Dancing viperfish, spinning rings of plankton and seven-metre-high corals. Just about every journey into the abyss reveals more surprises, says **Mark Schrope**

The undiscovered oceans

LAST year I found myself on a ship in the Gulf of Mexico, 240 kilometres south-east of New Orleans. I was tagging along with a team from Harbor Branch Oceanographic Institution in Florida, where I work as a writer. They were there to test a camera system called the Eye-in-the-Sea, which uses red light invisible to most denizens of the deep to avoid disturbing them.

When the team watched the first video back on the ship, they went absolutely bonkers, screaming and laughing with delight. After just an hour on the bottom, the camera had captured remarkable footage of a two-metre-long squid that might be a new species. This September, the group caught a glimpse of a similar squid hundreds of kilometres away, suggesting that it may not be uncommon. Imagine, a squid larger than a human, and we didn't even know it existed.

On an earlier test in Monterey Bay off California, something moved the entire – very heavy – camera system several metres. The video showed only a giant cloud of silt. Whatever was responsible remains a mystery.

You might think there is little left to discover on Earth in the 21st century, yet the deep sea remains almost entirely unknown. Only a tiny fraction of the sea floor has been explored. "Monterey Bay is the best observed sea floor in the world," says Charles Paull of the Monterey Bay Aquarium Research Institute (MBARI) in Moss Landing, California. "Yet we've only seen 1 per cent of the bottom." Even less is known about life that drifts in the mid waters – the largest biosphere on earth.

But in recent years the pace of exploration has started to pick up. New initiatives, new funding and new technologies are producing a steady stream of findings. Almost every time researchers venture into the abyss, they make surprising discoveries. It would be hard to point to an equivalent period on land without looking back generations. "It's the best place in the world to be," says Cindy Van Dover, a biologist at the College of William and Mary in Williamsburg in Virginia. "If you want to make a discovery, go to the deep sea."

There's a lot of it. The ocean covers 70 per cent of the planet and it is 4 kilometres deep on average. A huge underwater mountain range called the mid-ocean ridge stretches for 70,000 kilometres around the planet, while vast trenches plunge down as deep as 11 kilometres. For every island that breaks the surface of the water, there are thousands of underwater mountains called seamounts, rising thousands of metres above the sea floor. Down here in the abyss it is utterly dark, extremely cold, the water is often low in oxygen and the intense pressure renders many proteins used by surface creatures useless. And yet everywhere there is life.

Take the mud flats that cover vast stretches of the deep. It's been a long time since scientists thought of these abyssal plains as a sterile desert. The surface layer teems with tiny worms and crustaceans that feed off the organic "snow" that drifts down from the waters above. Further down, however, life was not thought to be possible.

Wrong again. John Parkes of Cardiff University in the UK and others have recently shown that there are active populations of bacteria hundreds of metres below the sea floor, feeding on ancient sediments. There may be more life, in terms of biomass, in the sediments than in the water above them. And many of the bacteria are different to anything seen before. "In the past five years we've found a new phylum of life and a completely new kind of metabolism," says Parkes.

Rather more spectacular are the deep-sea corals, found everywhere from 40 to 6000 metres down in waters as cold as 2 °C. Despite living in the dark depths, they rival their shallow-water tropical cousins in splendour. These animals, some of whose colonies grow up to 7 metres high, typically thrive on rocky walls or ridges where there are strong currents to bring them food and sweep away clogging sediments. Although they have long come up in trawl nets, it has only gradually become clear how numerous, diverse and widespread they are. Deep-sea corals are being found everywhere from Norway to New Zealand.

And while only six deep-sea species can build reefs, long belts of these reefs are turning up on the continental slopes around the Atlantic. There may be more in other oceans.

NOAA OFFICE OF OCEAN EXPLORATION NORBERT WU/NHPA GEORGE MATSUMO/MBARI NORBERT WU/MINDEN PICTURES

The deep sea is home to a bizarre array of creatures – and that's just the ones we know about

MBARI

The largest reef, near the Lofoten Islands off Norway, covers 100 square kilometres, yet was discovered only in 2002 thanks to special echo-sounding software that detects corals.

Little is known about deep reefs, such as just how important they are as nurseries for commercial fish species, but what is certain is that like many deep-sea creatures they are extremely slow-growing. Cold-water corals grow only around a millimetre a year compared, with several centimetres for tropical corals. That makes them vulnerable. There are records of 500-year-old corals being snagged in fishing nets, and several deep reefs have already been reduced to rubble by trawling. Only a few reefs have been granted protection.

"If we're going to be exploiting resources we need to understand how fragile they are," says Van Dover. "It's all so connected."

For many biologists like Van Dover, however, the most fascinating deep-sea ecosystems are hydrothermal vents, where superheated water rich in chemicals spews from the volcanically active mid-ocean ridge, and cold seeps, where cool, chemical-rich water oozes from the sea floor. Here, bacteria feeding on methane and sulphides support large communities of animals. The discovery of entire ecosystems that do not depend on photosynthesis revolutionised our view of life. Yet it now turns out that these communities are not as divorced from the sunlit world as we thought (see page 44).

There have been other surprises, too. Researchers are especially keen to study hydrothermal vents on the Gakkel Ridge in the Arctic, because this isolated section of mid-ocean ridge might harbour communities different to those found in the Atlantic and in the Pacific. A cruise to ice-free regions last summer organised by the University of Bergen in Norway found plentiful vents 500 metres down, together with all manner of wacky biology, whose significance was not explored because there were no biologists aboard.

Near the high-temperature vents known as black smokers, for instance, the team came across vast expanses of structures that looked uncannily like pineapples. These turned out to be small, low-temperature vent chimneys just 15 centimetres or so high, each with a sea lily on top and surrounded by bacterial mats stretching for hundreds of metres. No one had ever seen anything like it before, or has any explanation for this strange juxtaposition.

Islands under the sea

At the black smokers themselves, the geologists saw what looked to them like tube worms, previously found only on Pacific vents, suggesting the vents have a novel mix of species. But biologists who have seen videos of the vents are sceptical, saying they show stalked anemones, not tube worms. Another expedition – with biologists aboard – is planned for 2007.

At the opposite end of the planet in the Antarctic, an expedition this February to study the break-up of the gigantic Larson B ice shelf stumbled across vast cold-seep communities 850 metres down on the sea floor that until recently lay beneath the ice shelf. Large areas of the sea floor are covered by white mats of bacteria, with occasional mounds surrounded by clams up to 30 centimetres wide. It's unclear whether this ecosystem will survive now that the ice shelf above it has gone.

Bigfin squid (probably a species of *Magnapinna*)
This squid, seen on around 10 occasions as deep down as five kilometres, has huge wing-like fins extending from its mantle and very long, slender tentacles. The unique way it holds its tentacles – sticking stiffly out from its body, then bending at right angles and trailing downwards – suggests the bigfin waits for prey to blunder into them. Although the body is less than half a metre long, the tentacles extend seven metres or more. No full-grown bigfin squid has ever been captured, but it is now thought to be the adult form of juvenile *Magnapinna* squid, which live within a few hundred metres of the surface.

The discoveries are coming thick and fast. And there are still huge areas to explore. In the southern hemisphere, deep-sea biology has barely begun. Most research has involved relatively primitive camera sleds that take photographs as they are towed above the sea floor. Only recently have there been expeditions equipped with remotely operated vehicles (ROVs) and submersibles. Yet if surface waters are any clue, the depths of the southern oceans are more diverse than those of the north. A 2000 expedition to the abyssal plain five kilometres deep off Angola found more species per unit area than anywhere else in the oceans, and hundreds were new to science.

At least many of the creatures that inhabit the sea floor just sit around waiting to be discovered. In the dark waters below 1000 metres, exploration can be even more difficult. Nets destroy many of the delicate creatures found in this zone, while ROVs and submersibles often scare away the faster-moving ones, such as giant squid. "The bathypelagic zone is by far the largest living space on Earth and it's the one about which we know least," says Michael Vecchione of the Smithsonian Institution in Washington DC. "It's a really challenging place to explore." ▶

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NOAA/MBARI

DR RICHER DE FORGES

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Big red jelly (*Tiburonia granrojo*)
Found around a kilometre down in the Pacific, the bell of this jellyfish can be a metre across. But unlike most jellyfish, it has no stinging tentacles, just four to seven thick fleshy arms, and is deep red in colour. Big red represents a new subfamily, not just a new species. First sighted in 1993, only one small specimen has been collected intact and it was properly described only in 2003. Virtually nothing is known about its diet and behaviour.

Golden scale snail (*yet to be named*)
During the second ever expedition to hydrothermal vents in the Indian Ocean, biologists spotted a snail with a strange-looking foot. Many snails can close the opening to their shell with a flat, round bit of shell called an operculum. But this snail instead protects itself with scales, a feature seen before only in long extinct species, although the vent snail itself evolved recently. Even more unusually, the scales are reinforced with the iron sulphide minerals fool's gold and greigite, giving them a golden colour. No other multicellular animal is known to use these materials.

Vecchione was a member of a recent expedition that combined scans from the world's most sophisticated acoustic "fish-finder" with trawls and ROV surveys to build up the most comprehensive picture ever of life in the water column, above the Mid-Atlantic Ridge. The explorers found far higher concentrations of life than expected, including colossal spinning rings of plankton.

"There's an enormous amount of biomass," says Ron O'Dor, head scientist of the project that organised the expedition, the Census of Marine Life based in Washington DC. CoML is a 10-year international project involving researchers from 70 countries. It has the ambitious goal of trying to catalogue everything that lives, has lived or will live in the sea, including the deep.

The task is huge. Researchers at Rutgers University in New Brunswick, New Jersey, recently decided to have some fun with the six million entries in the Ocean Biogeographic Information System, an international database for recording information from expeditions. They found huge regional gaps, especially in the southern hemisphere (see left).

Below 3000 metres, the team found that if you collect an animal, the chances of it being a new species are an astonishing fifty-fifty. "That gives you an idea of the challenge," says O'Dor.

Among its achievements since it was set up five years ago, CoML has already found thousands of new species, along with numerous examples of familiar organisms in unexpected places. "We may have doubled biological sampling in the areas most poorly sampled, but it's clear that we have a huge task in front of us," O'Dor says.

Specific CoML programmes focus on particular environments, such as seamounts. Initial findings suggest they are the undersea equivalent of islands, with as many as half the species on some seamounts seemingly unique. But this might merely reflect our ignorance – without studying surrounding seamounts it's impossible to say whether seamounts are this diverse. "At the moment the jigsaw puzzle is so incomplete it's hard to make any sweeping generalisations," says Malcolm Clark at the National Institute of Water and Atmospheric Research in Wellington, New Zealand, who heads the programme.

Although there is heavy fishing around many of the 100,000 large seamounts in the oceans, we have detailed knowledge of only 100 or so, Clark points out. We know almost nothing about the seamounts in the southern Pacific, between New Zealand and Central America, and the deeper reaches of the famed Great Barrier Reef have never been visited.

At times the lack of deep-sea knowledge leads to situations that make it seem as if the ocean is toying with its visitors. Vecchione, a cephalopod expert, went on a 2002 CoML expedition to the Arctic that found no squid or octopus. So he sat out the next expedition, which turned into a cephalopod fest; a squid or octopus appeared during nearly every dive.

Many discoveries simply leave the experts baffled. The CoML expedition to the Mid-Atlantic Ridge found a strange path of small, symmetrically progressing burrows on the sea floor that looked like tracks. Just about every researcher who sees the tracks comes up with a different explanation.

Dancing viperfish

Then there's the strange case of the dancing viperfish. Edith Widder, now at the Ocean Research and Conservation Association in Fort Pierce, Florida, has seen numerous viperfish during submersible explorations, but in each case they froze like a rabbit in headlights. This is probably a natural response to the sub's frightening intrusion – it makes sense for the fish to freeze because countless tiny bioluminescent organisms can give away bigger creatures' positions if they move.

But using the Eye-in-the-Sea, which was developed by her team, Widder filmed a viper putting on a strange dance. "I have no idea what this little guy was doing," she says. "It almost seemed like he was a camera hog."

One problem with understanding behaviour like this is that the conventional tools of deep-sea biology – nets, submersibles and more lately ROVs – give only brief snapshots. Even retrievable "landers" equipped with cameras and sampling equipment last only so long before the batteries run out. It is like trying to understand the population at a tourist beach if you only visit it once a year in the winter, says Monty Priede at the University of Aberdeen's Oceanlab in the UK. "We need

JUSTIN MARSHALL/IMAGEQUESTMARINE.COM

The deep red colour of this helmet jelly may be a way to hide the bioluminescence of prey it has just captured

continuous observation in the deep sea, which is where long-term observatories come in."

The idea is to set up observatories with cable connections to land to provide constant power and stream data to labs and offices. There are already a few observatories of this type, but most focus on geological concerns such as seismic activity, or shallow habitats.

The first deep observatory with a biological focus is scheduled to be installed in 2006, 35 kilometres out from MBARI. Dubbed MARS, it will have space for plugging in a variety of instruments, such as a version of the Eye-in-the-Sea whose camera can be controlled from shore, and which will be able to record indefinitely, instead of being limited to short bursts. There will also be listening devices that can track the movement of whales and fish.

And observatories won't necessarily be limited to studying to their immediate vicinity. MBARI has a rover unit resembling a miniature tank that could roam around the surrounding area, while camera systems on floats could monitor the waters above.

Having all the equipment in place all the time should make it possible to observe rare and brief events such as sediment avalanches, as well as how the dwellers of the deep respond to them in the long-term. "We anticipate uncovering all sorts of new trends and linkages," says MARS project manager Keith Raybould of MBARI.

There are plans for a far more ambitious observatory programme called NEPTUNE, to monitor the Juan de Fuca tectonic plate off Washington State and Canada. Across the Atlantic, Priede and colleagues hope to set up observatories at 10 locations from the Black Sea to the Arctic, as part of a project called the European Sea Floor Observatory (ESONET).

For Paull, one of the most exciting things about the observatories is that they will make it much easier to do experiments in the deep. "We can move on from exploratory science to experimental science," he says. His team plans to set up an artificial cold seep, for instance.

Widder, meanwhile, has developed a glowing jellyfish lure, a plate ringed by LEDs that can mimic some of the common patterns of bioluminescence. By seeing how various creatures respond to it, she hopes to get a better understanding of how deep-sea animals use bioluminescence.

With so much under way, this is the most exciting time ever to be studying the deep sea. "Give me a map, give me a ship and I can take you to where we're going to discover entirely new things – not just new species, but new ecosystems and new ways of understanding how the ocean works," Van Dover says. "We could still find something totally different that we just can't imagine." ●

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ALBERTO LINDNER/COURTESY OF NOAA FISHERIES

Lush coral gardens are being found thousands of metres down, like this one off the Aleutian Islands in Alaska

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HARBOR BRANCH OCEANOGRAPHIC/WIDDER

Spiral shit animals (*Torquarator bullocki*)
These strange creatures were first spotted crawling on the sea floor in the 1960s. They feed on sediment and often leave spiral trails behind them, hence the name. Although they look like worms they actually belong to a group called the hemichordates, which have primitive spinal cords. Little was known about them until 2002, when the first one was collected two kilometres down on the Pacific sea floor. It turned out to be so different to known hemichordates that an entirely new family was created to accommodate it. Others, including the one pictured above, have yet to be collected and named.

Glowing sucker octopus (*Stauroteuthis syrtensis*)
One of several deep-sea species that can swim using the elephant-ear-like fins on their heads, earning them the nickname "Dumbo" octopuses. Their tentacles are also connected by membranes, forming a bell. And *S. syrtensis* has another unique trait. Its suckers have evolved into bioluminescent organs that emit a blue-green light, possibly to lure prey. Although bioluminescence is common in squid, only a handful of other octopuses produce light, and then only in a glowing ring around the mouths of females during the mating season.

Treasure trove

For many, the deep sea has to be explored just because it is there. But for others, it is a treasure trove of evolutionary inventions waiting to be turned into commercial products.

Shallow-water species have already yielded drugs such as spongosine, used to treat viral infections, along with the glowing green jellyfish protein beloved of genetic engineers. The Harbor Branch Oceanographic Institution in Fort Pierce, Florida, has looked for useful compounds in tens of thousands of invertebrates and microbes, including many deep-sea species, and has patented over 100 so far. The greatest success to date is discodermolide, a compound from a deep-sea sponge that has reached the first stage of clinical trials as a treatment for pancreatic cancer.

"Compounds such as discodermolide give us a glimpse of the potential the deep sea holds," says Amy Wright, head of the Harbor Branch biomedical programme. "We can only imagine what we'll find as we continue to search."

Other researchers are testing a deep-sea species called bamboo coral as a potential bone substitute. And a variety of skincare products now contain additives, produced by the French company Sederma and based on enzymes found in vent bacteria, that provide increasing levels of protection against ultraviolet radiation as the temperature increases.

There are industrial applications, too. Heat-tolerant DNA-copying enzymes from vent bacteria are now widely used for the PCR reaction, the basis of much molecular biology. Diversa of San Diego has found two enzymes in vent microbes that could dramatically reduce the costs and energy required to produce ethanol, as well as cold-tolerant fat-digesting enzymes in animals that make a living from eating the bones of dead whales (see page 50), which might be added to detergents. And Lucent Technologies' Bell Laboratories is trying to work out how deep-sea sponges manage to grow glass skeletons at low temperatures that are both tougher and better at transmitting light than optical fibres.

But when it comes to exploiting the deep, the prize must surely go to Koya USA of Hawaii. It is selling the deep sea itself. "Where do we find good, pure water with all the minerals and trace minerals needed for optimum human health? At the bottom of the sea," its website informs us. Where else, indeed? The company pipes water up from 915 metres down, desalinates it and sells it for $5 a bottle in Japan.