ABIOTIC EARTH - ESTABLISHING A BASELINE FOR EARLIEST LIFE, DATA FROM THE ARCHEAN OF WESTERN AUSTRALIA. J. F. Lindsay[1], M. D. Brasier[2], N. McLoughlin[2], O. R. Green[2], M. Fogel[3], K. M. McNamara[1], A. Steele[3] and S. A. Mertzman[4], [1]NASA-JSC, Houston, TX, 77058, USA, [2]Earth Sciences Department, Oxford University, OX1 3PR, U. K., [3]Carnegie Institution of Washington, Washington, DC, 20015, USA, [4]Department of Geosciences, Franklin and Marshall College, Lancaster, PA ,17604, USA

Introduction: Stromatolitic structures preserved at two stratigraphic levels within the 3.47-3.43 Ga Warrawoona Group of Western Australia have been interpreted as some of "the least controversial evidence of early life on earth" and "the oldest firmly established biogenic deposits now known from the geologic record" [1]. The structures were said to have formed in a shallow sub-tidal to intertidal setting as part of an evaporite succession [2]. In an extensive field program we have re-evaluated exposures of the Strelley Pool Chert from which stromatolites have been described and carried out detailed mapping and sampling of the Strelley Pool West [3] site 13.7 km west of the type locality [2]. Data from our ongoing program cast considerable doubt on the biogenic origins [4] of the stromatolitic structures and on the nature of their depositional setting.

Geology: The Archean stratigraphic succession on the Pilbara Craton of Western Australia consists of five unconformity bound megasequences that formed as a volcaniclastic carapace above the intruding Archean granitoid complex that underlies the protocontinent [5]. The succession is well preserved and for the most apart has been subjected to no greater than low greenschist-grade metamorphism [5]. The 10-15 km Warrawoona Group, which occurs close to the base of this ancient succession [6], includes the Strelley Pool Chert which is well known for containing stromatolites that are believed to provide some of the best evidence for earth's earliest biosphere [4].

The Strelley Pool Chert is widespread and ranges from 15 to 30m in thickness. The formation consists of grey or white, iron-rich, dolomitic carbonate or silicified carbonate interbedded with units of mega-quartz after barite(?) that are overlain by primary chert units. The carbonates can be followed laterally into the silicified intervals providing clear evidence of replacement. The carbonate and silicified carbonate intervals are generally laminated in planar or swaly units. Stromatolitic structures are found at well defined intervals of 1-2 m thickness in carbonate and silicified carbonates lower in the formation. The small crested domes and cone structures have been described in considerable detail elsewhere [cf 4]. The laminae of the stromatolitic structures are generally isopachous with occasional evidence of erosion around the base of some steeper domes.

The mega-quartz interbedded with the carbonate/chert units may be massive or botryoidal. Delicate fans of highly acicular pseudomorph crystals are preserved as are pronounced zones of "chicken-wire texture"[7, 8] locally draped by black chert. Primary chert always occurs toward the top of the formation. The stratigraphically earlier cherts are finely laminated black and white intervals whilst the later cherts are generally grey green and either massive or finely laminated and locally stained blue green by transition elements derived from the weathering of sulfides.

The 6 km thick Coonterunah Group, which consists largely of tholeiitic basalts, disconformably underlies the Strelley Pool Chert in the study area. Dated at 3.515 Ga it is the oldest of the five megasequences exposed on the Pilbara Craton [9]. Cross-cutting the steeply dipping Coonterunah Group (Coucal Formation) in the study area is a system of dykes and veins that extends for c. 1.7 km beneath the Strelley Pool Chert. Cavity fill lithologies within the dykes provide a record of hydrothermal activity through the dyke system. All of the lithologies identified in the overlying Strelley Pool Chert can be identified within the cavity fill preserved in the dyke system. Textural relationships show that they follow the same general depositional sequence as that preserved in the stratigraphy of the overlying depositional succession.

Mega-quartz after barite occurs throughout the dyke system to a depth of 1.7 km and to within 10 m of the Carlindi Granitoid complex. Black massive chert first appears at a depth of 1.5 km in the dyke system. Locally, to the west of the main dyke complex, a second set of smaller dykes extends upward into the Strelley Pool Chert where the black chert forming the dykes cuts across the stratigraphy and then turns over to blend with laminated chert at the top of the formation.

Iron-rich dolomitic carbonate appears in small amounts at 1.1 km depth in the dyke system but the main carbonate cavity fill appears at 550 m. Stable carbon isotope signatures for carbonates from both the cavity fill within the dykes and the bedded and stromatolitic carbonates within the Strelley Pool Chert are similar (∂C_{carb}=+1.2$\pm$0.6 p.p. mil.) as is their bulk chemistry (Fe=5.7$\pm$2.7%, Mg/Ca= 0.47$\pm$0.20).

Small gossans after sulfides first appear at a depth of 1.25 km in the dyke system. The gossans and associated staining by transition elements in the Strelley Pool Chert suggest the sulfides are a late stage phase which is consistent with declining temperatures in the evolving hydrothermal system.

Discussion: The Strelley Pool Chert is a complex deposit that accumulated around a series of hydrothermal vents fed by a network of deep-seated dykes and veins. The iron-rich dolomitic carbonates of the Strelley Pool Chert are simply part of this hydrothermal succession that began to precipitate from solutions well below the seafloor. Textural evidence from cavity filling within the dyke system feeding the hydrothermal vents suggests that degassing of CO_2 due to decreasing pressure and temperature (c.<300^o) began at depths of 1.1 km below the seafloor and became intense at 550 m. The stromatolitic structures were thus generated by direct precipitation of carbonate from hydrothermal fluids in a relatively deep marine setting. Silicification appears to have occurred in the later stages of the hydrothermal cycle as temperatures fell and silica was introduced into the system. Laminations within the stromatolitic structures are conspicuously isopachous and comparable with abiotic structures formed by direct precipitation of carbonate [10]. We find no direct evidence of biogenic mediation in their construction - they appear to be sedimentary structures modulated by localized ocean floor currents.

The high iron content of the dolomitic carbonate is atypical of biogenically deposited platform carbonates found in Late Archean and younger successions [11]. For example, Cambro-Ordovician limestones and dolostones from the Amadeus Basin of central Australia have a mean Fe content of 0.49$\pm$0.26%, an order of magnitude lower than the carbonates of the Strelley Pool Chert. If oxygenic photosynthesis had occurred during deposition of the iron-rich carbonates of the Strelley Pool Chert, Fe_2O_3 would have been deposited simultaneously and the carbonates would have a distinctive red coloration similar to those encountered in the much younger (<2.7 Ga) carbonates associated with banded iron formation in the overlying Hamersley Basin.

Stable carbon isotope data from the carbonates suggest that fractionation occurred as a consequence of degassing with isotopically lighter carbon being lost to the ocean and atmosphere while isotopically heavier carbon was retained in the precipitated carbonate. Carbon retained within the black cherts may well have been fractionated by a second mechanism, such as Fischer-Tropsch type synthesis (FTT), at depth (>1.5 km) within the hydrothermal system [12]. The abrupt disappearance of carbon from the cherts towards the top of the stratigraphic succession suggests that FTT ceased when temperatures dropped below c.200^o.

Sulfur occurs in two oxidation states as sulfide and sulfate. Sulfate was deposited at higher temperature (c.250^o) early in the hydrothermal cycle and occurs at the bottom of the dyke system (1.7 km deep) suggesting that it was derived directly from the underlying granitoid-complex magma chamber rather than from fluids generated by hydrothermal convection. Sulfides formed later at lower temperatures (<200^o) and shallower depths suggesting a hydrothermal source in the volcanics. It is thus unlikely that sulfates preserved in Archean successions reflect seawater chemistry or the oxidation state of the ocean and that mass independent fractionation proposed for the Archean sulfur cycle [13] may relate, at least in part, to the independent nature of the sulfur sources.

Conclusions: Our data shows that the stromatolic structures described from the Strelley Pool Chert are abiotic features deposited by direct precipitation from hydrothermal solutions that were modulated by ocean floor currents. This implies that oxygenic photosynthesis may not have become significant on Earth until after 2.8 Ga following the assembly of the first continents and the initiation of plate tectonics, that is, following the start of the supercontinent cycle. This in turn allowed the formation of broad shallow intracratonic basins that, with their shallow-water sunlit settings and declining hydrothermal activity, provided an ideal environment for the rapid expansion of photosynthesizing organisms [11]. At the same time the initiation of active plate margins allowed sequestration of carbon-rich sediments into the upper mantle thus defining the major carbon reservoirs that characterize the post Archean world.

The environmental setting in which life first evolved was thus dominated and defined by abiotic hydrothermal processes. These processes have the potential to emulate biogenic activity. It is thus essential that we understand the abiotic Archean hydrothermal environment and the context in which the resulting sediments were deposited if we are to detect the earliest evidence of the evolving biosphere. It is also important that we identify new biosignatures that stand out from this overwhelming abiotic hydrothermal background.

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