THE LATE ARCHEAN BIOSPHERIC EXPLOSION. J. F. Lindsay[1], V. Bennett[2]

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Introduction: The earliest Archean successions on Earth contain very limited information on the early biosphere and much of that limited evidence is difficult to validate [e.g., 1]. Evidence of life is, however, much more abundant in the latest Archean rocks (<3.0 Ga) in the form of black organic-rich shales [2], banded iron formations (BIF) [3] and biogenic platform carbonates [4]. By c.2.45 Ga oxygen levels had begun to rise in the Earth's atmosphere setting the stage for the evolution of the modern biosphere. Here we focus on concretionary structures, which can act as sensitive barometers of biological activity, to provide us with potential insights into the expansion of this early biosphere prior to the first appearance of oxygen in the atmosphere.

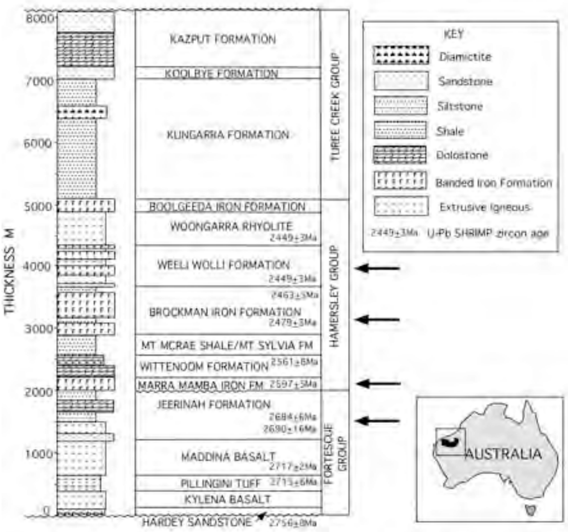
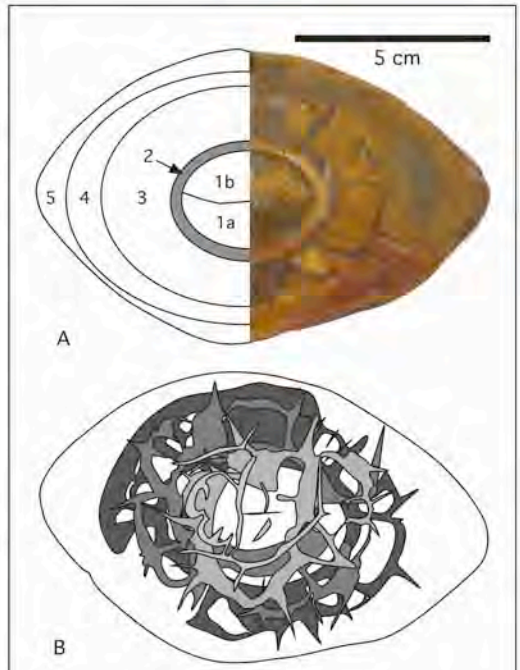


Figure 1. Simplified Hamersley Basin stratigraphy and inset location map. Arrows indicate location of concretions studied. These sample sites extend across the critical transition when atmospheric oxygen levels first began to rise. The architecture and composition of these concretions is directly comparable with Phanerozoic examples suggesting that they are all biogenic in origin.

Background: An intensive survey of the sedimentary record of the Pilbara Craton of Western Australia has shown that, while concretions are extremely rare in rocks older than 3.0 Ga, they are abundant in younger rocks (Fig. 1). A detailed analysis of these late Archean concretions suggests that they are most likely to be biomediated structures little different from Phanerozoic examples (Fig. 2) [5]. The concretions have five distinct annular zones the outer three of which are transected by a complex septarian vein network. Although now intensely silicified, remnant traces of the primary mineralogy shows that they were originally sideritic carbonate.

Model: The architecture of the concretions appears to have been determined early by the bacterial decay of biogenic materials in oxic and sub-oxic environments leading to the production of humic acids. As the humic acids diffused outwards they chelated the



Zone	Maximum Diameter mm	Volume Percent
1	36	10.9
2	42	7.4
3	78	34.6
4	95	21.9
5	110	25.2

Concretion Volume = 324.0 cm^3

Septarian Veins form:
8.1 % of total volume
23.4 % of zone 3
3.4 % Of zone 4
16.02 % of zones 3 + 4

Brockman Iron Formation (2.47 Ga)

Figure 2. (A) Median section through a typical concretion from the 2.47 Ga Brockman Iron Formation showing the five zones preserved internally. (B) Reconstruction of the septarian vein network for the upper half of the concretion based on 6 mm thick serial sections. Note the complexity of the vein network and its similarity to shrinkage cracks.

sedimentary pore waters, removing Ca, Mg and Fe, in particular, and, in the process, forming water-rich polymer gels that defined the architecture of the concretion. Later, as the concretions were buried more deeply and entered the sulfidic and methanogenic zones, the biogenic release of CO_2 stripped the humic-acid gels of their divalent cations resulting in the release of entrapped water and the collapse of the structure of the gels (Fig. 3). Shrinkage of the gels, as water is released, lead to the formation of the characteristic septarian veins systems. Carbonates were deposited in the place of the gels consolidating the architecture of the concretionary structure before dewatering and compaction of the host sediments. This model provides a solution to the 30-year dilemma regarding the origin of septarian concretions.

Conclusions: Concretions are subtle indicators of both the subsurface environment during sediment accumulation and of the overlying water column. They suggest that in the late Archean there was a major increase in microbial activity in the subsurface sediments in response to a rapid rise of the biomass in the overlying water column. The rapid increase in the biomass coincides with the appearance of the first large continental masses and the onset of global plate tectonics. This is consistent with our earlier observations that the evolution of the biosphere is being driven forward by the evolution of the planet [6]. An active planet is necessary to sequester excess carbon and to recycle critical nutrients. The modern biosphere may thus be the product of a fine balance between the availability of endogenic or planetary energy and exogenic or solar energy.

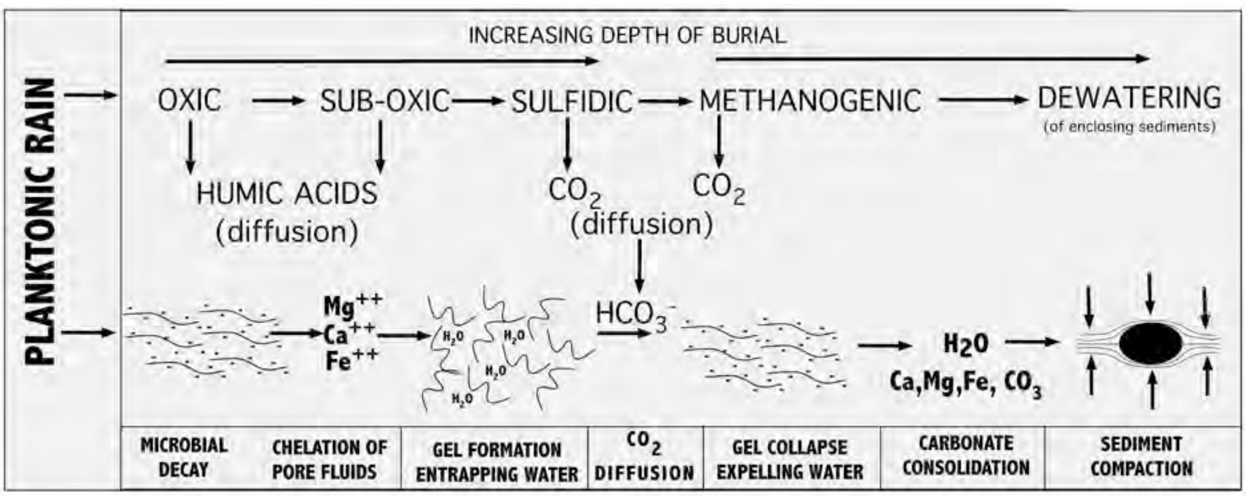


Figure 3. Simplified cartoon showing the stages in the development of a typical Archean concretion. Gel formation during the Oxic and Sub-oxic Stage locks in the concretion's architecture. CO_2 diffusion during the Sulfidic and Methanogenic Stages defines the septarian vein network and leads to carbonate formation and lithification that preserves the concretionary structure before final compaction and lithification of the enclosing sediments. Dissolution and silicification of the primary minerals has continued throughout geologic time This new model solves a 30-year dilemma by recognizing the intermediate role of humic acids in the deposition of the carbonate minerals forming the structures.

Understanding the concretions, in turn, allows us to reconstruct the early biosphere to some extent. They suggest that shortly after c.3.0 Ga the Earth's biomass increased rapidly. In particular, there appears to have been a significant rain of planktonic organic materials into deeper basin areas. During this time BIFs were being deposited rapidly. The concretions formed in at least a suboxic environment and quite possibly in an oxic environment in the sediments. This suggests that oxygen was being released in large quantities into the global ocean at least 300 m.y. prior to its appearance in the atmosphere.

References:

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