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Earliest organic evolution. Essay to the memory of Bartholomew Nagy

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Abstract

A review is presented of the currently available evidence of life in the Precambrian, with special reference to microfossils of the size range 0.1–3 μm. The particles are spotted in thin sections of the rock under high apertures of the light microscope, and have been examined in demineralized thick sections under the transmission electron microscope (TEM). They have been chemically analyzed utilizing microprobe and spectrophotometer microscopic techniques.

On the basis of such studies, the interaction of microorganisms with the formation of minerals can be traced back to early Archean times, 3800 million years ago. There is no indication supporting the assumption that some kind of prebiotic evolution took place in the recorded history of the Earth. The origin of life is open to alternative explanations, including extraterrestrial phenomena.

More information may be obtained from meteorites. Under high magnifications of the TEM, a portion of the carbonaceous matter in the Murchison, Orgueil and Allende meteorites appears to be structured. Particles of various morphology can be distinguished. Microprobe techniques are applied to confirm that the microstructures are organic and indigenous to the rock. Possible origins by self-assembly and morphogenesis are discussed.

Keywords: Precambrian microfossils; Carbonaceous chondrites; Self-assembly; Prebiotic evolution

1. Introduction

Precambrian sediments offer a continuous record of carbonaceous particles from their first appearance 3800 million years ago. These can be made visible in thin sections and demineralized sections of the rock, and chemically analyzed in situ by microprobes and spectrophotometer microscopes (Pflug and Reitz, 1992). Most of the finds exhibit a complex chemical composition comprising organic materials as well as inorganic compounds such as carbonates, oxides and sulfides. It is suggested, that most of these inorganic constituents are 'biominerals' produced directly or indirectly by the life activity of the involved organisms. After deposition and burial of the dead cell, the metals may react with H_2S produced by sulfate-reducing bacteria and form metallic sulfides. The organic structures are sometimes replaced by either a mixture of framboidal

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and microgranular sulfide, and some microbes may be preserved as pyritized fossils.

2. Techniques

A scheme of the technical procedure that has proven useful for the studies is shown in Fig. 1. Compact and unweathered rock samples are selected for the studies. The rock sample is sectioned into two halves. From one side of the main cut (1b), a normal *ca* 30 μm thin section is produced. It is used for polarization microscopy and microprobe analyses. From the opposite surface, a thick section is prepared for the purpose of den-fineralization. The procedure is carried out on a membrane filter of 0.01 μm pore diameter. The sample is exposed to vapors of HT and HCI, and the minerals present (or most them) are dissolved and removed through the pores of the filter (cf. Fig. 9a,b). The organic particles are not affected by the procedure and remain on the filter with little or no alteration of their original structure

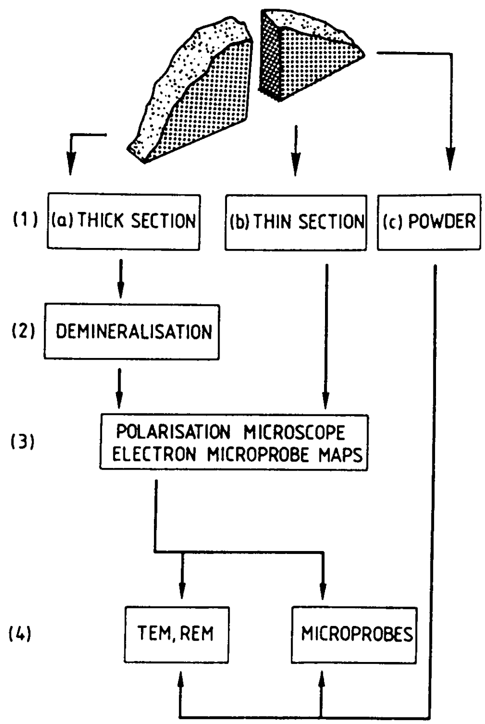

Fig. 1. Preparations and analytical procedure.

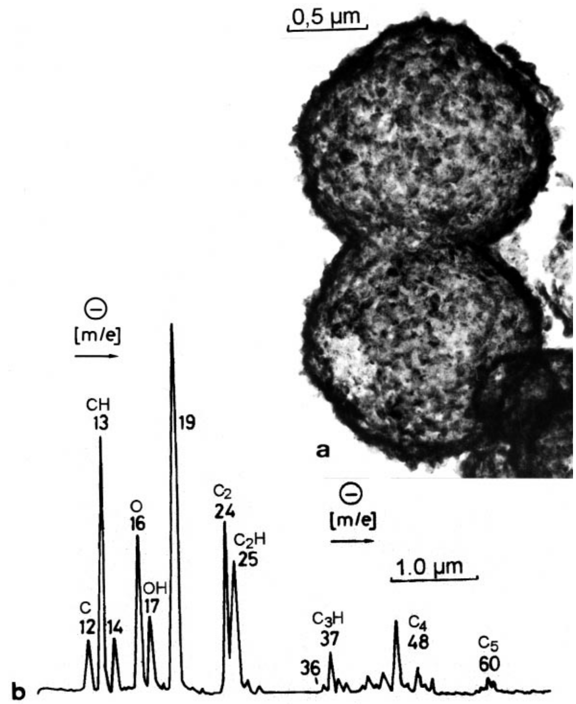

Fig. 2. Organic microstructure from the Bulawaya stromatolite, Zimbabwe (*ca* 2.7 Ga). (a) TEM-micrograph from demineralized rock section. (b) Laser mass spectrum from individual specimen of the same population (negative ions). Field of measurement *ca* 1 μm diameter. Attribution of signals: 12: C^-, 13: CH^-, 14: CH_2^-, 16: O^-, 17: OH^-, 19: F^-, 24: C_{-2}, 25: C_2H^-, 26: CN^-, 28: Si^-, 36: C_3^-, 37: C_3H^-, 40–42, 45: fragmental carbonaceous groups, 48: C_4^-, 49: C_4H^-, 50: $C_4H_2^-$, 60: SiO_2^-, resp. C_5^-, 61: C_5H^-.

and position. The demineralized section can be immediately examined under the light microscope together with the underlying filter as a support. Preparation for the TEM is not complicated.

Under the light microscope, the thin section reveals the original condition of the organic matter, with respect to its distribution and arrangement within the mineral matrix.

Microprobe techniques allow the in situ analysis of particles larger than 1 μm and of smaller particles if they occur united in clusters. Electron microprobe and Laser microprobe mass analyses require that the particle be exposed to the surface of the section. Bombardment with negative ions is not influenced by minerals, so that the analyses can be made before and after demineralization and then compared. It has been found that the spectra of the first and second measurements are nearly identical in all signals. Consequently, the organic material is not altered by the demineralization treatment.

Technique	Instrument	Spot of measurement (μm diameter)
1. Laser Raman	MOLE (J. S.A. Jobin Yvon)	1–5
2. Infrared absorption	NanoSpec/20 IR (Nanometrie)	33
3. UV/visible absorption	UMSP 1 (Zeiss) UV-microscope (Leitz)	1–5
4. Laser mass spectroscopy	LAMMA (Leybold)	1–5
5. Electron microprobe	AMR 1600 T/ WDX2A (Leitz/ MICROSPEC)	1–5

Laser microprobe mass analyzers permit mass spectrometric analysis of very small volumes (0.01–1 μm^3) of thin sections. Since the area to be analyzed is selected by an optical microscope, distribution of chemical constituents can be precisely correlated with morphologic structures. The Infrared (IR) spectra of fossil-organic particles show a limited number of rather broad bands which are due to well defined chemical groups. Laser Raman spectra generally match the corresponding IR-spectra, but the features in particular yield additional information.

The following information is obtained from the analyses. (1) Enrichments of elements such as carbon and sulfur are shown in the electron microprobe maps, (2) Aliphatic and aromatic stretching modes are visible in the Infrared and Raman spectra. A peak at about 1610 cm^{-1} is shown in the Raman spectra (Fig. 6), (3) C_n, H_m-clusters together with non-specific fragments such as CN and CNO are indicated in the Laser mass spectra (Fig. 8), (4) In the UV-spectra, a maximum absorption is located at 225 nm. Shoulders around 260/270 nm are comparable to the so-called ‘coal absorption bands’. The latter anal-

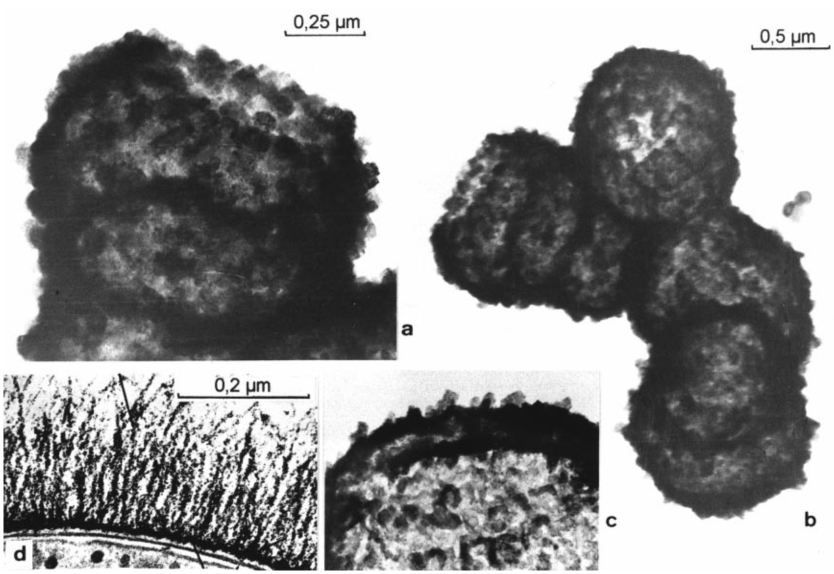

Fig. 3. (a,b) Organic microstructures from Kromberg Formation, Swaziland System, South Africa (*ca* 3.4 Ga). TEM-micrographs of demineralized specimens. (c) Portion of organic microstructure from Bulawaya stromatolite (see Fig. 2). (d) Portion of the mucilagenous sheath of recent *Anabaena* sp., cyanobacteria (Fig. d after Leak, 1967). For magnification of Fig. c see scale of Fig. a.

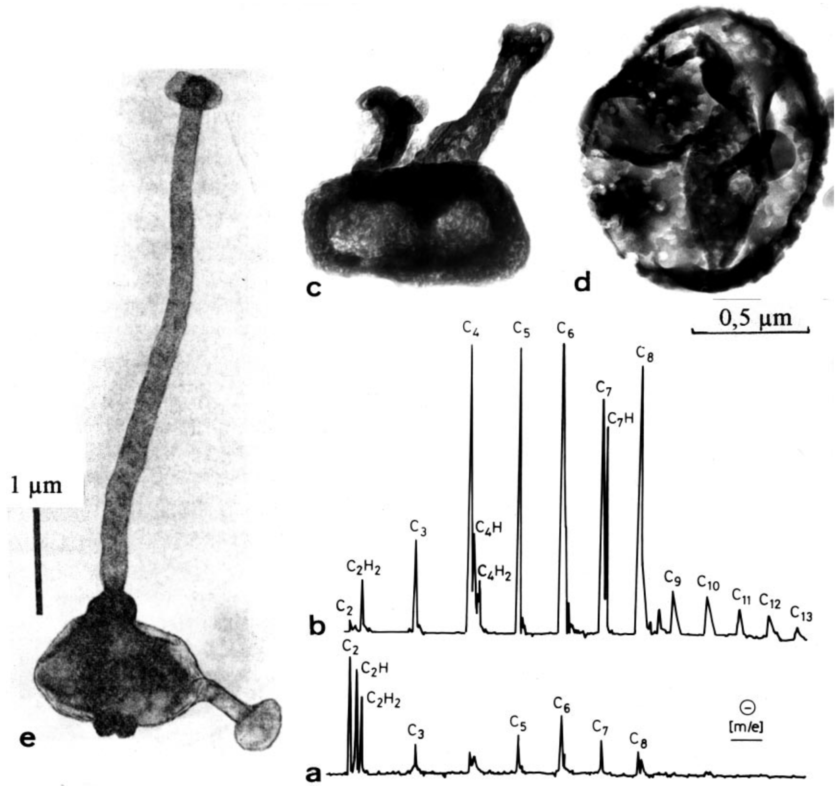

Fig. 4. (a–d) Organic microstructures from Swartkoppie chert, South Affica (*ca* 3.25 Ga). TEM-micrographs of demineralized specimen (a,b) Laser mass spectra (negative ions) from clusters of similar specimens. Field of measurement *ca* 1 µm diameter. (c,d) TEM-micrographs from demineralized Thin section. (e) Recent budding iron bacterium *Pedomicrobium* sp. (Fig. e from Ghiorse and Hirsch, 1979).

ysis is disturbed by iron compounds, so that these need to be completely removed before the measurements, (5) Inorganic constituents are shown in the Laser mass spectra (positive ions) (Fig. 9). In the IR- and Raman-spectra, absorptions of Si–O, O–Si–O and Si–O–Si atomic groups are sharply produced, indicating quartz and other silicates. In the region 1000–690 cm^{-1}, the absorption bands of metal oxides (Al, Fe, Mg)–O–O and the CO_3^{2-} group of carbonates are shown. A carbonate absorption often occurs at 1420 cm^{-1}, two weaker bands lie at 855/865 and 710/730 cm^{-1}. Sharp bands at 425 and 350 cm^{-1} are due to pyrite. Iron hydroxides appear in the IR-spectra with broad absorption around 3140 cm^{-1} together with two bands at about 900 cm -1 and 800 cm^{-1}, respectively. Particles containing Fe^{3+}-oxides and -hydroxides produce strong charge transfer bands in the UV-visible absorption spectra, one at 395 nm, the other at 465 nm, plus two ligand field bands at 650 nm and 900 nm respectively.

Possible biogenicity is checked up on the basis of the following criteria. (1) The particle has the size and morphology of a cell organism. (2) It consists of fossilized carbonaceous matter (kerogen). (3) It is often externally encrusted or impregnated with carbonates, pyrite or other mineral matter of possible biogenic origin. (4) Many specimens of the same kind occur together in a population. They are associated with non-structured carbonaceous debris of similar chemical composition. (5) The assemblages are arranged along bedding planes of the sediment which is a chert, stromatolite, banded iron formation, shale or related rock. (6) Well preserved specimens show

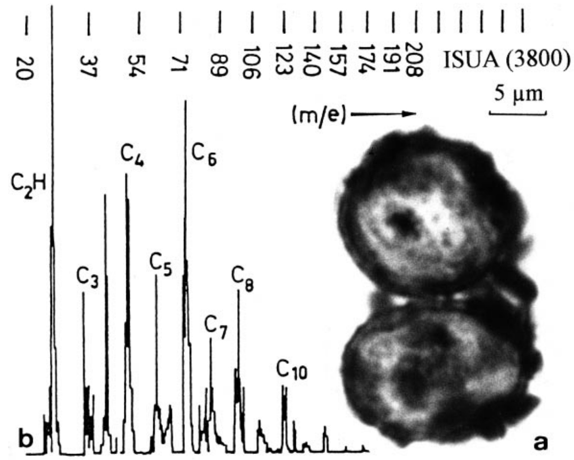

Fig. 5. (a) Carbonaceous microstructure from Isua Banded iron formation, SW-Greenland (*ca* 3.85 Ga). (b) Laser mass spectrum (negative ions) from similar specimen. Field of measurement *ca* 1 μm diameter.

structural details in cell wall and sheath. (7) Specimens occur in different stages of cell division, resembling a bisquit, a dumb-bell or pair of tears. (8) Daughter cells may stay enclosed in a common sheath. (9) Filaments display multicellular organization with cross walls intercalated at intervals. Branched and unbranched filaments may occur. (10) Individuals of the same population have a similar spectrochemistry. Typical spectra are compiled in Fig. 2, Fig. 4 and Fig. 5 together with the typical morphologies. It should be noted that the shown micrographs and the associated spectra are not from the same specimen but from individuals of the same population.

Using the above criteria, biological structures should be distinguishable from similar looking objects of non-biological origin in most cases. Independent of the above definition, the term 'microstructure' is used for all carbonaceous morphologies that occur as indigenous particles in rock matrices, regardless of their origin. It should be noted in this context that microstructures from meteorites may sometimes closely resemble terrestrial microfossils such as those from the Warrawoona and Gunflint (see Fig. 11). Apparently, morphology alone is no reliable criterion of biogenicity.

Apart from the palaentological record, there exists a biogeochernical record of life in the form of sedimentary organic carbon. It conveys a coherent signal of photosynthetic carbon fixation over the geologic past. Commonly, meteorites do not show this signature (though some exceptions are known).

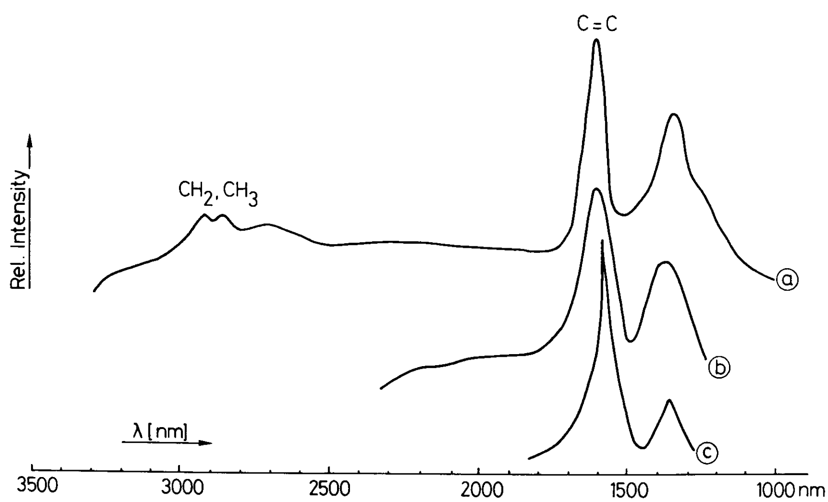

Fig. 6. Laser Raman spectra of fossil microstructures. (a) from Gunflint chert. (b) from Isua quarzite. (c) from graphite particle.

Fig. 7. Carbonaceous microstructures obtained from dernineralized rock section of Murchison meteorite. (a,c) Cluster of vesicles, (b) vesicle in higher magnification, (d) filament, (e) portion of filament in higher magnification (g = nanoglobule).

3. Occurrences

Nagy and his co-workers have spent a considerable amount of time working with the oldest sediments on Earth, and it is interesting to compare their findings with the more recent data. A well preserved stromatolite occurs in the *ca* 2.7 Ga Bulawaya rock sequence of Zimbabwe/South Africa. Nagy and Zumberge (1976) studied thin sections of the rock under the light microscope and detected spherical microfossils mineralized with quartz and dolomite which they assigned to endosporulating cyanobacteria. Later, Sklarew and Nagy (1979) isolated furaldehyde and benzonitrile from the rock organic matter and interpreted them as remnants of carbohydrates, proteins and fatty acids. I examined the Bulawaya microstructures in dernineralized sections under the TEM (Fig. 2a and Fig. 3c) and found similar morphologies. Laser mass spectra (Fig. 2b) obtained from the fossils are well comparable to the analytical results of Sklarew and Nagy.

The *ca* 3.2–3.4 Ga old Archean rocks of the Swaziland System in Transvaal/South Affica show a surprisingly low metamorphic grade, only incipient, minimal metamorphism. Nagy and Nagy (1968, 1969) studied samples of the Onverwacht rock sequence, and detected coccoid objects 2–6 μm in size resembling fossil microbes. I found similar morphologies in cherts of the Onverwacht (Fig. 3a,b) and the Swartkoppie/Fig Tree (Fig. 4c,d). Some of the finds resemble picophytoplankton (cf. Fig. 3d) others are similar to iron bacteria (see Fig. 4e). Microprobe spectra yield evidence of their organic composition (Fig. 4b).

In the 3.8 Ga old Isua supracrustai belt, South West Greenland, a banded iron formation occurs. Nagy et al. (1975) were the first to show that the Isua BIF contains microstructures which are evidently carbonaceous and indigenous to the sediment. The authors concluded that the finds are likely abiotic in origin, although a biological origin did not seem impossible. Subsequently Pflug (1982) found cellular structures of the *Huroniospora*-type (cyanobacteria) in the rock (Fig.

5b). Robbins (1987) described morphologies resembling capsules of iron bacteria.

The Isua sediments have suffered considerable metamorphism which complicates their study. But it is erroneous to believe that metamorphosed rocks no longer contain fossils or chemofossils. Organic particles located in a protected position of the mineral matrix may escape destruction and remain with their morphology intact. Once the microstructure is sealed within a single crystal of quartz, deformation of the surrounding rocks would be of less consequence. Carbon–carbon bonds are fairly resistant to thermal cracking, and particularily hydrocarbons possess a considerable preservation potential surviving as molecular fossils (Fig. 5a and Fig. 6b). Many metamorphic rocks have considerable amounts of carbonaceous matter which is not graphite. Locally, the matter may contain as much as 2.5% volatiles. Preserved plant fragments and cell structures have been described from rocks of the garnet facies, calculated heating temperature $>500°C$ (Hamilton et al., 1970).

The depositional palaeoenvironment deduced from the Isua BIF shows that aqueous sedimentation occurred and life was possible (Nutman et al., 1997). The isotopic composition of the Isua carbonaceous matter, though altered by rock metamorphisn ~ is decidedly compatible with a biogenetic derivation (Schidlowski, 1995). The isotope data of the carbonaceous microdomains in apatite are consistent with a bioorganic origin (Mojzsis et al., 1996). It should be noted that oldest microbiota reported from Australia (Schopf, 1993) are dated to *ca* 3500 million years, hence not much younger than Isua. Some of the Australian morphologies were described resembling extant photoautotrophic, chemoautotrophic, and chemoorganotrophic bacteria.

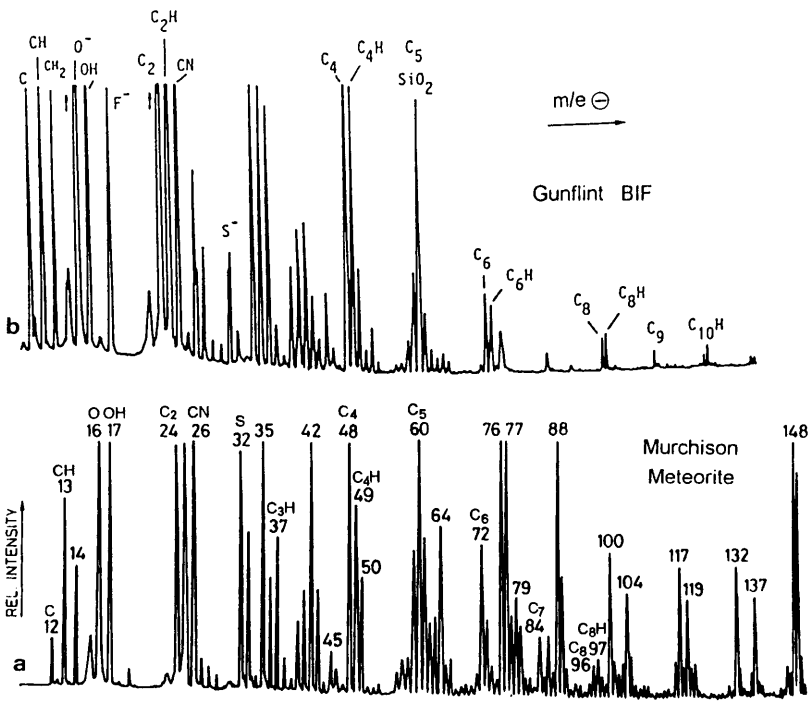

Fig. 8. Laser mass spectra (negative ions) from individual microstructures in thin section. (a) Murchison meteorite. (b) Gunflint chert. Field of measurement *ca* 1 μm. Attribution of signals: 12: C^-, 13: CH^-, 14: CH_2^-, 16: O^-, 17: OH^-, 19: F^-, 24: C_2^-, 25: C_2H^-, 26: CN^-, 28: Si^-, 32: S^-, 35: Cl^-, 36: C_3^-, 37: C_3H^-, 40–42, 45: fragmental carbonaceous groups, 48: C_4^-, 49: C_4H^-, 50: C_4H^-2, 60: SiO_2^-, resp. C_5^-, 61: C_5H^-, 72: C_6^-, 73: C_6H^-, 76: SiO_3^-, 96: C_8^-, 97: C_8H^-, 108: C_9^-, 120: C_{10}^-, 121: $C_{10}H^-$.

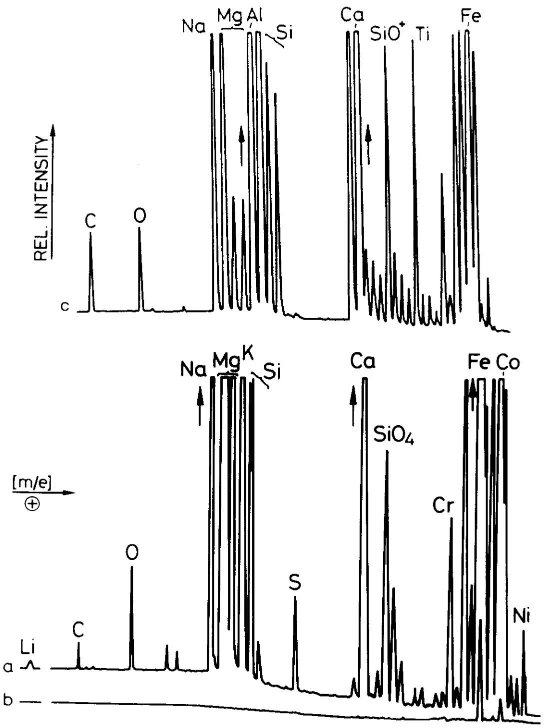

Fig. 9. Laser mass spectra (positive ions) from individual micro structures. (a,b) from Murchison meteorite, (c) from Gunflint chert, Figs. (a,c) before, Fig. (b) after dernineralization of the microstructure.

Summing up, the available findings suggest that a well developed biosphere was present on Earth 3800 million years ago. Consequently life's origin must be considerably older. The question arises whether the remaining time span of Earth history is long enough for the evolution from a simple compound to a perfect organism. Geologists have not found the prebiotic matter that chemists have so often attempted to simulate in the laboratory. Evidence for such processes may have to be looked for in other places, such as interstellar space and meteorites.

The fact cannot be ignored that microstructures known from meteorites closely resemble terrestrial microfossils, in morphology as well as in chemistry. In 1966, Nagy (Nagy, 1966) examined ultrafine thin sections of the Orgueil meteorite under the TEM and discovered well-formed carbonaceous particles embedded in the hydrosilicate matrix. The most common objects were filamental, sheet-like or spherical in shape, and some of the spheres showed a double wall structure. Rossignol-Strick and Barghoorn (1971) treated samples of the Orgueil meteorite with $KClO_3$ and HNO_3 followed by concentrated HF and HNO_3 and detected similar microstructures in the residue by use of a light microscope. The authors concluded from their study that the morphologies meet the requirements for biogenicity rather satisfactorily. In the electron microprobe, carbon and phosphorus were identified in the particles. Size distribution of the specimens was found to be evocative of populations of Precambrian organisms as shown in histograms of the microfossils in the Precambrian Gunflint chert.

I detected similar morphologies in the Murchison meteorites (Fig. 7). The Laser mass spectra (negative ions) resemble spectra of Gunflint microfossils (Fig. 8). But spectra of the posi-

Fig. 10. Portion of a chondrule from Murchison meteorite. (a) Thin section showing ferromagnesian silicates (transparent) and interstitial filling consisting of carbonaceous matter, Fe-sulfides and hydrosilicates (opaque). (b) Carbonaceous microstructure left after in situ demineralization of the thin section.

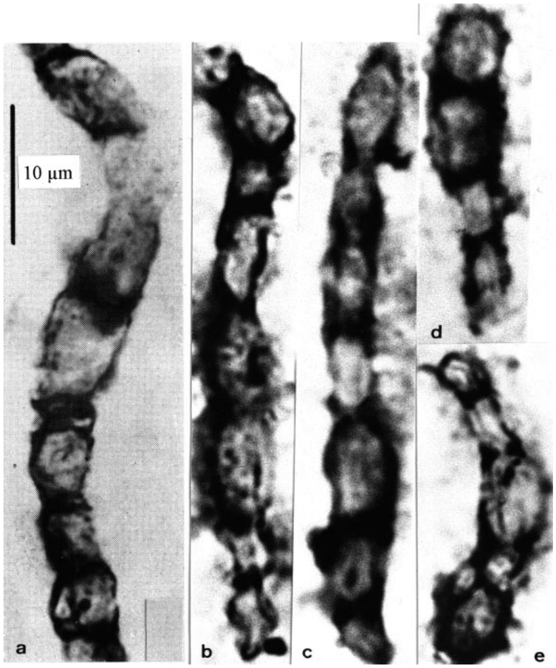

Fig. 11. Comparison of *Gunflintia grandis* from Gunflint chert (a) with microstructures obtained from dernineralized chondrules of the Murchison meteorite (b–e). For magnification of Figs. b–e see Fig. 10. Fig. a is from Barghoorn and Tyler (1965).

tive ions (inorganic constituents) are different (Fig. 9).

Two alternative explanations result from the findings: either the morphologies are remnants of cosmic life, or they are products of non-biotic cosmic syntheses simulating biotic structures. Rossignol-Strick and Barghoorn preferred the latter interpretation, mainly for the reason that the meteoritic texture does not conform satisfactorily with the usual sedimentary requirement associated with true fossils. They interpreted the organic hollow spheres as coatings on microchondrules and other mineral grains, which themselves did not withstand laboratory maceration. We studied chondrules of the Murchison meteorite in thin sections and found carbonaceous matter, phyllo silicates and fine-grained sulfides as coatings and interstitial fillings (Fig. 10). Evidently, such chondrules have a complex history including low temperature reactions in the final stages (Wasson, 1993).

After dernineralization, the carbonaceous particles remain from the filling and some of them resemble Precambrian microfossils (cf. Fig. 11a, 11b–e). Others are similar to organic particles isolated from interplanetary dust (see Bradley et al., 1984, Fig. 2). Apparently, structures of that kind can form biotically as well as abiotically.

4. Self-assemblages in aqueous media

Rossignol-Strick and Barghoorn (1971) had noted membraneous walls connected with the Orgueil microstructures. I found similar membraneous vesicles in demineralized samples of the Murchison meteorite (Fig. 7a–c). They sometimes have a bilayer composition resembling lipid membranes of biological systems. But membranes of that kind are also known to form non-biotically, e.g. from lipid molecules at the gas/water interface of an aqueous medium. Deamer (1985) isolated non-polar molecules from extracts of the Murchison meteorite and found lamellar structures, resembling biological membranes. Droplets of a yellow pigment isolated from the extract showed intense fluorescence. Similar fluorescent constituents have also been detected by Alpern and Benkheiri (1973) in the Orgueil meteorite.

Bilayers of fatty acids or layers of ordered water molecules can associate spontaneously. This is due to the hydrophobic effect, a fundamental interaction in wet environments. The water structure induced by the solutes is central to the phenomenon, and the interfaces formed by such assemblies will be dependent on dissolved gas. The dominant shapes would be minimal surfaces or close approximations to them. Vesicles of that kind are capable of birthing, healing, budding and other manifestations of cell behaviour. Osmotic stress, created by injection of solvents may cause the vesicles to undulate rapidly (Menger and Lee, 1995).

According to widespread opinion, the first biocatalytic molecule with the ability to produce replicas of itself was RNA. But there may have been a lower level of catalytic function in cubic bilayer membranes. Molecules that evolved to the first form of life would have found suitable protection in an encapsulating membrane, seperating inside from outside (Deamer and Barchfeld, 1982). Cubic bilayer type membranes can serve as a template for self-reproduction. Peptide synthesis would be possible by amino acids forming amide links to fatty acids, or by amino acids that are ester-bound to long chain alcohols. Additionally, the membranes may provide a matrix for enzymatic catalysis of structural proteins. Aggregation of proteins is driven by their amphility as much as by their molecular shape and chirality (Hyde et al., 1997).

5. Self-assembly in anhydrous environments

Hydrocarbons in carbonaceous meteorites are sometimes explained as products of a Fischer–Tropsch (FT)-catalysis on grains of magnetite or Fe–Mg-silicates. Related processes in the laboratory yield a variety of morphologies such as tubules, filaments, fibres and whiskers. Complex morphologies can form through the catalytic decomposition of carbon-containing gases at temperatures over the range 800–1200 K (Baker and Harris, 1978). The most efficient catalysts for the formation of tubules from hydrocarbons are the transition metals iron, cobalt and nickel. The gas decomposes at the surface of the catalytic particle to release hydrogen and carbon. Filamentous growth takes place through the building of carbon behind an iron-containing grain (Fig. 12a,b). The activity of iron is accompanied by a gradual conversion to iron carbide, but the catalyst can be reactivated by reaction with hydrogen, which converts the carbide back to iron. Rhythmic supply of the gas can lead to segmented tubules (Fig. 12c). If the catalyst is a well-formed crystalline particle with two or more active faces at oblique angles, helical structures may form. Also known are hollow carbon spheres ranging from 10 nm to 1 μm in diameter and consisting of concentric spherical shells. These particles are usually classified under the heading of carbon blacks. Comparable morphologies are observed in the Murchison meteorite.

Other types of carbon nanotubules can be prepared by a carbon arc process. Typically, their outer diameter ranges between 2 and 20 nm and the inner diameter between 1 and 3 nm. One interesting feature is the tendency for large numbers to grow parallel to each other forming a bundle of nanotubules, perhaps 50 nm in diameter. Often the tubules have screw axes and chirality, others have closed caps (Dresselhaus et al., 1995).

The Murchison tubule of Fig. 7d,e is about 20 nm in cross section, thickness of the wall is about 2–5 nm. The surface shows minute globules (g) connected by a network of helical fibres. Morphologies of that kind can be produced in the laboratory from a hot carbon plasma. The basic form appears to be the fullerene, which is a cage structure built by hexagons and pentagons with carbon atoms at the 60 vertices of the regular truncated icosahedron (Fig. 12d).

6. Conclusions

The infrared spectrum for solid C_{60}, vesicles contains four strong lines at 526, 576, 1182, 1428

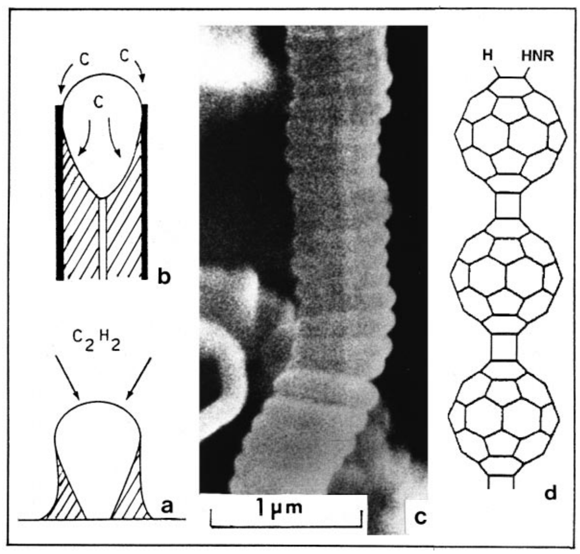

Fig. 12. (a–c) Artificial carbon filaments. (a,b) Principal growth, (c) REM micrograph (after Baker and Harris, 1978), (d) Bridge sites between C_{60}-fullerenes and attachment of primary amine group to a C_{60}-molecule (Fig. d compiled from Dresselhaus et al., 1995).

cm^{-1} and additional 60 weak lines in the 400–40000 cm^{-1} range. Comparable spectra are known from the red giant carbon stars, especially from the carbon clusters streaming out of the bodies. Because of its special geometry, the C_{60} molecule is rather resistant against stress, withstands collisons in the energy range of hundreds of eV and heating to above 1000°C. Such molecules formed under the most violent conditions may become widely distributed in Space. Surface catalyzed chemical processes may lead to the formation of various modifications. C_{60}-species would provide a durable catalyst and a topological nucleus for new organic products. Encapsulated guest molecules would be capable of controlling the flow of reactants and the catalyzing reactions. These could lead to larger capsules made from polyaromatic macrocycles which are held together by hydrogen bonds and water molecules (MacGillivray and Atwood, 1997).

Many emission features in the interstellar infrared spectra probably arise from polycyclic aromatic hydrocarbons. A 3.4 μm absorption feature is well fitted by a variety of hydrocarbon materials, but this band is not seen in the spectra of the carbon giants and other stardust birth sites. So, the hydrocarbon dust component may be a modification of preexisting elemental carbon (Tielens et al., 1996).

Fullerenes can be built in a left and a right handed form using the same structural units. Natural processes favouring one of the enantiomers are possible and may have operated long before the formation of the Solar system. Fullerenes exhibit diamagnetic and paramagnetic ring currents which exert subtle effects on the properties of these molecules (Haddon, 1995). On the time scale of evolution, the most stable molecules would be selected from a complex population. Generation of diversity, coupled with selective stabilization, may lead to specific structures. Theoretically, such processes could continue in interstellar space for billions of years (Nuth, 1988). An important point is that chemical groups can be attached to the fullerene shell, such as primary amines (RNH_2) where R is an alkyl or aryl group terminated by an amine group (-NH_2) (Fig. 12d). The specimen may survive in Space, may be added to interstellar dust and meteorite parent bodies.

Grains of SiC isolated from the Murchison meteorite matter are interpreted to stem from carbon stars (Lewis et al., 1990). Short-lived radionuclides and ^{16}O-signatures in the meteorites indicate condensation in expanding shells of novae or supernovae. Thus, a certain part of the Murchison carbon may stem from expanding shells of red giants, from novae, supernovae or from ion–molecule reactions in interstellar space. That prebiotic chemistry has been brought from interstellar space to Earth is an intriguing possibility. Meteorites may have served as vehicles in which the organic particles could non-destructively enter planetary atmospheres and finally settle on planets. An example is the occurrence of extraterrestrial fullerenes in the *ca*. 1,8 Ga old Sudbury impact structure of Canada (Becker et al., 1996).

But all this does not necessarily imply that cosmic material was involved in the formation of terrestrial life. Prebiotic syntheses may have occurred also on the young Earth. In recent sediments of the Atlantis II Deep in the Red Sea, smectites occur as a brown soupy mud containing about 80–90% interstitial brine. The soup is intermixed with hydrothermal precipitates and commonly interpreted as a product of low temperature reactions under reducing conditions. Contained particles display a variety of habits, with laths up to 10 × 1 μm and spheroidal aggregates 0.1–0.2 μm in diameter (see Güven, 1988, Fig. 8 and Fig. 12). Their walls appear to consist of organic layers intercalated between smectite layers. It is known that such arrays can act as templates for protein crystallization and lipid formation (Venuto, 1994).

Acknowledgements

A 1975 statement of Bartholomew Nagy

Chemical evolution must have preceded biological evolution and it is conceivable, that the carbonaceous meteorite micro structures might just represent the last prebiological step before

the emergence of life. The apparently complex chemical composition of the organized elements suggests that this possibility cannot be excluded. However, a word of caution is in order. This possibility is only one of several hypotheses. It is quite possible that organic matter in organized elements has nothing to do with the evolution of life or with life itself. (Nagy, 1975)

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