Podcast Interview: Ralph Pudritz and Ben Pearce

PNAS: I'm Brian Doctrow. Welcome to Science Sessions.

The RNA world is a leading hypothesis for the origin of life on Earth. RNA can store genetic information, just like DNA, but is also capable of catalyzing its own replication, whereas DNA replication requires assistance from enzymes. Therefore, the RNA world hypothesis proposes that the first living organisms were based on self-replicating RNA polymers. Where would these RNA polymers have come from? Ralph Pudritz, a physicist and founding director of the Origins Institute at McMaster University, and his Ph.D. student Ben Pearce, attempted to answer this question in a PNAS paper from 2017. Along with their co-authors, they modeled a plausible scenario for how nucleotides, the building blocks of RNA, could have formed and polymerized on the early Earth. This paper earned them the 2017 Cozzarelli Prize for excellence and originality in the Physical and Mathematical Sciences. I spoke with Pearce and Pudritz about their work during the 2018 PNAS Editorial Board Meeting. Currently there are two general hypotheses for how RNA-based life first arose.

Pudritz: One is that life may have begun in hydrothermal vents—fissures in the bottom of oceans—where biologists and geochemical studies showed there's lots of life gathered in these regions. Another picture is in warm little ponds, which might be fed by atmospheric biomolecules or by meteorite bombardment.

PNAS: Pudritz and Pearce thought the "warm little ponds" scenario to be more physically and chemically plausible than the hydrothermal vents scenario.

Pudritz: To make polymers, to make something like RNA, that requires a drying and wetting process. By basically getting rid of water, you have the chemical energy that propels the formation of these bonds. And it's unclear to us, in a hydrothermal vent picture, how that would be possible even supposing these nucleotides, these bases, are present in such conditions. So, we focused our work on this idea of warm little ponds because that's a natural environment—the drying and wetting of the ponds—to provide the optimal conditions for forming these polymer chains.

Pearce: There's been experiments which have exposed RNA building blocks to these wet and dry cycles, and they found within even just one wet-dry cycle, they can get polymers, which may be as long as 300 monomers long. This is something that you can't do in a hydrothermal vent environment, where similar experiments have shown that you can only really get two monomers to chain up to a dimer and that's it. And we're looking at things that need to be at least 40 monomers long to be catalytic—to be an RNA molecule, which can actually self-replicate.

PNAS: Pudritz and Pearce further assumed that nucleobases, key components of nucleotides, could have gotten into these ponds via meteorites landing in the ponds or via interplanetary dust particles (IDPs) gradually drifting down from space.

Pudritz: We know that the meteorite bombardment rates would have been billions, and probably much higher, in the early Earth as part of its formation. And we do know there's a class of meteorites called carbonaceous chondrites, which are rich in materials like this. There are 70 amino acids you can find in the very well-known Murchison meteorite; there are three of the five nucleobases that make DNA and RNA that have been found, and fatty acids, lipids, etc., so it's very rich.

Pearce: And then whatever could outflow from the pores of those meteorites would then make up the new pond solution.

PNAS: Pudritz and Pearce combined various data sources, including the nucleobase content of carbonaceous chondrites, the rate of meteorite impacts estimated from the lunar cratering record, models of precipitation on the early Earth, and the known chemistry of nucleobases, to model the concentration of nucleobases in ponds over time on the early Earth.

Pearce: We built a model based on sources and sinks of both pond water and nucleobases: the sources for nucleobases being the meteorites and the IDPs, sources of water being rain. And then there are several different sinks—these destructive forces within the pond that can remove nucleobases. For example, ultraviolet radiation, reactions with liquid water, and even just seeping through the pores in the base of the pond. What we found was that meteorites give you a concentration, which is high enough to actually react to form nucleotides and RNA. However, IDPs don't get anywhere close; it's a difference of 10 orders of magnitude. It's because meteorites deliver a large abundance of nucleobases in a single event, versus IDPs, which slowly rain down and allow the destructive forces to remove them as they're slowly coming in.

PNAS: The most interesting implication from the model was how quickly RNA could have formed under this scenario.

Pudritz: Given the destructive things that happen to molecules as they're delivered, you have a limited time by which you can polymerize things. The rate at which you can chain things together fortunately is fairly fast; you can do this within a few dry-wet cycles. It's this race, which is won by polymerization fairly quickly, which is the reason for our early timescale estimate that polymers may have occurred as early as 4.17 billion years ago.

Pearce: We found that thousands of carbon-rich meteorites would have actually landed in ponds from 4.5 billion years ago to 3.7 billion years ago. So, this essentially gives life thousands of opportunities, thousands of ponds in which RNA could form.

PNAS: I asked Pearce and Pudritz what their reaction was upon learning that they'd won the Cozzarelli Prize.

Pearce: It's an incredible honor. It's kind of one of those things that…you see the e-mail and you don't believe it, and you just open it up and it turns out to be true and don't really know how to react.

Pudritz: It took a while for it to sink in, naturally. This is really quite a great honor and it was an amazing chance for the kind of work that we were doing to be picked up in a journal like PNAS. We were very pleased.

PNAS: Thanks for listening. Look for more Science Sessions podcasts at www.pnas.org.