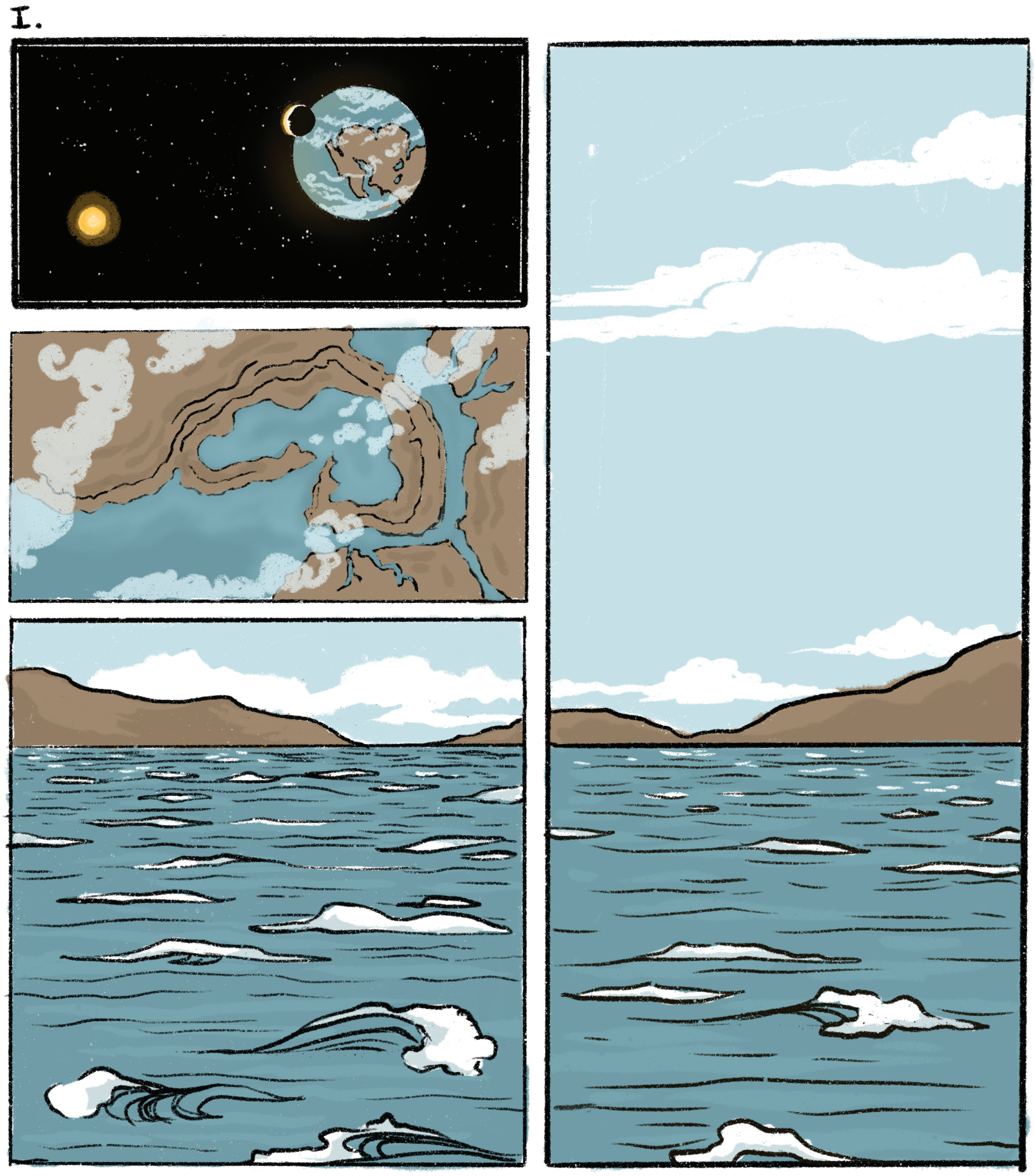
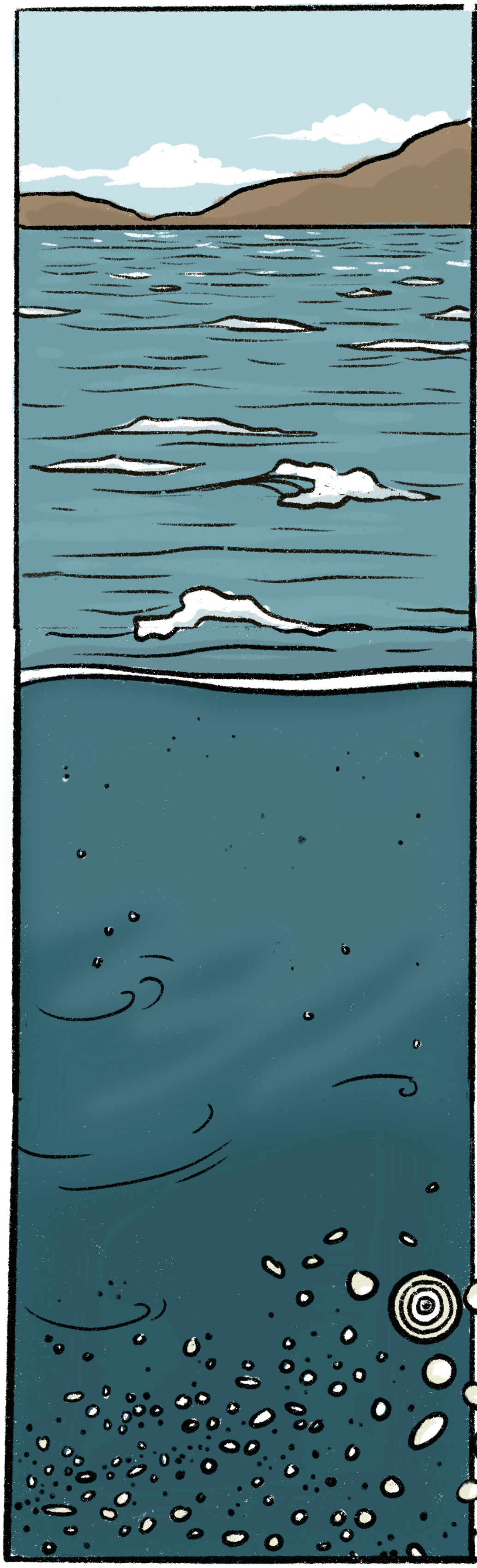


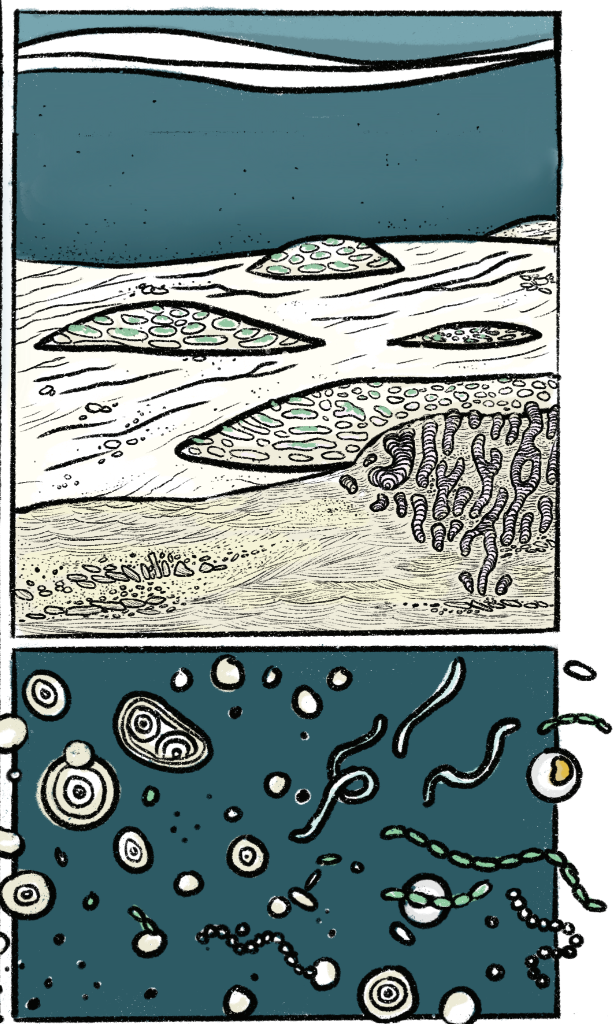
Introduction

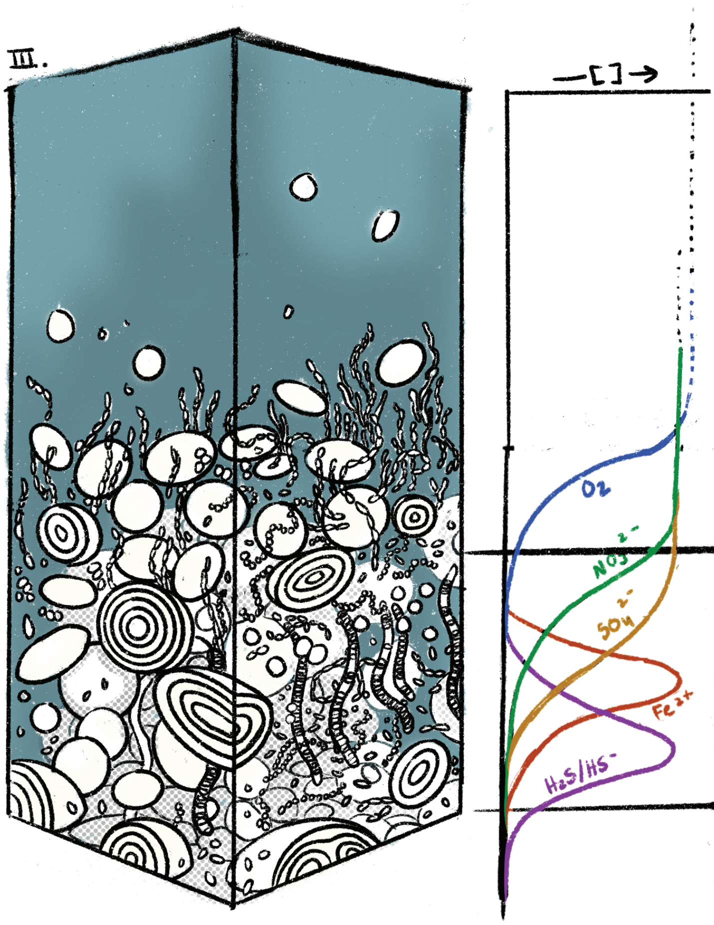
600 million years ago, the continents that we call Africa, South America, Eurasia, and Australia were one. They formed a “supercontinent” comprised of dozens of thick rocky plates sutured together, named Gondwana after the Gondi people who would one day settle upon its mangled remnants. At 600 Ma, much of Gondwana was warm and tropical.

II.

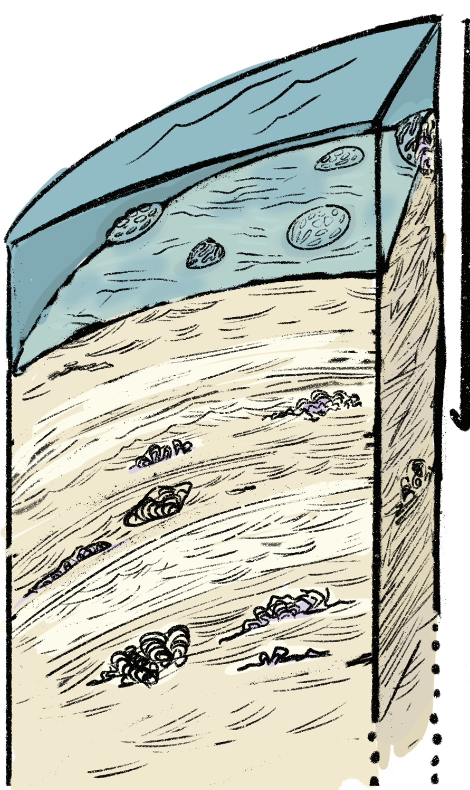


Where once there had been massive glaciers, there were now shallow wave-tossed seas. Their only inhabitants: quietly persistent, single-celled organisms, blue-green, olive, reddish-brown, translucent, gelatinous, and aggregated in films and mats – filaments waving in the shifting currents like so many microscopic strands of grass in a breeze. These simple, persistent lifeforms clung to each other and to the rain of carbonate sediment falling from the water column, forming pillars, domes, and great mounds of intricate latticework corridors – mindless, but astonishingly complex architectures – like so many sunken palaces among the shifting pearl-white shoals.





The sunken palaces sunk further still, not just beneath the waves but beneath the sea floor, under hundreds of meters, even kilometers, of carbonate grains and mud and later siliciclastic sands.



Beneath and around them, Gondwana shifted and split, its component cratons crashing into or straining apart from one another. Hundreds of millions of years of now-rock cracked, tilted, and then wore into wild new topographies under water, wind, roots, talons, paws, hoofs, and eventually feet. The ancient, sunken cities were laid bare and dessicated – alien ruins on a planet made anew.

IV.

6 years ago, I arrived in the Division of Geological and Planetary Sciences as a new graduate student. I was mad for aliens, determined to find and study life on a different planet. What would an alien fossil look like? How would we distinguish it from the million other abiogenic rocks? Are we alone in the solar system? I was ready, I told my advisers, to hike down into Gusev crater and kick apart clods of rusty dirt with my space boots yelling, “anybody home?” if that’s what it would take.

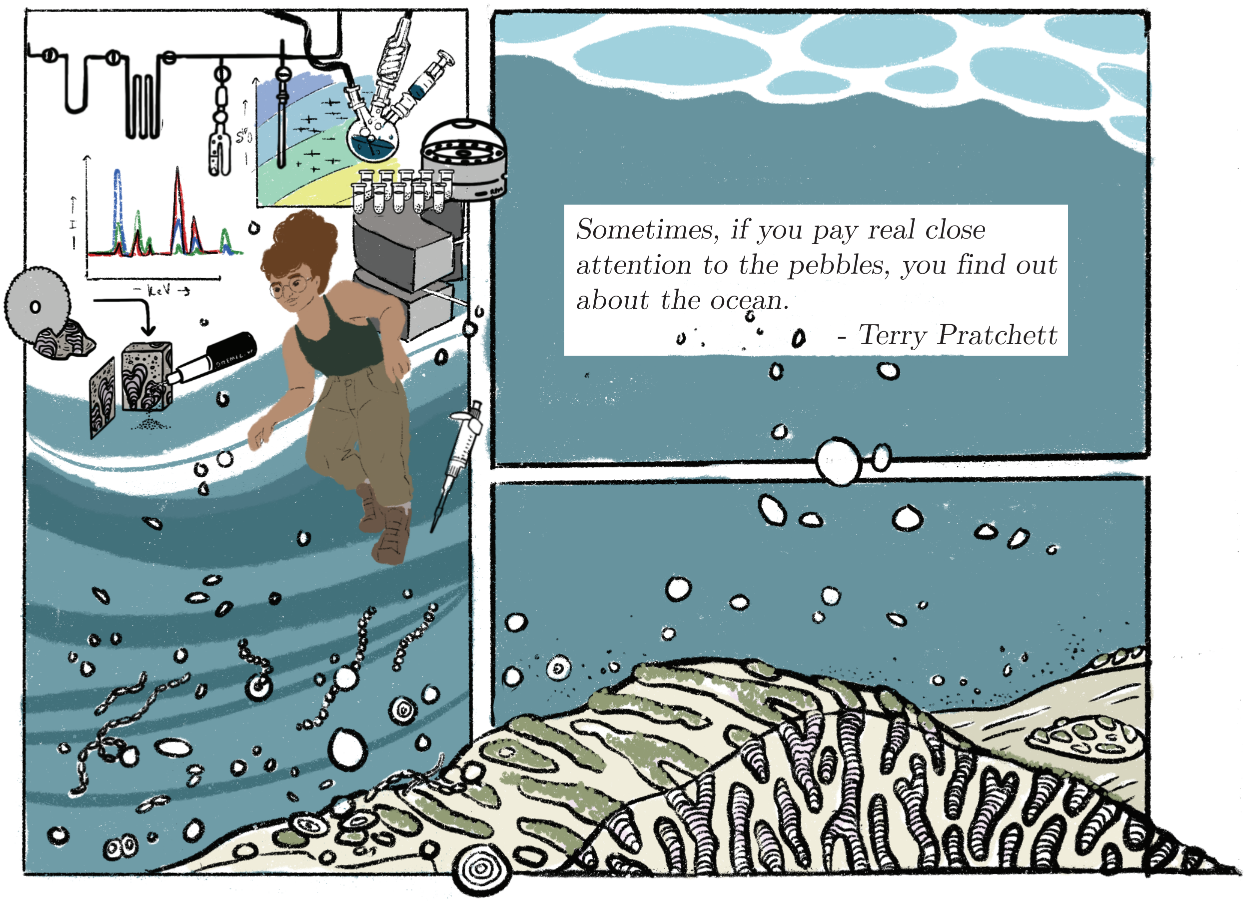
My advisers pointed out, tactfully, that this was perhaps not the best approach, and probably not plausible on the timescale of a graduate degree. My interest in life on other worlds had grown from my interest in life on Earth, hadn’t it? Perhaps, they suggested, you should study life somewhere we know it has been: the ancient Earth. This did not sound much like alien hunting, but I liked field geology and paleontology and I was intrigued. On a 2018 trip to Bahia, Brazil, I encountered the ruins of an alien city in a ditch on the side of the road. These were the sunken palaces, with their honeycomb galleries of pearly carbonate and delicately mauve calcium phosphate, the work of a million billion microbial architects a long time ago in an ocean far far away from the world I knew.

V.

How did these structures form, and were the microbes that formed them truly architects, actively guiding the construction of their own tombs? Or passive bystanders? How different did the chemistry of the water, and the interplay of living and non-living elements, have to be from one patch of seafloor to the next to determine whether a palace could grow or not? What information could these ruins hold about the world as it was when their miniscule bricks were first laid and cemented?

I immersed myself in the reconstruction of the paleoenvironment and paleoecology that had produced these structures, determined their composition, and sealed the fate of the remains of the organisms that lived on them.

VI.



In interrogating the phosphatic and non-phosphatic microbialite structures – which I still think of as alien cities – I was able to develop some understanding of the lifeforms that created them and the world they inhabited. More importantly, I also gained some understanding of the ecologies and the sequence and timing of environmental conditions necessary to preserve evidence of life on an alien world – and the tools that can be used to seek out that evidence.

This work has expanded the "alien" and "the unknown" and the "wondrous" for me beyond cold, remote Mars, to include even the most commonplace and next-door of subjects: gray-white heaps of stones in a ditch on the side of a rural road, etchings in sidewalk concrete, drab pebbles. In such heaps, we found ruined palaces. In such etchings, we might find vibrant communities of microorganisms tracing out a record of their lives that might last for hundreds of millions of years to come. In such drab pebbles, we find that we are not alone.

Geological and Geochemical Explorations of a Phosphatic Microbialite

Chapter I. I measured, described, and sketched hundreds of meters of stratigraphy across the São Francisco Craton, the remnant of Gondwana which had played host to the palace-builders' ancient sea. I used these to develop a depositional facies model: a picture of the depositional setting in which both phosphate- and carbonate-cemented microbialites formed as islands among wave-tossed carbonate sediments.

Chapter II. I took slivers of rock from among the measured strata, and examined at micrometer scales their mineral fabrics, by observing and measuring the interaction of the slivers with white light, green light, X-Rays, streams of electric current, and beams of ionized particles. These data allowed me to develop a relative timeline of the formation and recrystallization of different components of the rocks within and surrounding the microbialite buildups. I then collected powders of the earliest cement minerals I could identify, dissolved them in acids, and measured their oxygen and carbon isotopic compositions, and tendency of certain isotopes to bind together therein. These data allowed me to constrain the temperatures which the rocks had experienced, and the nature and origin of fluids that flowed through and interacted with the rock throughout its existence.

Chapter III. I identified targets for further isotopic analysis among well characterized slivers of rock in which early cements of phosphatic and non-phosphatic compositions could be identified and separated from one another. On our own planet – modern Earth – structures of similar composition to the Sao Francisco's ancient phosphatic microbialites actively form in select environments. Their formation being tied to the activity of certain community structures among sulfur-metabolizing microorganisms, I wished to examine the ancient structures for geochemical evidence of the same. I measured the sulfur isotopic composition of structural sulfate and sulfide in the cement-forming minerals within the target samples, and compared them – finding values consistent with the activity of such microbial metabolisms as are seen in modern analog environments.

Chapter IV. I explored possible relationships between organic matter from decaying microorganisms and the cementation and lithification of the rock itself. As with my sulfur isotope investigation, I took inspiration from analogous systems in the modern world to develop a hypothesis for the role of organic material in facilitating its own preservation: accumulation of cations around organic matter, enabling the formation of complexes between organic matter and the negatively charged components of precursor cement minerals. I used electron microscopy to look for geochemical evidence of cation-enrichment in well-characterized slivers of rock from my ancient phosphatic microbialites – finding none.