous Meteorite

The Orgueil meteorite was observed to fall 8:13 P.M on the evening of May 14, 1864 in a 15 -18 km east-west scatter ellipse enveloping the small villages of Orgueil (Tarn-et-Garonne) and Nohic near Montauban in the South of France. Immediately after the fall, the inhabitants of Orgueil and Nohic collected over twenty jet-black stones, some of which had mass in excess of 2 kilograms.⁶¹ A total weight of more than 13 kg of this extremely fragile, low-density meteorite was recovered. Gounelle *et al.*⁶² used the data of Daubree^{61,63} to compute the orbital parameters of the Orgueil parent body. They obtained a semi-axis of 2.4 - 13 AU with an eccentricity of 0.59-0.93, which is consistent with the Apollo Asteroid Orbits and the Jupiter family of comets. Ehrenfreund *et al.*⁶⁴ showed that the amino acids in the Orgueil and Ivuna meteorites were extraterrestrial in nature and they suggested that an extinct comet was the probable parent body for the CI carbonaceous chondrites. They compared the compositions of the extraterrestrial amino acids of the Orgueil and Ivuna CI meteorites with those of the Murchison and Murray CM carbonaceous chondrites and concluded that these groups of meteorites probably originated from different parent bodies.

In 1864, immediately after the Orgueil meteorite stones were collected, Cloëz conducted the first detailed chemical analysis of the Orgueil stones.^{65, 66} He found the stones to contain 5.3% water-soluble salts. The Orgueil meteorite contained magnetite, silicic acid, 5.9 % carbon, and a variety of evaporite minerals and salts - "*ammonium and chlorine salt, potassium chloride; sodium chloride, magnesium sulfate, and calcium sulfate.*" The Orgueil stones were found to be composed of a soft, black, extremely friable material, with ammonium salts, humic substances, magnetite, and silicic acid. Pisani concluded that the Orgueil silicate minerals are more properly designated serpentine rather than peridotite.⁶⁷ Leymeri described the clay-like character he observed as he used a knife to cut into one Orgueil stone immediately after

the fall - "The knife cut creates smooth and shiny surfaces which is an indication of a fine, paste-like matter." ⁶⁸ One of the Orgueil stones landed on hay in an attic but did not set the hay on fire, thus indicating a moderately low surface temperature. However, the fusion crust was still hot enough to burn the hand of the farmer who saw it fall through the roof and reached to pick it up while it was still hot. The presence of frost seen the next morning on some of the stones by others in the village indicated that the interior of the meteorite stones remained cold as the meteorite passed quickly through the atmosphere as ablative cooling from melting of the outermost layers carried away the heat. A few hours after the fall the frozen interior cooled the fusion crust such that moisture from the air condensed and froze on the surface as a layer of frost. ⁶⁹ The Orgueil meteorite has been found to contain an extensive array of extraterrestrial amino acids, nucleobases and other life critical biomolecules. The dominant portion of the carbonaceous material of the Orgueil meteorite is in the form of a kerogen-like complex polymeric carbon that is insoluble in water and similar to peat or lignite coal.

Figure 4 provides Scanning Electron Microscope images of possible sphaeromorph acritarchs in the Orgueil CI1 carbonaceous meteorite. They show small bumps on the exterior of the sphere and a larger opening possibly representing an excystment opening.

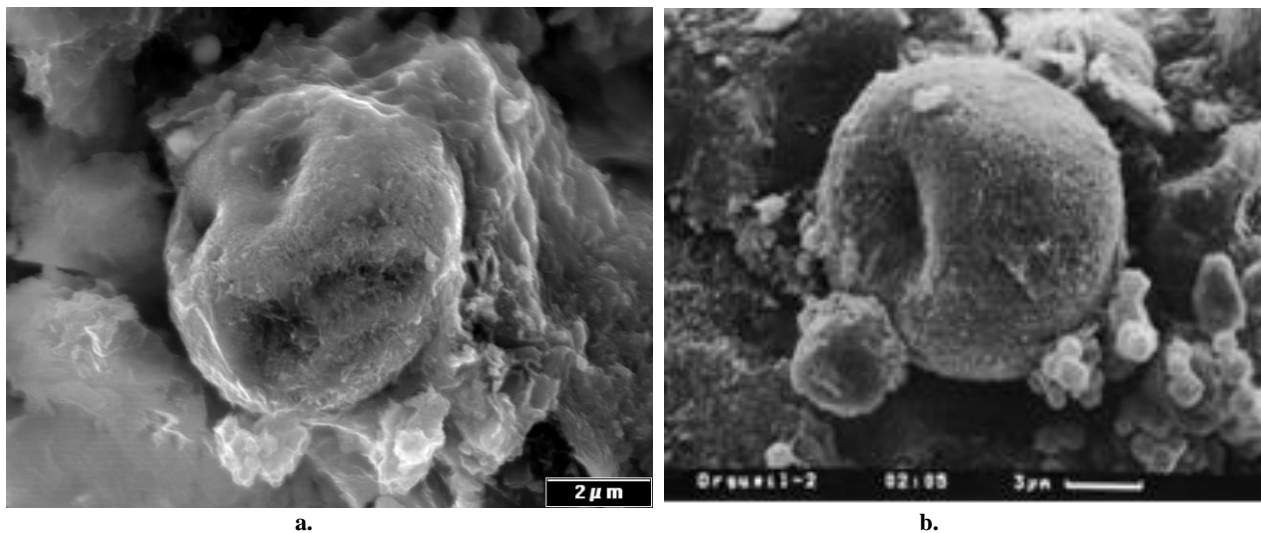
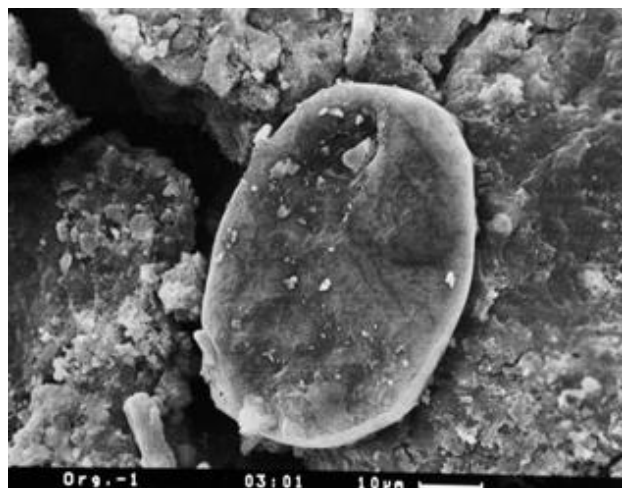
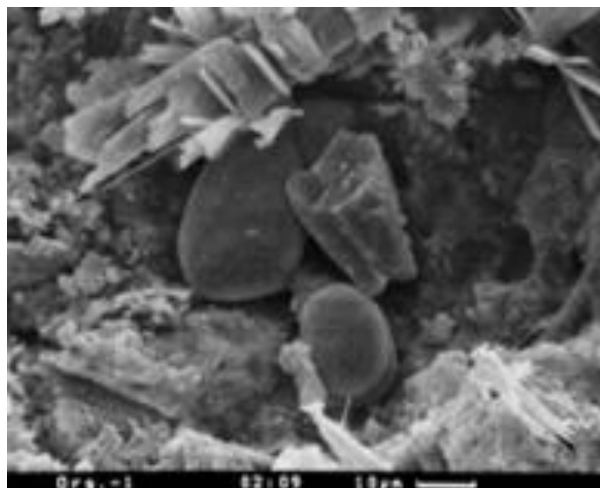


Fig. 4. Scanning Electron Microscope images of sphaeromorphs in Orgueil meteorite **a.** showing flattened and rounded spheroidal bodies with small bumps and **b.** with a possible excystment opening. **Photos:** **a.** Gregory Jerman and Richard B. Hoover, NASA/MSFC; **b.** Marina Astafieva and Alexei Yu. Rozanov, Paleontology Institute, Russian Academy of Sciences

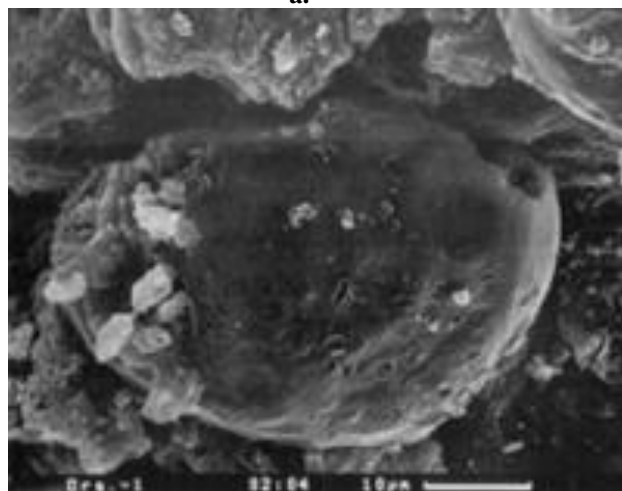
Figure 5 shows Scanning Electron Microscope images of ellipsoidal forms which may represent possible diacromorph acritarchs in the Orgueil meteorite. These ellipsoidal forms appear to have an opening or pylome at one pole.



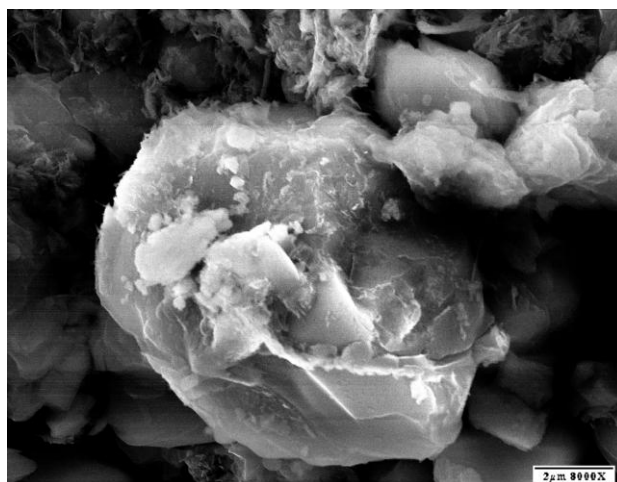
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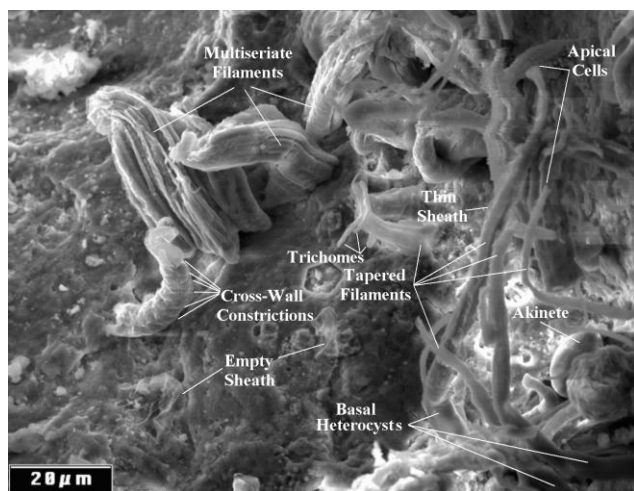


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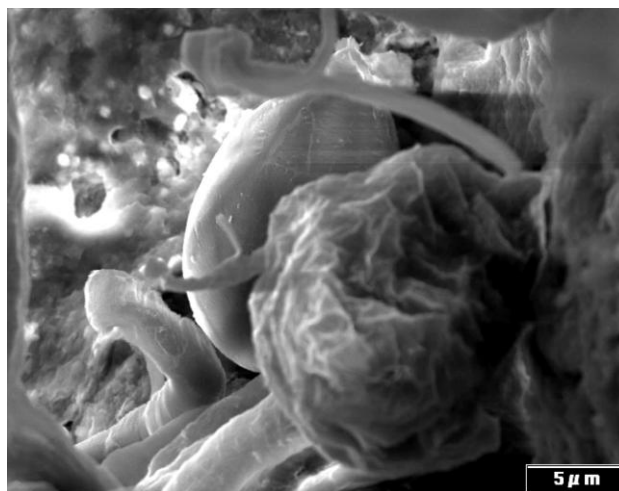


d.

Fig. 5.a.-d Scanning Electron Microscope images of ellipsoidal forms (possible diacromorphs) in Orgueil meteorite with possible excystment opening at pole. **Photos:** Marina Astafieva & Alexei Yu. Rozanov, Paleontology Institute, Russian Academy of Sciences



a.



b.

Fig. 6.a.b. FESEM images of cyanobacteria and acritarch in the Orgueil meteorite. **Photos:** G. Jerman & R. B. Hoover, NASA/MSFC

Figure 6.a provides labeled FESEM images of the permineralized remains of a large number filaments of different genera and species of cyanobacteria embedded in a freshly fractured interior surface of the Orgueil meteorite. There are multiseriate filaments in which multiple trichomes are encased within a common sheath. This is common in terrestrial filamentous cyanobacteria of genera such as *Microcoleus* and *Phormidium*. One form appears to be an escaped hormogonium with cross-wall constrictions visible making it possible to discern the size of the cells enclosed within the sheath. The image also shows several polarized and tapered filaments with diameters ranging from ~ 2 to 5 μm in close proximity to each other. Some of the filaments are fluted at the apex and adorned with nodules. They all exhibit smooth basal heterocyst (smooth oval cell) at the base where the filament is attached to the meteorite rock matrix. These smooth ovoid cells are interpreted as basal heterocysts which are used for nitrogen fixation in Nostocacean and Rivularian cyanobacteria. In the lower right of the image is a smooth egg-shaped body which is interpreted as an akinete behind a flattened and wrinkled sphaeromorph. **Figure 6.b.** is a higher magnification image of this region showing the detail of the akinete and the wrinkled sphaeromorph (~15 μm diameter) that is interpreted as a morphotype of an acritarch (cf. *Leiospheridia* sp.). The embedded and tapered polarized filaments are seen to have with funnel shaped apices, bulbous basal heterocysts and they are clearly visible along with akinete and permineralized remains of the acritarch (morphotype of *Leiospheridia* sp.) in the Orgueil CII carbonaceous meteorite. EDS data reveals that all of these forms are carbon rich and have undetectable (<0.5% atomic) or extremely low (Akinete ~ 1% atomic) levels of nitrogen, providing evidence that the bodies are not modern biological contaminants. (Prior EDS analyses with these instruments have shown that all modern living or dead biological cells have nitrogen levels from 2% atomic to 20% atomic).

4. CONCLUSIONS

Optical and scanning electron microscopy studies carried out in Russia and in the United States have revealed the presence of a large number of carbon-rich, organic-walled microstructures in a wide variety of CM2 and CII carbonaceous meteorites. Although a few of the forms are ellipsoidal, the vast majority are sphaeromorphs. They are interpreted as the indigenous remains of biogenic microstructures similar to the organic-walled acid resistant microfossils that represent the broad group of eukaryotic remains with unknown affinities investigated as acritarchs.

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