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INTRODUCTION

AS I awoke the morning of what was *supposed* to be my first deep-sea dive, I prayed to no one in particular, "Oh please, don't let my legs be slamming against my mattress." If they were, that would mean the seas were too rough to launch the submersible from the research ship where we were living and working for three weeks, hundreds of miles offshore in the Gulf of Mexico. And I wouldn't get a second shot at it. As my brain gradually regained consciousness, I began to smell bacon wafting from the galley below, I heard the whirr of air conditioning, and, miraculously, I came to realize that my bunk was as still as if I were on land. The water outside was like glass. Perfect conditions.

I leaped out of my bunk and began to gather my diving clothes. When it comes to submersibles, fashion is dictated by engineering and oceanography. The bottom of the ocean is universally cold, no matter where you are on Earth, and our submersible, the *Johnson-Sea-Link II*, would not offer me much thermal protection. Though the divers in the front of the vessel sit in a beautiful clear Plexiglass ball, which insulates it from the cold and gives a splendid half-sphere view of the ocean, this cozy throne only holds one scientist and one pilot. Being one of the lower-ranking scientists (I was a PhD student at the time), I would not get to travel in such luxury. Instead, I'd be stashed in "the coffin," located at the back of the submersible. The coffin is a rectangular box where a second scientist (that would be me, for this dive) and a second pilot lay side by side, with no room for either to sit up straight. They communicate with the folks in the Plexiglass ball via an internal headset, but otherwise the ball and the coffin are separate. Since the coffin is made of metal, I would get to experience the authentic temperature of the deep sea without insulation. And, as the name suggests, this can be a deadly cold: the first version of the *Sea-Link* snagged on the bottom of the ocean, where it stayed for more than a day. The two men in the back of the submersible, one of whom was the son of Edward Link, the submersible's designer, died from cold exposure and carbon dioxide accumulation. Their tragedy led to safety improvements that now make such accidents far less likely.

So I started dressing as if I were going outside in winter. There's something incongruous about pulling on a wool sweater to get into water; a wet suit would have felt more natural. But putting on a wet suit would've been silly. The only scenario in which I'd touch seawater half a mile deep in the ocean would be if the hull breached. And if the hull breached, I wouldn't live long enough to know it had happened.

Properly attired, I joined the crew at the submersible on the back deck of the ship. Frank (the extra pilot) and I (the extra scientist) climbed into the coffin and sealed ourselves in. From our confined space, we had no ability to drive, steer, or gather samples. We were just there to observe, advise—and perhaps save everyone's lives: Frank explained to me that if the three other people were "incapacitated," I should follow a protocol to drop external weights and the submersible would bob to the surface like a beach ball. I paid close attention. I didn't want to be the graduate student who killed everyone at the seafloor because she couldn't remember which switches to flip.

A moment later, I experienced the sensation of being lifted off the deck of the ship by the powerful A-frame winch and gently nestled into the ocean, where the submersible started bobbing fitfully. After the final checks, the main pilot released air ballast and we began our descent by freefall through the ocean. Frank, who was lying head-to-toe with me, announced that he was going to sleep and wished me a nice dive. I couldn't imagine sleeping. I was wired.

The thing that you should know about the oceans is that they are not empty. Sure, there are fish and whales and sea turtles—but I'm referring to the fact that every *inch* of the ocean is packed with invertebrates and other bits of floating goo. When you're free-falling through the ocean, all this schmutz bioluminesces—it glows—when your submersible hits it. The coffin had one porthole on each side. The one on my side was in between my shoulder and my chin—perfect for viewing the glittering ocean as long as I ignored the growing crick in my neck. Sparkly lights shot by, with the occasional crescendo of blue, red, and purple zipping through a long, segmented body. I could have hung out in the dark pelagic zone for hours, happy as a clam, just staring at the beauty.

The main pilot soon slowed to neutral buoyancy to prevent us from slamming into the seafloor. I had finally arrived at the place I had been researching for six years but had never actually visited. It was desolate. Somehow this made me like it even more. Two-thirds of the Earth is covered by oceans, and yet the seafloor remains largely unseen by humans. Chances are slim that anyone else will ever visit the exact area that I found myself in that day. It felt like I was looking at the truth.

While the folks up front discussed how to travel from where we landed to where we wanted to be, I was surprised to discover that there was more going on at the seafloor than I had anticipated. I watched as a deep-sea crab decided to go to war with us: it held up tiny menacing claws and stood stock-still, ready to destroy us. A bright purple jellyfish floated by, and long, slithery fish scurried along the seafloor, searching for invertebrates to munch. But my favorite animals were the holothurians, or sea cucumbers. These creatures are passive, hollow tubes, roughly the size of two bananas laid end to end, and just as charismatic. All they do, day in and day out, is suck mud through one end of their bodies and push it out the other. They wipe the nutritious bits of organic matter from the mud and then deposit pristine beach sand out of their butts.

While I was admiring these deep-sea Roombas, the other crew members were carefully navigating the landscape. At the bottom of the sea, there are two main challenges when it comes to finding one's way around. First, because the ocean drowns satellite signals as effectively as it drowns people, there is no GPS. Instead, we improvise our own X-Y grid system by sending acoustic "pings" between the submersible and the ship. These pings tell us our depth and angle from the ship, and the Pythagorean theorem does the rest. Second, the lights on the submersible are no match for the darkness of the sea, so it's impossible to view the whole landscape. We'd only see an underwater mountain if we were about to run into it. Sonar can help avoid major catastrophes, but there's no solution for the problem of being just a few meters away from the desired site and not knowing it. We used the X-Y grid to make our way to the general area, but then we had to nose around like a wobbly beetle until we found the spot.

Our target that day was a cold methane seep, where ancient, deeply buried methane burbles up to the seafloor through cracks caused by movements of tectonic plates or geological scouring.

In our normal lives, methane is the natural gas we use to heat our houses, but at the seafloor, it's "manna from heaven" (or perhaps, more accurately, "manna from hell"). Methane is a highly energetic food in what is otherwise a desert, so life crams around it like antelopes at a savanna watering hole. The animals here don't eat the methane, but they eat the microbes (tiny, single-celled organisms that include the bacteria) that do. So, although you can't see methane in water unless there's so much of it that it forms bubbles, you can tell when you're nearing a methane seep because they are jam-packed with clams, mussels, crabs, shrimp, fish, sea anemones, and creepy, otherworldly worms.

As I lay in the submersible, craning my neck to watch the seafloor go by my awkward porthole, I started to see bits of broken shells and eventually whole, live mussels packed tight and sticking out of the muck. Crabs were crawling across the mussels, picking off filamentous tendrils of bacteria and invertebrates to eat. Soon, every place that wasn't covered in mussels was carpeted with bright white mats of Beggiatoa—bacteria that transform stinky sulfide into pearls of pure elemental sulfur. We had arrived at the methane seep! We stopped the submersible and began our work.

I had spent the previous evening hose-clamping metal T-shaped handles to cylindrical plastic core tubes to make them compatible with the robotic grippers on the front of the submersible. To keep the cores from floating away while we descended, we strapped them onto milk crates on the front of the submersible with rubber bands, which the robotic arm was able to break when it picked up the tube. Low-tech workarounds like these are a mainstay of scientific exploration—when you're doing something that very few people do, you can't just buy the equipment you need, prefabricated, from a store shelf. The main pilot used the submersible's robotic arm to pick up the core tubes, punch cores of dark black mud, and retrieve them back into the milk crates.

While the work was going on, I lay in my little coffin, occasionally conferring with the main scientist about where we should take cores. After about eight hours, the main pilot dropped the weights, and we started our half-hour ascent.

The reason I was so eager to take this perilous journey, and the reason I immediately began plotting ways to return, is that I was searching for the answer to a question that had been gnawing at me for a long while: *Are there life-forms hiding inside Earth that are so strange that they change our conception of life itself?* Let's explore this question, shall we?

The Intraterrestrials

For much of my life, I have been tracking the strange types of microbes that live at the bottom of the oceans, inside volcanoes, and deep within the Arctic permafrost, in an attempt to answer this great driving question about hidden life on Earth. From my efforts and those of other scientists like me, we have learned that life can even exist kilometers under the seafloor, way deeper than you can get to by submersible. In fact, we have not yet encountered a depth at which life ceases to exist. And most of this subsurface life is entirely unlike anything we find at the surface: against all odds, it seems that Earth's subsurface may be a nice place to live, as long as you aren't too attached to multicellularity or oxygen. Luckily for us humans, these tiny life-forms promise to unlock some of the most important mysteries of life: they might tell us how life first developed on this planet, change our basic assumptions about the rules of life, even upend our understanding of what it means to be alive. As a bonus, they might save us from our self-destructive tendencies by helping alleviate the effects of climate change.

The biogeochemist Karsten Pedersen coined the term "intraterrestrials" to describe this abundant life within Earth's crust.[1] "Intra" means inside, and "terrestrial" means "of Earth," so intraterrestrial literally means an inhabitant inside the Earth. I like this word because it mirrors the term "extraterrestrial," which conveys some sense of the alien nature of these new life-forms. Now, I don't want to diminish the importance of finding new *animals*—new species of monkeys are thrilling. But the major categories of visible life on Earth are pretty much settled. The discoveries we're making within the Earth's crust are like finding the existence of *all* animals, many tens of times over, based on the evolutionary novelty of these organisms relative to previously known life. This ongoing discovery, which started in the late 1980s, is gradually revealing that we have been missing major branches on the tree of life.[2]

Part of the reason these creatures are so different from previously known life is that, although we share a planet with them, we inhabit vastly different worlds. David Valentine, another biogeochemist, has aptly described the "microbial purgatory deep below Earth's surface," in which these single-celled organisms thrive: "Bounded from below by the inhospitable temperature of Earth's interior, intraterrestrials face a chronic limitation of food-derived energy because they are far removed from sunlight-driven productivity."[3] Once we begin to peer downward past our feet into the deep, dark recesses of Earth's crust and oceans, a new world emerges. This new world raises a host of questions, such as: Without the sun, where do these creatures get energy? Without oxygen, what do they breathe? And how long, exactly, can any organism survive in harsh environments, where pH ranges from pure acid to pure alkaline? The answers to these questions—they get energy from chemical reactions, breathe rocks, and sometimes live for thousands or perhaps millions of years—will demonstrate that our assumptions about the boundaries of life, based on our narrow experience of living in the thin green layer at Earth's surface, are often wrong.

Our journey to understand these creatures will be divided into three sections. In part I of this book, I will describe what this subsurface habitat is like, how we exhume living beings from it, and how we use DNA sequencing to "see" these microscopic beings. In part II, I will describe how these intraterrestrials have changed what we know about the evolutionary relationships among all life on Earth, how they are able to thrive in previously unthinkable environmental conditions, and how they play with thermodynamics* in ways that are totally foreign to life on Earth's surface. In part III, I will suggest that intraterrestrials skew how life interacts with time itself, give us new perspectives on life's origins, and maybe, if we play our cards right, can help us with climate change. Finally, I'll imagine what life will be like a thousand years into the future, perhaps on other planetary bodies, based on the expanded vision shown to us by the intraterrestrials.

The journey we take in this book will not merely be one of intellectual awakening. My goal is not just to explain what we've discovered about these new life-forms, but also to describe *how* we've made these discoveries. To collect samples and conduct the research described in this book, I've chased intraterrestrials to the ends of the Earth, and I want to take you with me—to Argentina's desolate altiplano; to the frozen Arctic tundra of

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* I find the Wikipedia definition to be quite complete: "Thermodynamics is a branch of physics that deals with heat, work, and temperature, and their relation to energy, entropy, and the physical properties of matter and radiation" (https://en.wikipedia.org/wiki/Thermodynamics).

Svalbard; to the bottom of an active volcano in Costa Rica; to the muddy coastline of North Carolina; and, of course, to the bottom of the ocean.

Researching intraterrestrials involves long hours at a lab bench processing samples and at a computer analyzing data. But it also involves crawling on one's belly through spiders and bat guano, donning a mask to survive toxic fumes, and spending weeks or months in remote locations that test the limits of one's physiology. The mind-bending discoveries I describe in this book would simply not be possible without the hardships and triumphs of fieldwork. So, put on your diving clothes and climb into the coffin: we're about to embark on a journey to the depths of the Earth.

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