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Impact during the proterozoic era possibly inundated the earth with phosphorus

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Abstract: The stromatolites of the Precambrian Aravalli Supergroup outcropping around Udaipur, Rajasthan, India are classified into two distinct lithofacies: the older carbonate stromatolites facies and the younger phosphate-bearing stromatolite facies. Phosphate-bearing stromatolites of the same age have been reported from China, Russia and Australia. The phosphate-bearing stromatolites of Udaipur show fossil cyanobacteria. These cyanobacteria grew luxuriantly in the absence of any competitors and accumulated abnormal amounts of phosphorus from the novo phosphorus-rich environment, eventually forming a workable phosphate deposit owing to their post-mortem alteration. There is a sharp and abrupt contact between the two facies. This sharp contact or diastem underlying the phosphate-bearing stromatolites is of extreme importance as it denotes a stratigraphic hiatus characterizing a period of overall change in the environment. This change could be due to some catastrophic episode. The Earth during its geologic history has been subjected to several such episodes caused by certain high-energy events, such as impacts by extraterrestrial bodies. These impacts caused mass extinctions as occurred at the Permian–Triassic or Cretaceous–Tertiary boundary or the emergence of new flora and fauna as occurred at the Precambrian–Cambrian boundary. It is therefore argued that the diastem noted between carbonate and phosphate-bearing stromatolites is possibly due to an impact that inundated the Earth with phosphorus. Phosphorus is a key constituent of proteins, which are the major repository of chemical energy for metabolism. Its abundance after this event triggered the emergence of new advanced species.

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Introduction

Phosphorus does not occur in an elemental state in nature. It is almost exclusively hosted in a mineral apatite $Ca_5(PO_4)_3$ (OH,F,Cl), which is highly insoluble in water. Its incorporation into biomolecules, DNA, RNA, ATP, ADP, is however intimately associated with the origin and evolution of life on Earth. The Earth has about 1000 parts per million (ppm) phosphorus abundance in contrast to only 7 ppm in the Universe, which is intriguing for scientists. When and how Earth grew rich in geochemically functional phosphorus that caused complex life to evolve is one of the fundamental questions still to be answered. A possible event in time and space that inundated the Earth with phosphorus is discussed in this paper.

Stromatolitic phosphorite in the Precambrian Aravalli Supergroup of India

Phosphorus in the form of phosphate mineral deposits (which are mined for the fertilizer industry) is found throughout the geological column, from the Holocene era down to the Precambrian. It is formed as an igneous apatite, sedimentary phosphorite or guano (for more details see Cook & Shergold (1986)). The Precambrian Aravalli phosphorite of the Udaipur region of India does not fall into any of these three categories; it is altogether unusual and unique. It is exclusively confined to stromatolites, which are organo-sedimentary structures produced by sedimentary trapping, binding and/or precipitation as a result of the growth and metabolic activity of cyanobacteria.

The stromatolites of the Precambrian Aravalli Supergroup outcropping around the Udaipur region of India are composed of only carbonate (dolomite) or phosphate and carbonate (carbonate fluorapatite) occurring as two distinct lithofacies. The carbonate stromatolites occur as columnar or stratiform types composed of alternate laminae of micrite or microsparite, usually with an association of fine-grained quartz (Fig. 1(a)). They form a distinct horizon/bed with no trace of phosphorus. This bed of carbonate stromatolites is immediately overlain by another bed that contains phosphate-bearing stromatolites with a sharp and abrupt contact, called the diastem (a small unconformity) in between. The phosphate-bearing stromatolites also occur as columnar

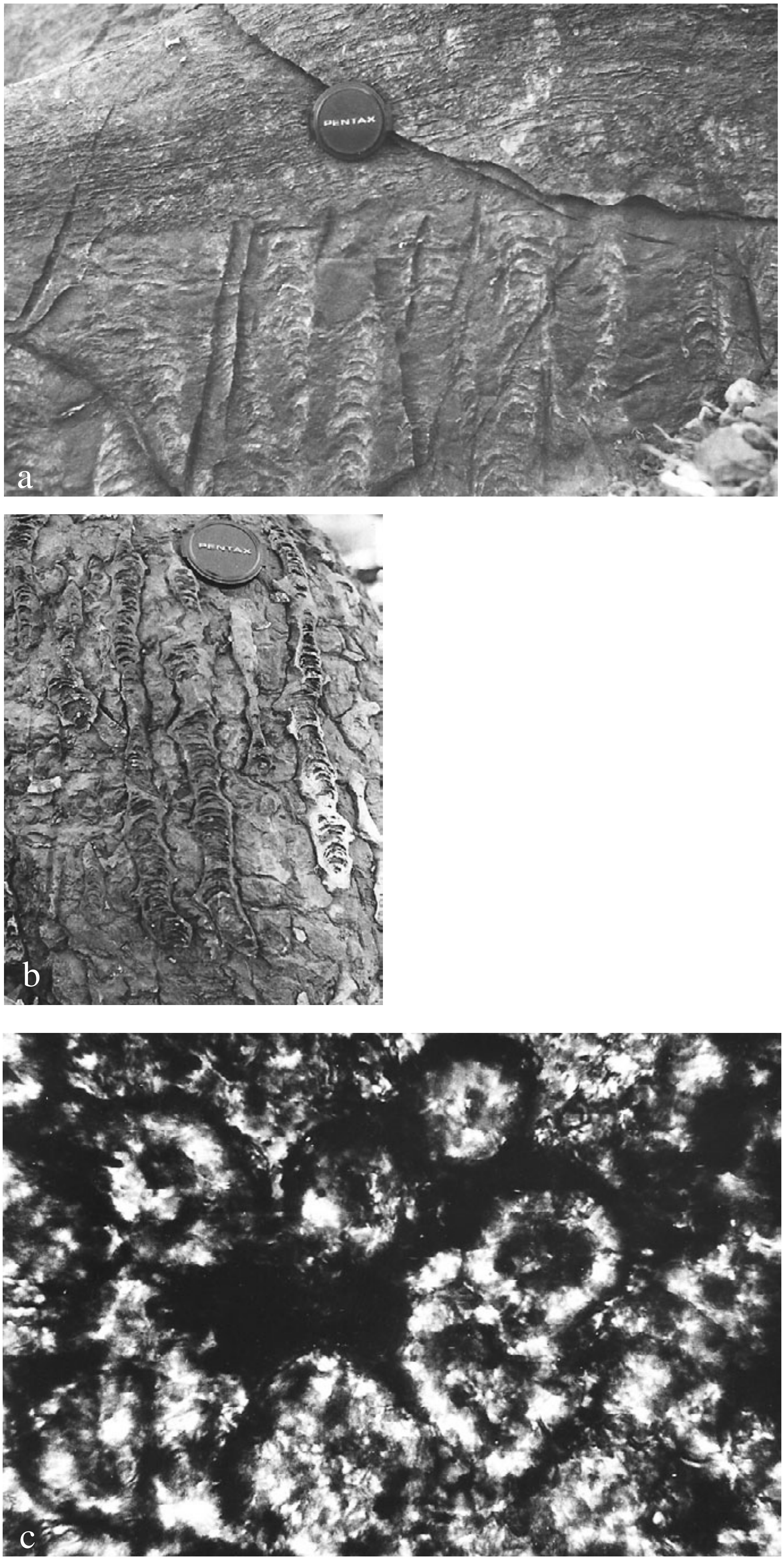

Fig. 1. For legend see opposite page.

and stratiform structures. The columnar structures are composed of laminae of phosphate and carbonate embodied within a phosphate sheath (Fig. 1(b)). The characteristic rhythmic pattern of the laminae as seen in the carbonate stromatolites is not observed in these stromatolites. They have been described by many scientists including Muktinath & Sant (1967), Banerjee (1971, 1983), Chauhan (1979), Sisodia & Chauhan (1990, 1998), among others. Phosphate-bearing stromatolites of the same age are found to occur in China, Russia and Australia. Sisodia (1991) observed cyanobacterial fossils in the phosphate-bearing stromatolites of Udaipur. These cyanobacteria occur singly or in massed colonies, are elliptical to circular in section and 20 to 100 μm in diameter. They have a nucleus of carbonaceous material surrounded by a zone of very fine radiating needles of francolite (Fig. 1(c)). These cyanobacteria were subjected to a sudden influx of phosphorus, which they accumulated in elevated amounts, and they underwent luxuriant growth because of the absence of any competitors or grazers. The assimilated phosphorus post-mortem transformed into apatite, eventually forming a workable phosphate deposit.

Age of the Aravalli stromatolitic phosphorite

A geochronological framework for the Precambrian Aravalli stromatolitic phosphorite is now available. The Aravalli Supergroup rests unconformably on the Banded Gneissic Complex and underlies the Delhi Supergroup (Heron 1953). Its span is between 2500 Ma and 1850 Ma, see Table 1. The stromatolitic phosphorite bed is lithostratigraphically placed in the Lower Aravalli Group (Roy & Jakher 2002), which is just above the Archaean Proterozoic boundary or, to be precise, during the Lower Proteozoic (see Table 2 and Fig. 2).

Table 1. *Geochronological framework of the Precambrian rocks of Rajasthan.*

Marwar Supergroup	
Malani Group (Volcanics)	–780 to 680 Ma[1]
Erinpura granite	–850 Ma[2]
Sirohi Group	
Intrusives (Gabbro, Diorite)	–1000 Ma[3]
Synorogenic granites	–1450 Ma[2]
Delhi Supergroup	
Metamorphics	–1725 to 1625 Ma[4,5]
Intrusives (Darwal granite)	–1850 Ma[2]
Aravalli Supergroup	
Archean–Proterozoic Boundary	
Intrusives (Granites: Untala, Berach, Gingla etc)	–2500 Ma[6]
Pre-Aravalli Basement (Mewar Gneiss or Banded Gneissic Complex	2600 Ma to –3300 Ma[7,8,9]

[1] Rathore (1995); [2] Choudhury *et al.* (1984); [3] Volpe & Mcdougal (1990); [4] Sarkar *et al.* (1989); [5] Fareeduddin & Kroner (1998); [6] Wiedenbeck *et al.* (1996); [7] Gopalan *et al.* (1990); [8] Wiedenbeck & Goswami (1994); [9] Roy & Kroner (1996).

Discussion

Phosphorus is a key constituent in the chemistry of life; however, the path leading to its incorporation in biomolecules, which triggered the origin and evolution of life, is yet to be ascertained. Planetary scientists have been in pursuit of answers to three pertinent questions for a long time: (1) What is the source of phosphorus? (2) When and how did Earth become rich in phosphorus? and (3) Could earlier life originate without phosphorus? That is when phosphorylated biomolecules play a major role in replication and information (as RNA and DNA, which are the major repository of chemical energy for metabolism). An attempt is made to answer some of these questions on the basis of data from Precambrian stromatolitic phosphorites. The Precambrian Aravalli stromatolites at Udaipur in India constitute two distinct lithofacies: the carbonate stromatolites facies and the phosphate-bearing stromatolites facies. The carbonate stromatolites facies are overlain by phosphate-bearing stromatolites facies with an abrupt and sharp contact (diastem). This sharp contact is of extreme importance as it explicitly denotes a stratigraphic hiatus. This deduction is further strengthened by noting an important inference drawn from the studies of ancient and modern stromatolites; that is, the change in the morphology of stromatolites reflects changes in the environment as well as in the composition of the microbial communities involved in their growth (Logan *et al.* 1964; Monty 1967; Serebryakov & Semikhatov 1974; Playford & Cockbain 1976). Another important observation is that there are well preserved cyanobacterial fossils in the phosphate-bearing stromatolites. Their preservation is probably a result of the fact that they are composed of apatite/francolite, which is comparatively more resistant to weathering. No such fossils could be observed in the carbonate stromatolites. The elevated amount of phosphorus that these cyanobacteria accumulated, so as to eventually form a workable deposit (as explained earlier), reveals that there was a sudden influx of phosphorus in the milieu. Why the environment suddenly grew rich in phosphorus needs attention. It has been accepted that dead organic matter is scavenged to the ocean bottoms by slow fluvial processes, where it rests until convection currents in the mantle heat it up so that it 'upwells' again to the shelf region (Kazakov 1937; McKelvey *et al.* 1959). However, such a scenario is not possible in the

Fig. 1. (a) Carbonate stromatolites. Stratiform stromatolites overlying columnar stromatolites. Locality: Jhamarkotra (Udaipur). (b) Phosphate-bearing columnar stromatolites. The carbonate part has been removed due to differential weathering. Locality: Bargaon (Udaipur). (c) Cyanobacterial fossils in the phosphate-bearing stromatolites, crossed-nicols, scale ×20.

Table 2. *Stratigraphic succession of the Aravalli Supergroup* (*after Roy & Jakhar* (*2002*)).

Upper Aravalli Group	Serpentinites (intrusives)	
	Lakhawali phyllite	
	Kabita dolomite	Quartzite, arkose
	Debari formation	
Middle Aravalli Group	Tidi formation	Slate, phyllite
	Bowa formation	Quartzite
	Mochia formation	Dolomite, carbonaceous phyllite
	Udaipur formation	Greywacke, phyllite
Lower Aravalli Group	Jhamarkotra formation	Dolomite, quartzite, **stromatolitic phosphorite**, copper and uranium deposits
	Delwara formation	Metabasalt, veins of baryte
Mewar Gneiss Complex		Pre Aravalli gneisses

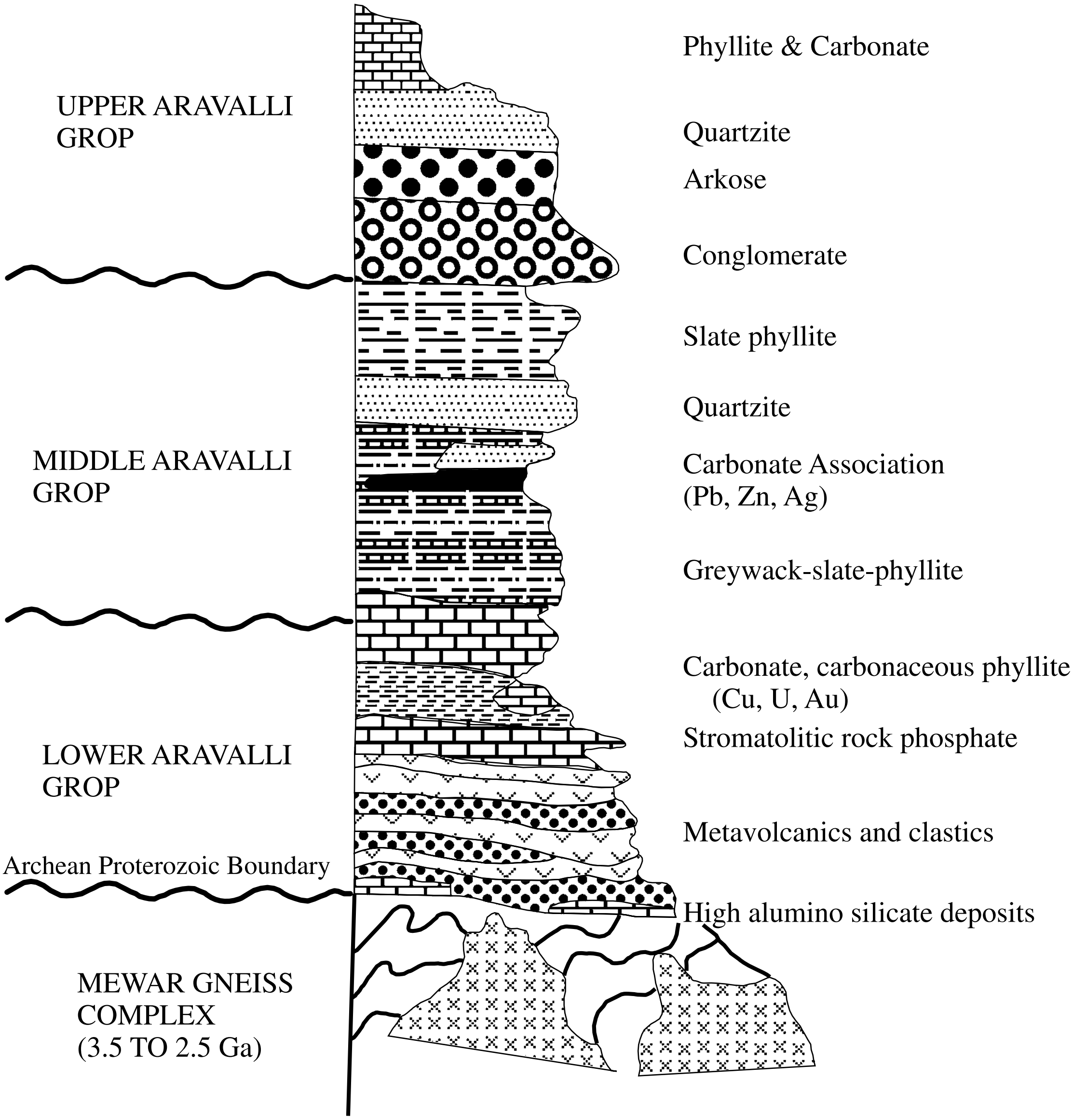

Fig. 2. Lithographical succession of the shelf facies rocks of the Aravalli Supergroup (after Roy & Jakhar 2002).

Precambrian era. Firstly, there was an insufficient amount of dead organic matter that could sink into the oceans and release phosphorus to be upwelled later. Secondly, the phosphorite under discussion is exclusively organic while the upwelled phosphorus gets precipitated inorganically at the shelf regions. A different approach to understand this asymmetry is therefore necessary. If the fossil records are taken into consideration, the data reveal impulsive initiation, speciation, diversification and extinction of various species (Sepkoski 1992). These impulses in the evolutionary history of life on Earth are believed to be the result of several catastrophic episodes caused by extraordinary high-energy events on the Earth during its geological history. Impacts on Earth by extraterrestrial bodies is one such category of extraordinary high-energy events, and they are conjectured to have caused mass extinctions, such as at the Permian–Triassic and Cretaceous–Tertiary boundary, or the emergence of new floral and faunal species, such as at the Precambrian–Cambrian boundary. On this premise, if we take into consideration the following observations it can very well be argued that there was a high-energy event during the Proterozoic era: the occurrence of two distinct cyanobacterial species during the Proterozoic, of which the younger, apatite-constituted species emerged suddenly and apparently after a brief stratigraphic hiatus; a very brief but distinct boundary between the two types of species; a sudden influx of a significant amount of phosphorus from nowhere in the milieu; consumption of anomalously high amounts of phosphorus by the cyanobacteria; the global occurrence of a cyanobacterial community with a similar constitution at the same specific age; This high-energy event could be an impact by an extraterrestrial body that inundated the Earth with phosphorus (Sisodia, 2008). The findings of Pasek and Lauretta (2005) are also quite relevant in this regard; he has proposed that the geochemistry of phosphorus (P) on the early Earth included reduced P compounds. These compounds originated from the oxidation of schreibersite (nickel iron phosphide, $(NiFe)_3P$) found in iron meteorites. The oxidation of schreibersite forms several prebiotic P species such as phosphite and pyrophosphate. Phosphite is specifically relevant to early Earth geochemistry because it is considerably more soluble, forms organic C–P compounds and is used as a P source by several bacteria. The study to find concrete evidence for an impact event is in progress.

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