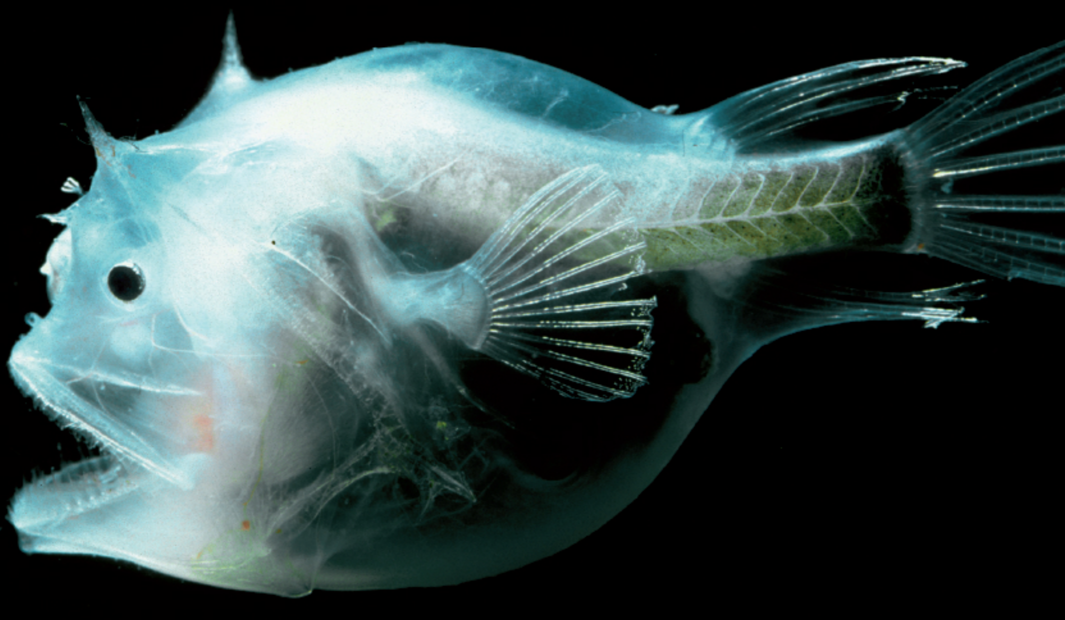
DEEPER THAN LIGHT



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Front cover: A deep water angler fish, *Haplophryne mollis*. Back cover: The amphipod *Phronima* is a parasite of salps in the North Atlantic. Both images © David Shale

The deep ocean: Discovering an unknown world

Daunted by its huge volume, mysterious due to its relative inaccessibility, the deep ocean continues to fascinate us.

© M. Ravassard/UNESCO

We know that it is there, but we cannot easily visit it. The deep ocean is the largest living space on Earth, but no other part of the biosphere is as poorly explored. Deep ocean research is little more than a hundred years old, much younger than most other science areas, and there are many reasons why this is the case: lack of priority, technology and resources; this is slowly changing. In the last decade, thanks to initiatives such as the global programme the Census of Marine Life (www.coml.org), its national and regional committees such as the European Census of Marine Life (www.eurocoml.org), and its field projects MAR-ECO, ChEss, COMARGE, and CeDAMar, we are making huge leaps towards a new and greater understanding of this environment. These international exploratory efforts generate exciting new insights into the biodiversity and ecology of many deepwater habitats from continental slopes to mid-ocean ridges and abyssal plains, using modern technology and vessels.

These efforts are very timely. The international nature management is challenged by global problems such as habitat degradation and biodiversity loss. This also happens or can happen in remote deepwater areas. Preventative actions are needed to stop destructive practices and protect vulnerable habitats and ecosystems still untouched and in near pristine condition. The deep ocean is our common heritage and most open ocean areas are in international waters, i.e. not under the jurisdiction of a single state. Thus international management is required and actions should be based on scientific knowledge and good advice from the international scientific community.

But underlying all exploratory science and effective ocean management is the appreciation of the deep ocean as a fascinating part of our common world. Fascination with nature and its diverse life forms drives ocean scientists to explore this vast environment. Written by scientists actively participating in the projects mentioned above and the project officer for the European Census of Marine Life, and illustrated by images from recent expeditions, this book aims to raise the awareness of everyone to the hidden and beautiful creatures of the deep ocean, how they live and how they are observed and studied. We wish you all a happy voyage "Deeper than Light".

Patricio Bernal

Executive Secretary of UNESCO's Intergovernmental Oceanographic Commission (IOC)

Introduction

Geographical Exploration

The earliest perception of the earth and the sea was that they were flat and if a sailor reached the horizon, he would fall off the edge! The geographical extent of the sea was unknown, its depth unfathomable, and unlikely to be tested as myth proclaimed that the deep waters were inhabited by monsters ready to take the unwary seaman.

Geographical exploration, especially in the 15th and 16th centuries showed that the sea extended far beyond the horizon visible from land. For another three hundred years the surface of the sea continued to be explored as it carried Europeans on great voyages of discovery. By comparison technological development was slow, although notable advances included the accurate measurement of longitude in the 18th Century by John Harrison and the development of steam power in the 19th Century.

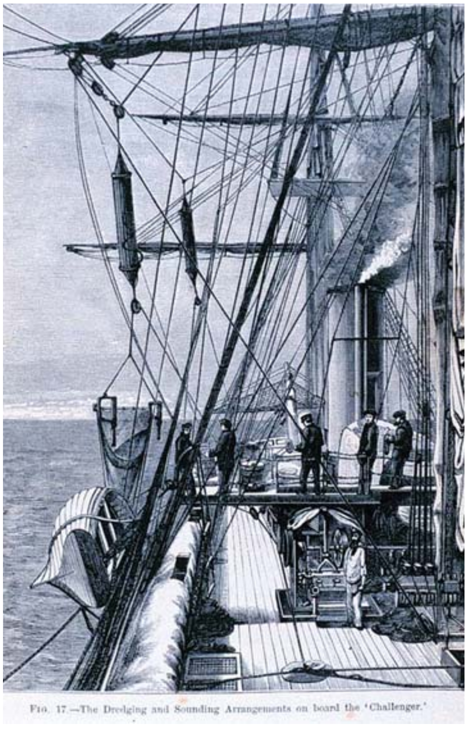
In the great age of geographic exploration the most important feature other than surface geography was the depth of the water particularly in relation to the closeness of land.

The snail, *Clione limacine*, "flying" through the water using its foot which has evolved into two wing-like lobes to be used for propulsion. © David Shale

Sounding lines had been in use from time immemorial to ensure that ships would not run aground. The first description of the 3-dimensional ocean was by soundings laid on a map of the sea in 1504. By 1521, Magellan had attempted to measure the depth of the ocean between the coral islands of St Paul and Los Tiburones, in the Pacific, and having found no bottom with a 600 m sounding line announced he had found the deepest part of the ocean. In the 16th and 17th century a series of apparatus were developed to determine depth. British Royal Navy ships were in the forefront of the establishment of **bathymetry** and as the great maritime surveys took place in the 18th and 19th centuries special devices to collect sediment samples were added to the sounding lines to give some idea of seabed composition. The late 18th century saw the deepest depth recorded in the ocean of 1300 m in the Arctic, and a sample of 'blue mud' from the seabed was bought up at the same time. The 19th century culmination of this approach was Maury's bathymetric map of the North Atlantic that, for the first time, showed the ocean seabed was not flat as had been imagined but that there were **abyssal plains** separated by a mountain chain running the length of the Atlantic.

Temperature measurements at depth were first taken on Cook's 1772-1773 voyage to the

Pacific. Later that century saw the development of the protected thermometer and by the mid-1800s there had been the development of the **reversing thermometer** that gave accurate temperature readings at depth.



Scientists and crew preparing sampling equipment during the HMS *Challenger* global expedition (1872-6). © NOAA Photo Library

A fantasy sea monster eyeing up a sailing ship. © Mary Evans Picture Library

Biological Exploration: The Heroic Age

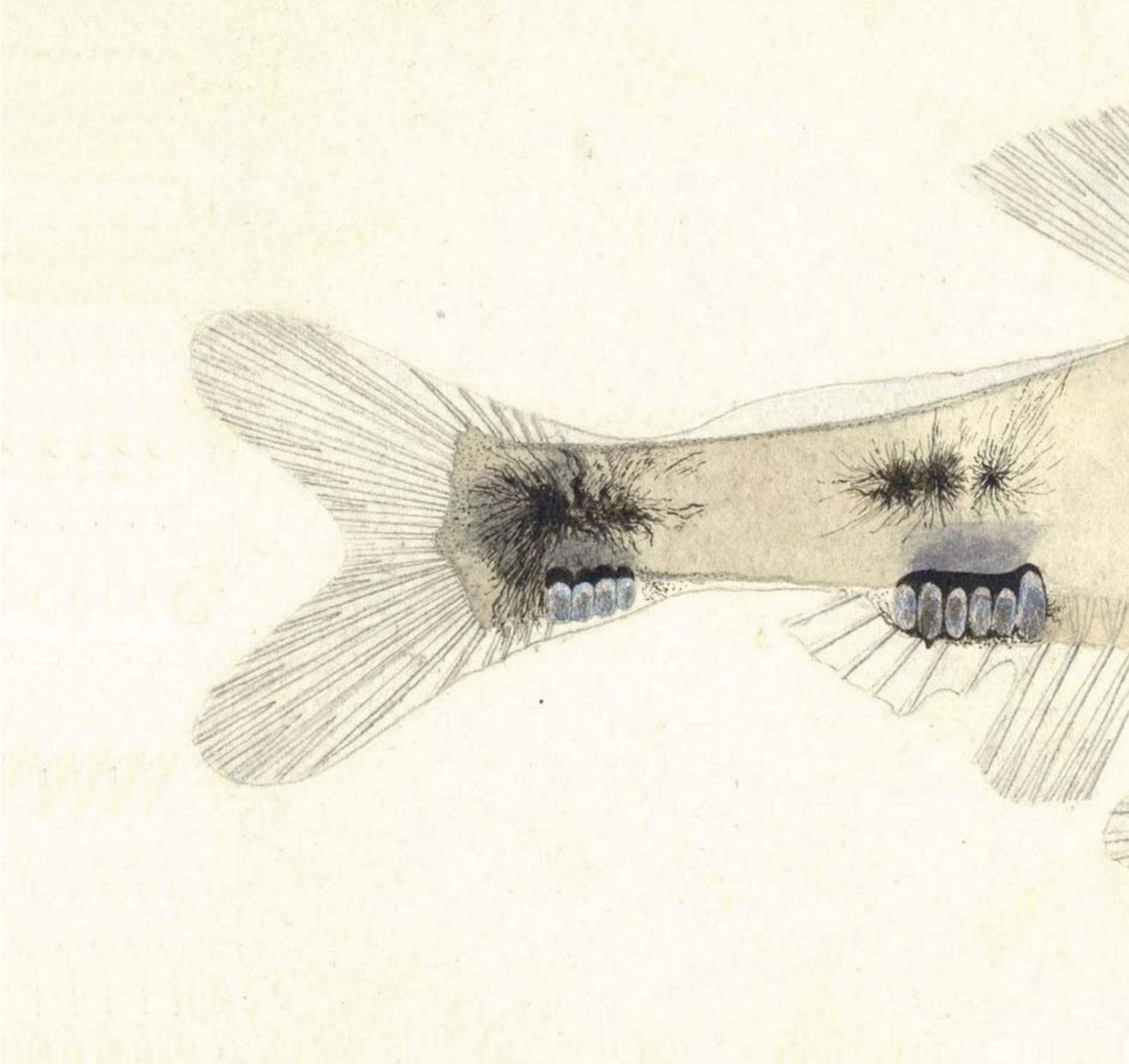
It is a sounding line that introduces us to deep sea biology. The Sir John Ross expedition undertook a survey in Baffin Bay, Canada, in 1818 at depths approaching 2000 m. Upon retrieval of the sounding line a large bottom-dwelling basket star **(echinoderm)** was recovered demonstrating that animals could be found at great depths in the ocean. This observation remained unknown by the scientific community for decades! Some 20 years later the great British naturalist Edward Forbes was sampling in the Aegean Sea. The choice was unfortunate as this is one of the more impoverished areas of the deep sea bed. On sampling below 600 m Forbes found no animals, and proposed that little or no life existed below this depth. Although not coined by Forbes, this became known as the **'azoic theory'**.

There is nothing like a theory to challenge scientists! At the same time as Forbes was proposing that there was no life below 600 m, Michael and Georg Ossian Sars, father and son, were sampling in the deep Norwegian fjords and finding rich communities of large animals, demonstrating that animals had the ability to thrive in waters of great depth. In addition, a telegraph cable laid at a depth of 2400 m in the Mediterranean was recovered and found to be covered in corals, **molluscs** and other animals. Other examples of the recovery of deep-water animals followed in quick succession but it was the systematic surveys of Charles Wyville-Thomson that set a new standard.

To determine if deep-water fauna occurred to the west of the British Isles, Wyville-Thomson and W.B. Carpenter of the Royal Society (UK) began to collaborate with the British Royal Navy resulting in the cruise of HMS *Lightning* (1868). Although not primarily biological, the cruise demonstrated the presence of a ridge, between Scotland and the Faroes, separating the Norwegian Sea from the North Atlantic. North of this ridge (now the Scotland-Faroes-Iceland-Greenland Ridge) was known as the 'cold' area (temperatures <5 °C), whilst to the south was the 'warm' area (temperatures 4.5 - 8.5 °C). Further expeditions were undertaken in 1869 and 1870 by Wyville-Thomson and Carpenter on HMS *Porcupine* to sample the Faroe-Shetland area, an area to the west and southwest of Ireland, and the western Mediterranean. At the deepest stations sampled the nets caught and retrieved large marine organisms. The 'azoic theory' was dead.

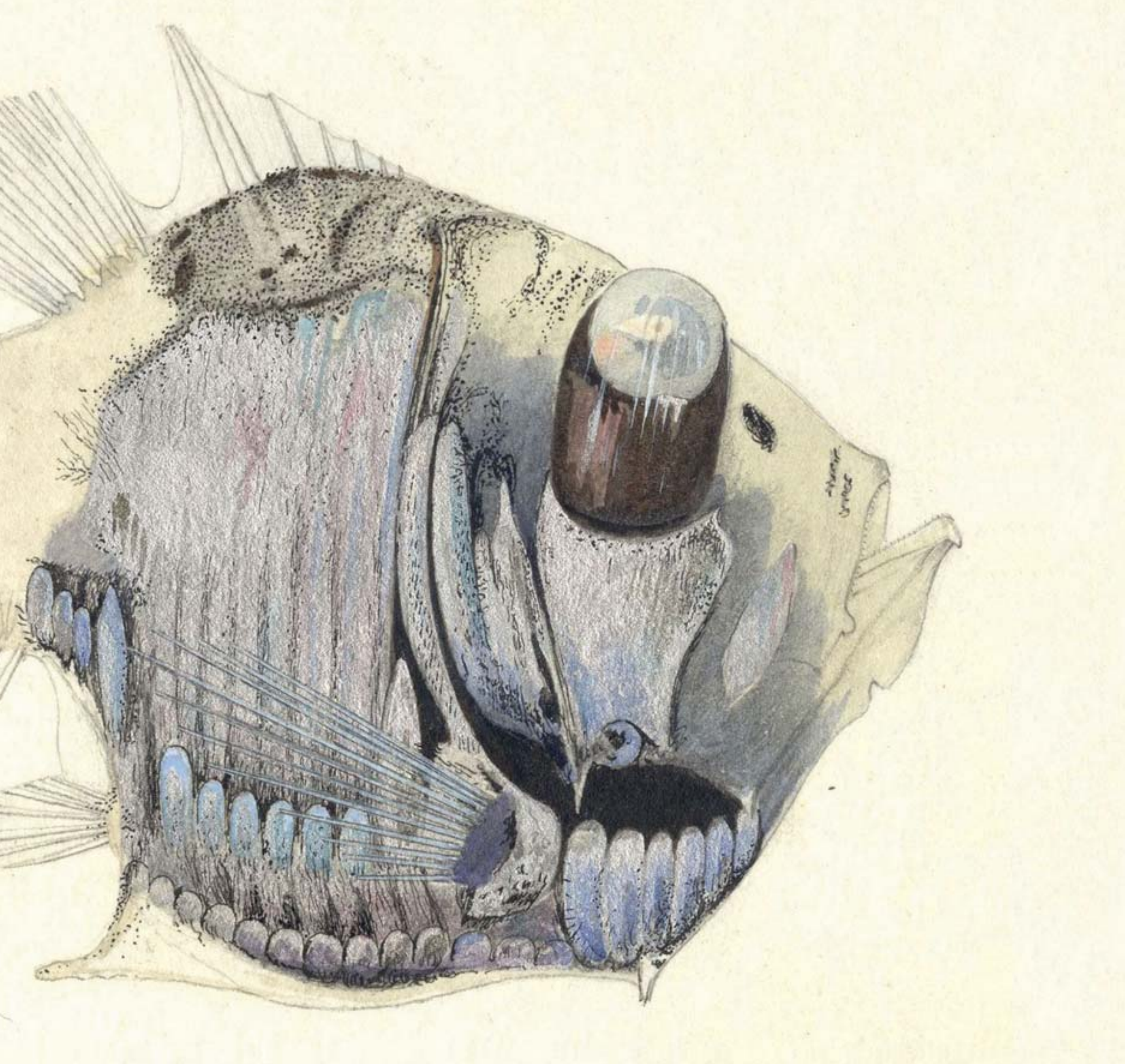
In continued discussions with the Admiralty, Wyville-Thomson established what became known as the *Challenger* Expedition. The plan was to circumnavigate the global oceans sampling to the greatest depths. This was carried out between 1872 and 1876 and *Challenger* sampled some 362 stations and collected a wide variety of truly deep sea animals. In addition, the *Challenger* cruise collected data on deep-water temperatures, chemistry and sediment type. The expedition showed that animals could live at the greatest depths and the deep sea appeared to be a refuge or 'hiding-place' for groups such as the stalked crinoids (echinoderm), long thought to be extinct. The *Challenger* Reports can be described as the first chronicle of deep sea biology.

Dolphins following a research vessel. © Leif Nøttestad



At the same time as the *Challenger* expedition, the US *Tuscarora* was taking physical measurements in the Pacific and the German *Gazelle* was circumnavigating the globe.

Thus interest in organisms found in the deep sea exploded with all the developing nations mounting deep sea expeditions. This has become known as the 'heroic age' of deep-sea exploration with the *Blake* (US) in the Caribbean and Gulf of Mexico and the *Albatross* (US) along the eastern seaboard of the USA. From the 1880s onwards the various ships of the Prince of Monaco sampled in the Mediterranean and eastern Atlantic, the *Ingolf* (Denmark) sampled along the Wyville-Thomson Ridge and the *Michael Sars* (Norway) in the North Atlantic. In the early part of the 20th Century deep sea exploration was eclipsed by the race to either pole and subsequently by the horrors of the Great War. Resource and manpower were being directed to other, more pressing causes.



A watercolour of the mid-water hatchet fish, *Argyropelecus hemigymnus*, by Thorolv Rasmussen from 1910 – The *Michael Sars* expedition. © Bergen Museum

By the end of the Great War the impetus of deep sea exploration had been lost and was not regained until the late 1920's and 1930's when the Anglo-Egyptian *Mabahiss* expedition explored the deep parts of the Indian Ocean and the Dutch *Snellius* Snellius explored the Dutch East Indies. At the same time the Swedish *Siboga* sampled worldwide, although very few stations were situated in the deep sea. War again intervened leading to a suspension of international research. Immediately after World War II the Swedes led the *Albatross* expedition of 1947-1948, amongst other places, the Gulf of California. The culmination of this 'heroic age' was the Danish *Galathea* expedition of 1950-1952 that specifically sampled the deepest trenches (>10 000 m) and showed that animals were capable of living in the very deepest parts of the worlds oceans. Although the many expeditions over this period collected numerous new species, the equipment used to collect them consisted mainly of coarse mesh trawls and fish traps, and virtually none of it retrieved quantitative samples. As a result the larger animals **(megafauna)** became well known and it was assumed that biodiversity was generally low in the deep sea. It was to be with new equipment and new vigour that the true contributors to biodiversity in the deep sea were to be recognised in the 1960s.

Modern Deep Sea Discovery

In the 1960s a more quantitative approach to sampling deep sea fauna was undertaken by Howard Sanders and Bob Hessler, both then at the Woods Hole Oceanographic Institute (US). They developed a number of dredges and sleds with which to sample deep sea animals. The significance of these samplers is that they sampled the sediment and retained smaller individuals of the community, known as the **macrofauna**. With careful sieving, using a finer mesh, and sorting of the samples, an astonishing high biodiversity was revealed. Dominant amongst the retained fauna were worms, **crustaceans** and small molluscs suggesting the deep sea may be one of the main repositories of biodiversity on earth.

Running in parallel to deep sea faunal discoveries was an understanding of the processes that maintained deep sea populations. The deep sea is a heterotrophic system, in that it relies on the input of organic matter from surface primary production or from large food falls such as whales, wood and other poten-

The manned submersible MIR-2 being launched. This scientific submersible can carry 3 people to the depths of the ocean (6000 m).
© Klokkargaarden Film AB

Far right: Bizarre new life found at hydrothermal vents in the Pacific Ocean in 1977.
© Emory Kristof (National Geographic Photographer), Richard A. Lutz and Woods Hole Oceanographic Institution

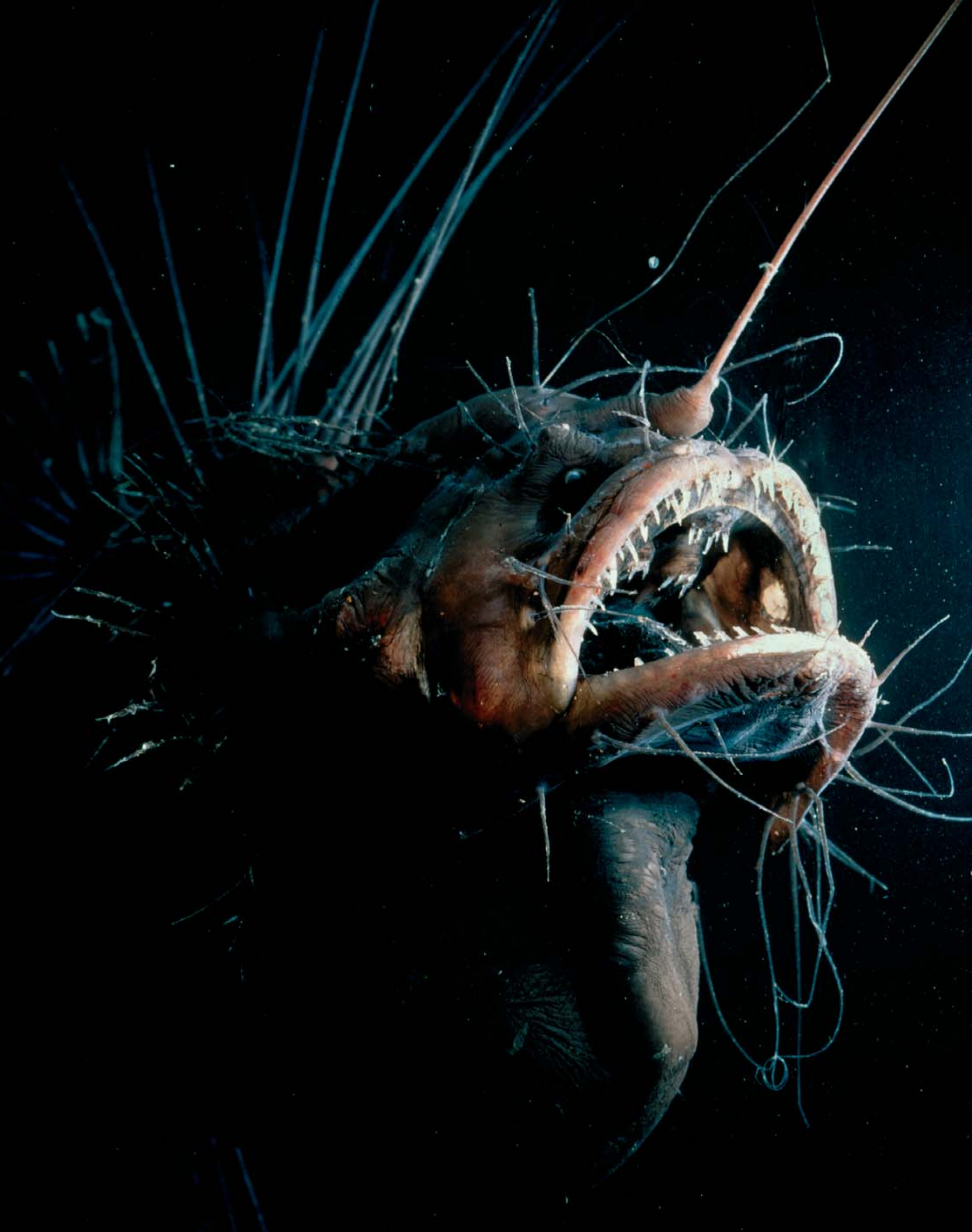
tial food focuses. Since the amount of organic material entering the deep sea is low, the populations were considered small, although diverse.

Further expeditions have led to other fascinating discoveries including the finding of hot water vents in the Eastern Pacific, where black smoke appeared to be emanating from chimneys. The first temperature measurements melted the probes suggesting very high temperatures but even more astounding was the huge biomass of unknown animals associated with these '**hydrothermal vents**'. Practically every species was new and biomass was much higher than at equivalent depths in the deep sea.

From **mid-ocean ridges** to **seamounts**, from the **continental margins** out to the abyssal plains, advances in technology and sheer good luck will influence future discoveries in the deep ocean. In the past we relied heavily on dredges and trawls which sampled large areas, making it impossible to discriminate local variation. The use of coring equipment and **submersibles**, and more recently remotely operated vehicles, has allowed us to study deep sea animals at a much smaller scale, almost as if working on the laboratory bench. Modern molecular techniques allow us to tell the difference between two individuals that look identical but in fact are two closely related species.

Lastly, but by no means least, serendipity will play its part. Hydrothermal vents were an unexpected but fortuitous discovery and of huge importance but there have been many unexpected discoveries in the deep sea on a smaller scale but of no less importance as they contribute to our understanding of this, the world's largest **ecosystem**.

Many new discoveries are just waiting to be made!



Extreme Ocean Adventure

Join us on an ocean adventure. Our journey begins in relatively shallow waters at the edge of the **continental shelf** (200 m), moving deeper towards the **continental slope** (200 – 3000 m) and then into the deepest, darkest part of the ocean – the abyssal plains (3000 - 6000 m). What interesting deep-sea features will we discover en route?

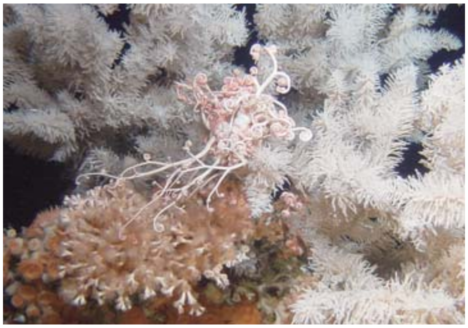
But be aware, this is going to be an extreme outdoor adventure! Be prepared to experience:

Crushing pressure: As you descend the pressure increases by 1 atmosphere or 1 kg/cm² every 10 m. When you reach the bottom of the abyssal plains, at a depth of 5000 m that is equal to 500 kg/cm², equivalent to the weight of an elephant sitting on you!

Freezing cold: The deep sea is bathed in cold, dense waters coming from Polar Regions. Temperature here can be as low as 0 °C and rarely reaches 4 °C. Train yourself by living in the fridge, do not forget the elephant!

Dimming darkness: Even the clearest waters absorb the sunlight quickly. Below a depth of 200 m you will experience eternal twilight and below 1000 m eternal night. Once you are in the fridge, do not forget to close the door!

The deep sea anglerfish, *Caulophryne sp.* has a spine protruding from its head which acts as a lure to attract prey. © David Shale



A basket star, *Gorgonocephalus sp.*, on top of stony corals, *Lophelia pertusa*. © Ifremer/Caracole cruise 2001.

Starving hunger: As there is no light, **algae** and plants, the basis of nearly all food chains on Earth, are absent in the deep sea. Seasonal food comes almost solely from small organic particles slowly sinking from the surface, the so-called **marine snow.** Now that you and the elephant are in the dark fridge, there is little room for food except for a few crumbs...You are now ready to experience life in the deep sea!

Sliding Down The Slope

Though conditions are extreme from the human point of view, an amazingly diverse animal life is found in the deep sea. Let us now discover where those animals live and who they are. We begin our journey sliding down what is known as the continental slope.

Mud, Mud Glorious Mud

Continental margins are the ultimate receptacle for most of the sediment generated by land erosion. Mud is therefore a prominent feature of the margins; sediment can be piled as high as 12 km but most life, except bacteria, inhabits the first few centimetres, where the food is found.

Deep sea sediments have long been viewed as a desert, which at first glance is true. Along the slope, the biomass of **benthic organisms** ranges between 10 – 20 g/m², one order of magnitude less than in deserts. Due to its remoteness as well as low numbers, deep sea fauna remained hidden until only half a century ago when scientists began to use new techniques to extract animals from the sediments. Much to their surprise a highly diverse fauna was revealed. Indeed, continental margin sediments later turned out to harbour one of the most diverse ecosystems on Earth; maybe as diverse as tropical rain forests and shallow coral reefs.

Low Oxygen Neighbourhood

While continental margins are basically muddy, food poor and highly diverse environments, there are many exceptions. One example is seafloor oxygen minimum zones (OMZs), especially in the eastern Pacific Ocean and Indian Ocean.

At a global scale, over one million km² of the seafloor, the size of Scandinavia (two times France/Spain, three times Germany, five times United Kingdom), is affected by a permanent shortage in oxygen. Oxygen minimum zones form in the oceans where high surface **productivity** is associated with more or less stagnant and already oxygen poor waters.

The degradation of organic matter in the water column consumes the oxygen until almost depleted. Very few organisms are able to cope with a shortfall of oxygen, therefore when oxygen-depleted waters touch the seafloor they impact and modify the ecosystem. **Diversity** is low but the few species able to live there take advantage of abundant food and low predation to flourish; thanks to special adaptations like highly developed **branchiae**.

Many of these specialised species are new to science and probably **endemic** to oxygen minimum zones.

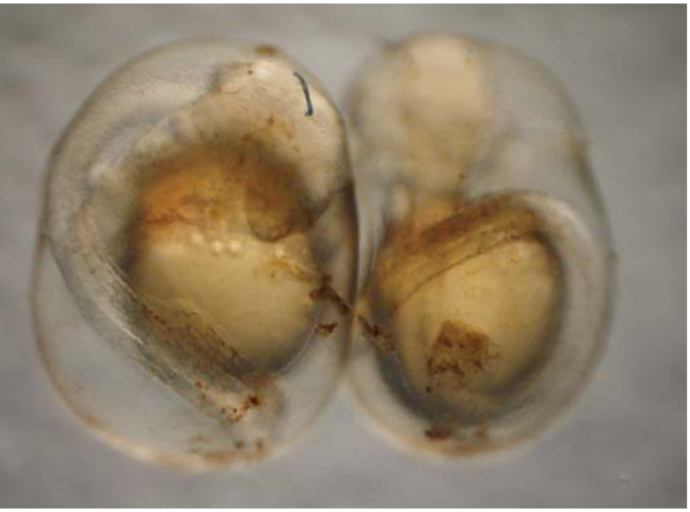
A large seastar leaves its mark as it wanders over muddy sediments in the deep Norwegian Sea.
© National Oceanography Centre, Southampton

Mayhem On The Slope

Continental margins are not the quiescent areas once imagined. The slopes bordering the continents can suffer catastrophic events; the most impressive catastrophe occurring on the continental slopes are the giant submarine landslides. One of the largest is the *Storegga* suite; three slides whose immense headwall, nearly 300 km long, runs along the edge of the continental shelf off the coast of Norway. The first and most impressive slide occurred 30 000 to 50 000 years ago giving rise to a tsunami on the West coast of Scotland. The slides, together with the last glaciation event, probably caused massive extinctions in the deep Nordic Seas. Since then, re-colonisation of the deep Nordic Seas has been slowed by the presence of shallow submarine sills acting as a barrier to dispersal. Even now these continental margins are less diverse than the rest of the North East Atlantic.

Grand Canyons

Canyons are deep incisions of the continental shelf and slope with many different origins, which explain the jagged outline of the European ocean margin. Not all canyons are connected to a river but where they are, they can quickly carry out huge quantities of sediment from the shelf to the abyssal plain. Sediments can also accumulate in the upper to middle



Above, right: In the abyssal Pacific Ocean at 5000 m, a sea cucumber, *Psychropotes longicauda*, ingests sediments from around a field of manganese nodules. © Ifremer/Nodinaut cruise (2004)

Above: These sea lilies, *Koehlermetra porrecta*, relatives of sea cucumbers and seastars, gracefully swim to find the best feeding spots. Here they are found at the top of a coral mound situated off Ireland. © Ifremer/Caracole cruise (2001)

Left: Deep-sea fish eggs with developing embryos. © Anne Stene

part of the canyon until they collapse creating a **turbidity flow**, which like an avalanche of mud can be devastating. Very few species are likely to survive such events, but in fact little is known regarding the fauna inhabiting active canyons.

Deep Secret Gardens

Coral reefs on continental margins have been known from the 18th century. It is only recently, due to submersibles, that they have revealed gorgeous sceneries, which have no reason to be envious of their shallow water tropical counterparts. Unlike their shallow-water cousins, deep-water corals always lack symbiotic light-dependent algae. Of the 672 species of these **non-symbiotic stony corals,** about 500 live in deep waters, up to a depth of 6000 m, but only a few of them are able to build large reefs in deep waters. The most common of these reef-building species is *Lophelia pertusa*. Over the last thousand to million years, this species has built giant **carbonate mounds** up to 300 m high and several kilometres in diameter on continental slopes, home to a diverse though fragile ecosystem in the deep sea.

The Great Expanse

Timeless And Endless ...

As we walk just a few steps away from the last foothills of the **continental rise**, take a look around and you will most likely be closer to experiencing the stillness of outer space than on any other place on Earth.

We have reached the endless expanse of the abyssal plains, consisting of a very thick blanket of mostly muddy sediments lying, on average, under 4000 - 5000 m of water, smoothing out any roughness of the underlying oceanic crust. The marine snow thins out with very little settling on the seafloor. It amounts to just a few millimetres to centimetres in a millennium; it is rarely disturbed by currents, and is only occasionally stirred up by fish or squid and sometimes human activity. Stones and boulders that have been released from the undersides of the melting icebergs, or rolled down the continental slopes, lie in the same position for tens of thousands of years until we pick them up by chance in our nets or cores.

Most of the Earth's unbroken abyssal plains are in the Atlantic Ocean because it is the quietest ocean as far as volcanic activity is concerned. The largest plain, the Sohm Plain east of Newfoundland, is hundreds of kilometres wide, thousands of kilometres long and encompasses an area of approximately 900 000 km². The well-known "ring of fire" surrounding the shores of the Pacific Ocean are responsible for the much greater dynamic conditions seen in this region. Thus the abyssal plain in the Pacific Ocean contains greater amounts of exposed rock compared to the Atlantic.

...But Not So Quiet

The apparent timelessness and endlessness of abyssal plains is only one side of the coin.

A sea lily, *Anthedon petasus*, fixed on corals spreads its arms in the current to feed on small particles in the water. © Ifremer/Caracole cruise (2001)

A brittle star climbs to the top of a sea pen to reach the best position for feeding on passing food particles. © David Shale

Turn it over, and you will be offered a closer look at this far away world through a magnifying glass. Regardless of having been proven wrong many times about the diversity of life in habitats that are foreign to us, even scientists used to think of the abyssal plains as deserts; practically devoid of life except for the occasional giant squid or bizarre looking fish waiting sluggishly for something edible to come by.

Eternal darkness, the pressure of several hundred atmospheres, a constantly low temperature close to freezing point, and the obvious scarcity of food do not appear very inviting to us.

An impressive deep-water fish,
Gonostoma sp © David Shale

We were proven wrong yet again! The wonders of life on the abyssal seafloor take place in the world of the small and very small organisms. The diversity of life here is just as breathtaking as in any other marine environment. As such diversity can only develop if a habitat can somehow be divided among the species inhabiting it. The organisms living in or on the sediments of abyssal plains have managed to do so in such a way that is still hidden to us.

Of course there are larger animals too. In fact, the first photographs ever taken in the deep sea, were published in 1971 by Bruce Heezen and Charles Hollister. The photographs showed large animals, all belonging to the echinoderms, mainly sea cucumbers, the somewhat sluggish cousins of sea stars and sea urchins. They were observed and photographed ploughing through the soft sediment, leaving characteristic trails behind them.

For all abyssal animals, large or small, life is either feast or famine. Over long periods of time, food is scarce because there is no plant life in the absence of light. But the seasons are felt, even down here five kilometres away from the sunlight. When conditions are right far above the seafloor, algae undergo mass developments, turning surface waters green, until the population finally dies as a result of lack of oxygen. Even though it takes several weeks for the dead cells to sink to the deep sea floor, they are perceived as a food pulse by the communities on the seabed, allowing the animals to store enough energy to reproduce, which is energetically a costly affair. Producing eggs and sperm is only the first step; somehow making sure that they get close enough for fertilisation is another, not to mention brooding behaviour that some species exhibit to protect their young from becoming their neighbours next tasty meal.

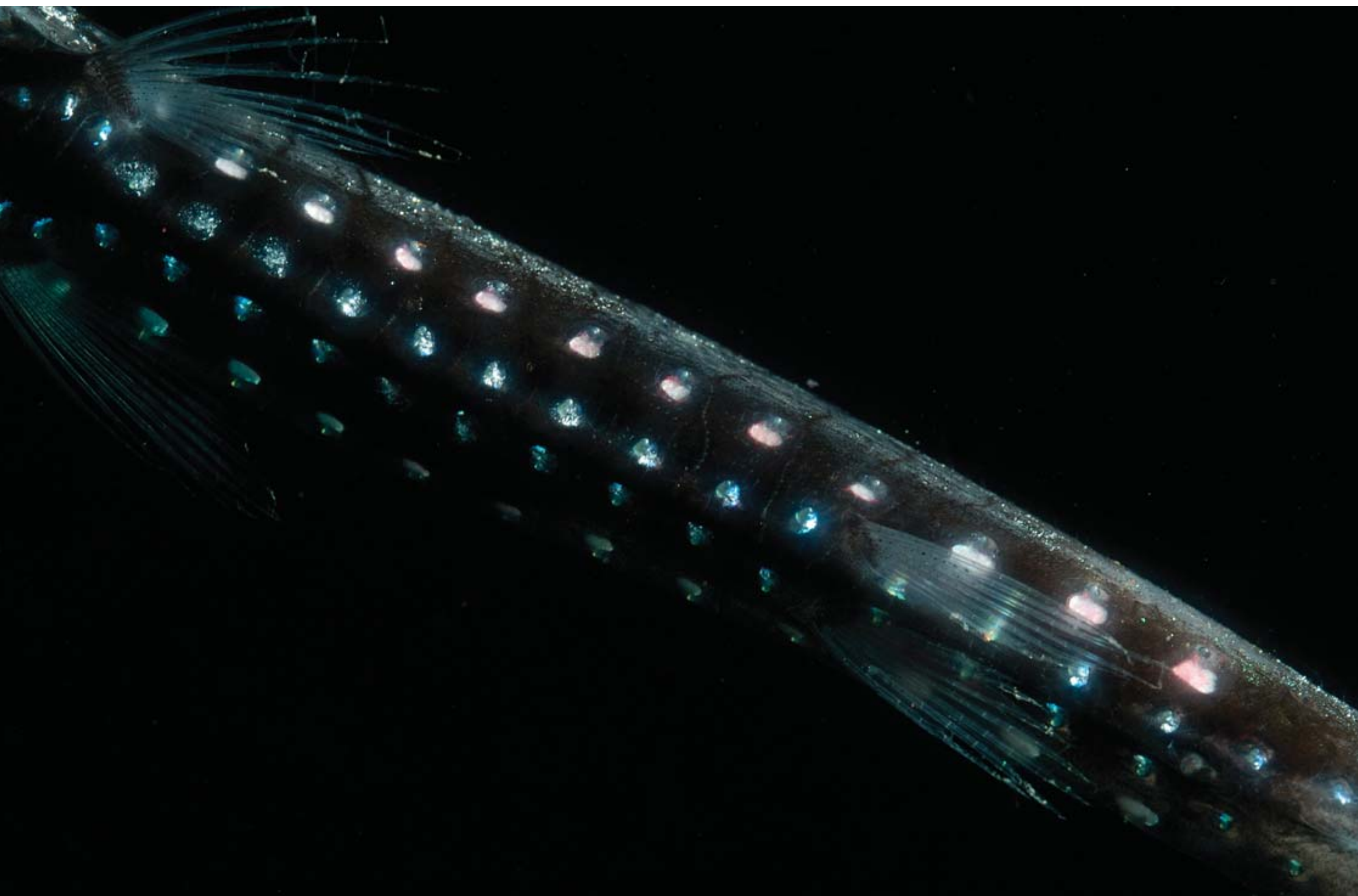
Himalaya In The Deep Sea

We started our gradual descent into the deep sea along the continental margin, taking in numerous different types of habitats: we have crawled through mud's dominated by worms, slid carefully down slopes trying not to cause an avalanche, clambered gently over the unexpected yet beautiful deep-water reefs, wandered through what at first glance appears to be an expanse of nothing and have now been stopped in our tracks by a Himalaya in the deep sea.

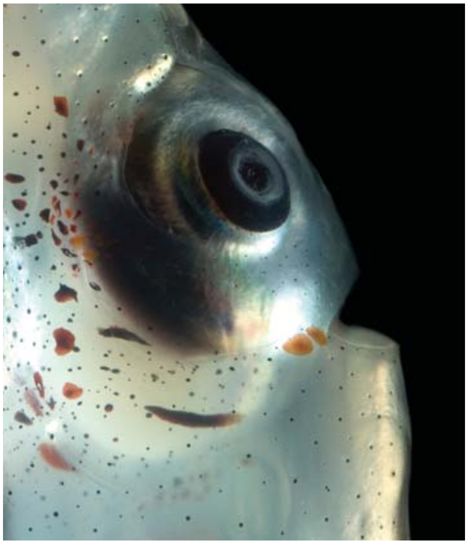
The Birth Of The Ocean Floor

The longest mountain ranges in the world exist in the depths of our oceans. At approximately 60 000 km in length and in some places more than 800 km wide, they are certainly impressive! These underwater mountain chains, known as mid-ocean ridge systems, are being created where the Earth's

Impressive light organs are found on the body of this fish *Gonostoma sp*. © David Shale



The keen eye of a cephalopod, *Gonatus steenstrupi.* © David Shale



tectonic plates are being pulled apart. New **magma** is constantly emerging onto the ocean floor at the ridge axes and as it crystallises, it forms new crust (basalt and gabbro). The rate at which a mid-ocean ridge creates new material is known as the spreading rate, and is generally measured in millimetres per year. These rates can very from ~10 mm/yr to over 100 mm/yr, depending upon location.

It is truly amazing that we knew little of their existence before 1950! These massive

A large deep-water octopus, *Benthoctopus sp.* © David Shale

A sea urchin makes tracks on the deep sea bed. © National Oceanography Centre, Southampton

ridge systems which wind their way between our continents lay undiscovered until a team of scientists led by Marie Tharp and Bruce Heezen discovered an enormous mountain chain running along the middle of the Atlantic Ocean.

It was initially thought that this phenomenon was only to be found in the Atlantic. However, data gathered by oceanographic surveys conducted by many nations over the next few years led to the discovery that every ocean contained parts of the ridge system and that they joined up to form this spectacular geological formation.

Mid-ocean ridges are dynamic environments and are literally renewing the surface of our planet. Thousands of volcanoes and volcanic ridge segments are found on the ridge and indeed, some of the most active volcanoes on Earth exist here – eruptions are frequent. Occasionally the ridge breaks the surface of the ocean to form islands; examples of these are Iceland and the Azores in the Atlantic. The landscape (topography) of

A 4 cm wide jellyfish, *Aeginura grimaldii*, collected from 900 m depth over the Mid-Atlantic Ridge. © David Shale

a mid-ocean ridge consists of numerous rugged hills, rising on average to about 4000 m above the sea floor, valleys, and deep fracture zones, the deepest of which can be more than 4000 m deep.

The Ridge Snack-Bar

The mid-ocean ridges have recently been discovered to house a much higher level of animal diversity than previously thought. Some of the reasons given are the high levels of productivity found around these ridges, a similar phenomenon seen around many seamounts. So why is productivity at these ridges so high when they are so far from land? After all there is no input of terrestrial nutrients and organic matter to these regions. The complex topography of the mid-ocean ridges strongly influences the **hydrography**, including the pathways of deep-water oceanic currents and water masses. As a result deep cold water containing lots of nutrients is sometimes forced upwards towards the surface of the ocean providing increased nutrients allowing for the explosion in biological production, in particular the growth of algae, the plants of the ocean. Feeding on the algae are other small animals and in turn they are preyed upon by larger animals. Production increases up the **trophic** levels.

Mid-ocean ridges act as vertical ladders for the movement and mixing of animals throughout the full depth of the ocean. Biological production in the surface-layer may be elevated around seamounts and ridges compared with the much deeper adjacent ocean basins. Scientists have for example thought of deep sea **pelagic** fish as nomadic wanderers, but recent studies along the Mid-Atlantic Ridge gives evidence that deep sea pelagic fish are more closely associated with the topography of the ridge, and that these fish are congregating at the ridge, ready for spawning.

Animals such as whales also appear to seek out such areas of high food abundance. Many of these "snack bars" also happen to coincide with the migration routes of whales and dolphins. In the Atlantic, an example of these are areas of the Mid-Atlantic Ridge between Iceland and the Azores. It seems to be a favoured migration route of some of the large whales.

This lizard fish, *Bathysaurus ferox,* is an ambush predator often observed resting on the seabed. © David Shale

Deep Chemical World

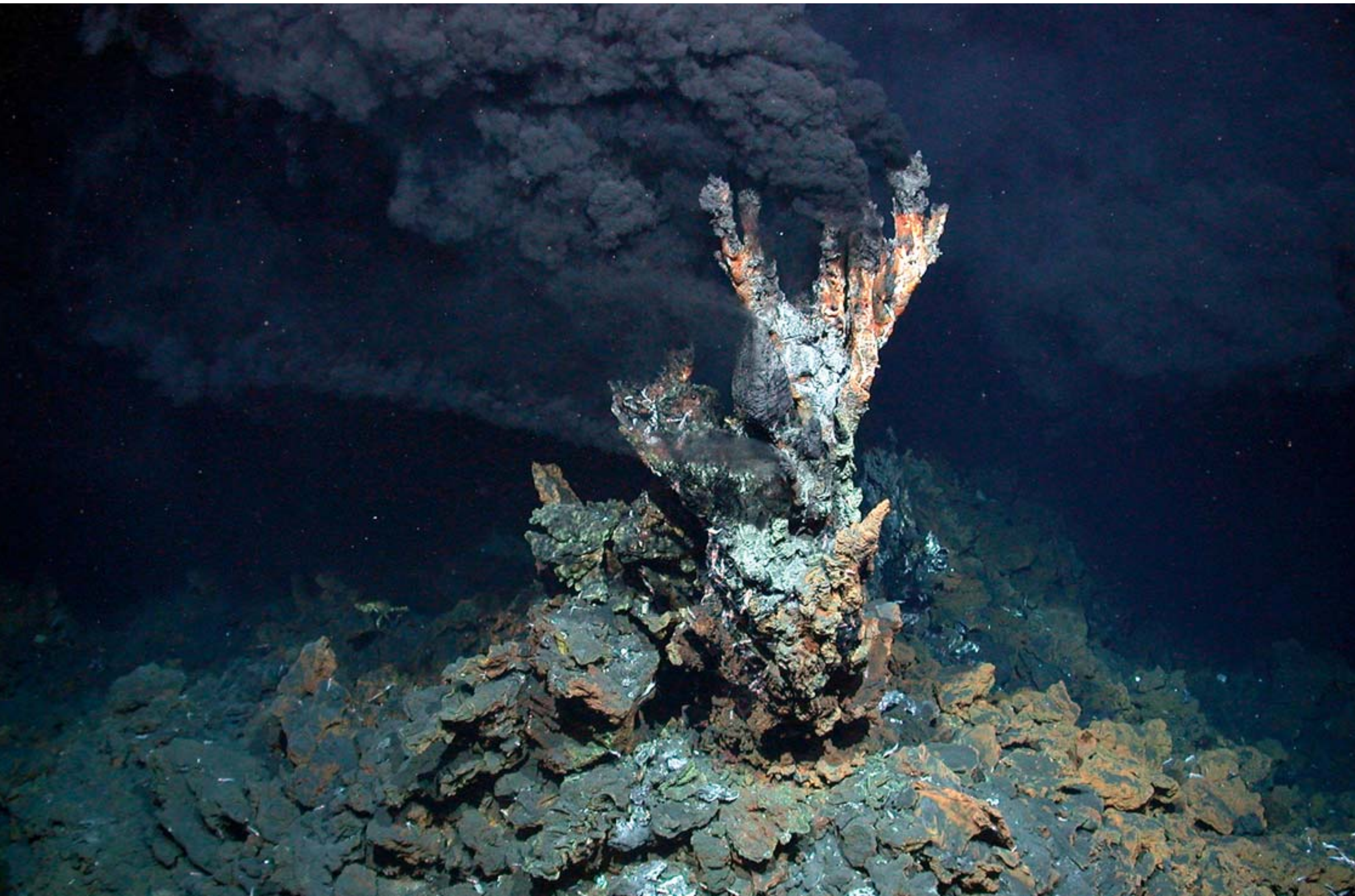
As we traverse the mid-ocean ridge we are shocked when we stumble into hot water... literally!!

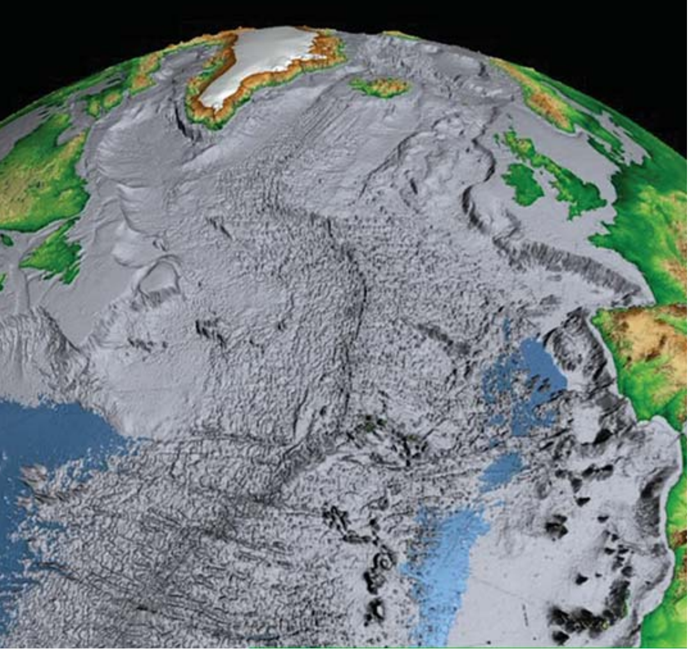
Black Smokers

1977 was the year of a major discovery that would change our understanding of life on our planet: an extraordinary landscape of underwater volcanoes – called hydrothermal vents - and new bizarre animals were found.

Vents are found on volcanic mountain ranges, called mid-ocean ridges. In these dramatic regions where tectonic plates are being pulled apart and new seafloor is being created, cold seawater (2 °C) penetrates the **ocean crust** and is heated to temperatures as high as 400 °C. This super-heated water, known as **hydrothermal fluid**, rises back to the seafloor

The first black smokers discovered on the south section of the Mid-Atlantic Ridge, 2005.
© University of Bremen





The ocean has been drained from this image of the Earth to reveal the northern portion of the Mid-Atlantic Ridge, which extends from pole to pole. © DLR and Nils Sparwasser

A computer generated image of the mid-ocean ridge system. © NRK

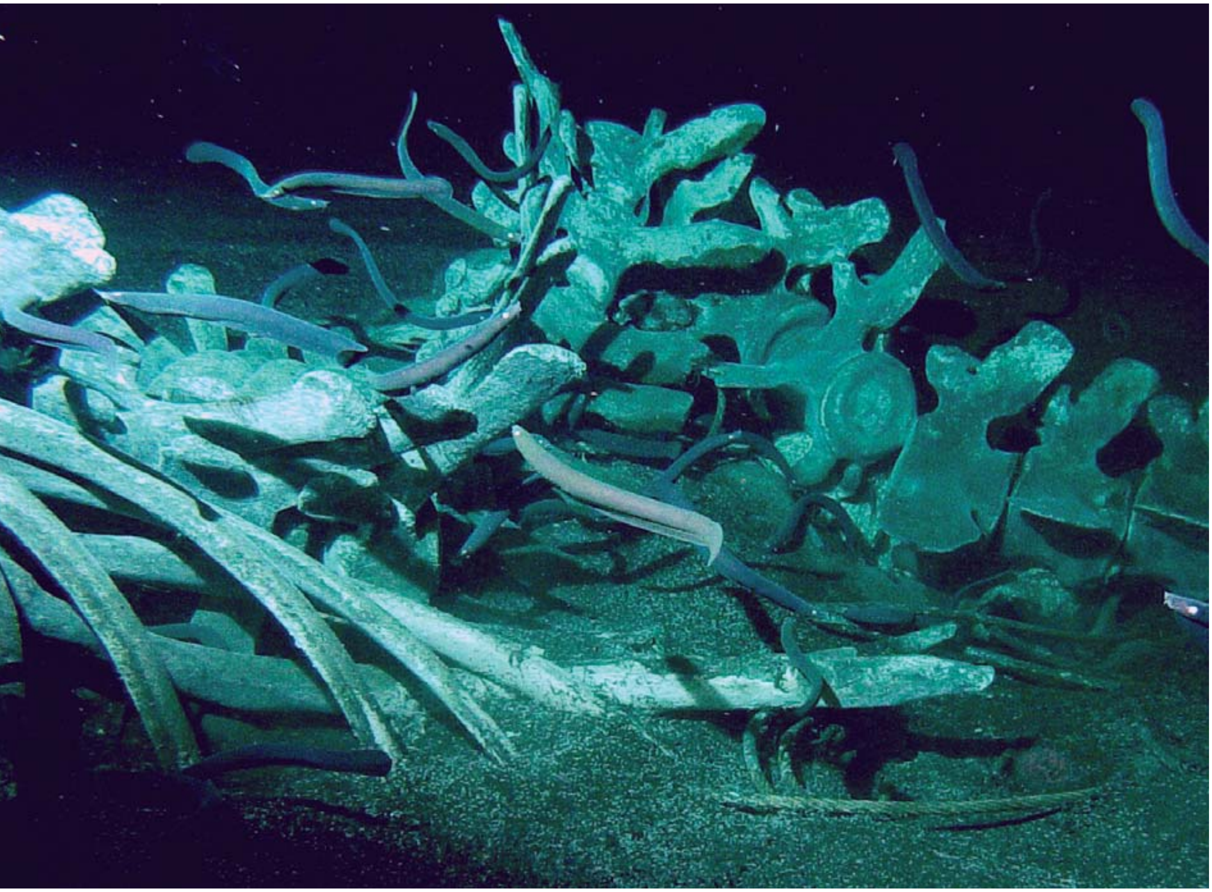
having lost all its oxygen and now is full of chemical compounds and dissolved metals. The fluid is spewed out back into the cold deep ocean where the metals come out of solution. The shimmering fluid looks like dense, black smoke coming out of chimneys which may be as tall as houses: the **black smokers!**

The vast majority of life on Earth relies directly or indirectly upon energy produced from the sun. This solar energy is used by plants, algae and some bacteria for the production of organic matter via a process called **photosynthesis**. This may then be used as food to sustain life forms ranging from bacteria to blue whales! Finding thriving communities of animals on the vents was really surprising, as the environmental conditions are extreme for life as we know it. The temperature varies from 2 °C to 400 °C in only a few centimetres! Some of the chemicals (methane and hydrogen sulphide) and metals found in the vent fluids are highly toxic. Surprisingly though, it is these same chemicals that provide the necessary energy needed for the development of such exotic life in the absence of sunlight. The vents are inhabited by micro-organisms, like bacteria, that use the energy of the chemicals to produce organic matter through a process called **chemosynthesis** as opposed to photosynthesis. These bacteria live free on the seafloor, forming large bacterial mats which are visible to the human eye! They are also found living with large animals in a mutually beneficial relationship (symbiosis) where the animal provides the necessary chemicals and in return the bacteria provide the newly formed organic matter for food. This relationship is the most important adaptation in the vent ecosystem and is responsible for the very high densities of ani-

An oasis of life on an East Pacific Rise hydrothermal vent, with giant tubeworms, mussels, vent crabs, snails and a fish.

mals on and around vents. These are the oases of the deep oceans! An explosion of life, but the number of different species is actually low, and is a characteristic of ecosystems with extreme environmental conditions.

Since the discovery of vents, hundreds of new species with interesting adaptations have been described. Take a submersible ride to the East Pacific vents and you will find giant tubeworms *(Riftia pachyptila)* that do not have a mouth or gut, feeding only from their symbiotic bacteria. Or you could see a group of smaller but just as fascinating worms (*Alvinella pompejana*), called the Pompeii worm because they live in tubes on active chimneys where the fluid can be, for short periods of time, as hot as 60 °C! Travelling south, you could come across Yeti crabs (*Kiwa hirsuta*),



A bacterial oasis forms on whale bones. © Craig Smith, University of Hawaii

a beautiful white crab with long hairy legs and arms! Change oceans now to the Atlantic, and from the submersible porthole the scene is very different. Thousands of shrimp (*Rimicaris exoculata*) cover the walls of the black smokers. They do not have eyes, but a modified organ, very sensitive to the low **radiation** of vents, which allows them to move around without getting burnt!

Deep-Sea Champagne

Hydrothermal vents are not the only deep sea ecosystem sustained by chemicals. Cold fluid, laden with hydrogen sulphide, methane and other hydrocarbons, seeps and bubbles through the sediment in certain areas on continental margins. In 1984, dense communities of golden mussels and white and red tubeworms were found for the first time on **cold seeps** in the Gulf of Mexico. Since then, similar habitats and striking animals have been discovered all around the globe, at depths between a few hundred to a few thousand metres.

Tubeworm bushes from the Gulf of Mexico cold seeps. © Charles Fisher, Penn State University

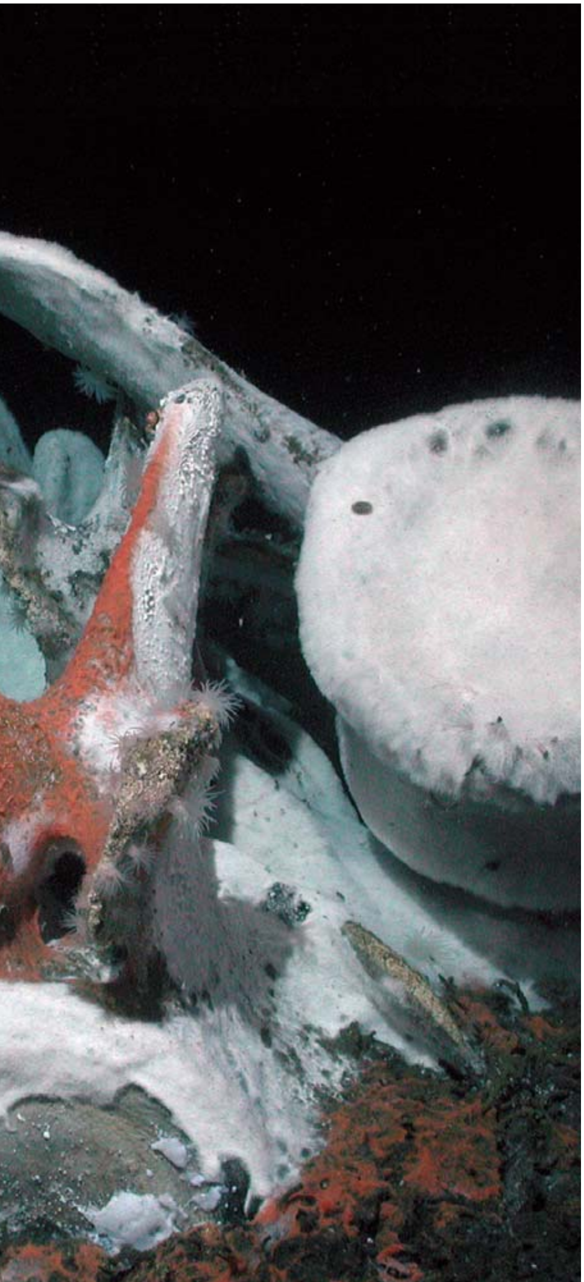
Fatty Bones

Five years on, further exciting discoveries were made…**whale falls!** In 1989, a whale skeleton was found, by chance, on the Pacific

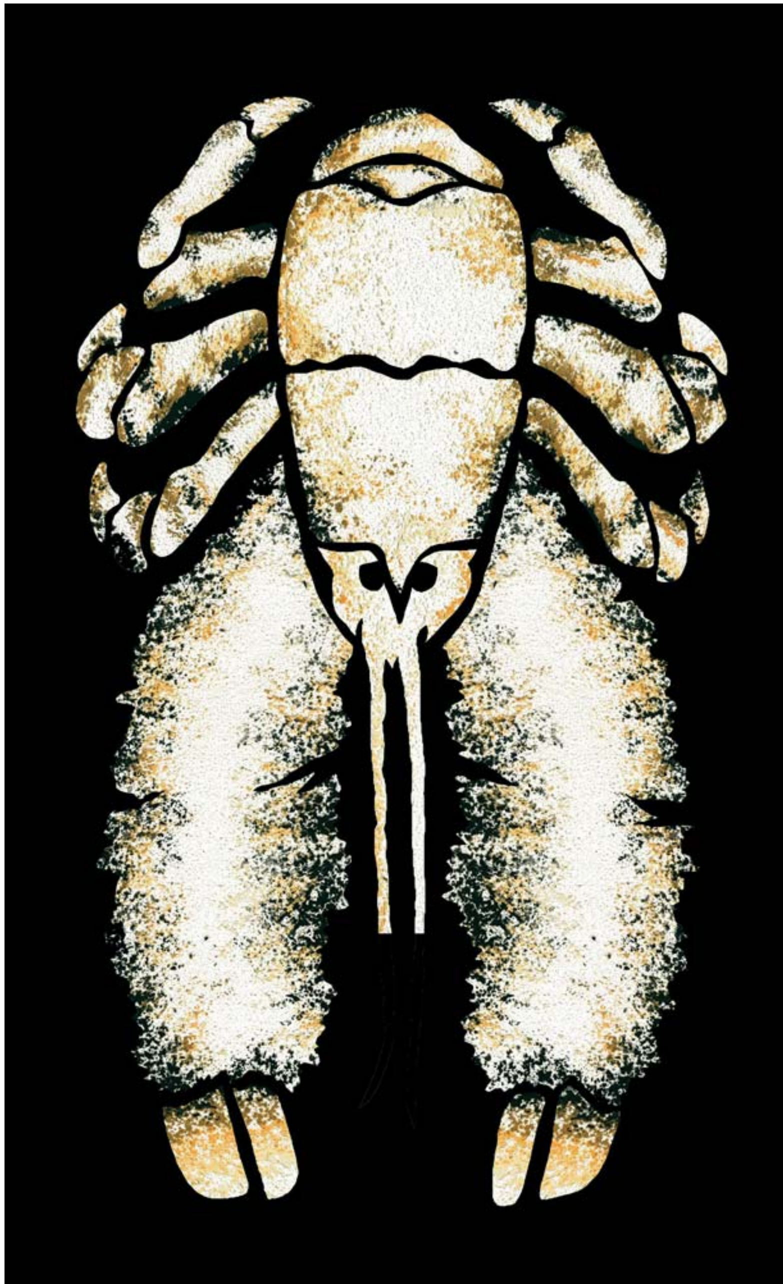
For over four years, the bones of this 35 ton grey whale have been on the bacteria. © Craig Smith, University of Hawaii

Ocean seafloor. When the scientists analysed the bones in the laboratory, they found chemosynthetic bacteria and associated animals which had adaptations similar to those found on vents and seeps. Since then, many studies have shown that the high concentrations of fats (lipids) in whale bones are broken down by bacteria producing chemicals such as hydrogen sulphide, which is the base for a chemosynthetic-based ecosystem.

seabed and are now covered with thick mats of chemical-loving



Artistic impression of the "Yeti crab" – a new species found at hydrothermal vents on the Easter Island microplate in 2005. Artist: Raymond Cowling, © ChEss



Free Fall From The Surface

Having tumbled down the continental slope and margin, walked on the flat abyssal plain, hauled ourselves over mountains and gazed in awe at billowing black smoke we suddenly wonder what is above us. It is now time to discover the animals and plants living in the water column.

Touched By The Sun - Down To 200 m

Almost all organisms of the oceans ultimately depend on the organic matter produced in this sunlit surface layer.

Plankton have limited mobility and must drift wherever the currents take them. Most are microscopic organisms and plants, but some are very big indeed, such as jellyfish, with tentacles longer than 30 m, and giant colonial animals such as **pyrosomes** that form tubes that even a diver can swim through!

Phytoplankton, the plants of the ocean, are eaten by small drifting organisms namely

A crustacean of the family of *Lophogastrida*, spec. *Gnathophausia zoea.* © David Shale

A majestic red octopus, *Stauroteuthis syrtensis*, found at depths ranging from 500 – 4000 m. © David Shale

zooplankton. Plant-eating zooplankton come from many different groups, but the copepods which are mm-sized crustacean, can really be regarded as the "cow or antelope of the oceans".

Big crustaceans such as shrimps, krill and amphipods, and a wide range of **gelatinous** zooplankton prey on the plant-eating zooplankton such as copepods. In turn these larger carnivores are consumed by schooling surface fish, cephalopods, baleen whales and even birds.

At high latitudes the surface waters are important nurseries for the floating eggs and larvae of some deep-living fishes as well as being inhabited by super-abundant small schooling plankton-eating fish. In the North Atlantic, typical species include herring, mackerel, capelin, and blue whiting. At low latitudes, zooplankton density is lower; therefore the abundance of schooling surface fish decreases.

Large fish such as high-speed tunas, billfish, and sharks migrate vast distances and roam the surface ocean waters.

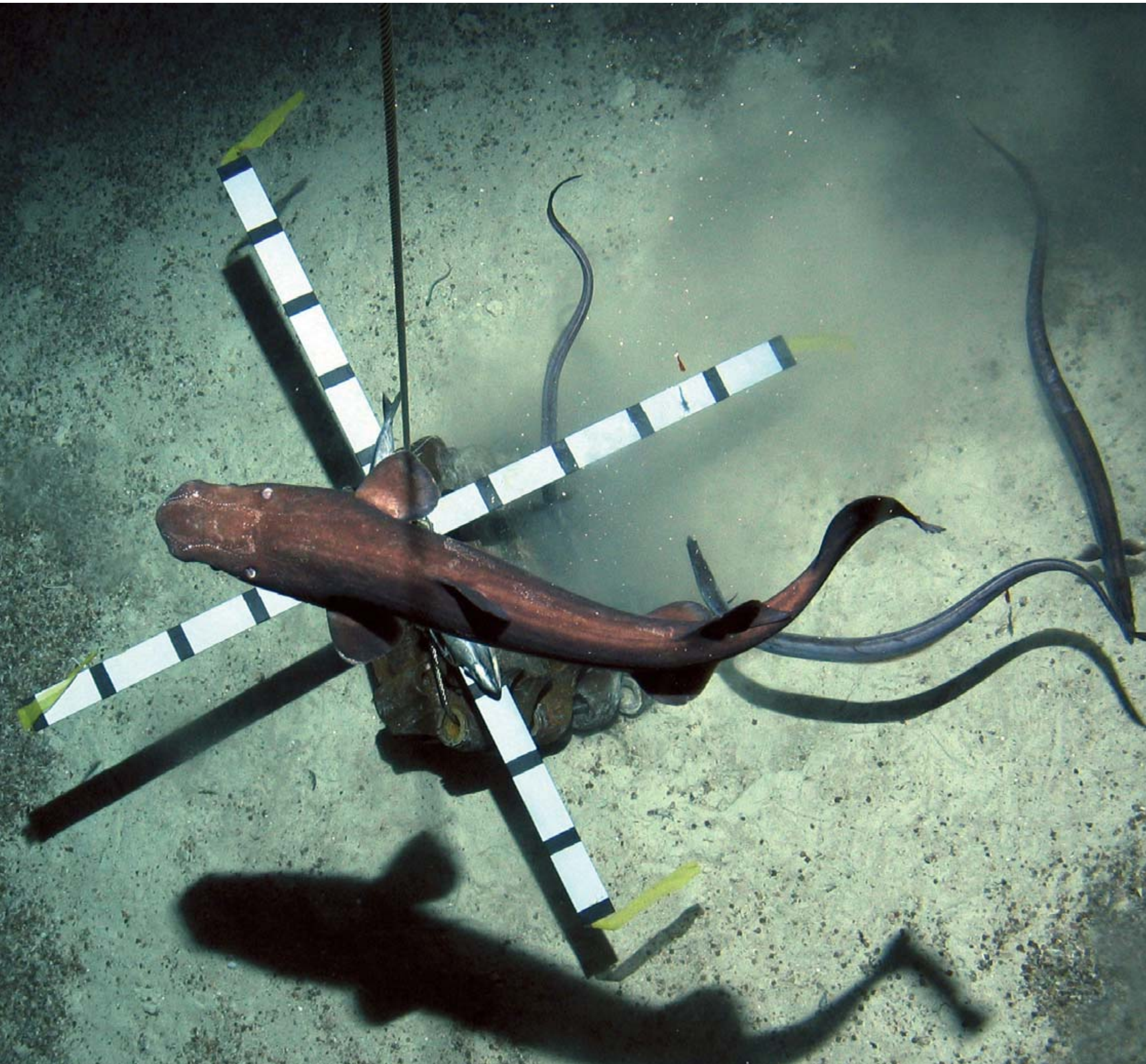
Whales are mammals which comprise animals from dolphins and porpoises to the baleen whales. Strangely, the baleen whales such as the blue whale at 33 m in length are the largest vertebrates on the planet, yet they eat by filtering tiny zooplankton from the water. The same is true for the world's two largest fishes, the whale shark and the basking shark. Toothed whales, which are generally smaller, prey mainly on fish and squid. The sperm whale, with its massive head and long lower jaw is an example of a toothed whale and hunts for squid and fish as deep as 2000 m.

Twilight Zone – Between 200 - 1000 m Depth

As we descend deeper and deeper the intensity of the sunlight gradually decreases with little left below 200 m. Animals below this depth experience an "eternal twilight". Many mid-water fishes migrate spectacular distances from their daytime depth of up to 1000 m to the surface layers at night, where they feed

Below: A squid showing off in the lights given off by the submersible from where this photograph was taken. © David Shale

A large shark investigates bait attached to scientific experimental equipment. © OCEANLAB, University of Aberdeen.



on zooplankton. Even small crustaceans migrate several hundred metres to graze on phytoplankton or smaller animals in the shallower depths. At night they are more difficult to spot by visual predators such as surface-dwelling fishes, birds and whales. This massive **diurnal migration** happening in all oceans is a primary mechanism for transport of matter and energy into the deep sea. Many of the migrators are red, silvery or black; colours that make them quite invisible at low light levels. Many also have rows of light organs along their underside. When they "turn their lights on" it is difficult for predators to see them against the background of the lighter surface waters.

Gelatinous plankton such as jellyfish, comb-jellies, sea butterflies and arrow worms consist mainly of water and are often transparent, making them almost invisible to predators. They are among the most beautiful and stunning organisms of the sea.

The majority of crustaceans living in the marine environment are hard to see in the dim blue light as many of them are red in colour. The most common are shrimps, krill, amphipods and copepods, many of which take part in the never-ceasing diurnal vertical migration cycle. The slogan is "eat and grow, but avoid being eaten", and many adaptations to avoid predators are remarkable. For example, some of the shrimps can create great clouds of light **(bioluminescence)** to blind potential predators.

This deep-water Oreo, *Neocyttus sp.*, inhabits rocky areas of seamounts and hills. © David Shale

The eye of a deep-sea squid is one of the most highly developed organs found in the marine world.
© David Shale

Deeper Than Light – Below 1000 m

Finally we reach the dark zone, the greatest living space in the ocean. Any light that is present here is produced solely by **bioluminescent** organisms. The water is uniformly cold, currents generally slower and the pressure is huge. At 1000 m the pressure is about 100 times greater than the pressure at the surface.

Deep sea organisms have therefore evolved special biochemical adaptations to enable them to cope with the elevated pressure. Even with a reduced food input at this depth, the dark zone has a rich diversity of drifting organisms. In the dark zone we find fishes with the weirdest adaptations to low food concentrations. Deep sea anglerfish have strange protrusions projecting from their heads; these are either sense organs or "fishing rods". The

The head of a snipe eel. © David Shale

tip of the modified first ray of the dorsal fin is an elaborate bioluminescent lure used to attract prey. Another unusual animal is the pelican eel; like the pelican bird, they have huge expandable mouths that they keep open almost as an inside-out umbrella in order to catch the rare prey.

Cephalopods have roamed all the world's oceans and all depths for more than 450 million years. All are carnivorous, preying on fishes, crustaceans and other cephalopods. They are also important prey items for larger fishes, whales, seals and seabirds. The deep-water cephalopods are particularly poorly known and new species are steadily being discovered. Octopods may swim by jet propulsion, by undulating interconnected tentacles and by fins. A long-armed squid reaching at least 3-4 m in length and displaying beautiful undulating wide fins was only recently filmed.

Glimpses Of The Deep

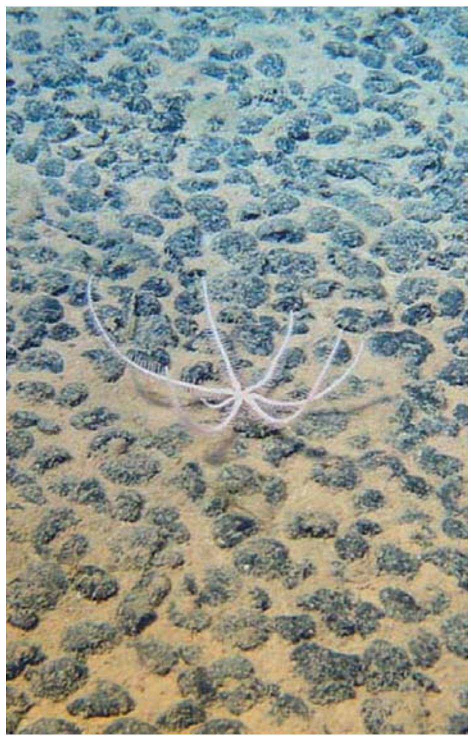
Now that you have been on your extreme ocean adventure, why not take a glimpse into the deep sea to find out more. Here follows a selection of fascinating snap shots of what lies beneath…

Reefs In The Dark

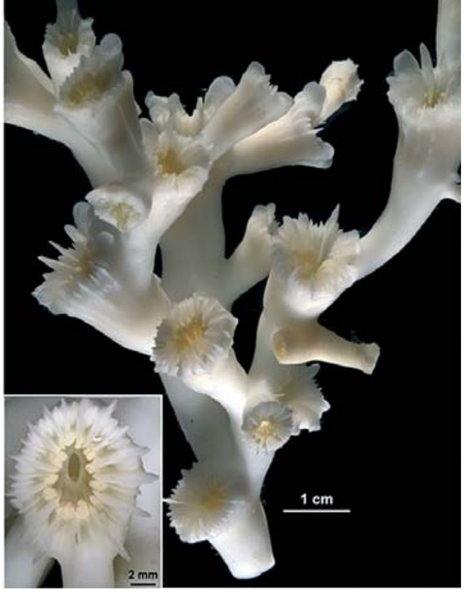
Let us go back about 10 000 years, at the end of the last **glacial era**. At that time, deep waters began to warm up; deep currents strengthened and hard **substrata** once buried under glacial deposits were exposed. This was the right time for cold stony corals to settle and grow in deep northern European waters, as they did repeatedly, during each interglacial era, for millions of years. Since then, some of these pioneers have built giant coral reefs. The largest one found was discovered in 2002, the Røst reef off Norway, and covers a total area of 100 km^2.

Colonies of the species *Lophelia pertusa* are the backbone of these reefs in the North-East Atlantic. Such colonies are made up of thousands of individuals called polyps, each of them sheltered in a skeleton. An individual colony builds up by budding, which means that polyps

Comb jellies are very common in the deep sea. This one, *Bolinopsis infundibulum*, is exhibiting the wonder of bioluminescence. © David Shale



Sitting on top of a nodule, rising its arms, this sea star *(Freyella sp.)* does its utmost to collect food at 5000 m water depth in the abyssal Pacific. © Ifremer/Nodinaut cruise (2004)



A gluttonous solitary coral, *Desmophyllum cristagalli,* feeds upon a fish, *Cyclothone sp.*, from the Santa Maria di Leuca bank off Italy. © RV Meteor M70/1, Erlangen

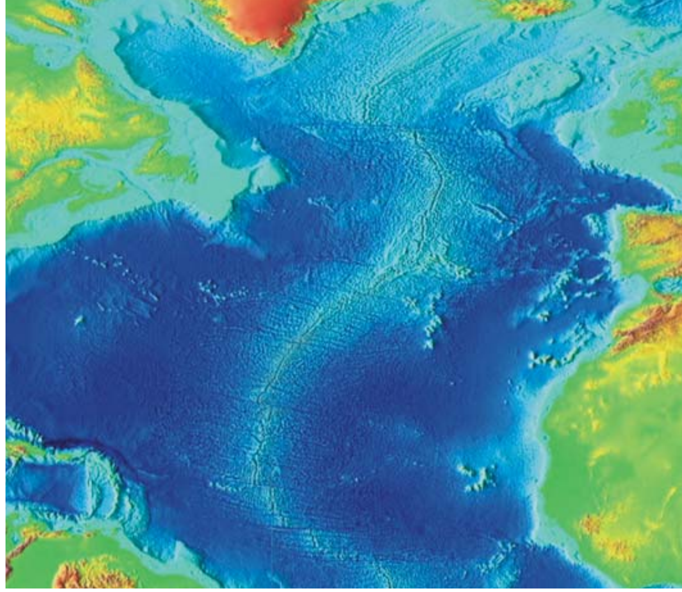
A fragment of a colony of the reef-building species *Lophelia pertusa*. The inset shows a close up of an individual polyp. © Ifremer/Caracole cruise (2001)

clone themselves. Their clones grow next to them, eventually forming a coral shrub. A colony is either male or female. New colonies are formed by sexual reproduction, the encounter between sperm and eggs hopefully ends up with larvae released in the sea, drifting with, and spread by currents. Some coral patches, the size of a basketball court and 1.5 m high, might have developed by the cloning of a single polyp, whose larvae once settled thousands of years ago. The tangle of white to yellow *Lophelia* shrubs harbours a variety of other, more delicate corals, which all benefit from this projection to literally fish for their food. Using their tentacles, they can poison live prey, which range in size from zooplankton to small fish.

Of Sponges And Worms

When one lives on the seafloor, places to hide are a precious commodity. Predators are able to attack you from all angles. If you are an animal that is able to burrow into the sediment, you can quite easily and quickly disappear. However, there are many animals such as small crustaceans, with legs and antennae ten times longer than their bodies that are much too delicate and therefore unable to penetrate the mud. Any suitable shelter is therefore most welcome, but is extremely hard to come by on the abyssal plains. The additional advantage of having a sheltering structure that extends above the surface of the sediment is their ability to trap sediment and food particles on the down-flow side, much like sand on the beach piling up behind sticks and stones. Whilst exploring the distribution of small sponges on the deep sea floor, scientists found that even a tiny single sponge can provide refuge for small threadlike worms, the **nematodes**, living in the soft sediment layers, suddenly giving structure to a seemingly endless expanse. Even the smallest amount of sponge **spicules**, the skeleton re-

A tangle of corals (*Lophelia pertusa* and *Madrepora oculata*), sponges, sea stars and sea urchins. © Ifremer/Caracole cruise (2001)



The North Atlantic Ocean. The rugged Mid-Atlantic Ridge rises from the deep ocean floor as a gigantic mountain chain. © IMR

mains of dead sponges, can influence the abundance of animals living in the surrounding sediment. The spicules may even be the single most important cause for variability seen in faunal abundance. As the nematodes crowding around sponges or sponge spicules do not live on a particular diet, it is safe to assume that their presence improvesnutrient availability generally rather than causing an increase of a particular nutrient for the nematodes.

Finding New Species On The Mid-Atlantic Ridge

Only a tiny fraction of deep sea habitats have been sampled to date, so scientists expected to find new species and even new genera or families during a major expedition to the Mid-Atlantic Ridge in 2004. During the expedition they were amazed at quite how many species they did not recognise and were new to science; for example 20 % of the deep-water fishes observed were new discoveries in this area of the Atlantic. During the two-month expedition, researchers collected a huge number of animals – in total 80 000 - and of these, 60 000 were fishes. High species diversity was also encountered from many different faunal groups; fishes, cephalopods, bottom-dwelling invertebrates, plankton, fish parasites, marine mammals and seabirds. Images and video footage helped resolve a mystery surrounding an unidentified worm-like creature that turned out to be a new family. As scientists have time to examine the material closely, it is quite possible that they will find more new and exciting species. Describing new species is a task for taxonomists. However, **taxonomy** is time-con-

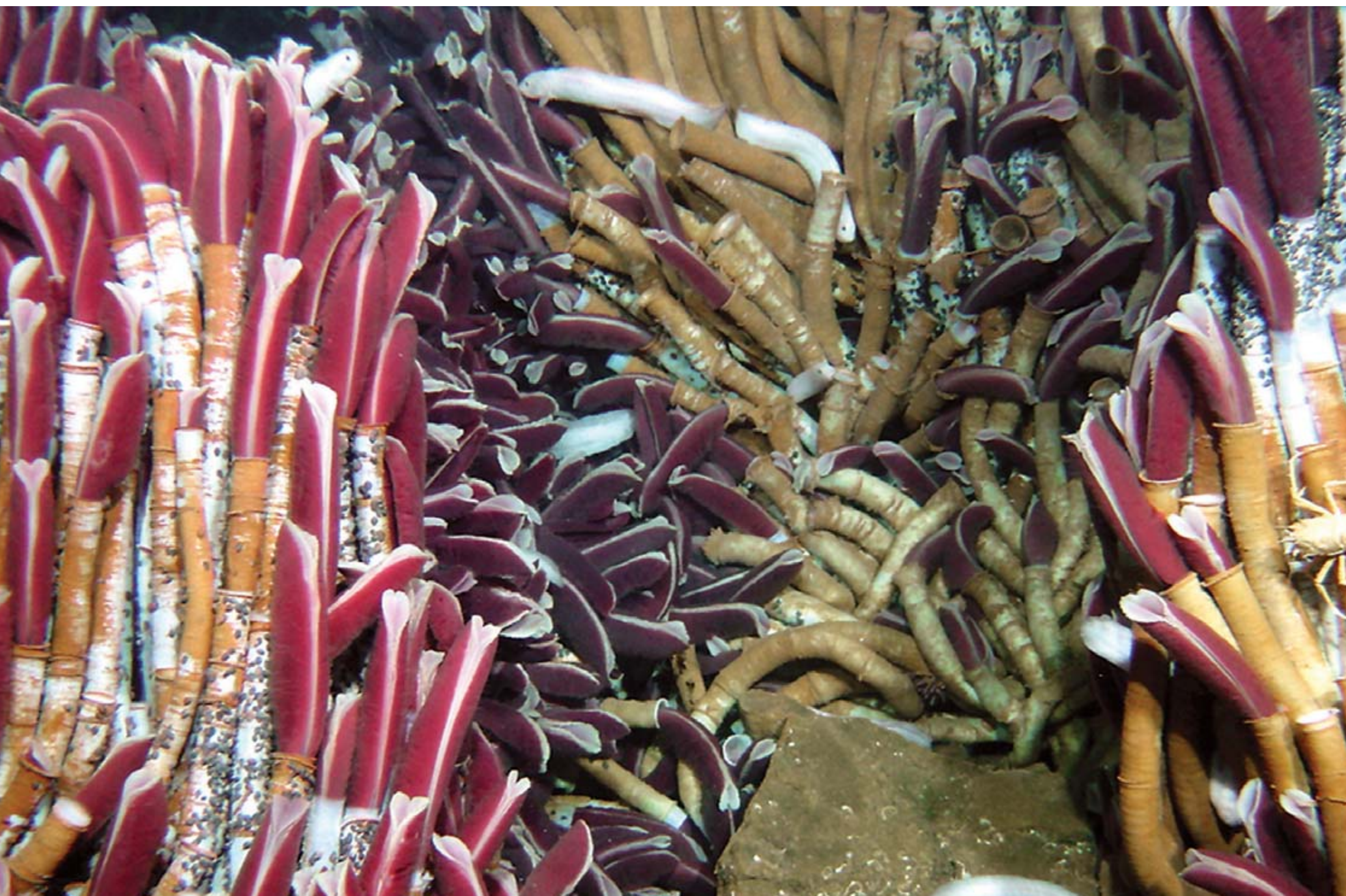
Page 48-49: This imposing-looking fangtooth fish, *Anoplogaster cornuta,* will actually fit in the palm of your hand! © David Shale

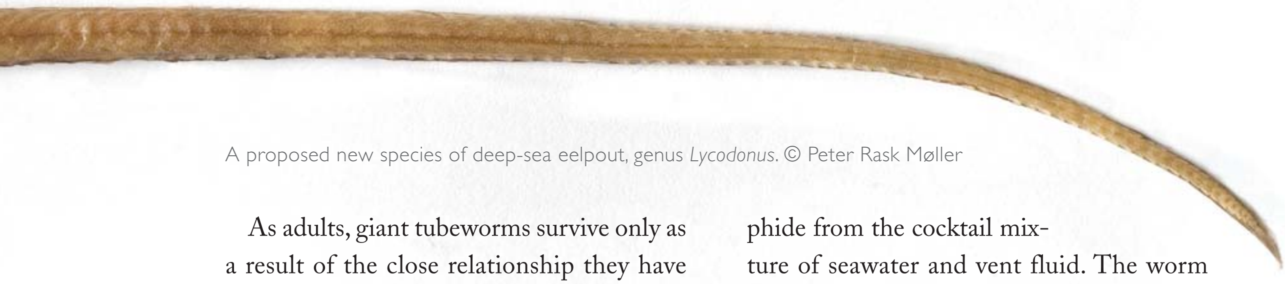
suming and there are stringent rules that have to be followed when describing a new species. The descriptions are not valid before a formal publication has been issued and a name has been accepted; all this takes time.

Gutless Worms!

Hydrothermal vents in the Pacific Ocean are home to one of the most astonishing creatures on Earth - the giant tubeworm, (meaning the thick feathered vent worm!). These giant worms can reach up to 1.5 meters long and may be as thick as a mans wrist - particularly amazing considering that when they are adults they have no mouth, stomach, intestine or anus! The worms live inside white tubes made out of a tough material called chitin (the same material your finger nails are made from).

A community of giant tubeworms, from the East Pacific hydrothermal vents showing off their beautiful bright red blood-filled plumes © Ifremer/Phare cruise 2002.

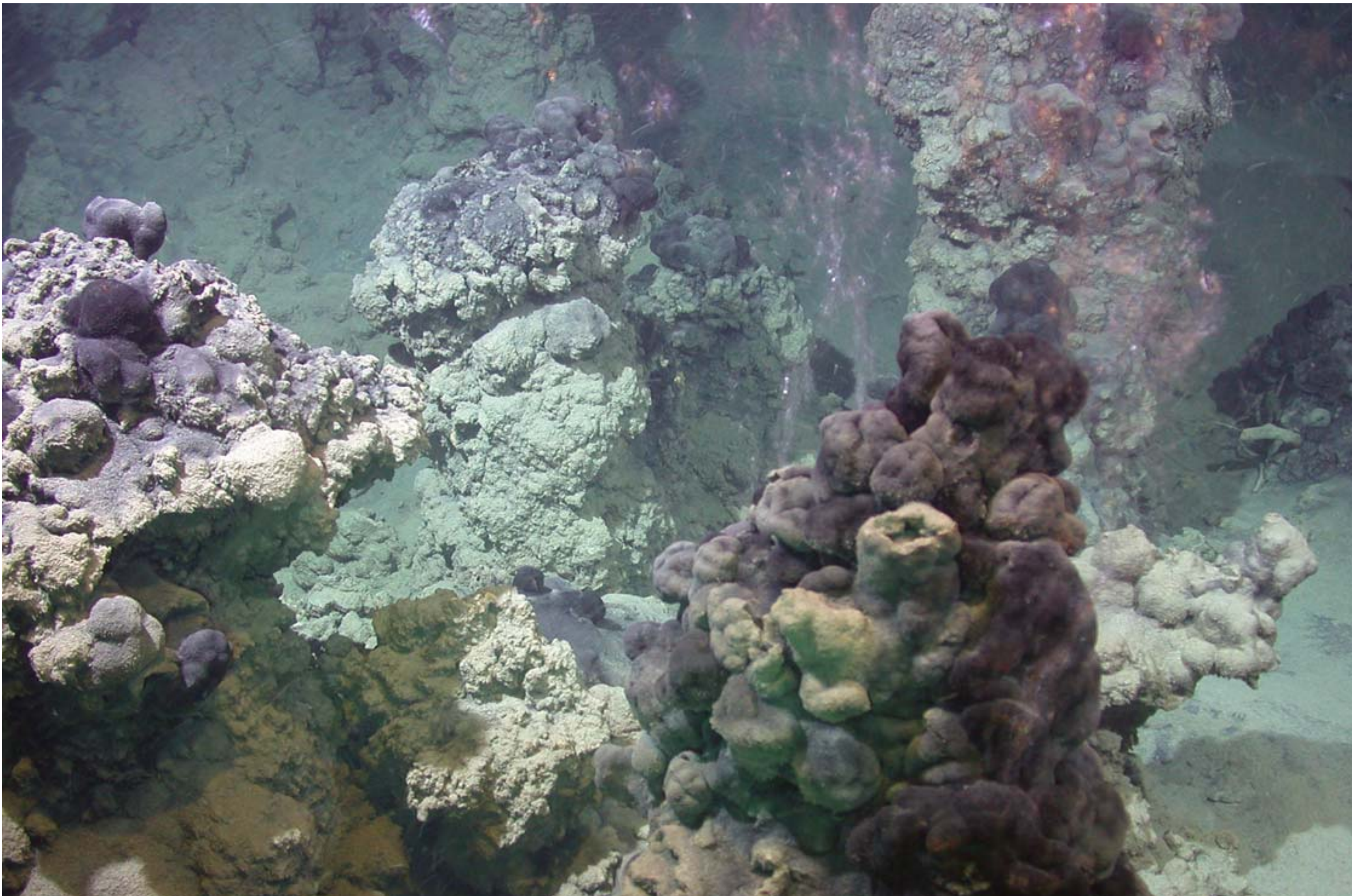




A proposed new species of deep-sea eelpout, genus *Lycodonus*. © Peter Rask Møller

As adults, giant tubeworms survive only as a result of the close relationship they have with bacteria. These bacteria enter the animal while it is still a juvenile through their primitive mouth and gut. As the worm matures, the mouth and gut disappear, trapping the bacteria inside the body cavity. The worms have a bright red plume of gills that poke out from the top of the tube. The blood-filled plume has the ability to take up oxygen, carbon dioxide and hydrogen sulphide from the cocktail mixture of seawater and vent fluid. The worm then transports these ingredients in its blood to a region called the **trophosome**. The trophosome is home to the billions of bacteria that act to sustain the life of the worm; these bacteria make up to about half the worms weight! They use the ingredients to manufacture food in the form of organic carbon that nourishes both the bacteria and the giant tubeworm.

A microbial reef that uses methane as a source of energy in the Black Sea.
© Antje Boetius, MAURM/Microhab



The Elusive Tube-Builders

Many of the animals living in abyssal sediments consist of only a single cell. Some of them protect the delicate **cytoplasm** surrounding the **nucleus** with shells, also called tests, which they build either out of substances that they produce themselves or out of sand and mud grains. These tests can be very solid, which makes it impossible to extract the animal from it to study.

A large group of unicellular organisms go by the strange name **Komokiacea**, Komokis for short. Their cytoplasm is strung out into a network of very fine extremities that are coated by tubules of sediment. In the spaces among the tubules, some species accumulate loose mud, resulting in shiny, drop-shaped or beadlike mudballs. Because of their unspectacular looks they have been overlooked for an inordinately long time, and to this day nobody has ever seen the cell itself. Recently, molecular geneticists tried to find out with modern methods just who the Komokis are related to. However, when they looked at the genes they found a whole cocktail of them, all belonging to other animals who apparently use the tubules as shelter. So even now we are still not quite sure who Komokis are related to, maybe sponges or another very common group of one-celled animals called **foraminiferans**. The generous tiny builder of the "little balls" continues to remain elusive, having proven resistant to even the most advanced methods in biology.

Mysterious Bacteria

If the 20th Century was marked by the discovery of high diversity in the deep sea, the 21st Century is possibly going to be marked by the recent discovery of a deep **biosphere**; that is to say bacteria in sediments living as deep as a thousand meters below the seafloor. This is a major discovery; in fact this deep biosphere may comprise a tenth of Earth's living bio-

A zoarcid fish swims over a community of the giant tubeworm Riftia pachyptila on an East Pacific Rise hydrothermal vent. © E. Kristof (National Geographic Photographer), R.A. Lutz and Woods Hole Oceanographic Institution.

Unusual bone-eating worms on whale bones found on the Japanese deep-sea floor. © Yoshi Fujiwara, JAMSTEC

mass. A striking feature of these bacteria is how they manage to feed and duplicate in deep sediments that are millions of years old. Scientists suggest that they may be able to fast for years, similar to a very long hibernation and that the community only duplicates once every 1000 years; something that scientists still cannot explain. Others suggest that the bacteria are in fact fuelled by some kind of radioactivity. Some of those strange organisms may also convert CO_2, the main greenhouse gas, into methane, a useful combustible, which already fuels chemosynthetic ecosystems where it leaks from deep sediments to the deep sea floor. Incidentally, large reserves of methane are known to lie below the seabed of the mysterious Bermuda Triangle. One theory now suggests that large leakages of gas might cause instability of the sea and an explosive mixture of air and methane above, enough for a ship or plane travelling over it to sink or burn. Between sustainable energy and piracy, the deep biosphere still has the capability to amaze us.

From Whales To Bone-Eating Worms!

A popular myth says that elderly elephants go to a special place at the end of their lives to die – the elephant graveyard. When a whale dies, it sinks to the depths of the ocean… a whale graveyard? There, it becomes part of the food chain and in an environment where food is scarce, it suddenly provides a feast! First to arrive are the scavengers, such as eel fish and crabs, which devour most of the flesh within months. They are followed by opportunistic worms and small crustaceans that thrive around the skeleton.

Splendid stalked barnacles growing near hydrothermal vents. © Charles Fisher, Penn State University

Finally, it is the turn of bacteria that break down the fats in the bones, producing sulphides. These chemicals are the energy source that then sustains the establishment of new animal communities. However, bacteria are not the only organisms to feed on the succulent lipids…

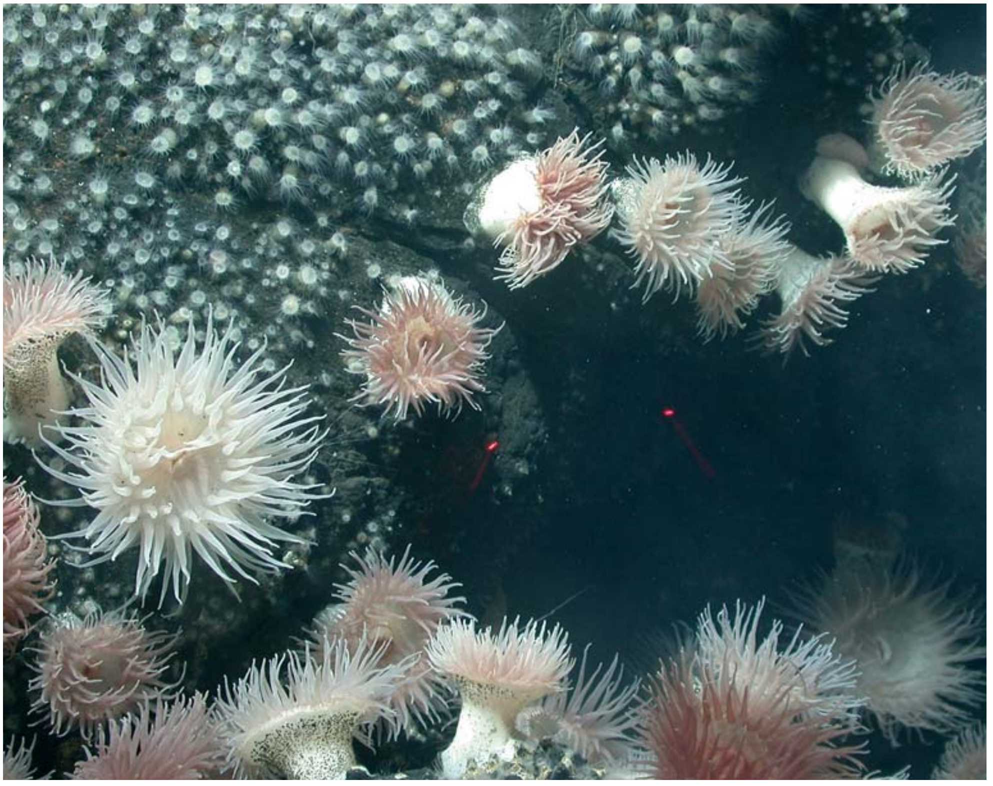
In 2004, a little worm called *Osedax*, or the zombie worm, was found on the skeleton of a grey whale in the Pacific. These worms, the size of a finger, have long roots on one end and beautiful red and white 'feathers' on the other. The roots penetrate the whale bones and are associated with bacteria that help digest the fats in the bones. The red 'feathers' are full of **haemoglobin** used for the transfer of oxygen from seawater to the animal and bacteria. Surprisingly, the worms seen on the whale skeletons are always females. The males never reach the bones, because, although attaining sexual maturity, they remain microscopic and live inside the females!

The deep-water amphipod crustacean, *Megalanceola stephenseni.* © David Shale

The History Book Of The Deep Sea

Think of a starry sky on a still cold winter's night and it seems to be the most peaceful place imaginable. A first glimpse of the deep sea and you also think how unbelievably tranquil and calm it is. However, if you look at time scales which are much longer than our lifetimes, the starry night is really a lively, vibrant environment, much like the deep sea which can be highly changeable and dynamic, although this can occur within our lifetimes; very different to the initial picture that we see.

Every so often, and probably much more often than we realise, giant avalanches of sediment roll down the steep slopes taking with them not only the usual fine-grained clay, but also quite coarse sand. If you were to cut out a piece of the abyssal sea floor, a bit like cutting a slice of cake with many fillings, you



Anemones from the Lau Basin hydrothermal vent region in the Western Pacific.
© Chuck Fisher, Penn State University.

would be surprised to see the number of layers of sediments of different grain sizes and colour. This is like a history book reporting on events of long ago. The origin of the sediment layers from the upper parts of the continental slope can be detected by the presence of millions of shells once made by shallow-water one-celled animals, such as the foraminiferans. In other layers, we also find shells (also called tests) of deep-water **protists** surrounded by very fine clay which have slowly settled through the water column.

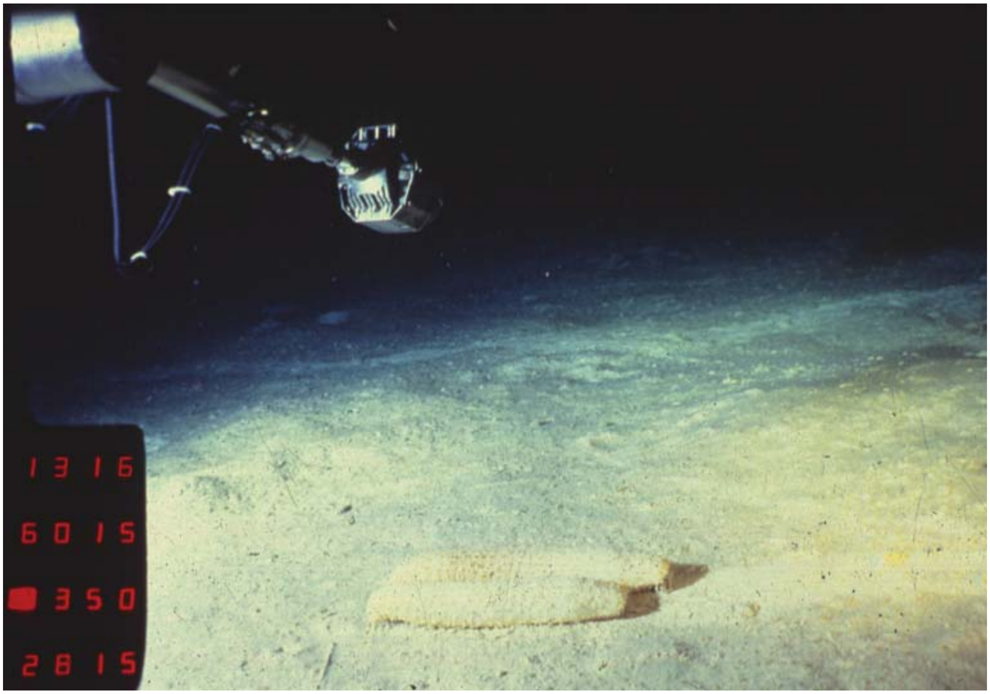
Deep Love Stories

Many marine animals produce offspring by releasing (spawning) large quantities of sperm and eggs in to the water column where fertilisation happens. This sounds easier than it is! Sperm and eggs quickly drift away from each other in the currents. However, when successful, embryos develop into microscopic larvae that are transported by the currents until they find a suitable home for settlement. In the deep sea, this is even more challenging... It is not always easy to find a mate when you are wandering around the vast expanse of the deep sea floor. To overcome this problem, some animals have developed interesting behaviour patterns. For example, sea cucumbers and sea urchins have been seen walking in pairs or herds around the deep sea floor. They cannot tell the sex of the individual next to them but when one starts spawning it may trigger the spawning of the rest….party time! By moving in groups, they increase the chances of their eggs and sperm finding each other. Other animals such as some worms, molluscs, crustaceans and fish have even more weird ways of ensuring they produce their next generation. The females of some species have normal-sized adult bodies…but the males are dwarfs, just a fraction of the female size, that attach to the females, their only role to produce sperm!

Earth's Hidden Diversity

Once upon a time, nearly 4 billion years ago, life appeared in the Ocean. During the following 3.5 billion years, life evolved solely in the seas. While the first plants invaded the land about 440 million years ago, almost all marine forms of life, including vertebrates, already existed. Today, most **phyla** are only found in the seas, which cover two thirds of our planet. Of

A pair of sea cucumbers find each other on the vast abyssal plains.
© Paul Tyler, National Oceanography Centre, Southampton



the 1.7 million species currently described, one million are insects but only 230 000 have been described from the marine environment and this is despite the overwhelming supremacy of sea over land. How can such a discrepancy be explained? Are the insects exceptionally gifted in terms of evolution or is there a hidden diversity in the ocean? Indeed hidden marine diversity may well lie in the deep oceans.

One of the most extensive studies undertaken on continental slopes suggests that over 10 million species may inhabit the deep sea floor even although the samples are equivalent to just 21 m^2 of mud. This estimation is controversial but it has the merit of highlighting how poorly known the deep sea ecosystem actually is. What is certain is that new species in the deep sea are collected at a much faster rate than the current ability of scientists to name them.

Light In Darkness

Below 1000 m all visible light disappears; here exists a twilight realm where organisms live in darkness, but are not completely without light. Bioluminescence is a visible light made by living creatures. It is the result of a highly efficient chemical reaction involving an enzyme called luciferase and a substrate called luciferin. The phenomenon is used by many organisms living in the deep sea.

Bioluminescent light has many functions. It can be used as camouflage, as a flashlight, for defence or to attract a mate. In the twilight depths the silhouette of an animal can be seen from below against the dim blue light filtering from above making it an easy target for predators. In order to camouflage themselves, some organisms emit light from their underside which they can control to make a perfect match in colour and intensity to the sunlight filtering down from above. This is called counter illumination. Others use bioluminescence to distract or blind a predator whilst some animals use light as a lure to attract their prey. The anglerfish uses a light organ at the end of a "fishing rod" that extends from its head in order to tempt prey to within easy reach. Finding a mate in the endless darkness can be difficult, especially since deep sea animals tend to be solitary and widely distributed. Therefore bioluminescence can be used in courtship and mate selection, which makes it easier for some species to locate partners of their own kind.

Salt Lake In The Deep

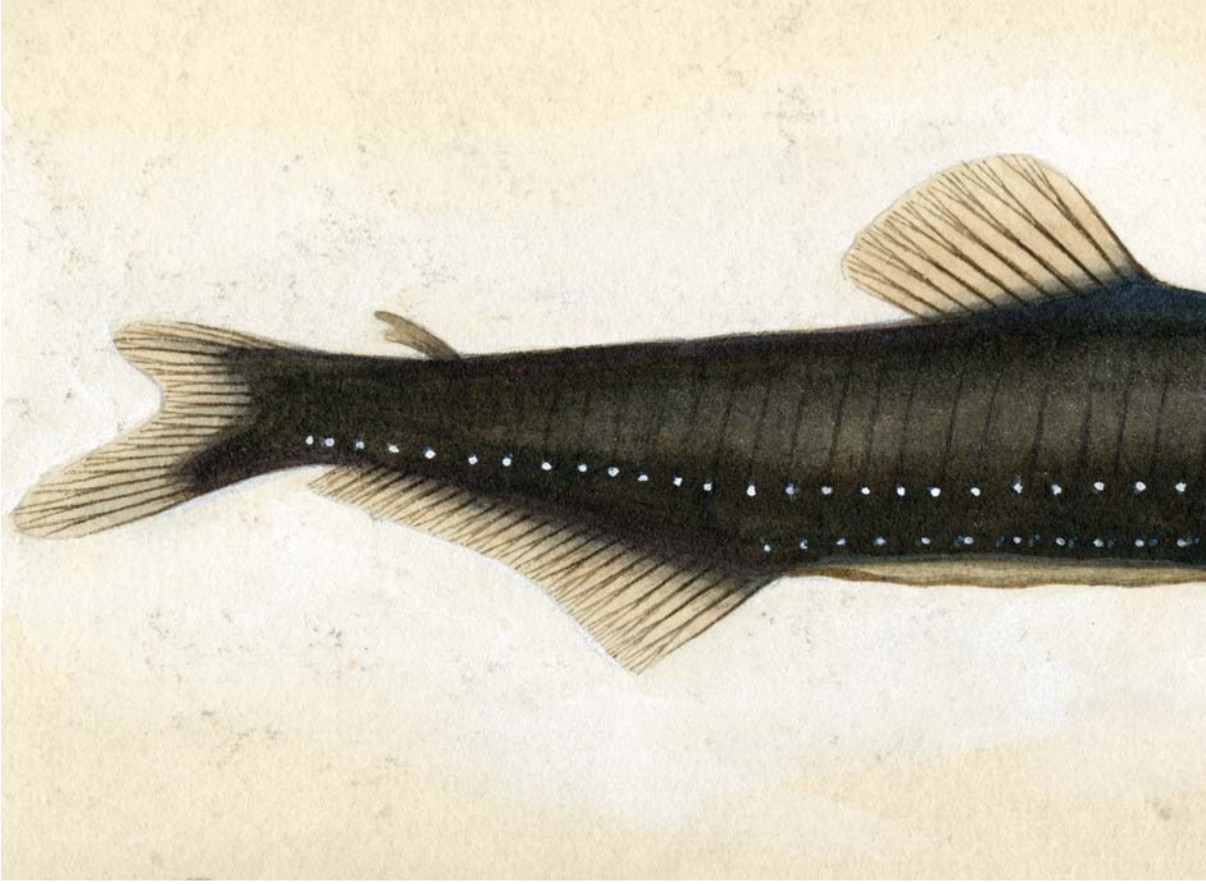
Historically, the Gulf of Mexico was a shallow sea that became isolated from the ocean. As it dried out, thick layers of salts were produced. The basin then deepened and the connection with the ocean was re-established. The salt layers were protected from dissolving into the water column by a covering of sediment. Over the years, the sediment layer became increasingly thicker and therefore heavier, causing the salt to deform and move. In some areas, the salt layer has erupted through the sediment. When salt deposits come into contact with seawater, they dissolve and form brines, many times saltier than seawater and therefore heavier. Throughout the

At over 600 m deep, a large community of mussels rings a pool of brine on the seafloor in the Gulf of Mexico.

Gulf of Mexico, warm salty fluids have pushed upwards through cracks in the sediments and have formed puddles, pools and lakes of brine with distinct surfaces and shorelines. One of the most studied of these features is named the "Brine Pool" and is a rich source of methane which acts as an energy supply for bacteria that supports dense colonies of mussels. The water in the lake is so dense that any animal that falls into it dies instantly - even the submersibles that investigate these habitats are not able to penetrate the surface!

Warm Abyssal Plains

Just as one gets used to the rules, an exception occurs, and this is true even for the deep sea.

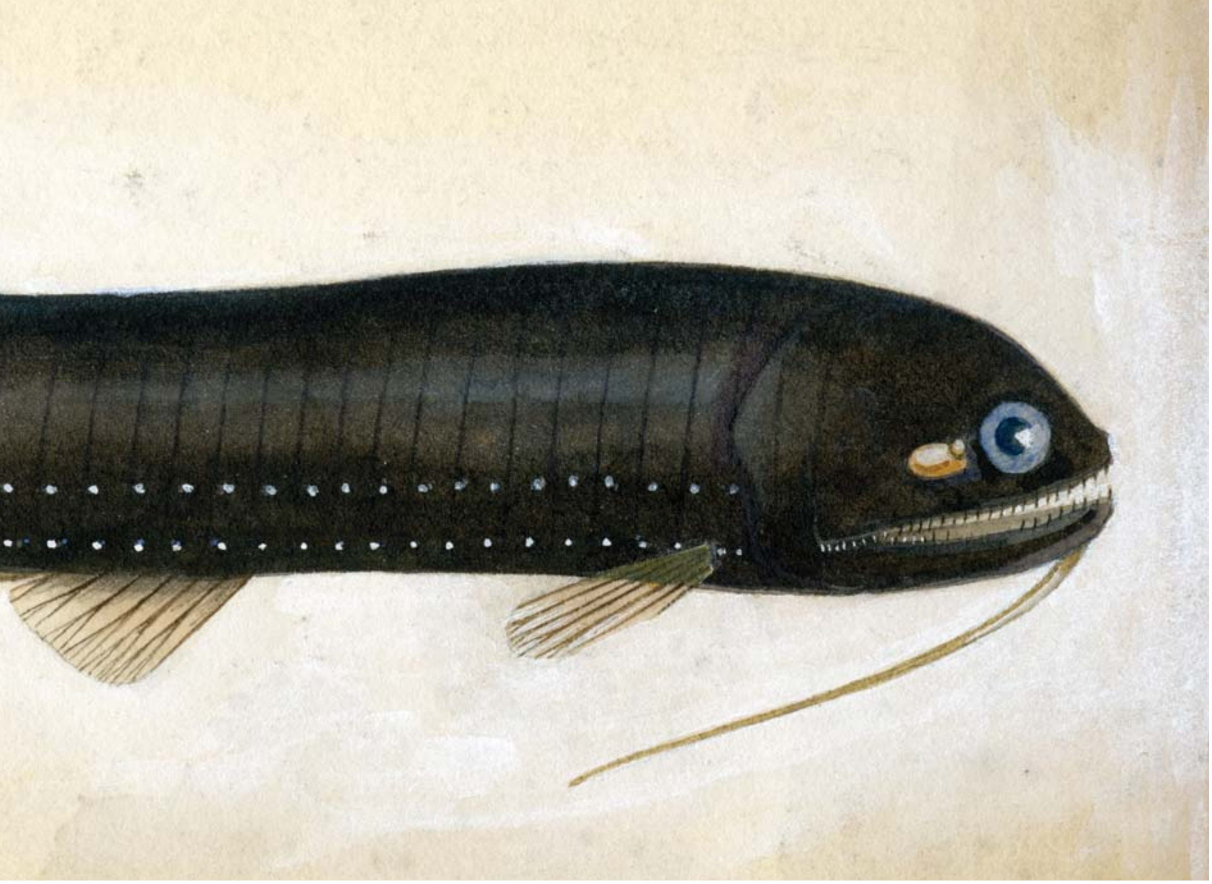


“Normal” abyssal plains are very cold because water is heaviest at temperatures just above freezing (ice, however, is lighter so that even huge icebergs swim), so the coldest water eventually sinks to the bottom. In the Mediterranean Sea, however, which is linked to the Atlantic Ocean through the narrow Straits of Gibraltar, relatively little water flows in to make up for the loss through evaporation caused by the warm sun.

Consequently, the surface water becomes saltier, just like in a salt pan, becomes heavier and heavier until it sinks to the bottom. The water column therefore has nearly the same temperature from surface to bottom, something known much better from cold Polar waters. The big difference is that near the poles, very little organic matter is consumed in the water so that much of it can be eaten on the seafloor. In the warm waters of the Mediterranean, almost all of the organic matter is eaten before it ever has a chance to get to the seafloor, which results in the Mediterranean being one of the most nutrient depleted deep sea regions on Earth. As a consequence, it is possible that the distribution of bottom-dwelling animals in the Mediterranean is not influenced by depth, but rather by distance from land. As so little rains down from the surface, nutrients coming from the dry land via rivers or storms may be an important alternative food source.

Larvae Go Home!

The life-cycle of a giant vent tubeworm is a treacherous and yet rather spectacular one!



A watercolour of the dragonfish, *Neonesthes capensis*, by Thorolv Rasmussen from 1910 – The *Michael Sars* expedition. © Bergen Museum

This worm *(Riftia pachyptila)*, releases its eggs and sperm into the surrounding waters, fertilisation occurs and larvae are formed. For years, scientists have puzzled over how these larvae manage to get from one place to another and how they manage to survive the sometimes lengthy journey in such cold, dark conditions.

Catastrophic volcanic eruptions can wipe out entire hydrothermal vent communities in just a few minutes! Therefore the ability to colonise new vent sites tens to hundreds of kilometres away is essential to the survival of the species.

Scientists decided they needed to collect some of the tubeworm larvae and see how long they could survive by simulating vent conditions in the laboratory. The little larvae survived for up to 38 days without food (they have internal stores of food) – time enough for them to find a new home many kilometres away. They may hitch a ride within hot vent waters that mix with the cold seawater, forming buoyant plumes. Water currents then transport the larvae on a kind of motorway in the sea, dropping them off at their final destination. For those that survive this perilous journey, they know when they have arrived at a decent spot – they can probably detect the toxic sulphide in the water or sense the elevated heat – a paradise for tubeworms is found!

An Extension Of The Human Senses

In 2004 an international team of scientists undertook an expedition to the Mid-Atlantic Ridge to uncover some of the mysteries of the deep. The following account is a day in the life of a scientist on board:

25 Hours On A Super Station

"The alarm clock goes an hour before the ship arrives on station. I dare not look at the time; all I know is that it is way too early for me to be up and working! We have 13 super stations, which we plan to sample and this station today is located at 3500 m water depth. A total of 25 hours is required in order for us to complete all our work which consists of trawling at different depths, collecting water and plankton samples and undertaking hydrographic operations to name but a few. Since the instruments we are using are technologically sophisticated, many of the tasks we have to do can be conducted simultaneously.

Firstly let me tell you about the ship. The Norwegian research vessel the *G.O. Sars* is a relatively new state-of-the- art research vessel. Like some other new vessels, it has vibration- and noise- damped diesel generators and propellers, which emits 99 % less noise than other conventional research vessels. This is a great advantage when scientists are doing acoustic monitoring of fish and animals in the sea and bliss when you are desperate for some sleep after a long hard shift.

The plan of work at each station is the same. The shift starts with the deployment of the ROBIO **Lander**. This a baited time-lapse camera attached to a tripod that free falls through the water column. Once on the seafloor it takes pictures of animals attracted to the bait but we have to wait until the system comes on to the ship before we can finally see what was there. As the Lander falls to the seabed, we then use a **CTD**-rosette to collect water samples from just below the surface to a few metres off the seafloor. Analysis of the temperature and salinity of the water at different depths gives us an idea of the type of environment that the animals inhabit. On the

A brittle star clings tightly to a gorgonian coral.
© David Shale

CTD rosette, a video camera mounted above a screen records bioluminescent organisms hitting the screen as the rosette descends through the water column. The frequency of flashes of light given off by different animals in the water column can be used to study abundance of light-producing organisms in different layers.

One of the major tasks is to trawl through the water column and on the seafloor. However, before we can do this we need to make a map of the seafloor; the existing ones are not detailed enough for us to trawl without damaging the nets. To map an area of 5 x 5 km, the ship steams back and forth over the area with the **multi-beam echosounder** switched on which allows us to see and hear what the seafloor looks like. Once the fisheries biologists are happy that they are not going to destroy their nets, the trawl is lowered into the water. The trawls used are enormous; the mouth of the trawl varies from a few centimetres to 85 m and the largest mid-water trawl used aboard the *G.O. Sars* is large enough to have fished up the Eiffel Tower!! Trawling takes a long time (about 4 hours), what with paying out 5000 m of wire, even though we are only in 3500 m of water, the trawling on the bottom and then the hauling in of a net that now weighs considerably more than when it was deployed. The trawl also has a camera attached to allow us to see what fishes, cephalopods and other animals enter the trawl.

For many years sampling in rocky areas has proved problematic to scientists. But with recent technological developments, such as

The *Nautile*, launched in 1984, is one of the few manned submersibles that can descend to 6000 m water depth. It is capable of exploring 97 % of the world's ocean floors. © Ifremer/Eric Lacoupelle

Right: A boxcorer, having been recovered from the abyssal seafloor is moved ready for researchers to investigate what inhabits this part of the deep sea. © Armin Rose

ROV's (Remotely Operated Vehicles) and Landers, we are able to view and sample the deep sea in ways that scientists of the past could never have imagined. Twenty-four hours after we arrived on station we have reached the end of our sampling programme, it is now time for me to head to my cabin, briefly make some notes on what has happened today, plan what is happening tomorrow and then head for my bunk."

The Remotely Operated Vehicle (ROV) *Isis* with the ability to explore the seabed down to 6500 m. © National Oceanography Centre, Southampton

Norwegian Research Vessel *G.O. Sars,* used for the 2004 MAR-ECO expedition to the Mid-Atlantic Ridge. © David Shale

Use Your Senses To Sample The Deep Sea

Deep sea biological exploration only began about 170 years ago. The fascinating creatures brought back by naturalists from the first pioneering expeditions stimulated the development of a host of new technology required to gain a glimpse of this remote habitat in which we cannot walk around to touch, see, hear or smell. So, as an extension of our senses, we use novel technology to explore the deep sea.

See – Submersible

There is nothing like "seeing for yourself" to understand life on the ocean floor, which can be achieved with a submersible or its unmanned cousin, a robot called ROV. Submersibles are about as big as a large car, with usually two scientists and one pilot sharing a 2 m sphere (a hollow body of any other shape would be crushed by the pressure). Energy for cameras, lights and propellers comes from batteries, limiting the time on the bottom to a precious few hours. However, the ROV is steered and powered from the ship and thus can be a lot smaller. Video and stills cameras are the scientist's eyes looking around whilst on the bottom, for potentially 24 hours a day. Sometimes the air in the crowded pilots' lab is so thick with excitement and suspense you can cut it with a knife!

The French Research Vessel *Porquoi Pas?*

The new British Research Vessel, *James Cook*.

Another interesting camera system is the Sediment Profile Imaging System (SPI camera). It can look through the top 20 cm of sediment; imagine slicing through a block of cheese. It is a way of seeing how animals living in the sediment interact with their environment. For example how burrowing worms change the oxygen concentration by their aerating activities. With a little bit of luck, the animals themselves are caught on camera.

Touch – Trawling And Coring

Stretching out your hand to pick up an object of interest is one of the most basic human reactions. How often you have heard or spoken the words "look but don't touch"?! To touch something from the deep sea floor, we have to extend our hands down through 5000 m of water.

For about 100 years this was achieved by either towing a net behind the ship or by cutting out a piece of the seafloor. Towed gear can be shaped in many different ways, depending on the reason for the sample being collected, not least the size of animals the researchers hope to catch. Nets with a solid metal frame at their opening are called dredges, and a metal frame keeping the net or nets at a defined distance from the seafloor (about 0.5 to 1 m) is called an epibenthic sled. Grabs and corers also come in different shapes and sizes, mostly developed to deliver samples of a defined area with undisturbed surfaces, which includes collecting a few centimetres of the overlying water. The animals have to be separated from the sediment by using a sieve, a delicate and often time consuming task.

The greatest living space on Earth is the mid-water realm. Sampling this 3D space is a great challenge, and mid-water samplers of various designs have been constructed to sample everything from the minute to the huge. The variability in the fauna related to depth is very pronounced, hence using gears that can sample discrete depth zones in a single operation is important. Large mid-water fish trawls can now capture animals from different depths in separate containers in just one operation. Multi-net zooplankton samplers of various designs have become very efficient, and the tiniest animals, algae and other particles can be recorded with profiling video camera systems.

Hear – Acoustics

Using reflected sound pulses, scientists are not only able to "see" underwater but also can "hear" underwater using sonar, a technique used many marine animals. The echosounders that are used by scientists are really an extension of our ears. They are devices that emit sound and listen to the echo from the water or seafloor. An echosounder lets you "hear" the depth of the seafloor (bathymetry) and also allows you to "hear" what the seabed is made of. For example soft mud may be differentiated from sand or rocky ground. Special echosounders let you "hear" under the sediment surface, and tell us something about the history of the seafloor. Sound can also be reflected off organisms found in the water column, a technique used in shallow water for many years to detect and identify fish.

Such techniques have greatly improved in recent years and modern echosounders operated from silent ships can detect organisms to about 3000 m. Echosounders mounted on landers on the seabed look (or listen) upwards and can be used to study movements of fish and plankton in the entire water column.

Smell – AUVs

"Smelling" under water seems hard to imagine, but smell is re-

The orange roughy, *Hoplostethus atlanticus,* is thought to be able to live for 150 years. This is an impressive specimen, probably close to the species' maximum size. © Thomas de Lange Wenneck,

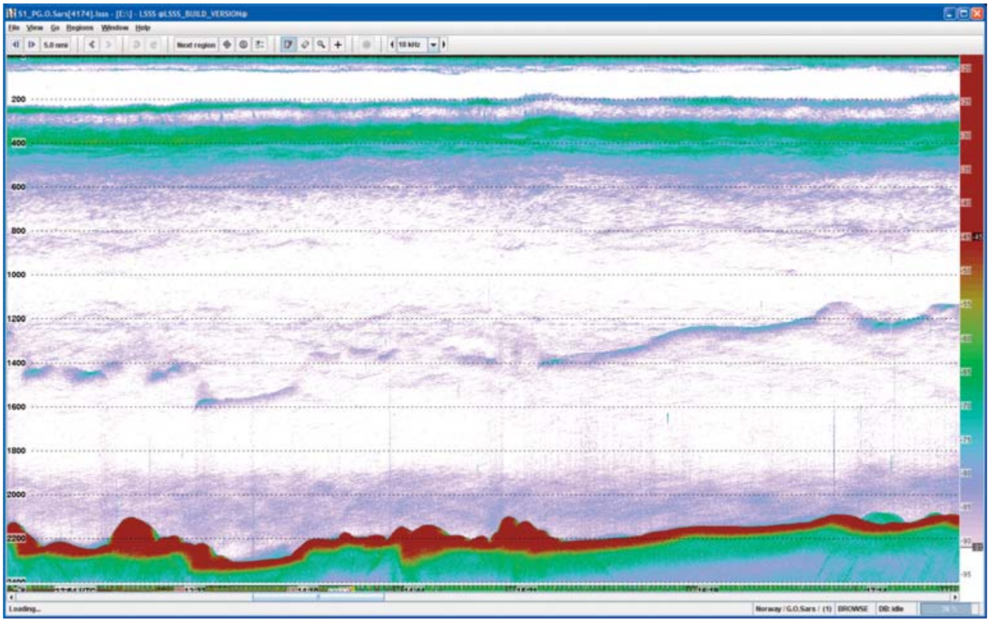
The cod-end aquarium being retrieved. The aquarium helps keep specimens in good condition. It also has an internal digital video camera. © MAR-ECO

ally nothing but a chemical sense, just detecting molecules. In the deep sea our noses are sensors mounted on a robot that can swim by itself on a pre-programmed route. These robots, which can operate in water as deep as 6000 m and cover large areas, are called Autonomous Underwater Vehicles **(AUVs)**.

Most sensors work electrically or electronically, measuring changes in electrical conductivity caused by a certain chemical such as oxygen. They basically consist of a glass


Deck-view of the RV *G.O. Sars* equipped ready for an expedition. © MAR-ECO.

probe that is held into the water to pick up the chemical it is built to "smell" and an instrument that makes the result visible to the human eye, usually as some kind of a deflection along a scale or graphically as a curve. Data are stored on board the AUV and transferred directly to a computer on the ship. Scientists may then use these data in conjunction with other oceanographic data to build a picture of ocean processes.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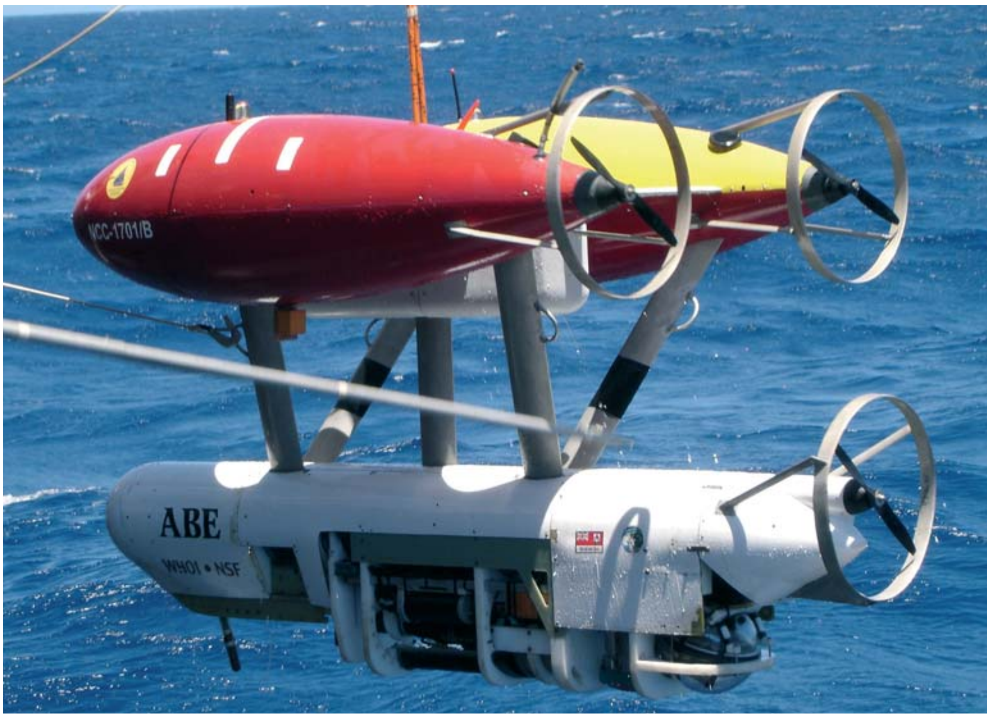
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Perspectives

The last 170 years of scientific discovery have brought about revolutionary changes in the way in which we understand the deep seas and open ocean.

These advances in marine science have been brought about by new technologies for sensing and measurement, new vehicles and navigation systems enabling work in remote and difficult areas, and the use of computers to synthesize and analyse vast amounts of data. Collectively, the collaborations of scientists and explorers of the physical, chemical and biological qualities of the deep oceans are providing a new framework for understanding the interdependence of the physical and biological realms, and issues of human influence on the environment as a whole.

A galatheid crab, *Munidopsis sp.* © David Shale

We now know that the deep ocean basins are relatively recent formations of the Earth's crust, made through the slow separation of the main continental land masses. And, although the first steps in the evolution of biological life took place in primitive seas, the present fauna of the deep ocean is based mostly on invasions of these basins by animal types already living closer to the surface. Key to the success of this colonisation is the supply of oxygen-rich, cold and salty water circulating into the deep ocean basins from the surface at the Polar Regions. This global ocean current system, driven by the cooling of surface water at the poles, is essential to maintaining life in the depths of the ocean. It underlies the discovery that the ocean basins are not some isolated and archaic world but a dynamic zone of the

Left, top: Echo sounder image showing layers of organisms form the surface to 2100 m depth, seen via sound scattering. © Ruben Patel

Left, bottom: The Autonomous Underwater Vehicle ABE (Autonomous Benthic Explorer) was the first underwater robot vehicle of its kind and can manouver independently in three dimensions.
© Chris German, WHOI

global ocean, potentially responsive to any changes in the global climate system affecting ocean circulation.

Conditions Of life

Key conditions in the deep ocean setting the boundaries of biological life have given rise to some of the most distinctive adaptive features of the marine animals. Notable are the lack of natural light, the effects of pressure from the depth of the water, and the low productivity of the environment.

Light production by deep living creatures is one of their most distinctive features and is involved in many fundamental aspects of their lives such as finding food, avoiding predators, or reproduction. It occurs within practically all groups of animals adapted to the dark environment and arises from a wide diversity of specialized structures and biochemical specialisms, often involving symbiotic relationships with micro-organisms.

The need for neutral buoyancy and energy conservation in the high pressure environment of the deep sea has led to the specialised biological adaptation of various structures. Animals of many sorts have made use of various biochemical and physical properties to lighten

A snipe eel, *Nemichthys sp.*, an extremely elongate midwater fish with a pair of very peculiar long, thin set jaws.

heavy skeletal tissues and to accumulate buoyant material in specialized ways allowing them to conserve energy while maintaining their position in space. Some of the most impressive adaptations in the deep sea can be seen in animals that inhabit the chemosynthetic environments of hydrothermal vents. Here, some animals have to cope not only with the dark and pressure, but also with massive changes in temperature. Many have also learned to thrive on the numerous chemoautotrophic bacteria by developing symbiotic relationships.

These highly specialized adaptations offer unique new sources of understanding and of genetic material of great potential value to science and medicine.

Vulnerability To The Human Impact

Current deep-sea research is making major contributions to the connectivity between the deep-sea environment and the world above. Although connectivity is intrinsic to the structure of the oceans and the continuity of water masses and biological life, it also means that the deep ocean is vulnerable to our present capacity to perturb conditions on a global scale.

A chimaera, *Harriotta haeckeli,* also known as the rabbitfish, is one of the deepest-living species of elasmobranch fishes.

Watercolour by Ørnulf Opdahl. Impressions from the MAR-ECO expedition - 2004.

The deep-sea world is on the verge of new scientific discovery daily, but already we can foresee many ways in which it can be affected by human activities either directly by targeted exploitation or indirectly through our impacts elsewhere in the global environment.

Evidence is already clear that uncontrolled extension of commercial fisheries targeted on deepwater resources can quickly damage their slow growing populations, and may inflict harmful effects on other by-catch species. The release of long-lived chemical contaminants such as radionuclides and organohalides anywhere in the sea is shown to spread within decades to almost any part of the ocean. And the results of careless dumping and discarding of human rubbish is ever present.

In the future, we can expect greatly increased pressure for exploitation of both mineral and biological resources. But perhaps the greatest threats to the health of the oceans come from the possible impact of changes in biological production at the sea surface and shifts in the pattern of current flow and water transport on which life in the great oceans depends.

So much of the recognised harmful human impact on the terrestrial environment occurred before Man was arguably conscious of his capability to affect the Earth and its systems so profoundly. Our new scientific knowledge, revealing the interdependence of the deep sea with the familiar world in which we live, must be brought urgently into commercial thinking and government policies concerning development of the oceans if we are to continue to make progress without unintended and potentially disastrous consequences.

Below: Watercolour by Ørnulf Opdahl. Impressions from the MAR-ECO expedition - 2004.
Page 78-79: An explosion of colour in the deep sea; the hydrothermal vent tubeworm *Ridgeia piscesae*, showing their beautiful red plumes. © Ian MacDonald, Texas A&M

Glossary

Abyssal Plains - vast expanses of flat seafloor covered by a thick layer of fine sediment. They are found between 3000 and 6000 m depth and cover approximately 40 % of the ocean floor.

Algae - relatively simple organisms that occur in most habitats. Through a process called photosynthesis, they convert inorganic substances into organic matter.

AUV - Autonomous Underwater Vehicle; a robot that is powered by batteries or sometimes fuel cells. They can operate in depths of up to 6000 m.

Azoic zone - a concept put forward by Edward Forbes where it was suggested that life would not exist below a depth of 600 m after undertaking dredging work at these depths in the Aegean sea.

Bathymetry - the study of underwater depth.

Benthic organisms or Benthos - organisms attached to, living on, or in the seabed.

Bioluminescence - is both the production and emission of light by a living organism. It is the result of a chemical reaction whereby chemical energy is converted to light energy.

Biosphere - part of the earth and its atmosphere in which living organisms exist or that is capable of supporting life.

Black Smoker - a type of hydrothermal vent found on the seabed. When superheated water in the vent comes in to contact with the cold seawater, many minerals are precipitated, creating the distinctive black colour.

Branchia - a synonym of gill. A respiratory organ of aquatic animals that breathe oxygen dissolved in water.

Carbonate Mounds - accumulation of dead coral skeletons, which over time form a mound on the seabed.

Chemosynthesis - the use of chemicals as an energy source as oppose to light (photosynthesis) to produce organic matter.

Cold Seeps - cold water laden with hydrogen sulphide, methane and other hydrocarbons, seeps onto the ocean floor. Cold seeps support chemosynthetic faunal communities alongside many non-chemosynthetic communities.

Continental Margin - a zone separating the emergent continents from the deep sea bottom, generally consisting of the continental shelf, slope and rise.

Continental Rise - area below the continental slope but before the abyssal plains are reached. The gradient of the continental rise is between 0.5 - 1°.

Continental Shelf - is characteristically of low inclination on the continental margin and extends from the coast to the shelf break, where the inclination increases and the continental slope begins (from 0 – 200 m depth).

Continental Slope - is characterised by steep inclination of the seabed (average 3°) and extends from the shelf break to the abyssal plain (from 200 – 3000 m).

Crustacean - group of animals belonging to the phylum *Arthropoda* containing many well known animals including crabs, shrimp and barnacles.

CTD - an oceanographic instrument that measures conductivity, temperature and depth.

Cytoplasm - is the semi-transparent, gelatinous like fluid which fills most cells.

Diurnal migration - the movement of animals through the water column on a daily basis.

Diversity - the number of species found in a specific habitat or community.

Echinoderm - a phylum of marine animals comprising of some well known groups such as sea stars and sea urchins, which are found at all depths of the world's oceans.

Ecosystem - this term refers to any collection of living and non-living components and processes that interact with each other.

Endemic - organisms that are only found in a specific area.

Foraminifera - these are a group of amoeboid fauna that generally produce a shell. They can have one or multiple chambers and are usually less than 1 mm in size.

Gelatinous - has a jelly like texture.

Glacial era or ice ages - intervals of time in the Earth's history when large areas are covered with ice sheets. Strictly speaking, because ice is found at the poles, the Earth experiences an ice age that has lasted for 30 million years. The last glacial maximum occurred 18 000 years ago when northern Europe and America were covered by the polar ice sheet.

Haemoglobin - is the iron-containing protein attached to red blood cells that transports oxygen around the body. The iron contained in haemoglobin gives the blood its red colour.

Hydrography - is the measurement and description of water.

Hydrothermal Fluid - is hot water laden with chemicals and metals emitted from hydrothermal vents.

Hydrothermal Vent - occur at fissures in the oceanic crust at mid-ocean ridges where geothermal super-heated fluid is expelled from the Earth's interior.

Komokiacea - similar to foraminifera. They have multiple openings, but lack true chambers.

Lander - autonomous lander vehicles are completely independent of the ship, and can be left to work on the seabed while the ship continues with other tasks.

Macrofauna - animals that are large enough to be seen with the naked eye. In the deep sea, fauna that are collected on a 0.25 mm sieve are also known as macrofauna.

Magma - molten rock found beneath the surface of the earth.

Marine snow - the basis of most deep sea food chains made of remains of plants and animals that drift down from the sunlit surface waters of the ocean to the depths.

Megafauna - animals that are large enough to be seen on photographs.

Mid-ocean ridges - volcanic mountain chain formed where two tectonic plates are being pulled apart and new seafloor is being formed.

Multi-beam echosounder - this is an instrument that is used to determine the distance of an object based on the time it takes for sound waves to travel to the object and back.

Nematode - also commonly known as roundworms. Extremely common in all environments and often outnumber other animals.

Nucleus - a membrane-enclosed organelle found within a cell, containing most of its genetic material.

Non-symbiotic corals - Corals that do not live in symbiosis with algae and have to sustain themselves by feeding on particles or live prey.

Ocean crust - part of the solid outermost shell (lithosphere) on Earth found in the ocean basins.

Pelagic - the part of the ocean or sea that is not near the sea floor or coast.

Plankton - plants and animals that inhabit, and drift, in the water column.

Photosynthesis - is the process undertaken by plants to convert water and carbon dioxide into sugars and carbohydrates using energy from the sun.

Phylum - a primary division of the animal kingdom e.g. Mollusca (squid, octopus, mussels) constitute a phylum.

Phytoplankton - plant like organisms of the sea that drift in the water column.

Productivity - the rate of production in an ecosystem.

Protists - a diverse group of organisms that cannot be classified in any another kingdom.

Pyrosome, a common name is corn cob jelly. Pyrosomes are not really jellyfish but instead belong to the phylum *Chordata*, animals with a backbone. The pyrosomes are hollow cylinders composed of thousands of individuals joined together in a gelatinous matrix.

Radiation - is energy transmitted in the form of waves, rays or particles.

Reversing thermometer - able to record the temperature at a given time and retain it until viewed later. When the thermometer is turned upside down the temperature reading will be preserved until the thermometer is turned the right way up.

ROV - Remotely Operated Vehicle; this is a tethered underwater robot operated from a research vessel.

Seamount - a mountain that rises from the ocean floor but does not reach the surface.

Spicule - form the skeleton of most sponges.

Stony coral - Scleractinia: are similar to sea anemones but produce a hard skeleton.

Submersible - an underwater, untethered vehicle which has limited mobility and is transported from one operational area to another by a ship or submarine.

Substrate - the surface on which an animal or plant may be attached.

Symbiosis - relationship between two different species with beneficial or deleterious consequences.

Taxonomy - is a scientific means of classifying organisms in an ordered system.

Tectonic Plates - seven large and many small rigid plates that form the Earth's crust and move in relation to one another.

Trophic - the position that an animal occupies in a food chain.

Trophosome - sac-like structure found in the bodies of hydrothermal vent and cold seep tubeworms filled with chemosynthetic bacteria.

Turbidity flow - A flow of dense, muddy water moving down the slope in strong underwater currents, which are usually triggered by earthquakes or slumping.

Whale fall - body of a dead whale sinking and transporting nutrients to the sea floor that may develop a chemosynthetic ecosystem.

Zooplankton - an animal which drifts within the water column of the oceans.

Acknowledgments

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We are very appreciative of all the people who have kindly agreed to let us use their photographs and drawings freely throughout the book; in particular we would like to thank Ørnulf Opdahl and David Shale.

We would also like to thank our colleagues who are individually working on the different deep-water Census of Marine Life projects, without whom this book would not be possible.

A sea anemone of the family *Hormathiidae* fixed on a colony of "black corals" *(Antipatharia).*
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