# Discovering the Unknown in the Deep Sea

I woke with a start as a particularly large roll tossed me out of my carefully wedged bunk position. The few items that had escaped being secured crashed to the floor A careful dance ensued, as I tried to keep my balance while grabbing (less than gracefully) at the objects cascading from one side of the cabin to the other. The Korean research icebreaker named "Araon" was making a turn into heavy seas at 63°S latitude between New Zealand and Antarctica, some 12000 miles from my London flat.

Why would anyone subject themselves to the worst weather in the world, in the far southern ocean, with ten meter swells and forty-five knot winds as far away from home as it was possible to be? Only for discovery.

We were at sea to study an unexplored portion the global system of ocean ridges, the grandest bathymetric feature of Earth's surface. If you can imagine removing all the water from the ocean to reveal just the bottom features, this mega-mountain range wraps around all the ocean basins like the seams of a baseball. More than 60,000 kilometers long, the ridge is a linked string of some 1000 volcanoes, where 80% of Earth's volcanism occurs and new sea floor is created. The ocean ridge was barely known 50 years ago, and only since the 1980's has the technology existed for scientists to map this giant feature at reasonable resolution. The first portions of the ridge that were well mapped were at equatorial latitudes where scientists can get tans in shorts and t-shirts, or near US or European ports. The portion of the ridge between New Zealand and Antarctica is furthest from such ports and boasts of the worst weather of any portion of the ridge system, making its exploration problematic, and making it hard for belongings to stay put anywhere they happen to be put down. What makes it worthwhile to study is that this is the last remaining large unexplored portion of the ocean ridge system (***Figure 1***). Along some 5000 km of plate boundary extending from south of Australia to the western Pacific Ocean, even the location of the ridge is poorly known, and no samples exist. In a world where the known seems to overwhelm the unknown, to be in conditions where every stone remains unturned is a rare privilege.

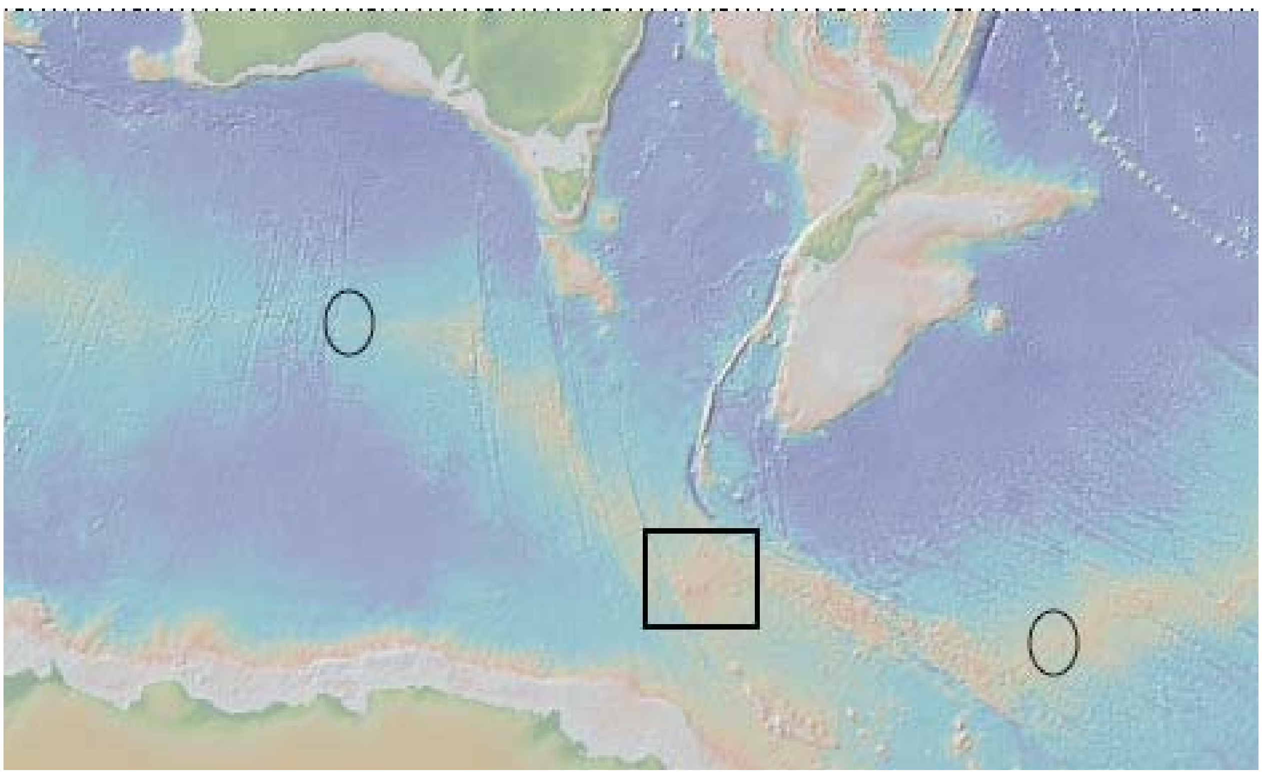

***Figure 1: Map to show the region studied by Korean ice breaker Araon in March, 2011. The ship departed from and returned to New Zealand to map, sample and look for hydrothermal vent signatls in the region of the box. The light brown feature is the rough outline of the ocean ridge. The ellipses are the closest previous data that were availalbe. Australia and Antarctica can be seen at the top and bottom of the image (from GeoMapAp, www/ geomapap.org).***

.A courageous team of Korean scientists and crew from the Korean Polar Research Institute (KOPRI) have undertaken the task to explore this difficult region. Korea is building a new base in Antarctica, and the transit from Korea to the new base passes over the unknown ridge. Will it be possible to do meaningful science during the transits despite the weather? When the Korean chief scientist Sung Hyun Park asked me and colleague Jian Lin from the Woods Hole Oceanographic Institution to give some ideas on what science might be done, we got involved. Part of the purpose of this cruise (a misnomer as these voyages lack any of the amenities of a cruise ship) is to incorporate knowledge and technology from experienced US scientists.

Another key part of the scientific motivation is to find new hot springs on the sea floor, called "hydrothermal vents," which would be a coup for the Koreans on this inaugural scientific voyage of Araon. The most dynamic and visually appealing parts of the ocean ridge system, the original discovery of these vents is also a remarkable story of discovery, where preconceptions are overturned by new observations.

## Discovery of the sea floor

For most of us the word "volcano" evokes an image of the majestic cones around the Pacific ring of fire or perhaps in southern Italy. Mt. Fuji, Mt. Ranier, Mt. St Helens, , Mt. Popocateptl, and Mt. Etna rise like fiery sentinels 2000 m above the surrounding plains. Associated with most of them are fumaroles, geysers and hot springs that bring hot, gas-laden water to the surface. The water is often acidic and laden with sulfur, and around these hot springs very little macroscopic life can survive, and they produce barren and brightly colored scars on the volcanic landscape (***Figure 2***).

The understanding scientists gained from working on land, however, turned out to be poor preparation for the discovery of ocean ridge volcanoes. The mid-Atlantic ridge that snakes down the middle of the Atlantic Ocean was a huge rift valley, in the center of which were small ridges about 100m high where volcanism occurred. At the faster spreading rates found in the Pacific, there was no rift valley, and the volcanoes were narrow ridges that could be more than 100km long , a few km wide and 200 m high ***(Figure 3***). For continental geologists, this was a whole new world.

We now understand that these differences between ocean ridge and continental volcanoes reflect the way magma gets from depth to the surface. Magma beneath continents has to find a passage through the thick continental crust, and forming a single pipe is the most efficient transport. In contrast, ocean ridge volcanism occurs by continuous opening of very long cracks in the sea floor as the plates spread apart. Magma oozes out along the cracks to form long, narrow ridges, like a wound that never heals. The spreading process can be rather rapid—plates move at about the rates that our hair or fingernails grow. (This may not sound fast, but it is when we are talking about plates thousands of km across).

Since the volcanoes are entirely covered with water, there is interaction between the volcanic heat and seawater, and we might expect hot springs. What would they be like? Early investigations of the mid-Atlantic Ridge found only rare hydrothermal staining on some rock surfaces, and many thought that hydrothermal

***Figure 2:*** *Photograph of a hot spring in Yellowstone National Park in the western United States. Notice that while the area is quite beautiful, the land influenced by the spring is devoid of macroscopic life because of the chemical composition and temperature of the water. Yellowstone is the site of a "supervolcano", so large as to be invisible.*

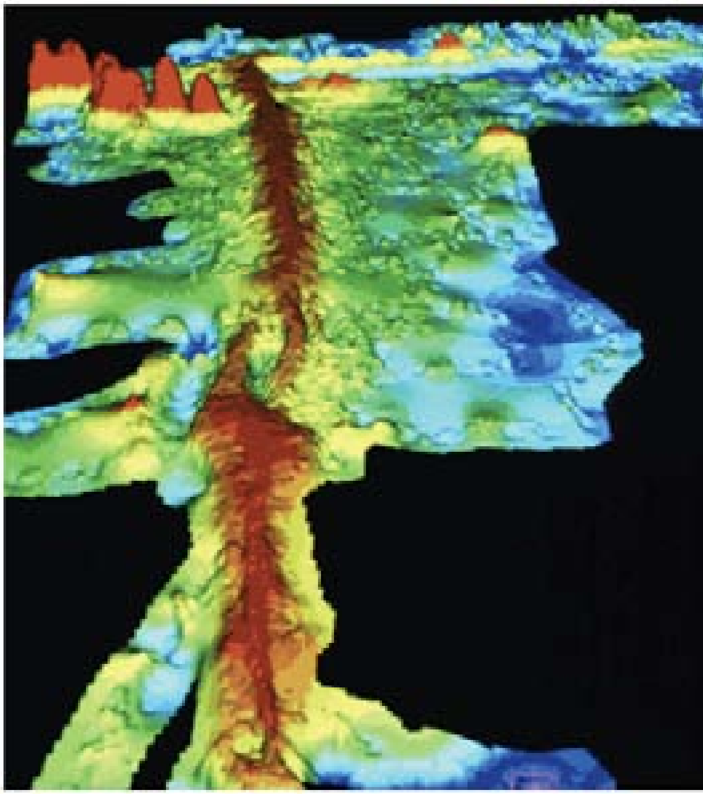

***Figure 3**: Topographic map of the East Pacific Rise showing two long linear volcanoes. Colors are 100m depth contours. The volcanoes are each about 100km long and rise about 300 m above the surrounding sea floor.*

activity at ocean ridges might be rather subdued. After all, the ocean provides a thick, cold insulating blanket and any seeps like those found on land would be dwarfed by the volume and thermal mass of the cold water of the deep ocean. Some preliminary data from the ocean ridge near the Galapagos Islands showed very small temperature variations of less than two degrees just above the sea floor, supporting the preconception of modest activity. Once again, those preconceptions would be overturned by new observations.

The first shock came from a closer investigation of the Galapagos region in 1979. Exploring the sea floor 2000 m below the surface in the submersible Alvin, scientists peering out the tiny portholes could not believe their eyes. More than 2000m below the surface where no sunlight penetrates, living organisms appeared in abundance on the sea floor, living along cracks where warm water was flowing upwards, The animals were unlike any others, including large clams a foot across with red flesh, and strange "tube worms" with bright red cassocks rising almost 8 feet off the sea floor (***Figure 4***).

These discoveries were so surprising and unpredictable that no biologists were even present on the cruise. The scientists planning the cruise expected to find a lifeless desert. The few tiny animals that did exist were thought to rely on the very small amount of dead food falling from the sun-filled surface waters. The sun does not penetrate below about 150m and the deep ocean is inky black. So having a rich and diverse ecosystem at depths was not only surprising, it should have been impossible. Every animal that was brought on board from the deep sea vents was a new organism unknown to science, some of them completely bizarre. When the tube worms were examined on board ship, they were found to have no mouths to take in food and no guts to digest it!

Just a few months later scientists in Alvin encountered an even greater surprise at the East Pacific Rise. Moving along the sea floor at about 1 mph, the Alvin pilot saw some clams and followed the "clam trail" looking for a warm spring. In the distance he saw what looked like a large circular chimney or smokestack in the distance, sticking vertically up six feet from the sea floor and billowing black "smoke" up into overlying water column (***Figure 5***). Cautiously approaching the structure, it was apparent that water was shooting upwards from it. Placing the temperature sensor into the plume the value went off scale and appeared to malfunction. Once the sub arrived at the surface, examination of the sensor showed that the plastic tip had melted! On later dives with modified temperature sensors, the temperature of the emitted fluids was found to be 350°C, hot enough to melt lead! Surrounding this "black smoker" was also an abundance of life. And so a new field of science was born, the discovery and understanding of hydrothermal vents on the sea floor, and the exploration of abundant life living off of "chemosynthesis" from Earth's interior rather than "photosynthesis" from the Sun.

"New discovery" is an oxymoron, because the essence of discovery is revelation of the unknown. When the discovery also overturns preconceptions, some magical energy appears as our world-view is altered. New connections and ideas appear naturally, and there is vigorous investigation that can ignite a field as new questions appear. How could abundant animal life exist in the deep sea? How do the species differ from sun-powered ecosystems? How many hydrothermal vents are there? Are the animals in different

***Figure 4****: Picture of the first tubeworm colony found on the Galapagos spreading center (near the Galapagos Islands) at a depth of about 2500m. The "tubes" are the white cylinders. The bright red flesh sticking out of the tubes is the top of the worm. The red color comes from hemoglobin. The stalks here are up to six feet tall.*

oceans different and why? What effects does the hydrothermal circulation have on seawater and the ocean crust? If sunlight is not required for life to be supported, what are the broader implications for life on Earth and on other planets? These questions required efficient vent discovery, and each year brings advances in this domain, as now more than 100 vent fields have been discovered around the ridges system.

## Araon Joins the Search

Perhaps that helps to explain the thrill of the Korean science cruise. A major aim of the Korean team is to add to this tally of vent discovery in the vast unexplored region of the Southeast Indian ocean. The bad news is that this is a difficult place to work. The good news is that 20 years of previous experience has provided methods and tools to locate vents billowing black smoke beneath miles of ocean water, so the chances of finding vents in a relatively short time are high.

Just as smokestacks from power plants create a dark cloud that spreads out and extends some distance through the atmosphere, the particle-laden water from the black smoking vents also rises to a level where the water is no longer buoyant, and the particle-laden water spreads horizontally over a kilometer or more (***Figure 6***). The vent itself is a needle in a haystack , a few meters wide and a few meters tall, located somewhere along a ridge segment tens of kilometers in length. But the manifestations of the vent extend much further afield, and by having instruments that are sensitive to

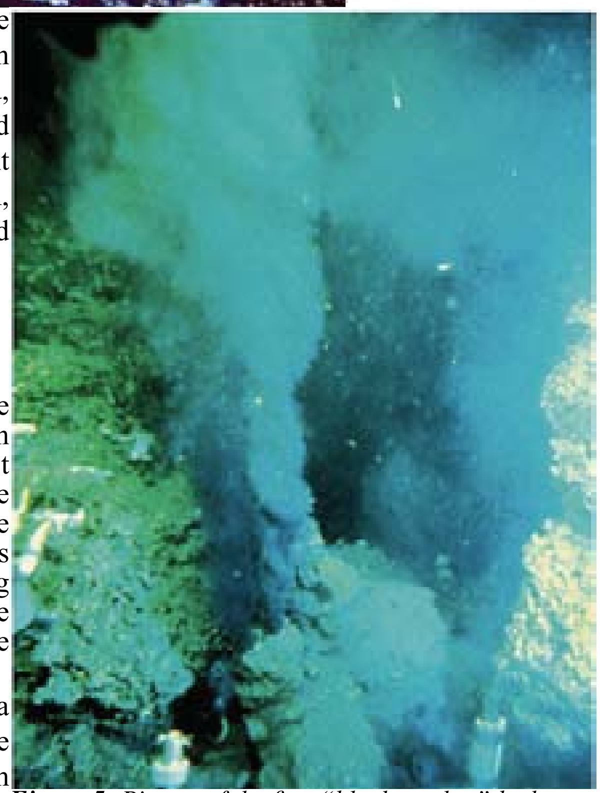

***Figure 5:*** *Picture of the first "black smoker" hydrothermal vent discovered on the East Pacific Rise. Mineral laden water at a temperature of 350°C comes out of the vent and the solids precipitate from the contact with the cold seawater, leading to the black "smoke" which is largely made up of small particles of sulfide minerals. The solid "chimneys" built by the smokers are sulfide minerals rich in copper, iron and zinc.*

the plumes emanating from the vents, it is possible to focus the search until the source is found. What is necessary are many observations, and sensitive instruments.

The discovery occurs step by step.  First map the terrain to have a suitably broad perspective to select targets. Sonar mounted on the ship's hull sends down hundreds of separate waves of sound that bounce off the sea floor and return to the surface to be sensed by receivers also mounted on the hull. The angle and the total travel time give the depths across a swath of sea floor 5 kilometers on both sides of the ship as it moves through the water. Moving over the surface at 8 knots, the unknown fabric of the sea floor beneath the ship is gradually revealed . Scientists stand transfixed before the screen, as new terrain never before seen by human eyes gradually becomes revealed.

To sample the rocks most rapidly, scientists lower a heavily weighted steel pipe with steel core cups filled with wax at its bottom end, called a "wax core".  When the object core hits the sea floor, the steel cracks the rock and the wax collects small fragments of black glass that provide the rock composition. Attached to the wire above the wax core is a hydrothermal sensor called a MAPR (miniature autonomous plume recorder). The MAPR measures the temperature and the electrical resistance of the water, and also shines a light that detects faint "sparkles "in the water that would be produced by plume particles reflecting the light. Scientists always bustle on to the fantail (stern) of the ship when the MAPR and wax core return from miles beneath the surface. Did we get samples? Are they fresh (meaning they were recently erupted from a volcano)? And did we find a vent plume (known after checking out the MAPR data.)

On Araon, the first few wax core lowerings recovered fresh rock samples but we could not see any

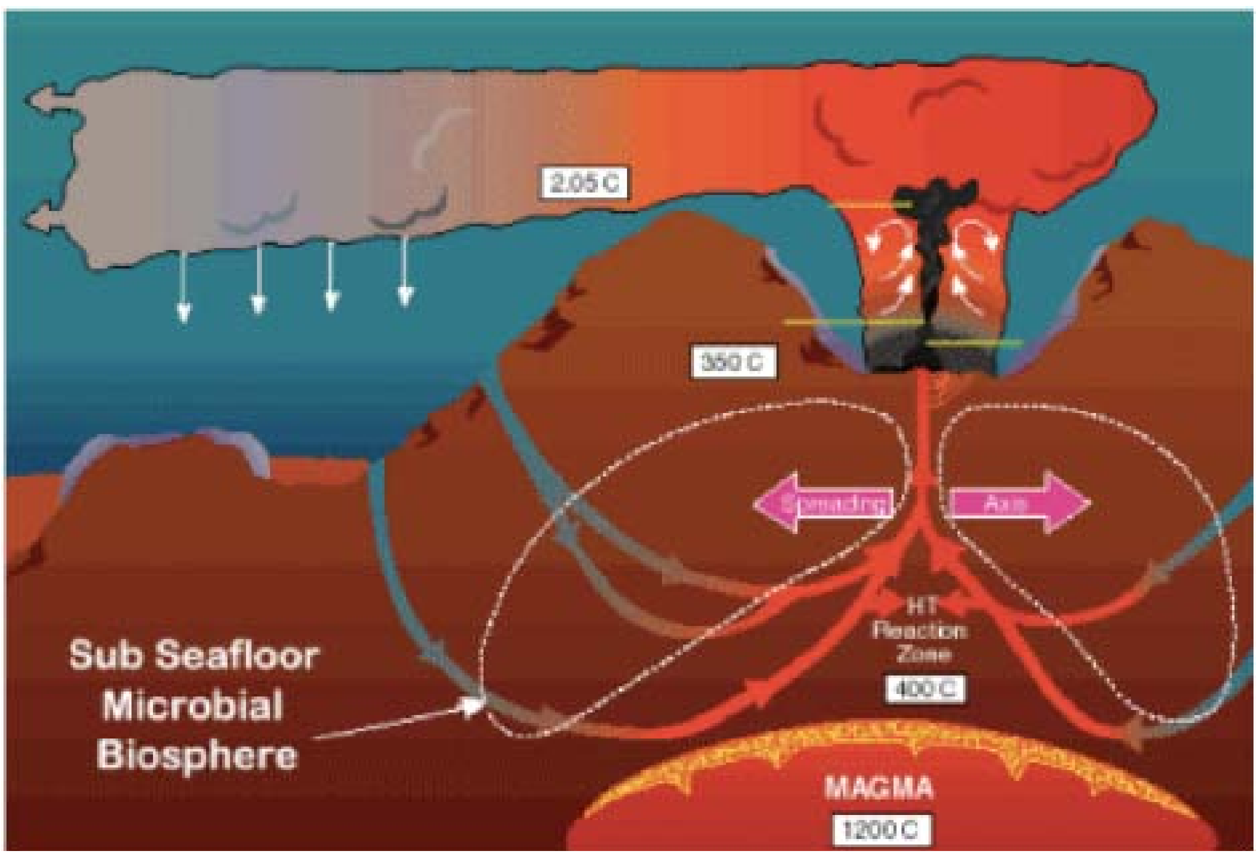


***Figure 6:*** *Cartoon illustrating the main features of a deep sea hydrothermal system. Magma from Earth's interior heats the cold seawater to 400°C causing it to chemically react with the rocks and dissolve minerals. THe mineral-laden fluid escapes to the surface creating a black smoker and dispersing a plume over a great distance. Sensors lowered form the surface are able to detect the plume, and zero-in on the vent location. The microbial biosphere reliant on Earth's internal heat forms the base of the food chain that suports the animals that thrive around the vent.*

evidence of a plume. Puzzling over the new map late into the night, we made our best guess on likely sites based on past experience. Finally, a great shout came up from the crowd of scientists looking at the MAPR data. Big plume!

With only eight days allotted to this exploratory first expedition, and sea states continually challenging the limits of ship and scientists, this cruise will not be able to finish the job and hone in on the likely vent site. The exciting first results, however, guarantee a future visit next year that will move the discovery process to its next stage. Only then will we know whether vents from this new region will once again vacate our preconceptions and open up new questions of the deep sea. As we steamed north, the seas gradually calmed as the ship passed the southern tip of New Zealand, heading to port. Stepping back on to land, there was a deeply felt appreciation for what I always take for granted—Earth beneath my feet that does not move!