Report to the American Philosophical Society – Lewis and Clark fund for field research in astrobiology

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My 2010 astrobiology field mission in Rajasthan was conducted between November 2nd and 20th with Dr. Marilyn Fogel, Ms. Himani Chobisa (field assistant), Dr. Ritesh Purohit (main local collaborator), and was led by Dr. Dominic Papineau. During the first week, our team visited several key Paleoproterozoic geobiological localities in the area around the city of Udaipur in Rajasthan, India. These included platformal carbonates from the open marine depositional environment of the Aravalli rift zone and several restricted basins where stromatolitic dolomites and phosphorites were studied and sampled. Figures 1a and b show two types of stromatolites studied in the area around Udaipur. Overall, seven days were spent in this area, which allowed for the sampling of several new outcrops, quarries, and mines, thereby completing the third phase of fieldwork in and around Udaipur (the first two missions were in 2006 and

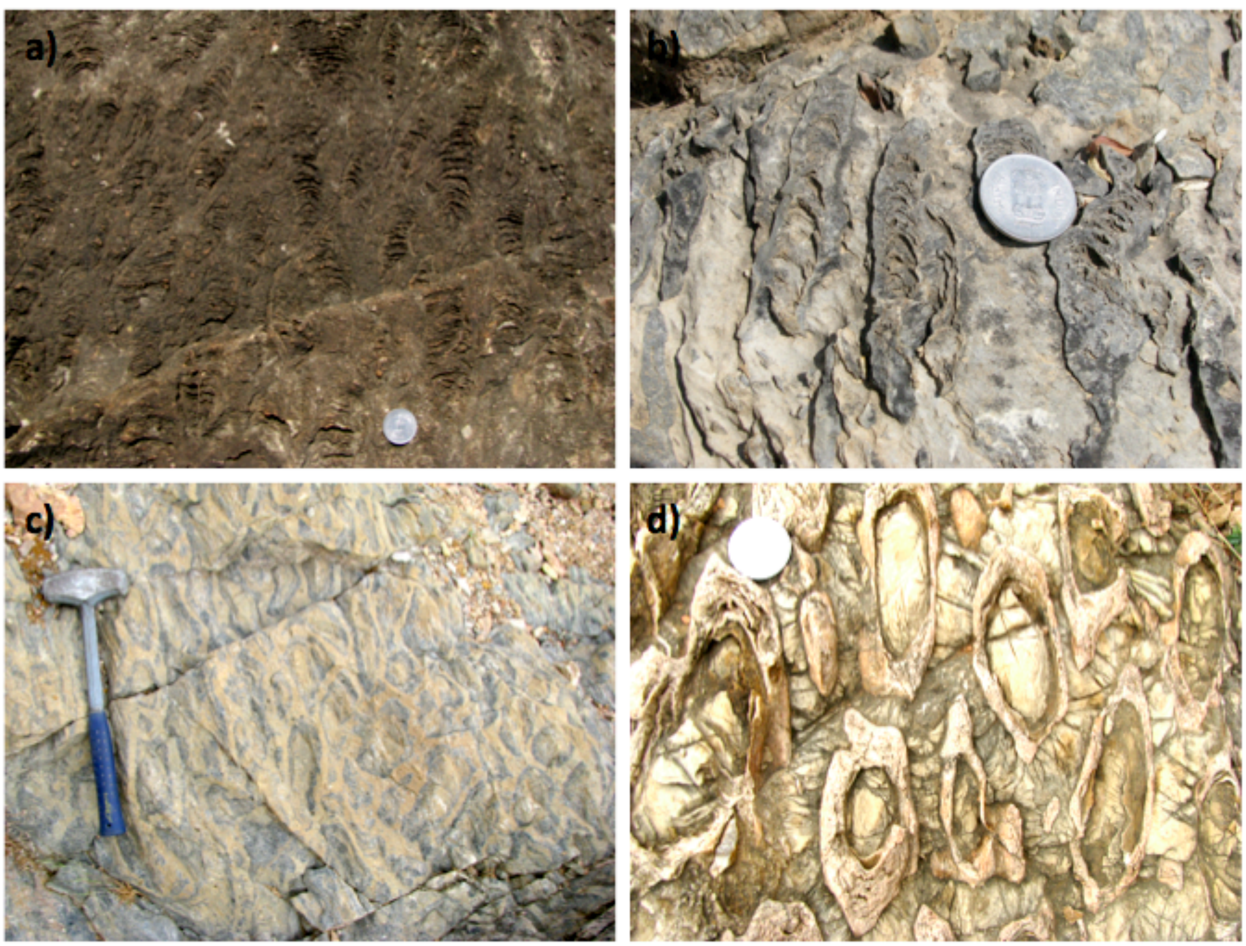

Figure 1: Stromatolites studied in the Lower Aravalli Group: a) stromatolitic dolomites from Neematch Mata; b) stromatolitic phosphorites from Jhamarkotra mines; c) stromatolitic phosphorites from Jhabua; and d) stromatolitic rhodochrosites from Jhabua.

2008). Notably we visited the famous Jhamarkotra (N: 24°27'42.3"; E:73°51'50.1"), Matoon (N: 24°32'49.1"; E:73°47'50.6"), and Kanpur (N: 24°33'10.2"; E:73°46'22.2") phosphate mines, which together contained an estimated total of more than 100 million tons of phosphate and represent one of the oldest–largest phosphate deposit in the world.

For an additional five days, our team undertook the exploratory portion of this field mission in the areas around the villages of Jhabua and Banswara. We also visited localities with organic-rich rocks, referred to as metahexhalites, near the village of Dugocha (N: 23°56'58.1"; E:74°15'25.4") and rhodochrosite-rich pink dolomite mines in Paloda (N: 23°45'38.1"; E:74°12'00.9"), all in Rajasthan, until we reached phosphorite-rhodochrosite mines in the neighboring state of Madhya Pradesh, in the south. We had the unique opportunity to visit an old phosphate mine near the village of Jhabua (N: 22°58'11.8"; E:74°25'33.6"), which is generally closed to visitors. There, we saw a unique, never-before reported, transition from stromatolitic rhodochrosites to stromatolitic phosphorites (Figure 1 c and d). These Paleoproterozoic microbial deposits are truly exceptional and constitute evidence for thriving communities of microorganisms, which adapted to changing environmental conditions and nutrient regimes. This was a truly exciting moment during our mission as it was unanticipated, yet, not completely unexpected. In fact, I had been considering that since the entire Aravalli volcano-sedimentary succession was deposited along a newly-created rift margin, there must have been an area of intense hydrothermal activity associated with sub-marine volcanic rocks. In fact prior to this field mission, I had been suspecting that there have been volcanic-associated hydrothermalism in the Aravalli (see below). I thus took the decision to explore the area towards stratigraphically older strata (i.e. towards the Archean basement rocks), which was the likeliest part of the sequence to preserve hydrothermal deposits. This was somewhat risky because time was getting short and we did not have a good geological map of the area. As we searched for field evidence or key outcrops, we learned from some local villagers about the existence of a manganese mine, which I immediately suspected of being hosted in a banded iron

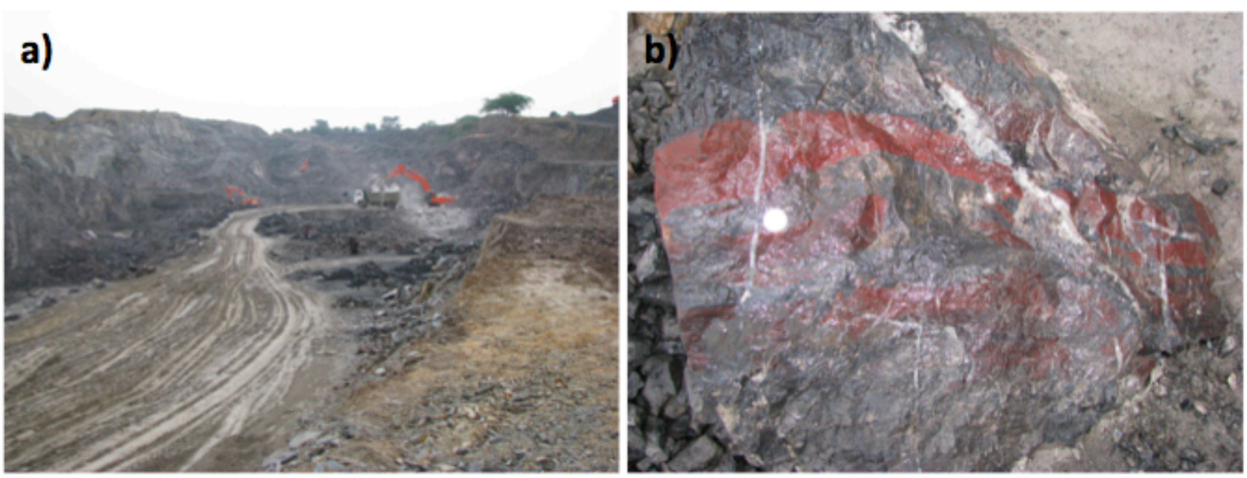

Figure 2: Field photographs from the Kaili Donri manganese mine (a) hosted in an unstudied and previously unreported unit of banded iron formation (b) from the area around Jhabua.

formation, a signature rock-type for hydrothermal activity on the seafloor… With very little time remaining in the field trip, we finally obtained permission to visit the Kajli Donri manganese mine (N: 22°56'43.4"; E:74°28'09.5") about 6 km east of the Jhabua phosphate mine, which was as expected a unit of banded iron formation (Figure 2). This was truly exciting because the banded iron formation occurred as a 5 to 15 meters thick layer in a shale unit, which is expected geological setting for such hydrothermal deposits. The discovery of this Paleoproterozoic manganiferous BIF unit in Madhya Pradesh is entirely consistent with my model for phosphogenesis, which I have been developing for over six years and which is shown in figure 3 below (from Papineau 2010, Astrobiology).

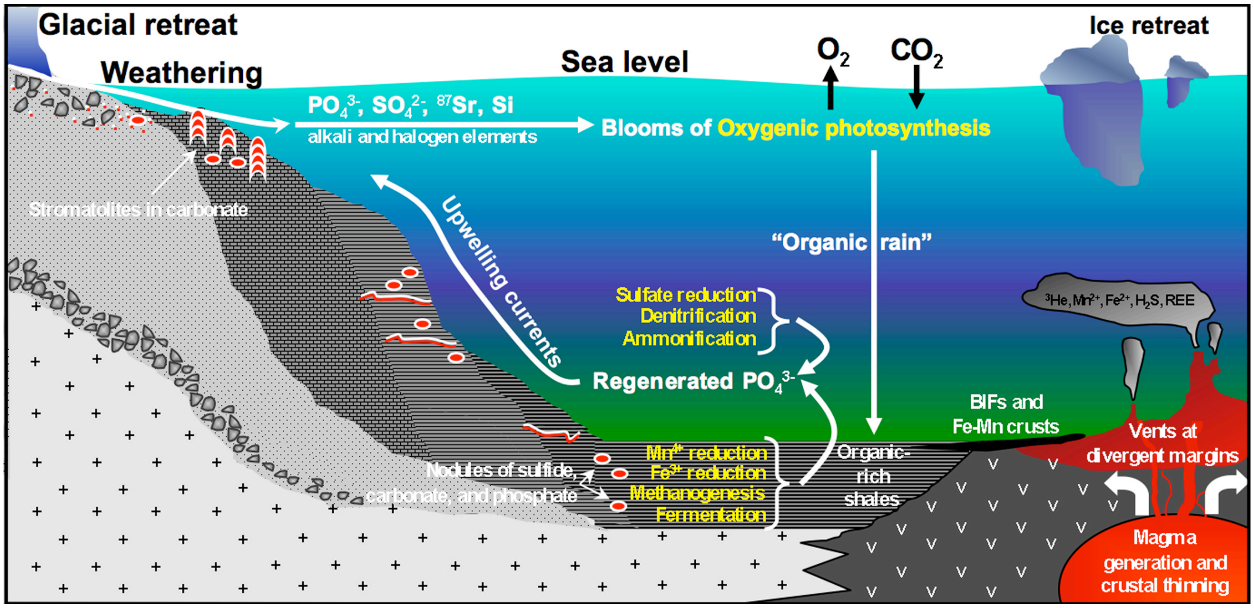

Figure 3: Simplified illustration of the upwelling model for phosphogenesis. Sedimentary phosphate accumulations in Precambrian sedimentary rocks are shown in red as ovals (for concretions or nodules), curved lines (for thin beds), stromatolite columns, and small dots (for fine disseminations). Various lithotypes represented include volcanic rock ("v" pattern), granitoids ("+" pattern), iron formations (black), shales (lines), limestone (bricks), sandstone-chert (dotted pattern), and conglomerate (fragmented pattern). Major metabolic pathways in the water column or in sediments are shown in yellow. The water column is color coded to represent redox states as turquoise (oxic photic zone), blue (redox transition zone), and green (anoxic zone). BIFs, banded iron formations; REE, rare Earth elements.