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Exploring the Hidden Face of Our Dark Deep Ocean Planet

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When we see images of our blue planet from space, it's easy to grasp how oceans cover 71 percent of the world. But what those images can't show us is how deep those oceans are. The Sun's rays are completely quenched by the top 1000 metres of the ocean, and the deepest point in the ocean lies nearly 11 kilometres down. Not all of the ocean is that deep, of course, so to grasp the reality of our world, we can look at a hypsographic curve, which shows the proportions of our planet's solid surface at different heights and depths relative to sea level. From that, we can see that the average depth of the ocean is around 3.4 kilometres -- more than two miles -- deep. Or to look at it another way, although the oceans cover 71 percent of the surface of the Earth, more than half of the solid surface of our world is covered by water more than 3.2 kilometres deep. So most of the surface of our world lies beyond the reach of sunlight -- the blue appearance of our planet from space is just the reflection from a thin veneer, and our world is really a dark deep ocean planet.

Our species perhaps began crossing the oceans at least 40,000 years ago, if we consider the dating of events such as the first human colonisation of Australia. But we only really developed the capability to explore the dark and deep reality of our planet -- its hidden face -- less than two centuries ago. That makes it a great time to be an ocean explorer, and what I would like to share with you is how we explore the oceans today, and some of the discoveries in the deep that have already changed our view of how our planet works; although there is plenty left to explore in the deep ocean, what we now know is as remarkable as the unknown that remains.

Mapping the Deep

The first fundamental step in exploring anything is to make a map of what you are interested in understanding, whether that is the terrain of the deep ocean floor to understand the processes that shape it, or a map of temperatures of deep waters to understand ocean circulation, or a map of what lives where to understand how species disperse and evolve in the deep. And it can be a map of how something changes in time, as well as space, so it's perhaps really a "mapping and monitoring" step. But this is our starting point: the "make a map" step of ocean exploration.

We sometimes hear that "we know more about Mars [or the Moon] than the deep ocean", but that's not really correct. We have more detailed maps of the surfaces of Mars and the Moon, because spacecraft orbiting them can map their terrain directly using radar. But seawater blocks the radio signals of radar, so we can't use the same technique to map the ocean floor directly in detail. But having a more detailed map isn't the same as "knowing more about". The total amount of rock that has been collected and analysed from the Moon to understand its geology is less than 500 kilograms, and the amount of Martian rock ever studied, either by rovers on its surface or from rare chunks of the Red Planet that have broken off and tumbled to Earth as Martian meteorites, is tiny. In contrast, thousands upon thousands times more samples, of rocks, sediments, water, and life, and vast volumes of other data, have been collected from the deep ocean to understand what's going on down there, from the geological processes that shape the ocean floor to the ecological processes that determine its patterns of life. So we really know far, far more about the deep ocean than the Moon or Mars.

Ferdinand Magellan was one of the first people to try to measure the depth of the ocean far from land, when he reached the Pacific with his flotilla in 1521. His crew reportedly joined together all the rope available aboard his ship, which came to a length of about 700 metres, and lowered a cannonball on it beneath their hull. When that cannonball showed no signs of touching the seabed, still swinging on its rope, Magellan declared the ocean to be "immeasurably deep". But of course we now know that he would have needed rather more than 700 metres of rope to reach the seabed, with the average ocean depth of 3.4 kilometres.

Making a map depends on knowing where you are when you make a measurement of whatever you're interested in mapping, so mapping the depths of the ocean floor to reveal its hidden terrain had to wait for improvements in technology for determining a ship's position far from land, such the increasingly accurate marine chronometers developed by John Harrison in the 18th century to help improve measurements of longitude. Armed with such technology, the first oceanographers of the 19th century could start to map the deep, and among them was one of my heroes of early ocean exploration: Matthew Fontaine Maury.

Matthew's older brother joined the US Navy, but died of Yellow Fever in the Service. Against the wishes of their grieving father, Matthew followed his brother into the Navy, and his service at sea included the *USS Vincennes*, which was the first US Navy ship to undertake a circumnavigation of the world. But at the age of 28, Matthew broke his leg in a stagecoach accident, which put an end to his sea-going career. By that time, he had already published a couple of books on navigation and meteorology, so he became superintended of the Navy's Depot of Charts and Instruments, which later became the United States Naval Observatory. In that role, Matthew improved the methods used by US naval vessels to make measurements at sea, and he collated those measurements coming ashore, including measurements of the depths of the ocean floor from sounding lines.

In 1853 he published a map of the ocean floor of the Atlantic, joining the dots of sparse measurements of ocean depths by US Navy ships into contours of a hidden terrain. With each depth measurement providing a pinprick into a vast unknown, his map needed rapid updating as new measurements came in, and in 1854 he produced a revised version, which you can see here, including new measurements of ocean depth north of the Azores made by the *USS Dolphin*. The darker stippled areas of his map indicate shallower seafloor, and this map of 1854 suggests a plateau running north of the Azores, shallower than the ocean basins either side of it. This was the first glimpse of something wonderful and far greater: the mid-ocean ridge, which we'll look at later. At the time, it looked like a promising place to attempt to lay the first trans-Atlantic telegraph cable, so it was named the "Telegraph Plateau" -- the first named feature of our planet's deep-sea landscape, I think.

That first telegraph cable across the ocean was laid in 1858, and although the first connection only lasted a few weeks, it changed the world, perhaps as profoundly as the printing press, with The Times for example exclaiming "The Atlantic is dried up, and we become in reality as well as in wish one country", and the communications revolution wrought by deep-sea cables later inspired a poem by Kipling, which ends: *"Joining hands in the gloom, a league from the last of the sun / Hush! Men talk to-day o'er the waste of the ultimate slime / And a new Word runs between: whispering, 'Let us be one!'"*.

Mapping the ocean floor for the laying of deep-sea telegraph cables was an important catalyst for ocean exploration in the late 19th century, providing an impetus for expeditions such as the round-the-world voyage of *HMS Challenger* from 1872 to 1876, and the expedition of the *USS Tuscarora* across the Pacific in 1873 to 1874. The *Tuscarora* trialled improved technology for measuring ocean depth, in the form of a machine devised by William Thomson -- later Lord Kelvin -- that used piano wire instead of rope. We can perhaps thank John Isaac Hawkins, born in Taunton, Somerset, in 1772, for an unsung yet musical contribution to ocean exploration. Hawkins invented an upright piano that became popular among the growing middle class of the 19th century, and Thomas Jefferson owned one and wrote in its praise. This led to the mass-production of piano wire, making it cheaply available in large quantities for mapping the deep.

But even with one of Thomson's wire-sounding machines and their further refinements, measuring the depth of the ocean by lowering a weighted line beneath a ship was still a laborious business, requiring stopping the ship for several hours just to get one measurement in one location. The next big leap in mapping the deep came with the invention of echosounding in the early 20th century, enabling ships to measure the depth of the ocean floor by bouncing pulses of sound off it, and make measurements almost continuously as the ship steamed ahead. In 1927 the German ship *Meteor* criss-crossed the Atlantic, recording the undulations of the deep seafloor with its echosounder, and revealing that Maury's "Telegraph Plateau" north of the Azores was part of something much larger: a "Mid-Atlantic Ridge" that extended south down the middle of the ocean before turning east towards the Indian Ocean.

So as ships equipped with echosounders plied the seas, 20th century oceanographers started to get much more detailed maps of the ocean floor, such as those pieced together by another of my heroes of ocean exploration, Marie Tharp. Tharp joined the Lamont Doherty Observatory in 1948, and at that time women were not allowed to work on US research ships at sea. So through the 1950s Tharp collated the echosounder traces from ships crossing the ocean to build up much more detailed maps of the ocean floor, culminating in this beautiful map of the global ocean floor, known as "The Floor Of The Ocean", which she produced with her colleague Bruce Heezen and artist Henrich Berann.

Today, we have maps of the entire ocean floor at around a 5 kilometre level of detail thanks to satellites, rather than sonar from ships. Although radar from satellites can measure the depth of the ocean floor directly, because seawater blocks those radio waves, satellites can measure bumps and dips in the surface of the sea in great detail. And with enough measurements, and a lot of maths, oceanographers can subtract the effects of winds and tides to see the bumps and dips that result from tiny local variations in gravity.

Where there is a mountain on the seafloor, the increased local gravity from its mass pulls the seawater into a tiny bump above it. Similarly, where there is a deep ocean trench, the mass of the solid Earth is further from the sea surface, so there's a dip in the sea surface from the slightly weaker local gravity. Reading these subtle undulations in the sea surface to deduce the landscape of the ocean floor below is an astonishing feat, but it gives us a map of 100 percent of the ocean floor, albeit only at a coarse level of detail -- we can't see features smaller than about 5 kilometres across on that map, so some undersea mountains, and features such as craters, are not revealed on it.

Today we also use sonar on ships to map the ocean floor, in a refinement of earlier echosounding techniques that now map wider strips of seafloor beneath ships as they steam ahead. These "multibeam" sonars from ships can map the seafloor to around a 100 metre level of detail, and the total area of the ocean floor that has now been mapped to that level of detail from ships is around 15 percent. That level of detail is similar to the maps we have for the entire Martian surface.

To make much more detailed maps of the seabed, revealing features just a couple of metres across or smaller, we need to take our sonars closer to the ocean floor on underwater vehicles, and the total area that has been mapped to that level of detail is around one two-hundredth of one percent. But these areas that have been mapped in more detail are growing all the time, with modern research ships are out there every day. So if you hear that the oceans are "only 5 percent explored", or "95 percent unexplored", that really is nonsense, because what do we mean by "explored"? If we mean "mapped", in terms of seafloor terrain, then we have a map of 100 percent of the ocean floor, but not in much detail. And at the highest possible level of detail, it's much less than 5 percent mapped.

Investigating Anomalies

Exploring starts with making a map, but that's only the first step. Maps reveal things that don't fit with our current understanding of how something works: for example, a vast a rift in the seafloor in the middle of the ocean, or a mysterious patch of warm water in the otherwise chilly ocean depths, or an astonishingly lush colony of animals where there's not supposed to be much food on the ocean floor. Maps reveal anomalies that challenge our understanding, so the next step in exploring the ocean is to investigate those anomalies, and thereby improve our understanding of what's going on and how the oceans work.

The "investigate the anomalies" step of ocean exploration often involves getting out there with a research ship to visit the anomalies on our maps, and sometimes diving into the deep ocean, so that we can make new observations and make more detailed measurements to test our possible explanations of what might be going on. When it comes to sending people into the deep ocean to investigate it close-up, the first "bathynauts" were William Beebe and Otis Barton, who eventually dived to 923 metres deep in their bathysphere in the early 1930s. There was then something of an "inner space race" to take people to greater depths in the ocean, and lack of time requires me to gloss over the details of that story here, but it culminated in Jacques Piccard and Don Walsh reaching the deepest point in the ocean -- the "Challenger Deep" of the Mariana Trench, nearly 11 kilometres deep -- aboard the bathyscaphe *Trieste* on 23 January 1960. So we have had the technology for people to visit any depth in the ocean since then.

Modern Human-Occupied Vehicles are much more sophisticated that the early deep-diving vehicles, and here are a couple that I've dived aboard, such as Japan's *Shinkai6500* that took me 5 kilometres down to the world's deepest undersea hot springs, and this is one of the minisubs that we used during the filming of BBC Blue Planet II to dive 1 kilometre deep in the Antarctic for the first time.

As well as vehicles that can carry people into the ocean depths, today we also have Remotely Operated Vehicles that allow us to send our minds, rather than our bodies, into the deep. This is the UK's deep-diving Remotely Operate Vehicle for science -- it's about the size of a family car, and it can reach 6.5 kilometres deep. Unlike Human-Occupied Vehicles, it's attached to a ship by a cable, and we stay aboard the ship, operating the ROV from a control centre. And these days we can also link up from ship to shore via satellite, so scientists around the world can take part live in the exploration.

Deep-Sea Discoveries

With all this technology, what has exploring the deep ocean revealed so far? I'd like to share two deep-sea discoveries in particular that have revolutionised the understanding of how our world works. The first we can trace back to Maury's map of 1854, and that plateau north of the Azores. That turned out to be part of something much larger -- the Mid-Atlantic Ridge -- which was itself part of something even larger still: the global mid-ocean ridge. As Marie Tharp pieced together the echosounder traces of ships crossing the oceans, she found that there was there a ridge around the world in the middle of the oceans, like the seam on a tennis ball. And with the more detailed measurements of echosounders, she could even see that there was what looked like a rift valley running along its crest. The idea that the seafloor could be drifting apart along this 60,000 kilometre mid-ocean ridge was scientific heresy at the time -- Alfred Wegener had proposed his theory of continental drift back in 1913, based on similarities in the coastlines of continents, but it was still considered fringe science at best. Tharp had a very hard time convincing other scientists about the vast undersea rift that she had discovered, but by the early 1960s other evidence, for example from maps of the distribution of undersea earthquakes, and maps of the magnetic signatures of rocks, fitted with the idea and let to the development of plate tectonics -- the understanding of the geological processes that literally shape our world.

The discovery of the mid-ocean ridge and its role in the perpetual reshaping of our planet's surface was as perhaps as profound for Earth sciences as the discovery of DNA for biology -- a "Rosetta stone" moment that allowed scientists finally to make sense of observations in fields from geophysics to palaeontology. In 1973 and 1974, scientists visited the mid-ocean ridge for the first time in deep-diving vehicles -- such as the French bathyscaphe Archimède here -- to investigate it close-up in detail, working south of the Azores in a project called "FAMOUS", which stood for French-American Mid-Ocean Undersea Study". Afterwards, they reported in the journal *Science* that "the ocean floor is disturbingly different from what we had imagined".

Just a few years later, the mid-ocean ridge in the Pacific was the epicentre for another scientific revelation, when scientists diving in the submersible Alvin visited hot springs on the ocean floor, known as hydrothermal vents. These are really like the geysers of Iceland or Yellowstone, but underwater, and although their existence had been predicted, what was a total surprise were lush colonies of deep-sea animals thriving around them, at a depth where food should be too sparse to support them. But at deep-sea hydrothermal vents, bacteria are nourished by minerals dissolved in the hot fluids gushing out of the ocean floor, and those bacteria in turn provide food for animals. So hydrothermal vents provide island-like homes for colonies of deep-sea animals, dotted around the ocean floor. And just as 19th century naturalists studied life on islands above the waves to understand how species disperse and evolve on land, we can do the same for life in the deep ocean by exploring these island-like colonies on the ocean floor. That's what I've spent most of my career doing as a scientist, helping to piece together a global jigsaw-puzzle of what lives where at hydrothermal vents around the world, and understand the network of life between them.

Biologists have found more than 400 new species of animals living at hydrothermal vents around the world in the fifty years that we've been exploring them, and here are a couple that I've been involved in discovering and describing with my students: *Rimicaris hybisae* is a species of shrimp described by Dr Verity Nye during her PhD research, and it lives at the world's deepest known hydrothermal vents, 5 kilometres down in the Cayman Trough of the Caribbean Sea. Instead of eyes on stalks, an adult Rimicaris has a light-sensing patch on its back to detect the very faint glow of the hot vents on the seafloor. And the adult Rimicaris feed on bacteria that grow around their mouthparts and gills, scraping them off with a brush-like appendage to eat them.

Here's another new species from hydrothermal vents in the Cayman Trough, which undergraduate student Russell Somerville worked on describing: this species of eelpout fish feeds on the *Rimicaris* shrimp, and while we found adults of the fish at vents in the Cayman Trough, juveniles of this species turned up where blocks of bizarre methane ice poke out of the seabed 2000 kilometres away on the other side of the Caribbean. Whether the fish migrate between those two habitats during their lives, rather like eels migrating between oceans and rivers, is just one of the mysteries still for us to explore.

Using our Understanding

During the past 25 years that I've been exploring the deep ocean, perhaps the biggest change has been the motivation for our exploration. When I started out, our goal was the pursuit of knowledge about how our planet works, perhaps similar to the goal of space exploration today. But one of the discoveries of recent decades has been the impacts that our everyday lives are having on the deep ocean, and so now our motivation to explore the deep has increasingly focused on understanding those impacts, so that we can make more informed choices for the future in our use of ocean resources.

So the final step in exploring the deep ocean is really "using our understanding", and that is a step in which we are all involved. Each of you have almost certainly used the deep ocean today, albeit without realising it: if you have visited a webpage, sent an email, or used social media, you have almost certainly shared information with a computer on another continent, and that communication has been carried by a modern network of fibre-optic cables across the ocean floor, where telegraph cables used to run. That modern network of deep-sea cables carries 99 percent of global telecommunications traffic, and not just the internet but phone calls as well -- when we call someone on another continent, our conversation no longer bounces there off a satellite, but travels across the ocean floor in a fibre-optic cable instead.

But deep-sea cables are a relatively passive use of the deep ocean, with little impact beyond where the cables are buried. Some of our other everyday activities have much more widespread impacts. I have encountered visible rubbish in almost every ocean I have dived in: this bin bag and drinks can were at 2.3 kilometres deep in the Cayman Trough of the Caribbean. And then there are the smaller, and even more pervasive, microplastic particles that we can't see from our deep-diving vehicles, but which turn up in samples of deep-sea sediments around the world.

As a society, we've become more aware of the plastics problem and been motivated to take steps to tackle it though legislation, such as the shopping bag charge and the ban on microbeads in cosmetics. But the elephant in the room comes from something even smaller than microplastics: the carbon dioxide molecules that we also pour into the atmosphere, from burning fossil fuels. The oceans are a major part of the climate system, linked both to the atmosphere and the "cryosphere" -- the ice masses of the world. Extra heat initially trapped in the atmosphere by increasing carbon dioxide there ends up in the oceans, where it has several impacts, from thermal expansion of the ocean itself that contributes to sea level rise, to altering patterns of ocean circulation that carry oxygen into and around the deep. And as carbon dioxide itself dissolves in the ocean, it reduces its alkalinity, which in also affects ocean chemistry and life. Together, these effects are even more widespread than those of plastic, yet seemingly harder for us to tackle as a society.

Our extraction of resources from the ocean also has impacts in the deep sea, for example with trawling of fish in deeper waters damaging habitats such as slow-growing deep-sea corals that are home to hundreds of other species of marine life -- this is a photo of a known illegal trawler that we encountered at a remote seamount in the middle of the Indian Ocean a few years ago during an expedition led by Prof Alex Rogers, now at RevOcean. And now we're seeing the development towards the mining of minerals from the deep-sea floor, with would-be miners targeting metals in three different seafloor habitats, including hydrothermal vents like those we saw earlier. Each of these seafloor habitats is very different in their ecology, and will be affected by mining in different ways, and we are still discovering new species in each of these types of habitat.

Exploring life in the deep ocean is also offers benefits for our everyday lives, for example inspiring new medical treatments. This headline, from December 2016, described trials of a new treatment for prostate cancer, which uses a modified form of a chlorophyll molecule originally discovered in deep-sea bacteria. And here's a species of deep-sea snail described by one of my former students, Dr Chong Chen, during his PhD research, from deep-sea vents in the Indian Ocean. Unlike every other species of snail known on land or in the sea, it has plates of a metal mineral on its fleshy foot, and an unusual layered structure in its shell that is giving materials scientists new insights for designing better crash-helmets and body armour.

So the life that we are still exploring in the deep ocean is like a library of the ingenuity of nature, which we can learn from. But it reminds me of the great library of Alexandria here, because it seems like we're playing with matches while we're browsing its shelves, and we risk losing some of its volumes before we have had the chance to learn from them.

The challenge of exploring the deep ocean is no longer technological: we have the technology to chart its depths, and vehicles with which we can investigate its mysteries in detail. The deep ocean is no longer just a frontier of our knowledge either: it is also a frontier that allows us to explore who we are as a species, or perhaps who we hope to be. We have a poor track record elsewhere of achieving a balance between chasing resources for short-term gain and protecting environments and biodiversity so that we can continue to learn from them in future. But if we believe we are better than that, and that we have grown in wisdom as well as technological capability, then the deep ocean offers a chance to prove it. Why we explore the hidden face of our dark deep ocean planet, and what we do with the knowledge that we gain, defines its future and our own.

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Further reading:

Ask An Ocean Explorer by Jon Copley, published by Hodder & Stoughton on 21 February 2019, ISBN: 9781473696877; available for pre-order from Amazon, Waterstones, Guardian Bookshop, WH Smiths.