Introduction

The Neoproterozoic era is one of the most fascinating times of Earth's geological record. Basins that developed during the rifting of the supercontinent Rodinia hold sediments that record wild swings in biogeochemical cycling, low latitude glaciations, the evolution of metazoa and progressive oxygenation of the atmosphere. Of particular utility to studies of Neoproterozoic sediments has been the stable carbon isotope record gleaned from carbonate rocks. This chemostratigraphic data has allowed for correlations of otherwise hard to date rocks in addition to providing insight into biogeochemical cycling on a Earth that was experiencing dramatic environmental change (e.g. [1]). Increasingly, isotopic records of carbonate associated and pyritic sulfur are being utilized to better understand the timing and tempo of oxygenation of the ocean-atmosphere system (e.g. [2]).

Intervals of relatively light carbon isotopes in the Neoproterozoic are commonly associated with regional or global glaciation. The first low ^{13}C excursion in the Neoproterozoic, the Bitter Springs Stage (BSS) (800 Ma), is an exception, as the BSS precedes all the known Neoproterozoic glacial events. Carbon isotopes, which are faithfully recorded in carbonate rocks, shift from a 250 My average ^{13}C of +6 to a 10 My excursion of -1.5 during the BSS. Records of ^{13}C from carbonate rocks in Svalbard Norway, NW Canada and Central Australia, are nearly identical and confirm that the excursion is a global seawater signal, likely reflecting the change in the global fraction of carbon being buried as isotopically light organic matter.

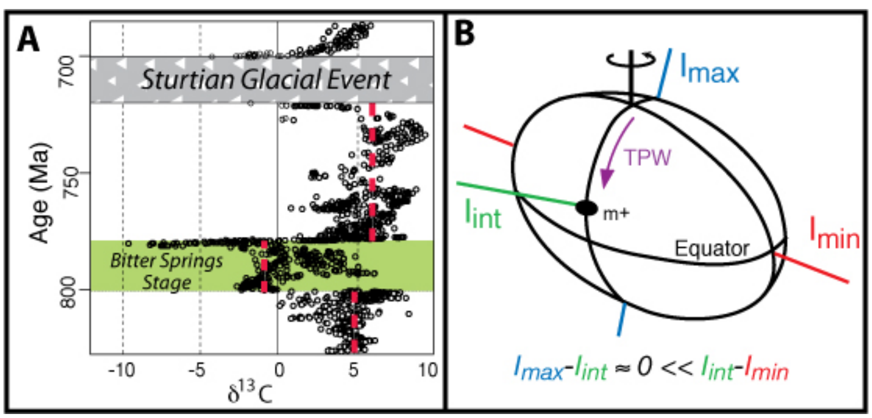

Figure 1: (a) Global composite carbon isotope profile for the Bitter Springs stage and through the Sturtian glacial event (from [1]). Note the enriched values that bracket the BSS (0) and the generally depleted values during the stage (0). (b) Non-hydrostatic figure of the Earth during a large-scale true polar wander (TPW) event. 90°of TPW can occur when mantle density heterogeneities cause changes in the relative magnitudes of the earths principal inertia axes. If a threshold is reached where the maximum inertial axis (I_{max}) becomes less than the intermediate inertial axis (I_{int}) then the entire silicate Earth will rotate quickly around the minimum inertial axis (I_{min}) until the new Imax is aligned with the spin vector.

In their study of the BSS in Svalbard, Maloof et al. ([3]) observed that this interval of relatively low ^{13}C is bracketed by paleomagnetic reorientations and transient changes in sea level. They explain these coincidental changes by inferring rapid shifts in paleogeography associated with a pair of true polar wander (TPW) events. The possibility of TPW, in which there is relative motion between the silicate earth and the spin vector of up to 90°at rates that far exceed those of normal plate tectonics, has been discussed and shown to be a theoretic possibility for years in the geophysical literature. Such an event would occur to keep the Earth in rotational equilibrium during mass shifts in the mantle. It has been suggested that the resulting rapid change in global geography would have profound effects on the Earth system and possibly the history of life. There is evidence for TPW on other terrestrial planets (notably Mars) and such motions would dominate in the absence of plate tectonics.

The goal of the current research, and the reason behind the 2006 field season, is to test the TPW hypothesis by performing integrated physical, chemical and magnetic stratigraphy on the carbonates of the Bitter Springs Formation and other 800 Ma equivalents in Australia where the ^{13}C interval was first observed. These ancient carbonate sediments have been uplifted and remarkably preserved in the interior of the Australian continent. If we can document the BSS through high resolution ^{13}C data, we can assess whether this perturbation to the global carbon cycle is related to changes in the physical sedimentology of the carbonates and assess, through paleomagnetic analyses, wether there is a unique magnetic signature within the stage.

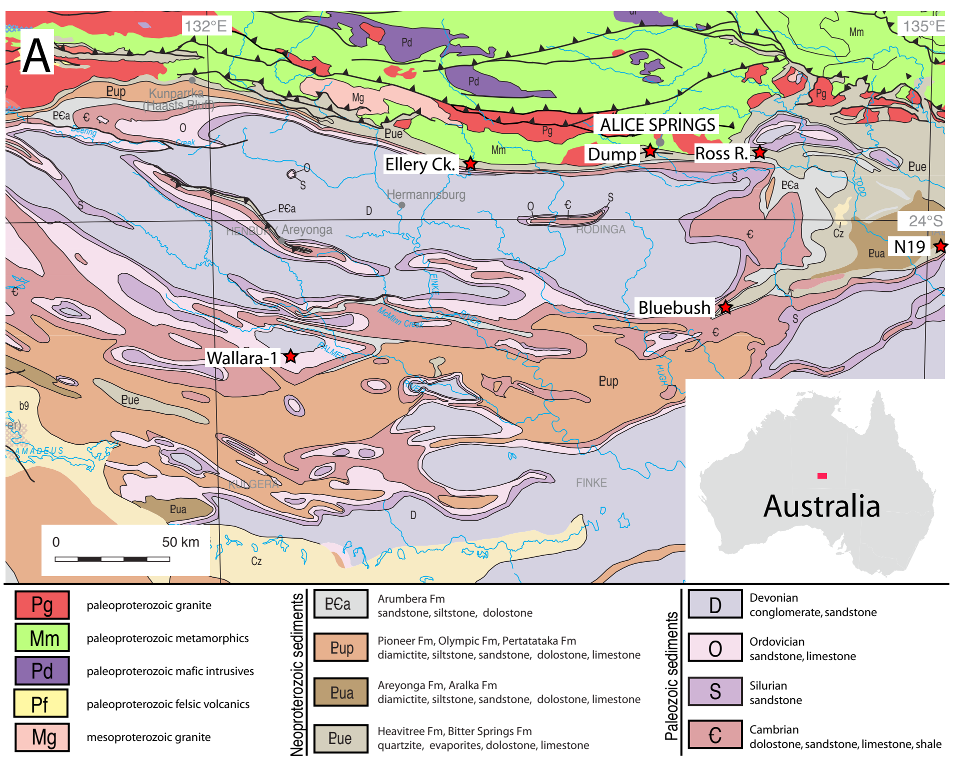

Figure 2: (a) Simplified geological map of a portion of the Amadeus basin. The 2006 field season focused on collecting stratigraphic data and samples from the localities marked with red stars (note that Wallara-1 is a exploration core that was drilled at the marked locaility but is stored in Alice Springs). The location of marked measured sections: Ellery Creek 23°46'55" S, 133°05'03" E; Alice Springs "Dump" section 23°43'24" S, 133°50'20.60" E; Ross River section 23°34'56.58" S, 134°30'33.08" E; Wallara-1 24°36' S, 132°20' E; N19 24°04'23" S, 135°07'57" E; Bluebush 24°31'25" S, 134°17'03" E.

The Field Work

The 2006 field season focused on the lower part of the sedimentary succession in the Amadeus basin of Central Austalia. Previous work by Hill et al. ([4]) had roughly established the position of the isotope excursion in a petroleum exploration core–Wallara 1. We examined this core (stored in the geological survey core shed in Alice Springs) and sampled it at high resolution for isotopic and magnetic analysis. In addition to the sampling, we logged the physical stratigraphy of the core in detail, in order to establish the sedimentary and basinal response to the perturbation that led to the negative ^{13}C excursion.

The majority of our field work focused on outcrop sections along the southern flank of the Macdonnell Range (Fig. 2; Ross River, Dump and Ellery Creek sections). We also investigated two exposures of the Bitter Springs Formation that outcrop basinward-to the south of the Macdonnell Range (Fig. 2; N19 and Bluebush). Each measured section was sampled for paleomagnetic, ^{13}C, $^{87}Sr/^{86}Sr$ and ^{34}S analyses. Additionally some basalts, that occur rarely in the uppermost part of the Bitter Springs Fm., were sampled at section N19 with the hopes that they might provide a radiometric age constraint for deposition. An example stratigraphic section is attached as Figure 3. Preliminary ^{13}C data from this section, measured near Ellery Creek, documents the BSS in its entirety and shows that it is coincident with a microbialite/stomatolite reef. This high-resolution chemostratigraphic dataset from a single section is a significant improvement over past attempts to develop the chemostratigraphy through somewhat tenuous stratigraphic correlations.

In addition to our work in the Amadeus Basin we investigated multiple sections in the Adelaide Rift Complex. While a tentative correlation had been established between the Bitter Springs Stage of the Amadeus Basin and the Curdimurka Group (exposed in the Peak and Dennison and Willouran inliers of the Adeliade Basin), we found those formations to be extensively recrystallized. As the goal of chemostratigraphy is to establish what the chemical composition was of seawater when the rock was deposited, such secondary alteration is a worrisome indicater that the geochemical proxies from those rocks may not record a primary signal. Windows of lower metamorphic grade do exist in the Adelaide succession, and we logged and sampled a petroleum exploration core (Manya-5; stored at the PIRSA drill core storage facility in Adelaide) which contains the purported BSS time-equivelants. The isotopic work on these samples is in progress and should reveal wether they do contain the BSS.

Ongoing lab analyses

Paleomagnetic lab analyses were recently initiated at the Caltech maglab and the initial data is currently being analyzed. More than 1000 samples for ^{13}C analysis were prepped this fall at Princeton and sent to the stable isotope lab at the University of Michigan where they are currently being processed. Collaborators at Northwestern University are beginning ^{34}S analyses attempting to constrain the magnitude and tempo of the response in ^{34}S through the BSS. This could potentially lend insight to the size of the sulfate reservoir and the oxidation state of Earth prior to the Sturtian glaciation.

References

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[2] Fike, D. A., Grotzinger, J. P., Pratt, L. M., and Summon, R. E. Nature **444**, 744–747 (2006).

[3] Maloof, A., Halverson, G., Kirschvink, J., Schrag, D., Weiss, B., and Hoffman, P. GSA Bulletin **118**(9), 1099–1124 (2006).

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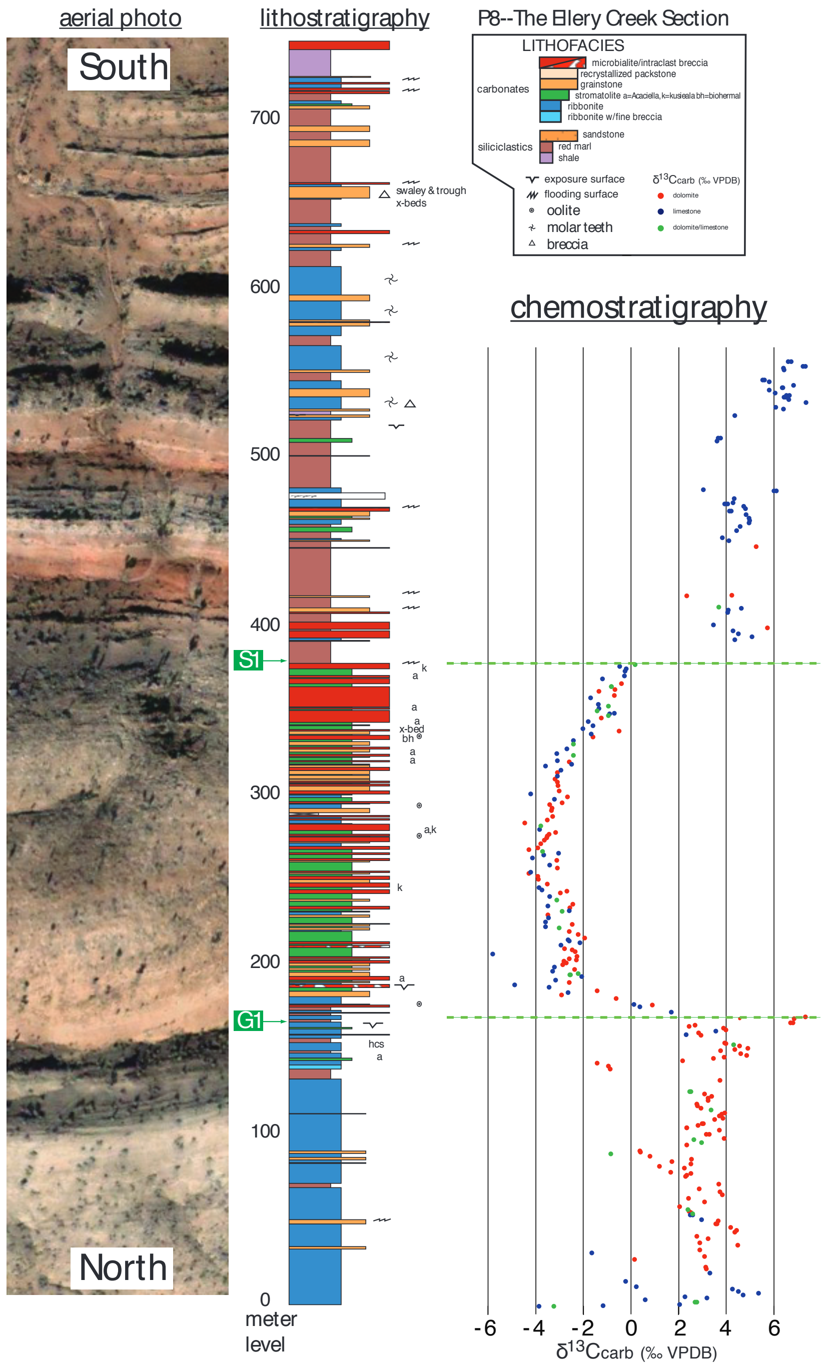

Figure 3: (a) Litho- and chemostratigraphy of the Ellery Creek section of the Bitter Springs Formation in the Amadeus basin. Because the beds are tilted at 90° an aerial photo of the section can be shown next to the lithographic log. Preliminary ^{13}C data from samples collected during the 2006 summer field season show a marked negative shift 170 meters into the section corresponding with an exposure surface and a transition in the carbonate sediments from a ribbonite facies to a microbialite/stromatolite reef. After 210 meters of negative ^{13}C values, there is a return to typical Neoproterozoic values of (5) associated with a flooding surface and a transition into the red marl facies that is typical of the uppermost member of the Bitter Springs Formation.