Report to the American Philosophical Society:

FIELD TRIP TO EXPLORE ARCHEAN AND PROTEROZOIC GEOLOGY OF WESTERN AUSTRALIA (11–18 SEPTEMBER, 2010)

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The NASA Astrobiology Institute node at the University of Wisconsin–Madison, of which I am a member, has as one of its main areas of investigation, the development of biosignatures for the study of the origin and early evolution of life on Earth and beyond. One of the biosignatures we are developing in our group is based on iron isotope fractionation. My role in our astrobiology group is to use this tool to study the biogeochemical conditions that prevailed in ancient sedimentary basins, including the Hamersley Basin of Western Australia during the Late Archean (2.7–2.5 Ga), by use of integrated Fe isotope and whole-rock geochemical analyses of sedimentary rocks. However, it has been demonstrated that biological Fe isotope can only be distinguished from non-biologically mediated redox reactions based on a detailed study of the geologic, petrographic, and geochemical context of well-preserved rock samples (e.g., Johnson et al., 2008; Heimann et al., 2010). To aid us in our research, I, and several other geologists from UW–Madison, attended the 5th International Archean Symposium in Perth, Western Australia, September 5–9, 2010 and an eight-day post-conference field trip through the Pilbara Craton in northwestern Western Australia, September 11–18. This trip provided a geologic overview of the whole region and allowed us to observe first-hand, both spatially and temporally, the most complete record of the geological and ecological changes that took place on the early Earth, and provided a framework for the geochemical changes we measure in the lab. Drs. Martin Van Kranendonk and Mark Barley, both of who are experts in the geology of the Archean and Proterozoic of Australia, led the trip.

Following the symposium, we departed from Perth in a four-wheel drive excursion bus and drove up the coast to Shark Bay where we camped the first night. The theme of our trip, 3.5 billion years of life on Earth, was dramatically introduced the next day, which was spent at Carbla Point on Hamelin Pool in Shark Bay exploring the extraordinary stromatolitic communities on display (**Fig. 1**). These and other stromatolites around the world are being investigated in detail by microbiologists as analogs of some of the earliest microbial communities on earth. Such an experience gave a lateral (spatial) view of the depositional environment of a living community, and how it might have looked in the Archean, rather than just the vertical (temporal) view typically allowed by outcrops.

From Shark Bay we continued back in time to the 1.8 Ga Duck Creek Dolomite on Mount Stewart Station and the nearby ~2.4 Ga Turee Creek Group. The Duck Creek Dolomite contains fossil versions of the stromatolites that

Figure 1. Modern (living) stromatolites at Carbla Point, Hamelin Pool, Shark Bay, Western Australia.

we saw the previous day, and we were amazed by the diversity of forms and the exquisite preservation (**Fig. 2A and B**). From there we continued east and explored the stromatolites of the Kazput Formation (~2.4 Ga) as well as the contact that has been proposed to officially mark the boundary between the Archean and Proterozoic (~2.45 Ga). The contact separates the Boolgeeda Iron Formation, the uppermost unit of the Hamersley Group, from the Meteorite Bore Member of the Kunganna Formation, the lowermost unit of the Turee Creek Group. This was an important time in Earth history, marking the change from a reducing atmosphere to a more oxidizing atmosphere, a change that was not only caused by biological evolution (the advent of oxygen producing microorganisms at least a few hundred million years earlier), but also influenced the direction of biological evolution, ultimately leading to multicellular organisms. It was awe-inspiring to be able to put one's finger on the spot that represented the time when these changes were taking place (**Fig. 2C**).

The next leg of our journey took us back a little further in time to the world-famous, ~2.5 Ga Brockman Iron Formation in Karajini National Park. The continental shelf-scale depositional areas of banded iron formation (BIFs) and the fact that they do not form under the Earth's present surface conditions suggest that they can tell us something about the conditions in the Archean. The deposition of BIFs has been proposed to involve Fe-oxidizing and Fe-reducing microbial processes, and is the subject of intense study amongst geologists and geochemists, including members of our NAI group at UW–Madison. My only previous experience with BIFs came from drill core and images in journal articles, so getting to see these famous BIFs up close and examine the banding

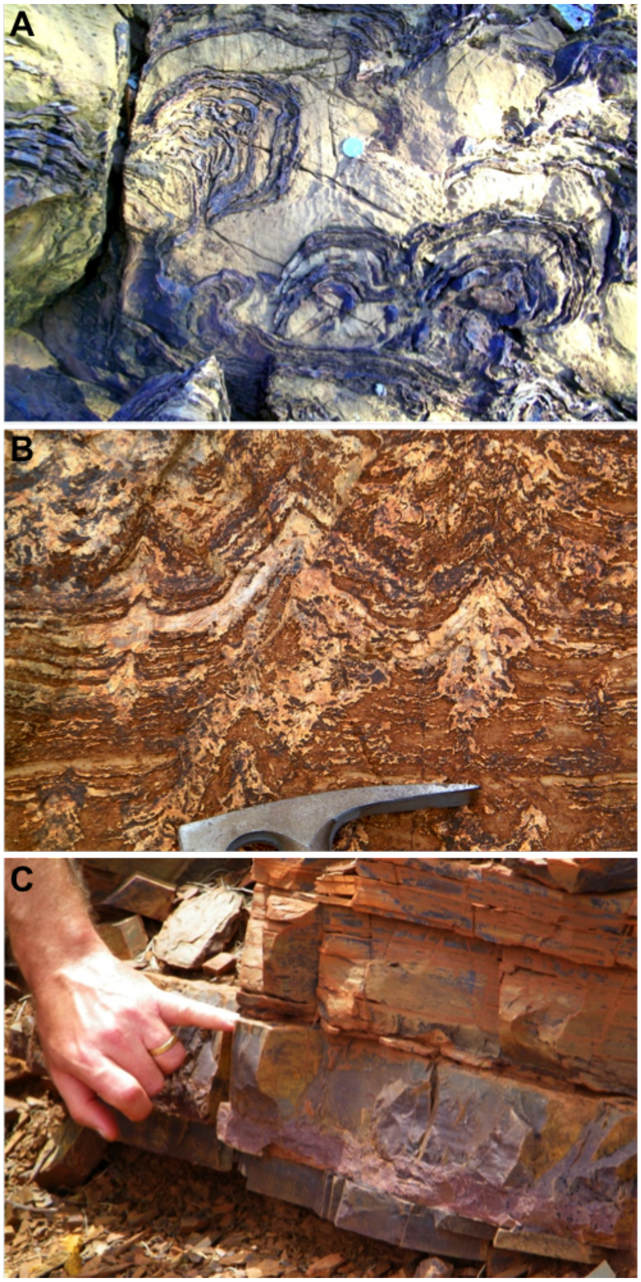

Figure 2. Fossil stromatolites at Duck Creek, Mount Stewart Station, Western Australia, showing some of the diversity of forms: domical (A), and coniform (B). (C) Contact between Hamersley Group (below pinky) and Turee Creek Group (above pinky), proposed as the Global Stratigraphic Section and Point for the Archean–Proterozoic boundary.

and other depositional features really gave us a better understanding of these rocks and how they form (**Fig. 3**).

After the BIFs of Karajini, we headed northeast to the Paleoarchean East Pilbara Terrane, and on the way we saw a ~2.6 Ga impact layer in the Carawine Dolomite, and ~2.7 Ga stromatolites of the Tumbiana formation, furthering our geologic understanding of the Pilbara Craton. The East Pilbara Terrane is home to some of the oldest evidence of life on Earth. We started at the famous ~3.5 Ga Marble Bar Chert Member of the Duffer Formation, which is

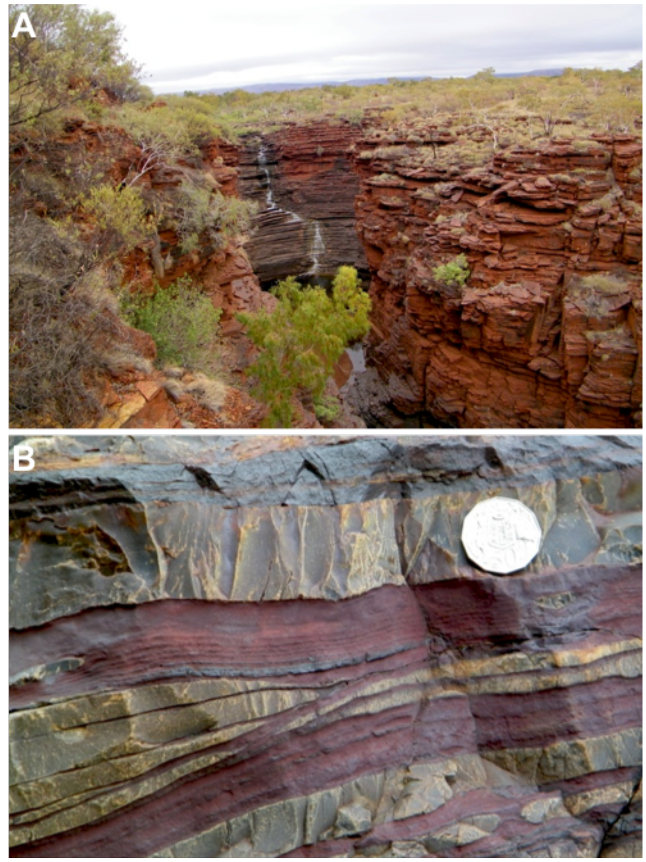

Figure 3. Brockman Iron Formation in the Dales Gorge, Karajini National Park, Western Australia. (A) Joffre Falls. (B) Banding in the Dales Gorge Member if the Brockman Iron Formation, showing complexity.

composed of interlayered blue-black, white, and red chert (**Fig. 4A**). The red (jasper) layers (composed in part of hematite, a fully oxidized Fe mineral) have been proposed to indicate the presence of oxidizing conditions at the time these units were deposited. Most evidence, however, including evidence that can only be seen in outcrop, points to later oxidative alteration of reduced iron in the chert, suggesting a reducing atmosphere at 3.5 Ga. From there, a short hike up a valley between chert ridges brought us to Chinaman Creek and the "Schopf microfossil locality", site of the discovery of some of the world's oldest microfossils in the 3.46 Ga Apex Chert (**Fig. 4B**). Here we had a discussion about the evidence for and against these contentious fossils, including a reinterpretation of the geological context, which indicates that this was a hydrothermal setting. It turns out that such a setting does not preclude a biological interpretation of the microfossils, but it does highlight the importance of a thorough understanding of geologic context and of getting out into the field to see things for oneself.

Our final leg of the journey back in time took us to the Trendall locality of the 3.35 Ga Strelley Pool Formation and the 3.48 Ga Dresser Formation. At each of these sites we saw some of the best-preserved stromatolites, including domical, conical, and branching forms (**Fig. 5**). The preponderance of evidence indicates that these structures have a sedimentary origin, and in most cases display morphological features that are inconsistent with an abiological origin, and thus provide strong evidence of life on Earth in the early Archean. Again, these features were all familiar to me from museum specimens and images in journals and books, but seeing them in person showed the geologic context as well as the full extents of the outcrops, which are substantial.

[Note: The scientific detail provided here for the field trip stops was communicated to the participants by our leaders Martin Van Kranendonk and Mark Barley and is published in our field trip guidebook (Van Kranendonk, 2010; and references therein). For interested parties, the guidebook also contains maps and directions to the sites visited, as well as much additional scientific detail.]

References:

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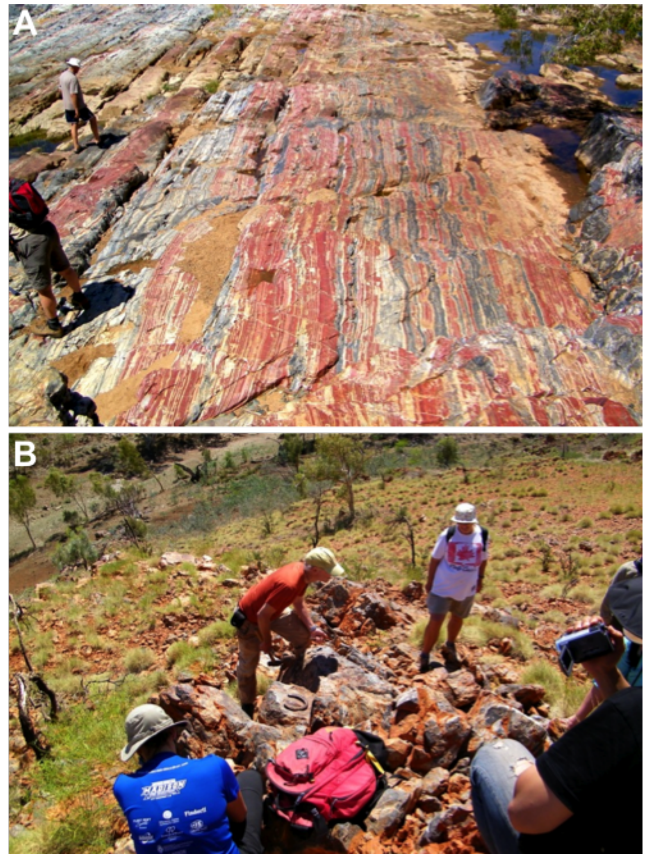

Figure 4. 3.5 Ga old Duffer Formation and Apex Chert near Marble Bar, Western Australia. (A) The Marble Bar Chert showing interlayered blue-black, white, and red chert. (B) Schopf microfossil locality in the Apex Chert.

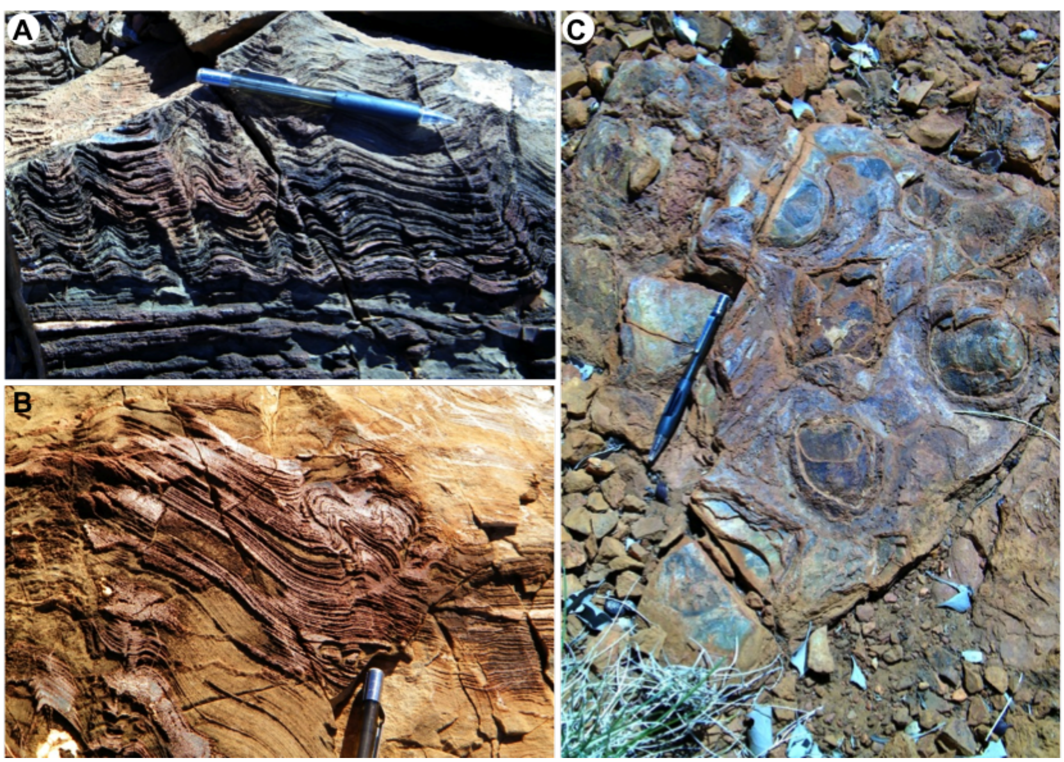

Figure 5. Some of the diversity of stromatolites from the Trendall locality of the 3.35 Ga Strelley Pool Chert (A and B) and the 3.48 Ga Dresser Formation (C), Western Australia.