UNFATHOMABLE

THOUGH IT'S THE LARGEST ECOSYSTEM ON EARTH, WE KNOW LESS ABOUT THE DEEP OCEAN THAN THE SURFACE OF THE MOON. AS THE THREAT OF MINING LOOMS, WILL ITS FATE BE DECIDED BEFORE WE KNOW ENOUGH TO MAKE SUCH A FAR-REACHING CHOICE?

BY **LESLIE ANTHONY**
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FIRST COME THE PILLOW lavas, plumped in irregular rows and fissured by time. Then heaps of crumbled rock, geologic edifices no longer there. Finally, a narrow tower, rust-coloured and looming like a medieval fort, parapets hung with wispy banners.

As we draw closer, the streamers become tangles of microbial filaments. Arrayed on the tower, other organisms come into focus, each fan, polyp, stalk and antenna a lifeform more ethereal than the next. Fish flutter like ghosts at the edge of illumination, their size impossible to judge. Ditto a bottom-dwelling comb jelly resembling a pair of fluorescent pink lungs. Above it all, like stars in the firmament, pinprick creatures float white against an inky backdrop, gobbling the dross rising from this alien industry.

A vignette both harsh and phantasmagorical, this is but a tiny slice of the largest part of the planet on which we dwell: the deep ocean.

Defined as the volume of water below 200 metres, beyond which sunlight is insufficient for photosynthesis, "the deep" — as referenced by generations of mariners — comprises some 70 per cent of Earth's surface and 90 per cent of its ocean volume. Between 200 and 1,000 metres, where scatterings of light infiltrate, lies the twilight zone; from 1,000 to 4,000 metres, the midnight zone, chilling at a constant 4 C; from around 4,000 to 6,000 metres (three-quarters of the deep seabed), the near-freezing abyssal zone; and finally, from 6,000 to 11,000 metres, the hadal zone, where pressure reaches a crushing 1,100 atmospheres (1,100 times the Earth's surface pressure — about 7 tonnes psi for those who think in tire pressure).

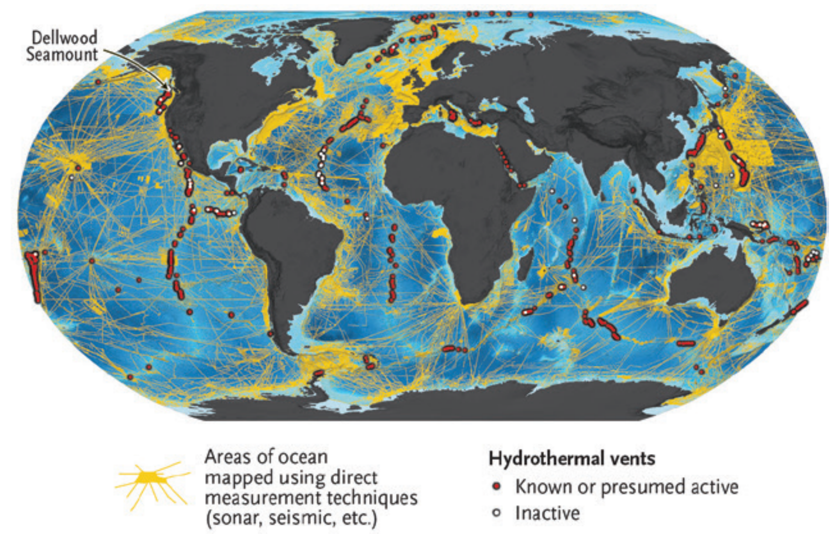
Surviving such conditions requires an array of astounding adaptations, from soft bodies to bioluminescence to pressure-resisting cell chemistry to enormous mouths that vacuum blindly through the gloom. Encountering any of these creatures, even on film, is startling; they resemble gargoyles, ghouls and goblins more than the sea life we're used to. (Cue David Attenborough: *The giant squid: a near-mythical monster that lives in the deep ocean. Other creatures are so strange and bizarre they could come from a nightmare, while some dazzle us with their lights and colours…*)

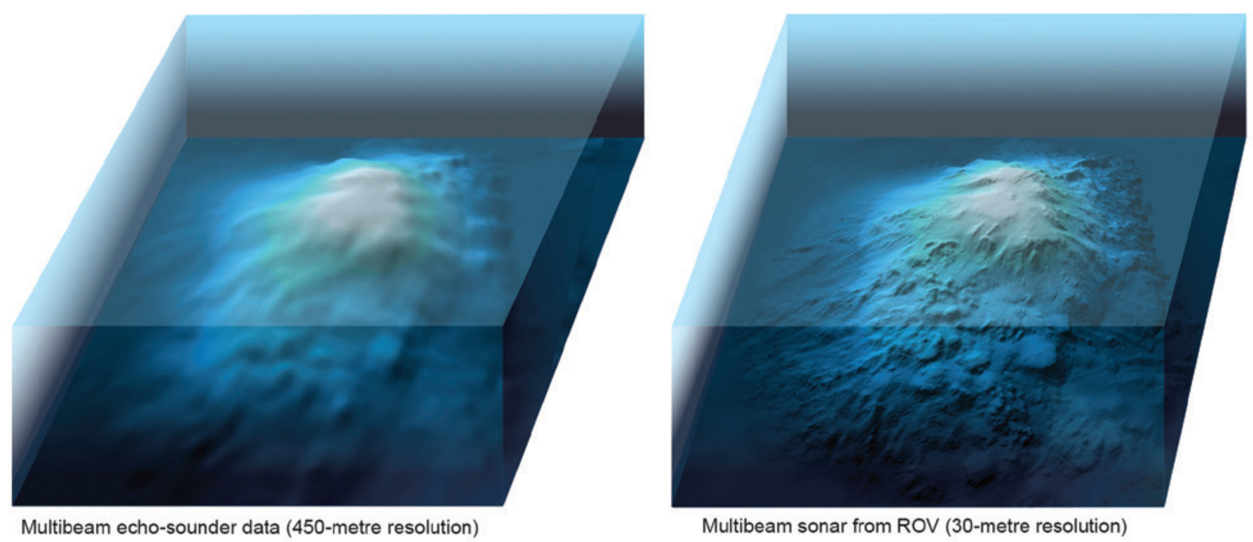
As the world's most continuous single environment, the deep ocean is also its largest ecosystem — yet the one we know least about. Only a small percentage is mapped at any informative resolution, and less than five per cent has had human eyes on it. Which is why — 1,547 metres below the surface on the edge of a large volcanic caldera in the Galápagos Archipelago — we're staring at a rocky tower no person has ever seen.

SPOILER ALERT: no one is *literally* on the sea bottom. But we're all figuratively here, courtesy of a live camera feed from a remotely operated vehicle known as ROV SuBastian. It's being deployed from Schmidt Ocean Institute's research vessel *Falkor (too)*, whose latest expedition is testing new technology for ultra-fine-scale seafloor mapping. On board the ship is an international team led by a mostly Canadian mix of oceanographers, geologists, ecologists and biologists alongside skilled operators controlling SuBastian and other high-tech toys.

While the scientists float somewhere above SuBastian, most of us are scattered around the globe, following on YouTube. Here, in a lively chat, are deep sea aficionados of every description, from professors to graduate students to plain ol' Neptune nerds, some of whom woke up in the middle of the night to sit through this nine-hour dive — the ultimate binge watch. I may have joined for journalistic reasons, but after hours staring into the literal abyss, I too am mesmerized by this descent into the unknown, which seems the purest form of exploration on such a well-trod planet. I'm also enjoying the encyclopedic knowledge of my virtual companions; no sooner does a bizarrely spiked white sea cucumber appear than someone notes it must belong to the genus *Oneirophanta*.

"It's so amazing that technology allows people to join in a communal voyage of discovery," says expedition member Cherisse Du Preez, a spatial ecologist with Fisheries and Oceans Canada. "Schoolkids whose class tuned in can say to





DELLWOOD SEAMOUNT

Dellwood Seamount is in the proposed Tang.ɢwan – ḥačxʷiqak – Tsigis marine protected area off the west coast of Vancouver Island.

MAP: CHRIS BRACKLEY/CAN GEO; DATA: OCEANS MAP: INTERRIDGE VENTS DATABASE VERSION 3.3; INTERACTIVE MAP PRODUCED BY S. BEAULIEU, WOODS HOLE OCEANOGRAPHIC INSTITUTION, 2015; GLOBAL MAP: NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION, 2022; DELLWOOD SEAMOUNT: MULTIBEAM ECHO-SOUNDER DATA (450M RESOLUTION): GEBCO COMPILATION GROUP (2023) GEBCO 2023 GRID; MULTIBEAM SONAR FROM ROV (30M RESOLUTION), 2022: PROCESSED ACOUSTIC BACKSCATTER, SIDESCAN AND SWATH BATHYMETRY DATA FROM THE NORTH PACIFIC OCEAN ACQUIRED DURING E/V NAUTILUS EXPEDITION NA097 (2018).

each other 'remember when we saw *that* animal?' I love when people talk about the *we* of discovery... They're taking ownership of the deep sea, making that important connection."

Back at the tower, a rock sample snapped off by SuBastian's manipulator arm almost disintegrates en route to the sample bin. That's because this formation is actually an "extinct" hydrothermal vent, the polymetallic sulphides comprising it rendered friable by the volcanic gases and magma-heated waters (up to 400 C) that deposited them. Shells from once-living mussels at the tower's base suggest to one biologist that this tap may have turned off only recently — perhaps less than five years ago. Such rapid changeover — from an active vent ecosystem based on one set of microorganisms and dominated by mussels, worms, crabs and predatory fish, to an inactive vent ecosystem based on *entirely different* microbes and dominated by corals, sponges and arthropod scavengers — shows just how dynamic the seafloor environment is.

And how vulnerable, since inactive vents, found in undersea volcanic zones the world over, are one of three targets in the emerging and controversial frontier of deepsea mining.

The mere *prospect* of deepsea mining has triggered unprecedented interest and activity in the deep ocean, turbocharging climate research, mining impact studies, high-tech biodiversity work, and mapping efforts (there's a drive to map the entire seabed in high resolution by 2030).

"We're at a point in history right now where the world is going to have to make some really big decisions. Not just the scientists, not just the policymakers, but people in general," says Du Preez. "It's so important to come out here on expeditions like this to gather the science so that all decisions are informed."

So, deepsea vents are a good starting point to explore what we know about the deep, what we're learning — and what we stand to lose should mining actually begin.

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A LONG-HELD SUSPICION that the ocean's deepest parts could not support life was convincingly dispelled by HMS *Challenger*, which dredged up a litany of strange creatures during its global marine-research expedition of 1872-1876. Notably, in 1875, *Challenger* found the Mariana Trench, in which the current deepest-known point on Earth's surface — known as Challenger Deep, 10,984 metres below sea level — resides. As well as record bathymetry (a potentially deeper nearby point of 11,034 metres awaits confirmation), the trench has been measured at 2,550 kilometres long and 69 kilometres wide — a lot of water for a small sliver of ocean. Yet despite knowledge of the deep's vastness and wide-eyed encounters with its oddest denizens, it took another century before we had an inkling of how such a sun-starved ecosystem might exist.

That dawning occurred when the first deepsea hydrothermal vent was discovered in 1977 — also in the Galápagos — by an expedition that included famed submersible pilot Robert Ballard, who'd go on to locate *Titanic* in 1985. Shattering our biogeochemical naiveté, vents quickly became a poster child for the wonders of the deep. What Ballard and cohorts saw in the darkness — a chimney adorned in a riot of previously unknown life dominated by giant, red-feathered tubeworms taller than a person — defied explanation save for the shimmer of water exiting its top. Packed with dissolved minerals from the crust of the earth, the scalding fluid proved to be fuel for heat-loving bacteria and archaea that used its energy to fix carbon and produce organic molecules by oxidizing compounds like hydrogen sulfide, a process called chemosynthesis (unlike photosynthesis, in which production of organic molecules is powered by light).

As more vents were discovered, two things became clear. First, they were diverse, including not only relatively short-lived black-smokers and white-smokers — so-called for their respectively coloured precipitates when superheated waters hit icy ocean — but also more stable, long-lasting cold seeps, whose water is closer in temperature to the surrounding ocean. Second, though each vent differed slightly from the next — even from neighbours — all supported unique chemosynthetic ecosystems. The result is an unheralded biodiversity of microbes, meiofauna (invertebrates larger

than microfauna but smaller than macrofauna) and macro-organisms. Though each was an island unto itself, vents collectively produced enough energy for an entire bottom-up ecosystem connected to, but not reliant on, the more familiar photosynthetic machinery above.

"We've always thought of hydrothermal vents as being sort of 'over there' — their own isolated ecosystems. But they also turn out to be food sources and nurseries for wider-ranging creatures," says Du Preez, who collected eggs from a vent-area Pacific white skate nursery on the Galápagos trip for DNA work to determine whether gene flow exists between that location and another nursery recently discovered off Canada's west coast.

The Pacific white skate is a charismatic giant up to two metres across, living as deep as 2,900 metres. "It resembles shallow-water skate species, so people can relate to it," says Du Preez.

On a research cruise south of Haida Gwaii in summer 2023, skates were found laying eggs atop a seamount 1,500 metres below the surface. "There was also a coral garden there, so we stopped the sub, grabbed the temperature probe and found hot water coming out of the volcano," says Du Preez. The energy source explained the existence of this deep oasis, and a back-of-the-envelope calculation suggested there might be up to five million skate eggs there — in a prime fishing area. "You need science and serious justification to carve parts away from people's fishing grounds, so finding a nursery is important. It's totally unique and clearly needs protection," she says.

As it turns out, hydrothermal vents don't just provide habitat and nutrients for ocean life, but also a range of ecosystem services — from marine genetic resources used in medicine and industry, to fixing and sequestering deepsea CO_2 as organic carbon, to cycling nutrients like iron, sulphur and nitrogen up from the depths. By helping regulate ocean chemistry, vents likely also have a role in regulating climate and even fish populations. "There's not even two degrees of separation between you and the health of the deep ocean," notes Du Preez.

> "There's not even two degrees of separation **BETWEEN YOU** and the health of **THE DEEP OCEAN**."

IT HAS TAKEN A WHILE for the world to wrap its head around this new realm of life, if it has at all. Thriving communities of microbial "extremophiles" that survive both freezing and scalding waters, perpetual darkness, high pressure and toxic chemicals revolutionized our understanding of how and where life can exist. Do these chemosynthetic crucibles hold answers to the question of life's origin on Earth? Do they suggest how life might survive on less hospitable planets? Absolutely, say scientists, though they also raise more earthly considerations: if thousands of hydrothermal vents are spewing hot fluids into the world's oceans, where does the water come from?

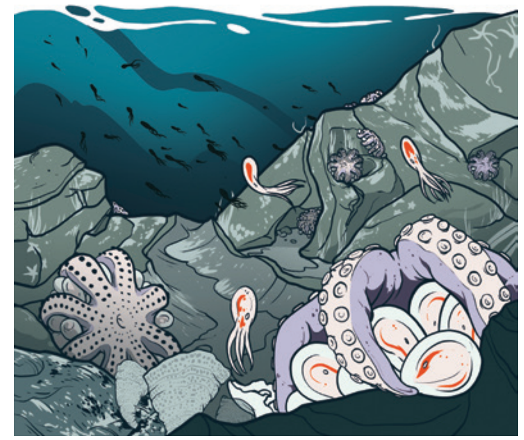
Questions of seabed plumbing often land on the desk of University of Calgary marine hydrogeologist Rachel Lauer. "My PhD is in a field that exists for like four people on the planet," she quips. Lauer began her career studying how fluid dynamics in oceanic subduction zones might influence earthquakes, before teaming up with microbiologists who needed her geophysics savvy to understand fluid flux with respect to microbes in the Earth's crust. "In oceanic hydrothermal circulation, cold, dense water is pulled into recharge sites and flows below the seafloor," she explains. "Discharge sites release warmer, less-dense water. The difference in density sets up a pressure gradient that drives the process."

This system accounts for a astonishing 18-20 per cent of global heat loss from the Earth. Like a radiator, this crustal reservoir of water is recycled every 1,000 to 10,000 years, with the entire ocean recycled every 100,000 to 500,000 years. Though these seem hefty time spans, "they're like a week to a geologist," says Lauer.

Studying anything on the ocean bottom virtually guarantees surprises. In 2013, some 3,000 metres below the surface off Costa Rica, Lauer and other geologists were using an ROV to look at fluid discharge when they unexpectedly observed around 100 octopuses brooding eggs in the rocks around the vent. Scientists returned the next year in the submersible *Alvin* to have a closer look. After studying expedition video, biologists hypothesized the animals had blundered by placing eggs in warm seeps, where heat stress and low oxygen could kill them.

But it was only a hypothesis, and someone needed to actually look at the eggs. In June 2023, Lauer had a chance to return to the site. Not only did the eggs turn out to be viable, but double the number of adults were seen — a veritable octopus garden. The vent water (10 C warmer than the 2 C ocean) was acting as an incubator to speed egg development, "like a maternity spa," says Lauer.

Ultimately, Lauer hopes to collaborate with more biologists and use geophysics to determine why certain species are found on particular outcrops or seamounts or use a species' biology to predict hydrothermal regimens — biogeographic reverse engineering. "My entire focus pivoted as a result of this trip — I've never been so passionate about a project. By bringing disciplines together, maybe we can predict where other [biodiversity] hotspots might be to help us better steward our ocean — before we start thinking about destroying it."



SEAMOUNTS are volcanic mountains rising from the seafloor. The title requires that they be at least 1,000 metres high — the size detectable by orbiting satellites measuring anomalies on the ocean's surface, which bulges up and down with gravity. Outcrops — seafloor volcanoes under 1,000 metres where fluids more often pour out — are undetected by this method of mapping, yet they're of utmost importance to our understanding of the seabed. How to locate them?

While satellite mapping has covered all of the world's oceans, it remains a coarse methodology (oceanographers have wryly noted we have more detailed maps of the moon). Vessel-mounted multibeam sonar gives a better picture, resolving features with an accuracy of 15 to 50 metres — but much of the ocean is deeper than that. ROV-mounted multibeam sonar offers a huge improvement of scale, and the tech tested on Du Preez's recent Galápagos expedition is an order of magnitude better still. The latter two in tandem yield maps with millimetre-level resolution that can reveal individual organisms and, thus, ecosystem information. This can help track human impacts to the seafloor environment. "Our mapping was such high resolution we actually discovered some hydrothermal vents that led to new animal finds," says Du Preez, referring to 15 species not previously recorded from the region, including a "living fossil" mollusc known as a monoplacophoran.

Like any modern deepsea explorer, Du Preez relies heavily on ROVs to map and characterize complex 3D environments. With her work for Fisheries and Oceans Canada focused on the establishment and monitoring of marine protected areas around hydrothermal vents, seamounts, cold seeps and other biodiversity hotspots off Canada's Pacific coast, Du Preez's research program has discovered 45 seamounts — "Rocky Mountain kinds of features we had no idea were in our waters," as she puts it. Despite this, she notes, when it comes to the deep sea, Canada is quite dialled in. "It has the world's first MPA for hydrothermal vents, and some of the first for seamounts." But if a country that's actually paying attention didn't know about all these mountains and seeps and nurseries off its coast, says Du Preez, what do other less science-focused countries know? "And how little is known of the high seas *beyond* territorial waters?"

Du Preez has also aligned her research on marine protected areas with commitments to the co-creation of knowledge with Indigenous Peoples, as well as cooperative management and monitoring — initiatives that converge in the proposed **Tang.ɢ̱wan – ḥačxʷiqak – Tsig̱is** marine protected area, an enormous 133,019 square-kilometre area west of Vancouver Island and Haida Gwaii that accounts for 2.31 per cent of Canada's ocean territory. Identified for consideration as an area of interest in 2017 as a cooperative venture between Canada, the Haida Nation, the Nuu-chah-nulth Tribal Council, the Pacheedaht First Nation and the Quatsino First Nation, it was formally announced at a major marine-protection conference in Vancouver in 2022.

"All known hydrothermal vents in Canadian waters — some 35 fields — are included in it," says Du Preez, "and over 80 per cent of seamounts. The ones not included are all too deep to be impacted directly by human activity — with the exception of the [skate nursery] seamount from last summer that might be one of the country's most important."

Rayne Boyko, a marine planner with the Haida Nation who joined last summer's cruise with Du Preez,

anticipates an official joint designation announcement sometime in 2024. "These habitats are sensitive and fragile," she begins, the experience of watching deepsea magic appear on a control-room screen lingering in her voice. "The longer these habitats are in a safe state, the more they'll produce spillover effects for unprotected areas. That's the goal; that's what we want," she says, eschewing the creation of many smaller marine protected areas in favour of protecting large swathes that can provide sanctuary from trawling, long-lining, pollution and other threats.

For Boyko, the expedition was a personal eye-opener, the kind that makes you re-evaluate your personal path in the world. "It strengthened my own connection to the deep sea and inspired me to work harder," she says. "It's up to those of us capable of establishing MPAs and enforcing protection from external forces to make sure we do so."

IF YOU'VE SENSED a subtle angst being shared by the marine science and conservation communities, you're correct: something is coming that instills fear for an ocean already reeling from overfishing, plastic pollution and climate-induced warming and acidification. That something is deepsea mining.

On its celebrated tour of the world's oceans, HMS *Challenger* consistently dredged up dark, fist-sized rocks from the extensive, sediment-laden plains of the abyssal zone. These were polymetallic nodules, concretions of iron and manganese formed over millions of years, also high in other commercially valuable metals like nickel, copper and cobalt. A 1981 estimate put the total oceanic stash at 500 billion tons. Occurring in a largely inaccessible place and containing metals available more cheaply on land, few thought seriously about nodules until the past few decades. Now deepsea mining keeners insist these deposits will meet growing demand for critical minerals — particularly those needed for digital and clean-energy tech such as electric-vehicle batteries, wind turbines and solar panels. Cobalt crusts on the slopes of seamounts that similarly take millions of years to form, along with mineral-rich inactive hydrothermal vents, are also threatened.

It's the **UNFATHOMABLE** time frames and wonder of the **DEEP OCEAN** that most inspire a desire to protect it.

The sales pitch from deepsea mining interests is that extracting critical minerals from the seabed will help negate potential shortages, reduce what they describe as the demonstrably worse impacts of terrestrial mining, and cut greenhouse gas emissions. Critics, however, have a potent counterargument: the almost complete lack of knowledge of seabed ecosystems means an inability to predict impacts to marine life reliant on nodules, seamounts and vent structures — most of which is still unknown to science. A recent meta-study that analyzed DNA from almost 1,700 sediment samples collected globally revealed deep-seabed biodiversity up to three times that of the waters above it, with 60 per cent of total organisms previously unknown lifeforms. Some of these creatures may function within the biological carbon pump — the life-driven sequestration of carbon to the ocean interior and seafloor that helps regulate climate.

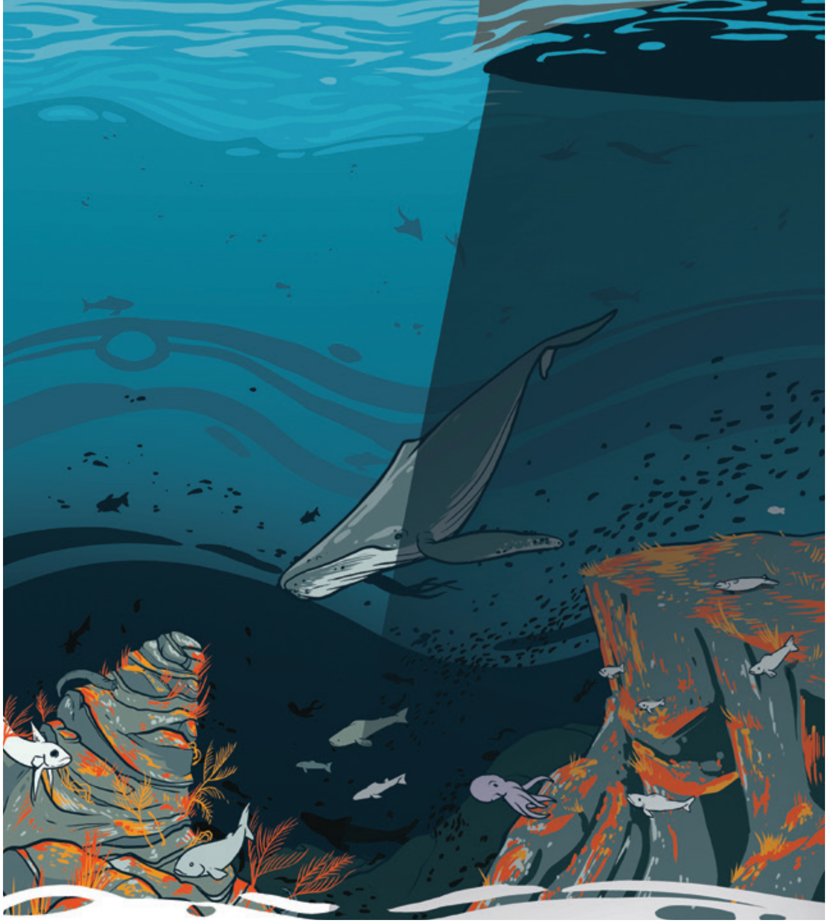
While it's acknowledged on both sides that the direct impact of massive robotic mining vehicles vacuuming up nodules, grinding down vents and stripping seamount crusts will result in 100 per cent mortality for organisms on those structures (in one impact study, an area test-mined in 1978 still hadn't recovered after 37 years), the extent to which sediment plumes stirred by these activities will also damage habitats, interfere with nutrient cycling and cause oxygen depletion over wider areas is hotly debated. "Most of the fluid circulation that creates mineral deposits is adjacent to seamounts, so that's where the mining opportunities are," says Rachel Lauer. "But the idea that 'what happens there stays there' is ludicrous to oceanographers."

Opponents of deepsea mining — whose lengthy list includes conservationists, scientists, oceanographers, nation states, Indigenous Peoples and civil society — have called for a ban, or at least postponement until impacts are better understood and regulations put in place by the UN-backed International Seabed Authority. Though some 22 countries have now called for a precautionary pause (Canada took a strong moratorium position in July 2023), a pause seems unlikely given that the International Seabed Authority's mandate requires it to ultimately be financed by royalties from mining contracts — 31 of which have already been granted for exploratory purposes. So, the fact that the authority's very existence depends on deepsea mining appears to conflict with its other mandated obligation to protect the marine environment.

Which brings us to the very visible campaign by The Metals Company, the Vancouver-based holder of three International Seabed Authority exploration permits located in the mid-Pacific's Clarion-Clipperton Zone sponsored, one each, by the Pacific nations of Tonga, Nauru and Kiribati. The company's website shills deepsea mining as humankind's existential saviour from the climate crisis — and economic salvation for sponsoring nations. Greenwashing a clearly impactive resource industry isn't new but has perhaps never been as cleverly crafted — nor so fortuitously enabled, given an emerging real-world demand for EVs and renewable energy.

While The Metals Company is funding, to the tune of $100 million, a range of basic research it claims as "independent," we have seen this before. Conducted independently or not, there's always the danger of research designed to deliver the answers you want, echoing the policy-based science making versus science-based policymaking practised by governments and industries like Big Tobacco, Big Oil, Big Fish, etc.

An investigative 2022 *New York Times* piece on deepsea mining — "Secret Data, Tiny Islands and a Quest for Treasure on the Ocean Floor" — was an instant cause célèbre for the anti-mining movement, a scathing indictment of secretive dealings between the International Seabed Authority and mining companies, particularly The Metals Company, that quoted several employees who'd abandoned the organization over



ethical breaches. Among its numerous transgressions, members of one of the authority's top policy bodies also work for mining contractors, a five-alarm conflict of interest.

For his part, The Metals Company's flashy CEO Gerard Barron — who once conjured pre-*Challenger* ignorance by referring to abyssal plains as barren deserts — dismissed the criticism to the *New York Times*, responding that his company's undertaking is of utmost importance to the planet's future climate health (not to mention stockholders): "This could be one of those projects that could really make a difference — that could really move the needle," reads his quote.

But there's a fine margin between moving the needle and pricking your finger.

IT'S THE VASTNESS, unfathomable time frames and wonder associated with the deep ocean that most inspire a desire to protect it. "The idea that we're on the precipice of doing something to an environment that may take millions of years to recover from is motivating," says Lauer. "Especially given the huge impact we've already had on the ocean."

Rayne Boyko grew up surrounded by the sea but was still viscerally moved by her deep-ocean experience. At a cold seep where they saw basket stars, red king crabs and small octopuses sitting upside down on their eggs, the scene was "like a children's colouring book." On another seamount dive, the ROV dropped directly onto the skeleton of a whale. "Animals use seamounts for many reasons," she says. "There are actually old Haida stories about whales using places far out to sea as resting places. With all the other creatures and sea life down there, it was all very beautiful and emotional."

Countless other stories connect the deep to life on land, and Boyko believes Canada's conservation efforts are heading in the right direction by embracing the rich culture and history of coastal First Nations. Sharing stories may not involve a front-row seat on an ROV dive, but it can just as easily breathe life into an important relationship.