single parameter — their present mass. In particular, they pointed out that the morphologies of galaxies exhibit little dependence on their structural properties. Therefore, such factors as environment and initial spin induce only second-order effects on the overall evolution of galaxies. Surprisingly, Gavazzi et al. note that the correlation between the radii and the luminosities of galaxies seems to differ little, if at all, between relatively isolated galaxies and galaxies that are located in rich clusters. They conclude from these results that gravitational interactions between galaxies may have played a lesser part than previously believed.

A similar result was obtained by Girardi et al.[3], who divided observations of galaxies in the Virgo cluster into subregions: an inner region within a radius $R = 0.5$ megaparsec (Mpc); an intermediate shell with $0.5 < R < 1$ Mpc; and an outer zone with $R > 1$ Mpc from the cluster centre. In all three of these regions, Girardi et al. found that galaxies obeyed similar luminosity–radius relations. In other words, galaxy evolution does not seem to be strongly affected by environment.

To check whether the luminosity–radius relation of galaxies is indeed not strongly correlated with galaxy environment, I have compared[4] the radii and the luminosities of the 80 brightest galaxies within a distance of 10 Mpc (33 million light years) from the Sun. These data show that nearby galaxies seem to exhibit the same luminosity–radius relation as do the galaxies in great clusters such as those of Virgo and Coma. Furthermore, these nearby galaxies seem to show no obvious correlations between their luminosity–radius relation and their current environment. In particular, no dependence is found on the mass density of the local neighbourhood as defined by Karachentsev and Makarov[5].

The mounting volume of evidence discussed above suggests that galaxies constitute an (almost) one-parameter family based on their mass, with little or no indication of a major dependence on their environment. This conclusion poses several challenges to the prevailing theory of hierarchical galaxy merging. But this is not a theory that will crumble easily. One is reminded of the saying by the Danish poet Piet Hein: "Problems worthy of attack prove their worth by hitting back." ∎

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BIOGEOCHEMISTRY

Life before the rise of oxygen

Woodward W. Fischer

The discovery of molecular fossils in 2.7-billion-year-old rocks prompted a re-evaluation of microbial evolution, and of the advent of photosynthesis and rise of atmospheric oxygen. That discovery now comes into question.

Go back to Archaean time, the interval of Earth's history between about 4 billion and 2.5 billion years ago, and we're in largely unknown biological territory. Attempts to identify a fossil record of life have produced meagre results[1], and controversy persists about whether certain microfossil-like structures are of biological origin[2].

Almost a decade ago, however, Archaean palaeontology received a big boost with the discovery by Brocks et al.[3] of a diverse assemblage of lipid 'biomarkers' in 2.7-billion-year-old geological samples from Western Australia. Biomarkers, or molecular fossils, are natural products (often hydrocarbons) whose synthesis can be linked to a specific biological origin — and, by physiological proxy, to environmental conditions. Together, this report and a subsequent study[4] hinted at a much richer biological diversity than had previously been recognized. On page 1101 of this issue, however, Rasmussen et al.[5] provide a robust challenge to the age of these biomarkers, and the palaeontological and palaeoenvironmental insights that they offered.

The suite of lipid biomarkers reported by Brocks et al.[3,4] included specific hopane and sterane compounds, respectively interpreted as the membrane remnants of cyanobacteria (a group of organisms characterized by oxygen-producing photosynthesis) and of eukaryotes (cells bearing a membrane-bound nucleus and a complex cytoskeleton). This discovery was so remarkable because it pushed back the minimum time for the origin of these groups by more than 700 million years (Fig. 1). The oldest unambiguous fossil cyanobacteria were found in tidal-flat sedimentary rocks, some 2 billion years old, from Canada's Belcher Islands[6]. It is probable that the evolution of cyanobacteria occurred much earlier; they must have existed by 2.4 billion years ago[7], because their metabolism is required, at least in part, to explain the appearance and rise of environmental oxygen at that time. But this still leaves a gap of 300 million years.

The discordance between the sterane biomarkers and the oldest accepted eukaryotic fossils is even larger. The most convincing evidence for early eukaryotes comes from ornamented and ultrastructurally complex microfossils known as acritarchs in the Roper Group of Northern Australia[8]. These rocks are about 1.5 billion years old, leaving a gap of more than a billion years between unequivocal eukaryotic fossils and sterane biomarkers.

As well as creating a yawning palaeontological divide, the lipid biomarker data[3,4] underscored an apparent paradox concerning the relative timing between the evolution of oxygenic photosynthesis and one of the most fundamental transitions in Earth history — the appearance and rise of atmospheric oxygen. Several lines of evidence indicate that a secular
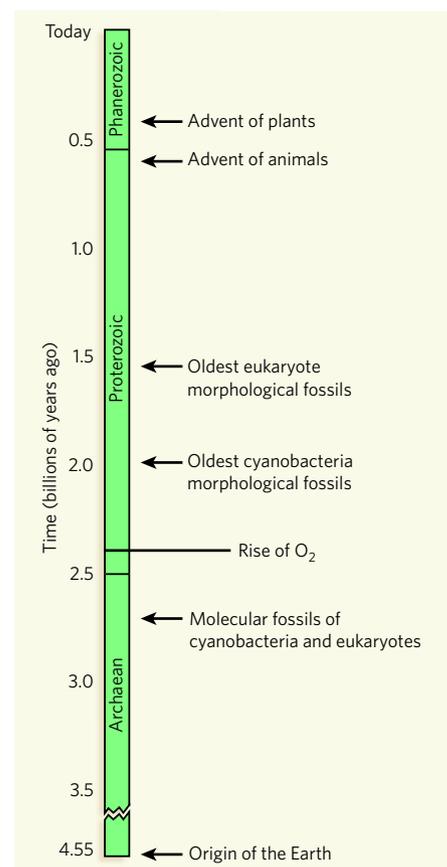

Figure 1 | The evolution of eukaryotes and cyanobacteria, and the rise of atmospheric oxygen. There are large gaps in time between the first morphological fossil evidence for cyanobacteria and eukaryotes, and the molecular-fossil occurrences inferred by Brocks et al.[3,4] from lipid biomarkers. This discrepancy may disappear if the results of Rasmussen et al.[5], showing that the biomarkers are younger than their host rocks, are confirmed — as may the 300-million-year delay before the later rise in atmospheric oxygen. Because oxygenic photosynthesis is the ultimate source of environmental oxygen, cyanobacteria must have evolved by a minimum of 2.4 billion years ago. This still leaves a gap of about 400 million years in the other direction, between the rise of oxygen and the first firm fossil evidence of cyanobacteria.

50 YEARS AGO

Current theory tends to emphasize the importance of interference in forgetting and to minimize the role of time lapse in the decay of the memory trace. Conrad, however, has recently shown that the immediate recall of eight-digit numbers is better when the numbers are presented and reproduced by subjects at a fast rate than when they are presented and reproduced at a slow rate ... I tested two groups of subjects for their ability to retain eight-digit numbers when presented and reproduced at different rates. Group *A* consisted of 26 teachers, aged 18–29, drawn from different regions of Canada. Group *B* consisted of 26 teachers, aged 30–55 ... [T]here is no significant difference between the two groups in the proportion of digits recalled at the fast rate, but there is a significant difference between the two groups ($P = 0.05$) in the proportion of digits recalled at the slower rate ... [I]t appears that the span of immediate memory is the same for the two age groups, but that the rate of decay of immediate memory tends to increase with age.
From Nature 25 October 1958.

100 YEARS AGO

Dr. F. A. Dixey pointed out that when Fritz Müller put forward, in 1879, his theory of common warning colours, or the assimilation of one distasteful form to another for the sake of mutual protection against insectivorous enemies, he recognised the probability, or even certainty, that the approach would not necessarily be one-sided, but might be convergent, each form in some respects advancing to meet the other. This suggestion, however, was never developed by Fritz Müller ... Dr. Dixey showed that there is much evidence that such reciprocal approach, or interchange of obvious characters ... does actually occur, and he exhibited some cases of mimicry the peculiar features of which are difficult to explain on any other hypothesis.
From Nature 22 October 1908.

change in the oxidation–reduction potential of the fluid Earth — the oceans and atmosphere — was captured in the geological record around 2.4 billion years ago[7]. The rise of oxygen can, in principle, be understood in terms of the proximal evolution of cyanobacterial oxygenic photosynthesis (and thus of oxygen production). But the molecular fossils called for an earlier origin of cyanobacteria, again some 300 million years before the rise of oxygen. This gap is approximately two orders of magnitude too large for standard geochemical thinking to accommodate, and much effort has been expended in developing models in which the time lag can be explained by first-order changes in chemical interactions between the solid and the fluid Earth[9]. But given Rasmussen and colleagues' results[5], are such models required?

The biggest analytical challenge for those undertaking Archaean biomarker studies is contamination by younger hydrocarbons. Although Archaean rock samples may contain up to several per cent organic carbon by weight, biomarker compounds are present at only trace concentrations — parts per billion or less — and potential sources of contamination are ever-present in our petroleum-filled world. It was difficult for Brocks *et al.*[3,4] to show with certainty that the extracted biomarkers were indigenous and syngenetic (that is, the timing of their synthesis corresponded to the age of the rock), but the biomarker abundance and distribution made a reasonable case against contamination.

However, one piece of evidence was at odds with an indigenous interpretation. The carbon isotope ratios ($^{13}C/^{12}C$) of the extracted lipid hydrocarbons did not match those of the solvent-resistant, macromolecular, residual organic carbon — termed kerogen — present in the rocks. Late Archaean kerogens are unique in the context of Earth history in that they commonly have carbon isotope ratios several per cent lower than those of organic carbon found in younger sedimentary deposits[10]. The kerogens analysed by Brocks *et al.*[4] contained this unique isotopic signature, whereas the lipid biomarkers did not. Two hypotheses are compatible with this relationship. The first interprets the lipid biomarkers as younger contamination. The second posits that the biomarkers are indeed indigenous, but that the lipid hydrocarbons (oil) released during geological burial and heating of the sediments were derived from a different source from that which produces the bulk of the residual kerogen, and therefore would not share the same isotopic composition. This latter view was taken by Brocks *et al.*[4].

The outstanding question, then, is whether the oil generated by these organic-rich sedimentary rocks was derived from a different isotopic source from the kerogen. Rasmussen *et al.*[5] have addressed the problem by making use of new technology, the NanoSIMS ion microprobe (secondary ion mass spectrometry with 50-nanometre resolution). The advantage offered by NanoSIMS over standard, bulk-rock analytical methods is the ability to assay, *in situ*, the carbon isotopic composition with a spatial resolution fine enough to resolve isotopic differences between micrometre-scale textures present in the rock.

Working on organic-rich samples from one of the Late Archaean sedimentary deposits in Western Australia from which the lipid biomarkers were first reported, the authors measured carbon isotope ratios of micrometre-sized particles of kerogen and pyrobitumen (residues of solidified petroleum). The pyrobitumen fraction, which represents indigenous petroleum, carries essentially the same unique carbon isotopic composition as the kerogen, not the heavier isotopic ratios of the extracted lipid hydrocarbons. This result reveals that the molecular fossils extracted from these samples probably came from contamination that was introduced some time after these rocks experienced their peak metamorphic temperatures about 2.15 billion years ago.

So does this study[5] nullify the lipid-biomarker evidence for oxygenic photosynthesis some 300 million years before the rise of atmospheric oxygen, and does it close the gap between the morphological and molecular-fossil records of the evolution of eukaryotes? Not yet. Since the appearance of the papers by Brocks and colleagues[3,4], there have been other reports of lipid biomarkers — including hopanes and steranes — in sedimentary rocks deposited in other parts of the world before the rise of oxygen[11–13]. The rocks concerned have very different geological histories, and there are insufficient data to say whether contamination also affected these studies.

The creative breakthrough offered by Rasmussen *et al.*[5], however, is an analytical approach that seeks to link the isotopic composition of extracted lipid biomarkers with that of indigenous pyrobitumen. Perhaps by serendipity, the unique isotopic composition of Late Archaean sedimentary organic matter will provide an exceedingly useful screen for contamination in future investigations of ancient molecular fossils. ■

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