potential tool for working out deformational fabrics in rocks where mesoscopic signatures are obscure and use of this technique needs to be more fully explored to trace the strain variations across the cratons, to work out basement cover relations and to deduce direction of magmatic flow, especially in the light of recent investigations in the Mackenzie swarm of the Lawrentian Shield. The preliminary palaeointensity results on Cretaceous dykes have shown that there is scope for further work, particularly for understanding the secular variations of the magnetic field and polarity transitions. Studies on the Himalayan foreland basins are regarded as crucial for establishing stratigraphic correlations, evaluating the neotectonic movements and uplift history, resolving rates of sedimentation and determining palaeoclimatic changes during the latter part of Cenozoic–Recent times. The workshop recommended upgrading and enhancement of facilities with introduction of SQUID and JR-5 spinner magnetometers, AF demagnetizers with ranges up to 200 mT, thermal demagnetizers, KLY-3S Kappabridge, Curie balance, IRM, VSM and thermomagnetic experimental facility for VFTB and AFGM and to hold two contact programmes/summer schools on advanced palaeomagnetic techniques and on application of AMS techniques. The vital link of palaeomagnetism with isotope dating is well recognized and it is imperative that additional isotope dating facilities are established. Other aspects that came up for discussion included applications to archaeomagnetism, laterites, soils, suspended particles in oceans and atmosphere for understanding monsoon climatic changes. A more detailed report has appeared in the *DST Newsletter* (2002, **12**, 13–14).

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RESEARCH NEWS

The controversy over early-Archaean microfossils

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Few events in early earth history – whether they were concerned with the chemical, physical or biological aspects of the planet's evolution – have remained undebated, emerging views uncontested and which did not polarize the debating scientists into differing groups. The latest example is about discoveries of ancient fossils[1–6] from the Archaean (2.5–3.8 b.y. period) which have generated much controversy about their authenticity and antiquity. Palaeontologists were undoubtedly excited when these discoveries were first reported, since these helped to modify the view that the Archaean era represented an 'azoic' or lifeless geological time. Besides bringing about this change in their perspective, the finds also infused fresh 'life' to fossil studies and shifted the emphasis from conventional approaches based on geology or morphology to sophisticated analytical techniques to solve not only problems about biogenecity or antiquity, but also enhance our understanding of organic metamorphism and biochemical evolution of the organisms. Though plenty of new data emerged from these innovative approaches, they also triggered a fresh volley of debates.

The life forms that existed during the Archaean and pre-Archaean were bacteria and single-celled archaea lacking nucleus (prokaryotes), and they thrived in aquatic environments. Hence sediments deposited in water were the obvious choice of palaeontologists to look for early life. Unfortunately, the first half-billion years of the earth's history were marked by high flux of harmful UV radiation and impacting meteorites leading to development of extreme temperature, all disastrous for preservation of sedimentary rock-records of bacterial life. Hence the hunt for the fossils necessarily had to be limited to the few surviving sedimentary domains (cherts, greywackes, metapelites, banded iron formations) and to sites of structures known to be influenced by bacterial colonies[7]. Thin sections of such sedimentary rocks and structures (stromatolites and oncolites) from several countries have, in fact, shown fossilized cells of filamentous organisms, replaced by pyrite (Fe-sulphide), hematite (Fe-oxide) or silica. Some of them are from Warawoona Group, Pilbara Block, NW Australia[2,8–12], Onverwacht Group, Barberton Mountain land, South Africa[4,13], Gunflint Formations, Canada[3] and a few more sites in USA[14] and India (schists and iron formations in Karnataka, Orissa and Madhya Pradesh)[15–17]. While these are direct fossil-finds, indirect clues like isotopic, spectral or other signatures typical of biologic origin preserved in the rocks and minerals have indicated existence of life during Archaean and even earlier times. For example, forms of life even prior to 3.8 b.y. have been inferred from apatites hosting distinctly biogenic carbonaceous inclusions occurring in banded iron formations (BIFs), Isua Supracrustals, Greenland[1,6].

Initial excitement over the discoveries of Archaean fossils waned soon as questions were raised about their biogenecity, antiquity and contemporaneity with host rock formation. Some of the finds were rejected as they did not meet these criteria for acceptance as genuine fossils. Especially, two well-cited early Archaean-period occurrences have been challenged in recent years. One of them is about the biogenecity of the reported 'oldest microfossils' (3.3–3.5 b.y.) from western Australia[2,5,10]. These were first observed in 1986 by Schopf and Packer[2], University of California, Los Angeles and a detailed work on them was presented in 1993 and 2002 (refs 10 and 18). The other discovery to be questioned is about antiquity of life inferred from carbonaceous inclusions in 3.8 b.y.-old rocks in Akilia island in Greenland, reported jointly by scientists from USA, Australia, UK, and headed by S. J. Mojzsis of the Scripps Institute of Oceanography, USA[1].

The 'oldest microfossil' discovery reported from western Australia came from sedimentary cherts (microcrystalline silica) occurring extensively within a few basalt members (Apex Basalt, Towers Formations) of a 14-km thick volcanic sequence known as the Warawoona Group. This mode of occurrence is claimed to confirm indigenous and syngenetic origin of the microfossils which are seen as three-dimensionally preserved colonies of sheath-enclosed cells, highly carbonized and as unbranched filamentous forms surrounded by kerogen (carbonaceous matter). Their cellular organization and complex morphology, comparable to modern forms of cyanobacteria, are considered to confirm their biogenecity. As many as 11 distinct taxa were recognized in these formations. Such a diversity of life forms, some of them oxygen-producing cyanobacteria, indicated that not only was evolution of life by early Archaean quite advanced but it also implied rise of oxygen in the atmosphere[19] even before mid-Proterozoic, contrary to accepted views.

To bolster their claims that the Warawoona finds are really fossils and not pseudo-fossils created by abiogenic processes, Schopf along with a fresh team of scientists looked for presence of biologically-derived molecules in them through laser-Raman spectroscopy[18,20], a non-invasive, non-destructive technique applicable to both mega- as well as micro-specimens. They used an ion-probe focused through a microscope onto a single or individual microfossil and noticed vibrational Raman bands (~ 1350 cm^{-1} and ~ 1600 cm^{-1}) of molecules characteristic of kerogenous and graphitic matter, derived biologically. However, their claims to biogenecity based on Raman and other investigations were not accepted by a few critics, notably by a team from UK and Australia, led by M. D. Brasier, a micro-palaeontologist at the University of Oxford, UK. The latter group reinvestigated the occurrence, did fresh mapping and examined the fossils under high-power microscope and also carried out Raman studies[21].

Differing from most of the observations put out by Schopf and co-workers, Brasier's team found that (i) the fossiliferous cherts are not part of the bedded succession as described and therefore not indigenous to or syngenetic with the host rocks. Instead, they are part of a breccia (hence transported from some other place) present within one of a series of veins of chert which cut across the basalt formation and therefore formed later. (ii) Oxygen and sulphur isotopic ratios indicated that the veins are produced during hydrothermal alteration of a neighbouring pillow basalt formation. (iii) The biologically produced sedimentary structures, considered earlier as stromatolites, are in fact, isopachous internal cements formed during multi-generation fissure fillings. (iv) Occurrence of microfossils in successive generations of fissure fillings and chert matrix casts doubts on the claimed primary origin of the latter. (v) Presence of similar graphitic structures within glass-rims of volcanic fragments and associated chalcedony matrix of felsic tuffs contradicts claims to biogenecity. (vi) Contrary to the reported unbranched nature, a feature typical of Archaean bacteria, the 'microfossils' are seen to be branched – an evolutionary trend that developed only during later geological times (~ 900– ~ 800 m.y.). This branched feature is observable when the depth of focus of the microscope is increased. (vii) High-resolution micro-Raman spectra suggest that the chert-enclosed graphite is dilute and thermally protected by the host quartz, as there was little absorption of kerogens expected. (viii) The septate appearance of the filaments is abiogenic, created by quartz which is interspersed in graphite. (ix) The 'microfossils' cannot be oxygen-producing photosynthesizers, as claimed in view of their deep-sea habitat.

Brasier's team concluded that the Warawoona chert 'microfossils' are 'secondary artefacts formed from amorphous graphite within multiple generation of metalliferous hydrothermal vein-chert and volcanic glass'[21]. The structures were developed into such suggestive forms through geochemical processing and shaping of organic compounds, possibly by thriving hyperthermophilic bacteria in the hydrothermal vents. As for the biologic carbon noticed in the graphitic cherts, they were possibly derived from unpreserved thermophilic bacteria. The team concluded that it is also possible to be misled to such conclusions about existence of life from the presence of light carbon isotope which can be non-biogenic as well. For example, transformation of volcanic CO into isotopically light carbon compounds by catalytic reactions in the presence of certain metals (Fischer–Tropsch process) abundant in hydrothermal vents can also take place. It now appears that Schopf erred in his identification of Warawoona chert fossils as ocean-bottom deposits through his dependence on field data of other workers. He has also revised his initial classification of the microfossils as cyanobacteria[22]. However, Schopf insists that the microfossils are not artefacts but real unbranched bacteria, and that Brasier obviously had mistaken folded cell chains (appearing under deep focus) as branched structure. He has also discounted Fischer–Tropsch-type synthesis of organic compounds since such reaction compounds are actually not observed in hydrothermal vents anywhere.

The other controversy is over the report by Mojzsis and others[1,6] of possible life even prior to 3.8 b.y., inferred from biogenic carbonaceous inclusions in apatites from BIFs of Akilia island, Greenland. Some critics dispute this inference since this time-span is known to coincide with highly energetic asteroid impacts, big and small, one of which is also believed to have led to the formation of the moon[23], and would have destroyed life in near-surface habitats and possibly affected the earth's hydrosphere also[24]. But this view is dismissed on the grounds that there may yet be deep marine or crustal habitats where life may have survived[6]. Also, the Greenland samples of the period 3.5–3.9 b.y. show no unusual enrichment of Ir, a metal extremely poor on the earth but rich in meteorites, thus endorsing the view that the bombardment apparently was not continuous but infrequent, with quiet conditions more dominant[6]. In fact, from lunar cratering records and dating, the period on the earth between 4.4 and 4.0 b.y. is believed to have been relatively calm, with cooler surface temperature quite fit for the origin of life[25, 26].

The claimed age of the apatite hosting these inclusions has also been challenged by a group of Japanese scientists[27]. Their dating of the apatite by U–Pb and Pb–Pb isotopes indicated a much younger age, around 1500 m.y. and not 3850 m.y. as claimed by Mojzsis. According to them, the apatites must have either formed during a metamorphic episode that occurred around 1500 m.y. when biogenic carbon must have been introduced into the rocks or the apatites may have formed earlier, 3.8 b.y. ago, but were re-set along with graphite inclusions during the 1500 m.y. thermal event[27]. Now on the basis of geologic, petrologic and trace element data, a recent study[28] rejects the identity of BIFs. Instead, they are considered as quartz-pyroxene ultramafic igneous rocks, metasomatically invaded and veined by silica and iron giving banded appearance typical of BIFs. Such an ultramafic igneous rock is unlikely to host biogenic carbon derived from earlier life forms, and in all probability the latter carbon was generated abiogenically through decarbonation of the carbonates. Another critique[29] supports possibility of life before 3.8 b.y., but feels such deductions should be based on study of bio-organic carbonaceous inclusions within minerals tectonically more robust and resistant like zircon, instead of apatite. This is vital since the problem relates to a period noted for intense terrestrial and extraterrestrial activities which led to considerable ductile shearing and high-grade metamorphism, obscuring correlation of rocks and inferences about when the BIFs were deposited and when apatites with biogenic carbon grew.

In defence, Mojzsis[27] group argues that the observed younger age is due to diffusion of radiogenic Pb during the metamorphic event and that crystallization of apatite, a Ca, F, PO_4 mineral, is unlikely from an essentially quartzitic rock like the BIFs (70% quartz) through metamorphic reactions. Also they suspect that the latest field and laboratory data[28] must be from the igneous matter intruded into the older BIFs that had led to erroneous labelling of the latter as ultramafics. As for the comment about possible disturbance to carbon isotope ratios through diffusion, it is considered improbable since the self-diffusion rate of carbon in graphite is extremely slow even at 600ºC (ref. 27). Isotopic analyses of carbonaceous matter within early Archaen, Proterozoic and younger rocks have shown general presence of isotopically light carbon consistent with bio-organic origin[6,30]. Therefore, Mojzsis[27] group considers that the graphitic carbon in the apatites and other sediments is definitely biogenic, derived from organisms having complex metabolism such as phosphate-utilizing photoautotrophs and chemoautotrophs. They feel that these must have colonized the earth even before 3.85 b.y., toward the close of the Hadean era (4.0–3.8 b.y.), which implies that life on earth had progressed considerably since its origin during still earlier times[6, 31].

Undoubtedly, the present controversy over some of these old microfossils, coming in the wake of the recent imbroglio over the ‘life forms’ in the Martian meteorite ALH84001 (ref. 32), may keep simmering for a long time. Only more detailed fieldwork and searches for more convincing bio-signature and tests, perhaps based on stable isotopes (C, N, S), directly on suspected fossils or their look-alikes can answer the nagging issues which fodder unending debates on the authenticity of fossils. In their dedicated quest to get at fossils going back in time, scientists will be stalking in the realms of transient rock records more often jumbled up with debris from extraterrestrial bodies[25]. Though their efforts may bear fruit and perhaps also lead them to answers on the way life began on earth, a consensus among them may be hard to achieve without acrimonious discussions.

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