

CORAL REEFS

CORAL REEFS ARE SOLID STRUCTURES built from the remains of small marine organisms, principally a group of colony-forming animals called stony (or hard) corals. Reefs cover about 100,000 square miles (300,000 square km) of the world's shallow marine areas, growing gradually as the organisms that form their living surfaces multiply, spread, and die, adding their limestone skeletons to the reef. Coral reefs are among the most complex and beautiful of Earth's ecosystems, and are home to a fantastic variety of animals and other organisms; but they are also among the most heavily utilized and economically valuable. Today, the world's reefs are under pressure from numerous threats to their health.

TYPES OF REEFS

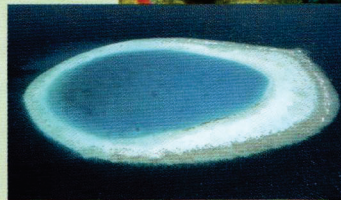
Coral reefs fall into three main types: fringing reefs, barrier reefs, and atolls. The most common are fringing reefs. These occur adjacent to land, with little or no separation from the shore, and develop through upward growth of reef-forming corals on an area of continental shelf. Barrier reefs are broader and separated from land by a stretch of water, called a lagoon, that can be many miles wide and dozens of yards deep.

Atolls are large, ring-shaped reefs, enclosing a central lagoon; most atolls are found well away from large landmasses, such as in the South Pacific. Parts of the reef structure in both atolls and barrier reefs often protrude above sea level as low-lying coral islands—these develop as wave action deposits coral fragments broken off from the reef itself.

Two other types of reefs are patch reefs—small structures found within the lagoons of other reef types—and bank reefs, comprising various reef structures that have no obvious link to a coastline.

CORAL DIVERSITY

In this seascape off a Fijian island, groups of shoaling sea goldies hover over diverse species of coral, sponges, and other reef organisms.



FRINGING REEF

A fringing reef directly borders the shore of an island or large landmass, with no deep lagoon.

BARRIER REEF

A barrier reef is separated from the coast by a lagoon. In this aerial view, the light blue area is the reef and the distant dark blue area is the lagoon.

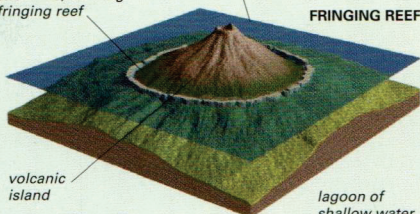
ATOLL

An atoll is a ring of coral reefs or coral islands enclosing a central lagoon. It may be elliptical or irregular in shape.

coral grows on shoreline, forming fringing reef

sea level

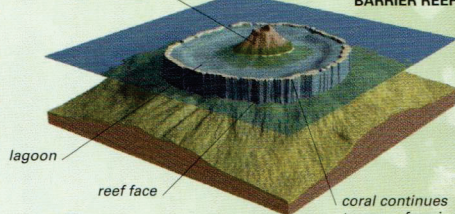
FRINGING REEF



volcanic island

island subsides when volcano has become inactive

BARRIER REEF



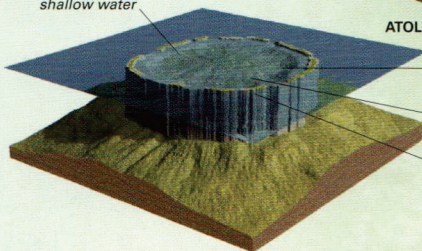
lagoon

reef face

coral continues to grow, forming barrier reef

ATOLL FORMATION

An atoll is shown here forming around a volcanic island. First, the island's shore is colonized by corals forming a fringing reef (above). Over time, the island subsides, but coral growth continues, forming a barrier reef (above right). Finally, the island disappears, but the coral maintains growth, forming an atoll (right). Atolls can also form as a result of sea-level rise.



ATOLL

volcanic island becomes submerged

central area filled by reef limestone

coral continues to grow where waves bring food



REEF FORMATION

The individual animals that make up corals are called polyps. The polyps of the main group of reef-building corals, stony corals, secrete limestone, building on the substrate underneath. The polyps also form colonies that create community skeletons in a variety of shapes. An important contributor to the life of these corals is the presence within the polyps of tiny organisms called zooxanthellae, which provide much of the polyps' nutritional needs.

Other organisms that add their skeletal remains to the reef include mollusks and echinoderms.

Grazing and boring organisms also contribute, by breaking coral skeletons into sand, which fills gaps in the developing reef. Algae and other encrusting organisms help bind the sand and coral fragments together. Most reefs do not grow continuously but experience spurts of growth interspersed with quieter periods, which are sometimes associated with recovery from storm damage.



OPEN POLYPS

At the center of each polyp is an opening, the mouth, which leads to an internal gut. The tissue around the gut secretes limestone, which builds the reef.



STONY CORAL

This group of branching hard corals is growing at a depth of about 16 ft (5 m) off the coast of eastern Indonesia. Individual stony corals can grow up to a few inches per year.

DISTRIBUTION OF REEFS

Stony corals can grow only in clear, sunlit, shallow water where the temperature is at least 64°F (18°C), and preferably 77–84°F (25–29°C). They grow best where the average salinity of the water is 36 ppt (parts per thousand) and there is little wave action or sedimentation from river runoff. These conditions occur only in some tropical and subtropical areas. The highest concentration of coral reefs is found in the Indo-Pacific region, which stretches from the Red Sea to the central Pacific. A smaller concentration of reefs occurs around the Caribbean Sea. In addition to warm-water reefs, awareness is growing about other corals that do not depend on sunlight, and form deep, cold-water reefs—some of them outside the tropics (see p.178).



WARM-WATER REEF AREAS

The conditions needed for the growth of warm-water coral reefs are found mainly within tropical areas of the Indian, Pacific, and Atlantic oceans. The reefs are chiefly in the western parts of these oceans, where the waters are warmer than in the eastern areas.



COLD-WATER CORAL

This species, *Lophelia pertusa*, is one of a few of the reef-forming corals that grow in cold water, at depths to 1,650 ft (500 m).

HUMAN IMPACT

CORAL BLEACHING

Bleaching refers to color loss in reef-building corals and occurs when the tiny organisms called zooxanthellae, which give corals their colors, are ejected from coral polyps or lose their pigment. In extreme cases, this can lead to the coral's death. Various stresses can cause bleaching, including pollution and ocean temperature rises. In recent decades, several mass bleaching events have been recorded, affecting corals over wide areas of ocean.



PARTS OF A REEF

Distinct zones exist on coral reefs, each with characteristic levels of light intensity, wave action, and other parameters. Each zone's characteristics determine the organisms that live there. The reef slope, or forereef, is the part that faces the sea. The upper parts of the reef slope are dominated by branching coral colonies and intermediate depths by massive forms. These are the areas of the reef with the greatest diversity of species.

At the top of the reef slope is the reef crest. This takes the brunt of the wave action and is subject to high light levels. Shoreward of the reef crest is the reef flat, a shallow, relatively flat expanse of limestone, sand, and coral fragments that may become exposed at high tide. The number of corals decreases toward the shore. Barrier reefs and atolls have a final zone, the lagoon area.

SPECIES DIVERSITY

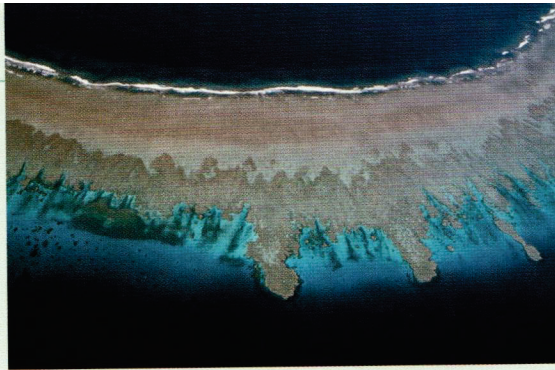
In addition to reef-building corals, the warm, sunny waters of a reef are populated by a huge variety of other animals as well as seaweeds. The richest and healthiest reefs are home to thousands of species of fish and other marine vertebrates, such as turtles, while all the major groups of invertebrate animals are also represented.

These include sponges, worms, anemones, and non-reef-building corals (such as sea fans, crustaceans, mollusks (which include snails, clams, and octopuses), and echinoderms (sea urchins and relatives). Every nook and cranny of a reef is used by some animal as a hiding place and shelter. All the organisms in the reef are part of a complex web of relationships. Many organisms are also involved in mutualistic partnerships with other organisms, in which both species benefit.



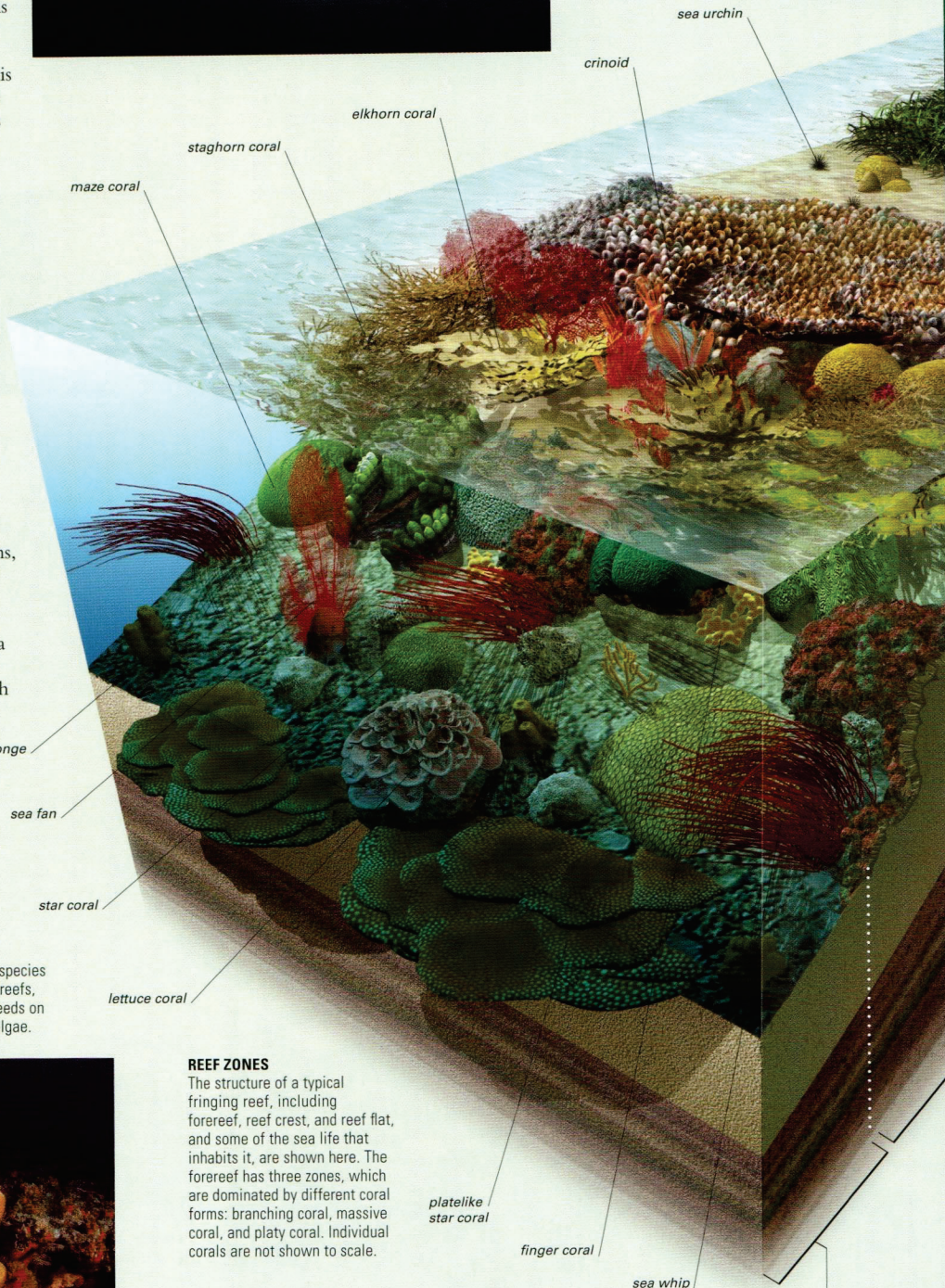
QUEEN ANGEL FISH

One of hundreds of fish species found on the Caribbean reefs, this juvenile angelfish feeds on small crustaceans and algae.



REEF CREST

In front of the reef crest (the uppermost, seaward part of a reef), spurs of coral sometimes grow out into the sea, separated by grooves.



REEF ZONES

The structure of a typical fringing reef, including forereef, reef crest, and reef flat, and some of the sea life that inhabits it, are shown here. The forereef has three zones, which are dominated by different coral forms: branching coral, massive coral, and platy coral. Individual corals are not shown to scale.

TUBE SPONGES

Different species of sponges are found in many parts of the reef, including caves and cavities, as well as on the open reef slope.

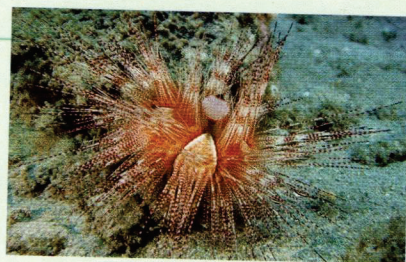
PLATY CORAL ZONE

Corals in this deep, dark part of the forereef expand horizontally to capture maximum sunlight, forming platelike colonies.



THE IMPORTANCE OF REEFS

Coral reefs are of inestimable value for many reasons. First, they provide a protective barrier around islands and coasts: without the reefs, these would erode away into the ocean. Second, reefs are highly productive, creating more living biomass than any other marine ecosystem and providing an important food source for many coastal peoples. Third, they support more species per square unit area than any other marine environment. In addition to known coral-reef species, scientists estimate that there may be several million undiscovered species of organisms living in and around coral reefs. This biodiversity may be vital in finding new medicines for the 21st century—many reef organisms contain biochemically potent substances that are being studied as possible cures for arthritis, cancer, and other diseases. Finally, because of their outstanding beauty, reefs contribute to local economies through tourism, particularly attracting snorkelers and scuba-diving enthusiasts (see p.474).



SEA URCHIN
Sea urchins graze on algae and are important in preventing algal overgrowth on coral reefs.

seagrass

golf ball coral

sea anemone

SAND AND ALGAL ZONE
This area is dominated by sand and seagrass, which may harbor small marine life.

REEF FLAT
The animals living here must be able to endure high temperatures and salinity.

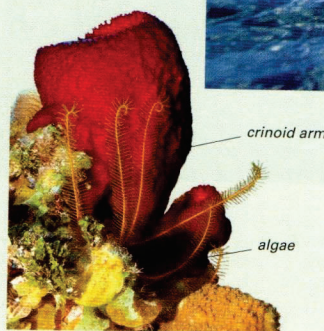
REEF CREST
The corals inhabiting this zone are invariably robust, as they must withstand energetic wave action.

BRANCHING CORAL ZONE
This zone is just below the reef crest and is dominated by corals with branching forms, such as staghorn coral.

MASSIVE CORAL ZONE
This central part of the forereef is usually dominated by massive corals—that is, colonies with rounded shapes.

SUBMARINE STUDY
Here researchers record the frequency of algal species on a reef in the Hawaiian Islands, using a camera, a frame for delineating areas of reef, and underwater writing implements.

REEF FISHING
Small-scale fishing using hand nets, often transported to a suitable site by canoe, is common throughout the Indian and Pacific oceans, as shown here off Pantar Island in eastern Indonesia.



crinoid arm

algae

GOLDEN CRINOID
Crinoids, or feather stars, are related to starfish. They usually live in a hole or other shelter on the reef, extending their elegant arms to catch food.

VULNERABLE REEFS

Many types of stress can damage reefs and are doing so on a massive scale. Much of the harm is caused by human activity, including coastal pollution, uncontrolled development of coasts, and diving tourism. Other problems include collection of corals and reef organisms for the aquarium and jewelry trades, uncontrolled mining of reefs for building materials, and destructive fishing practices. Natural disturbances include tropical storms and mass die-offs of animals that help to maintain reef health. Coral bleaching, linked to rises in sea temperatures (see p.153), is particularly worrisome. Coral reefs can recover from periodic natural traumas, but if they are subjected to multiple sustained stresses, they perish. It has recently been estimated that two-thirds of the world's warm-water reefs are at risk of disappearing in the near future.

HUMAN IMPACT

CORAL POISONING

One of the most destructive fishing practices, liable to kill corals over wide areas of reef, involves the use of poison to help catch tropical fish for the aquarium trade. This is practiced in parts of Southeast Asia such as the Philippines. The young boy photographed below, swimming at a depth of about 70 ft (20 m), carries a catch bag, net, and a squirt bottle containing a solution of sodium cyanide. The cyanide is used to immobilize selected reef fish, making them easier to catch, but kills all the living corals that it comes in contact with, taking a terrible toll on the health of the reef.



ATLANTIC OCEAN WEST

Bermuda Platform



TYPE Atoll with fringing and patch reefs

AREA 150 square miles (370 square km)

CONDITION Localized areas of damage

LOCATION Northwest Atlantic, extending west and north of the islands of Bermuda

The Bermuda Platform is the elliptical, flattened summit of a huge volcanic submarine mountain (seamount) in the northwest Atlantic. Its surface lies 45–60 ft (14–18 m) below sea level and is covered in a thick layer of limestone, formed over millions of years from the

BOILER REEFS

These small reefs, close to the surface, are called “boilers” after their frothy appearance when waves break on them.

remains of corals and other organisms growing on the platform. Along the platform’s southern and eastern edges, limestone sand has gradually built up to form the Bermuda islands. Coral reefs are present around the other edges of the platform, forming an atoll, while patch reefs grow on its central surface. The diversity of reef flora and fauna here is less than that associated with the reefs in the Caribbean Sea to the south.



Nevertheless, 21 different species of stony coral, 17 species of soft (non-reef-building) coral, including many spectacular purple sea fans, and about 120 different species of fish have been recorded here.

ATLANTIC OCEAN WEST

Florida Reef Tract



TYPE Barrier reef, patch reefs

AREA 400 square miles (1,000 square km)

CONDITION Degraded; some recent recovery

LOCATION From offshore Miami Beach to south of Key West, Florida, US

This system of coral reefs is 160 miles (260 km) long and curves to the east and south of the Florida Keys. Some geologists classify it as a barrier reef, others as a barrier-like collection of bank reefs. It is the largest area of coral reefs in the US and has a high biodiversity, being home to about 60 species of stony coral, 1,300 species of mollusk, and 500 species of fish. The reefs’ health has declined over

the past 30 years, mainly due to human impact. Live coral cover has decreased, coral diseases have become extensive, inhabitants that were once common (such as the queen conch) have virtually disappeared, and the area of reef encroached on by mats



of algae has expanded. Causes of this degradation include overfishing, fertilizer runoff from south Florida, sedimentation onto the reefs as a result of dredging, and sewage pollution from boats. Other contributing factors include hurricane damage, declines in algae-grazing sea urchins, and direct damage from dive-boat anchors and ship groundings. Steps are being taken to reverse the decline, with some signs of success.

CARYSFORT REEF

Carysfort Reef, part of the Florida Reef Tract, lies close to Key Largo and is the site of many ancient shipwrecks.

ATLANTIC OCEAN WEST

Bahama Banks



TYPE Fringing reefs, patch reefs, barrier reef

AREA 1,200 square miles (3,150 square km)

CONDITION Generally healthy

LOCATION Bahamas, southeast of Florida, US, and northeast of Cuba

The Bahamas is an archipelago of some 700 islands scattered over two limestone platforms, the Little Bahama and Great Bahama Banks, in the West Indies. The platforms have been accumulating for at least 70 million years—the Great Bahama Bank is over 15,000 ft (4,500 m) thick—yet their surfaces remain 33–80 ft (10–25 m) below sea level. Many of the islands have fringing coral reefs; there are also many patch reefs on the Banks and a

barrier reef near the island of Andros. The reefs are home to a range of corals and coral reef-dwelling animals that is typical for the western tropical Atlantic. Although local declines in coral cover and occasional outbreaks of coral disease have been recorded, the reefs are generally healthy. There has been concern about overgrowth of algae, but for now the algae are being kept in check by a thriving population of parrotfish, which graze the reefs.

ATLANTIC OCEAN WEST

Lighthouse Reef



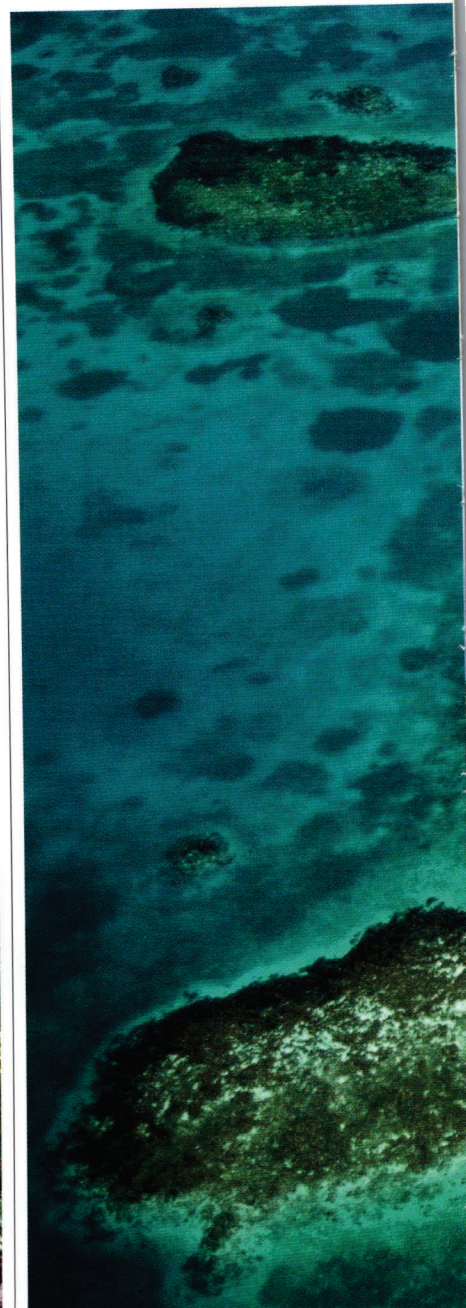
TYPE Atoll with patch reefs

AREA 120 square miles (300 square km)

CONDITION Generally healthy

LOCATION Western Caribbean, 60 miles (80 km) east of central Belize

Lighthouse Reef is an atoll lying 35 miles (55 km) east of the huge Belize barrier reef, off the coast of central Belize. It is roughly oval-shaped, about 23 miles (38 km) long, and 5 miles (8 km) wide on average.



HARD AND SOFT CORALS

This diverse group of corals, including a large purple sea fan, was photographed off the island of New Providence.

Like all atolls, it is bounded by a ring-like outer structure of coral formations, many of which break the surface.

These form a natural barrier against the sea and surround a lagoon, which sits on top of a mass of limestone. The lagoon is relatively deep but contains numerous patch reefs along with six small, sandy, low-lying islands, or cays (one containing a dive center). At its center is Lighthouse Reef's most remarkable feature—a large, almost circular sinkhole in the limestone, known as the Great Blue Hole.

Approximately 480 ft (145 m) deep, this feature formed some 18,000 years ago during the last ice age, when much of Lighthouse Reef was above sea level. At that time, freshwater erosion

produced a complex of air-filled caves and tunnels in the limestone. At some point, the ceiling of one of the caves collapsed, producing what is now the entrance to the Blue Hole. Later, as sea level rose, the cave complex flooded, and it is now accessible only by adventurous scuba divers.

Apart from the Blue Hole, the atoll boasts large areas of healthy, abundant, mainly unexplored coral formations. As well as patch reefs within the atoll, around its margins are many spectacular coral-encrusted walls (dropoffs) that descend to depths of several hundred yards. Lighthouse Reef exhibits a biological diversity typical of the region; it is home to some 200 fish species and 60 species of stony corals.

HUMAN IMPACT

DIVING THE GREAT BLUE HOLE

The Great Blue Hole is one of the world's most exciting dive sites. It is not recommended for the fainthearted (as sharks are commonly encountered) or for novice divers (because perfect buoyancy control is needed).

At 125 ft (38 m) depth, an array of impressive ancient stalactites can be seen hanging from the slanting walls of the hole. The entrance to a system of caves and tunnels lies a few yards farther down.



GREAT BLUE HOLE

The water in this sinkhole descends to a depth of 480 ft (145 m), producing the deep blue color after which it is named.

INDIAN OCEAN NORTHWEST

Red Sea Reefs



TYPE Fringing, patch, and barrier reefs; atolls

AREA 6,300 square miles (16,500 square km)

CONDITION Generally good; localized damage

LOCATION Red Sea coasts of Egypt, Israel, Jordan, Saudi Arabia, Sudan, Eritrea, and Yemen

The Red Sea contains arguably the richest, most biologically diverse, and most spectacular coral reefs outside Southeast Asia. The coral reefs in the northern and southern areas of the sea differ considerably. In much of the northern section, the coasts shelf extremely steeply and there are few offshore islands. The coral reefs here are mainly narrow fringing reefs, with reef flats typically only a few yards wide, and slopes that plunge steeply toward the sea floor. In the south, off Eritrea and southwestern Saudi Arabia, is a much wider area of shallow continental shelf. Many of the reefs

in this area surround offshore islands, and there are fewer steep dropoffs. The southern Red Sea also receives a continuous inflow of water from the Gulf of Aden to its south that is high in nutrients and plankton, making the waters more turbid, or cloudy, which restricts reef development. Live coral cover throughout the Red Sea reefs is generally high, at about 60–70 percent, as is the diversity of stony and soft corals, fish (including the famous Red Sea lionfish), and other reef organisms. More than 260 different species of stony coral have been identified in the central Red Sea.

Although the Red Sea reefs are mainly healthy, intense diving tourism, especially in parts of Egypt, has caused severe local damage. Coral predation by the crown-of-thorns starfish has also been a problem, and there is a threat of oil spillages from tankers heading toward the Suez Canal.

GULF OF AQABA REEF

Groups of little red fish of the genus *Anthias* fluttering around hard coral heads, or colonies, are a familiar sight on Red Sea reefs.



INDIAN OCEAN NORTHWEST

Aldabra Atoll



TYPE Atoll

AREA 60 square miles (155 square km)

CONDITION Excellent, although it has suffered some coral bleaching

LOCATION Western extremity of the Republic of Seychelles archipelago, northwest of Madagascar

At 20 miles (34 km) long and 9 miles (14.5 km) wide, Aldabra is the largest raised coral atoll in the world. The term “raised” refers to the fact that the

limestone structures forming its rim, which originated from coral reefs, have grown into four islands that protrude as much as 27 ft (8 m) above sea level. Situated on top of an ancient volcanic pinnacle, the islands enclose a shallow lagoon, which partially empties and then fills again twice a day with the tides. Because of its remote location, and its status as a Special Nature Reserve and (since 1982) UNESCO World Heritage Site, Aldabra has escaped the worst of the stresses that human activities have placed on most of the world’s coral reefs. Although, in common with many Indian Ocean locations, the atoll was affected by

a severe coral bleaching event in 1997–98, its external reefs are in a near-pristine state. They are rich in marine life, featuring large schools of reef fish, green and hawksbill turtles, forests of yellow, pink, and purple sea-fans, groupers, hammerhead sharks, and barracuda. The atoll’s inner lagoon contains numerous healthy patch reefs, is fringed by mangrove swamps, and is inhabited by turtles, parrotfish, and eagle rays.

On land, Aldabra is famous for its giant tortoises, rare exotic birds such as the flightless rail, and giant robber crabs, which have claws big enough to crack open coconuts.

INDIAN OCEAN WEST

Bazaruto Archipelago



TYPE Fringing reefs, patch reefs

AREA 60 square miles (150 square km)

CONDITION Generally good; some damage

LOCATION Southeastern coast of Mozambique, northeast of Maputo

The Bazaruto Archipelago is a chain of sparsely populated islands on the coast of Mozambique, formed where sand was deposited over hundreds of thousands of years by the Limpopo River. A Marine National Park, established in 2001, covers most of the archipelago, protecting its impressive fringing reefs and kaleidoscopic range of marine life. More than 2,000 fish species, 100 species of stony corals, and 27 dazzling soft-coral species, including unusual “green tree” corals, are found on Bazaruto’s reefs, as well as eagle rays, manta rays, and five species of turtles. The archipelago is also a refuge for one of the remaining populations of dugongs (see p.423) in the western Indian Ocean.

REEF SAFARI

A peaceful way of visiting the shallow, crystal-clear waters around the Bazaruto reefs is on a dhow, as part of a reef safari.



MUSHROOM ROCK

Strong tidal flows of ocean water into and out of Aldabra’s lagoon have sculpted some raised clumps of old reef into mushroom-shaped islets known as champignons.

INDIAN OCEAN CENTRAL

Diego Garcia Atoll



TYPE Atoll
AREA 17 square miles (44 square km)
CONDITION Generally good; recovering from coral bleaching in 1998

LOCATION Chagos Archipelago, south of Sri Lanka, central Indian Ocean

This atoll, best known as a US military base, is also home to one of the world's largest populations of breeding sea birds. The atoll is unusual in that its coral limestone-based rim, raised above sea level, is a single island that runs almost completely round the central lagoon, which is 65–100 ft (20–30 m) deep. The reefs within the lagoon and around the atoll's edges are home to 220 species of stony coral.



WESTERN SIDE OF DIEGO GARCIA

INDIAN OCEAN CENTRAL

Maldives



TYPE Atolls, fringing reefs
AREA 3,500 square miles (9,000 square km)
CONDITION Recovering from coral bleaching

LOCATION Off southern India, southwest of Sri Lanka, in the Indian Ocean

The Maldives are a group of 26 atolls, many of them very large, in the Indian Ocean. The majority are composed of numerous separate reefs and coralline islets (some 1,200 in all), arranged in ringlike structures. Within most of the atoll lagoons, which are 60–180 ft (18–55 m) in depth, there are usually many patch reefs and numerous structures called faros, which are rare outside the Maldives. These look like mini-atolls and consist of roughly elliptical reefs with a central lagoon.

Most of the Maldivian atolls are themselves arranged in a large, elliptical ring, some 500 miles (800 km) long and 60 miles (100 km) wide. The reefs that fringe all the Maldivian atolls, islets, and faros contain more than 200 species of colorful stony coral, more than 1,000 different fish species, and are abundant in other marine life. Groupers, snappers, and sharks, for example, are frequently encountered.

In 1998, a severe coral bleaching event killed up to 90 percent of the corals in some areas, and had a strong negative impact on diving and snorkeling tourism. By early 2006, however, some areas were effectively recolonizing with corals.

ATOLLS WITHIN ATOLLS

The numerous ringlike structures in this aerial view are faros—mini-atolls within a larger Maldivian atoll.

HUMAN IMPACT

ATOLL CITY

Male, the Maldives' capital city, covers the entire surface area of a coral island that forms part of an atoll rim. Its reef has been mined to provide building materials for artificially extending the island.

The partly dismantled reef leaves the island poorly protected from storms, so a sea wall has been built around much of its perimeter, preventing major damage during the 2004 Indian Ocean tsunami.



INDIAN OCEAN NORTHEAST

Andaman Sea Reefs



TYPE Fringing reefs
AREA 2,000 square miles (5,000 square km)
CONDITION Some areas poor due to coral bleaching, diver damage

LOCATION Andaman Sea coasts: Thailand, Myanmar, Andaman and Nicobar Islands, Malaysia, Sumatra

Most Andaman Sea reefs are fringing reefs around islands off the coasts of Thailand and Myanmar or, in the northwest, off the eastern coasts of the Andaman and Nicobar islands—the site of the largest continuous area of reefs in south Asia. About 200 coral species and more than 500 fish species have been recorded here. The reefs and islands are also important feeding

and breeding grounds for endangered sea turtles. A coral bleaching event in 1998 badly damaged reefs around the Andaman and Nicobar islands, which until then were some of the most pristine anywhere, but hardly touched the Thailand reefs. The 2004 Indian Ocean tsunami caused relatively little damage. Other threats to these reefs include collection of marine life for aquariums, destructive fishing techniques, siltation caused by poorly managed deforestation on some of the islands, and anchor damage from dive boats.

SOFT CORAL COLONIES

These soft corals and glass fish, which are almost transparent, were photographed off southwest Thailand.

PACIFIC OCEAN WEST

Shiraho Reef



TYPE Fringing reef
AREA 4 square miles (10 square km)
CONDITION Reasonable; recovering from severe coral bleaching in 1998

LOCATION Southeast coast of Ishigaki Island, at the southwestern extremity of Japanese archipelago

Shiraho Reef, off Ishigaki Island, part of the Japanese archipelago, came to notice in the 1980s as an outstanding example of biodiversity, with some 120 species of coral and 300 fish



species concentrated in a few square miles. The reef also contains the world's largest colony of rare blue ridge coral (*Heliopora coerulea*). For decades, environmentalists have battled to save the reef from the building of a new airport for Ishigaki. A proposal to construct the airport on top of the reef was dropped, but concern remains over plans to build it on land, as soil runoff and sedimentation in the reef area is likely to have an adverse effect.

BLUE RIDGE CORAL

Despite its name, the color of this coral varies from violet through blue, turquoise, and green to yellow-brown. Its branching vertical plates can form massive colonies.

PACIFIC OCEAN WEST

Tubbataha Reefs



TYPE Atolls
AREA 130 square miles (330 square km)
CONDITION Good; recovering from coral bleaching in 1998

LOCATION Central Sulu Sea, between the Philippines and northern Borneo

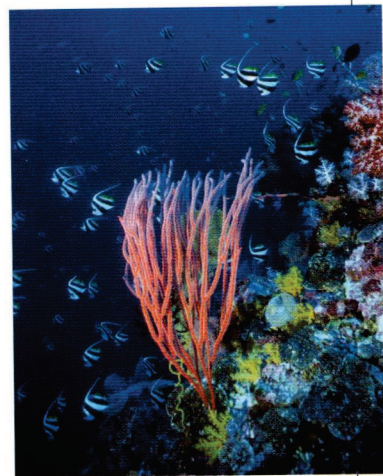
The Tubbataha Reefs lie around two atolls in the center of the Sulu Sea and are famous for the many large pelagic (open ocean) marine animals attracted to them—such as sharks, manta rays, turtles, and barracuda. The steeply shelving reefs here are also rich in smaller life, including many species of crustaceans, colorful nudibranchs (sea slugs), and more than 350 species of stony and soft coral.

In the early 1990s, the Tubbataha Reefs were rated by scuba divers among the top ten dive sites in the world. However, during the 1980s they suffered considerable damage from destructive fishing practices and the establishment of a seaweed farm.

CORAL DROPOFF

In this photograph of a steeply shelving reef slope, several species of soft coral are visible, together with a shoal of longfin bannerfish.

In 1988, the Philippines government intervened, declaring the area a National Marine Park, and since 1993 it has also been a UNESCO World Heritage Site. Today, the condition of the Tubbataha reefs has much improved, due to the enforcement of measures such as a prohibition on fishing and a ban on boats anchoring on the reefs (visiting craft must use mooring buoys). Live coral cover in most sites in 2004 showed significant increases after a coral bleaching episode in 1998.



PACIFIC OCEAN WEST

Nusa Tenggara



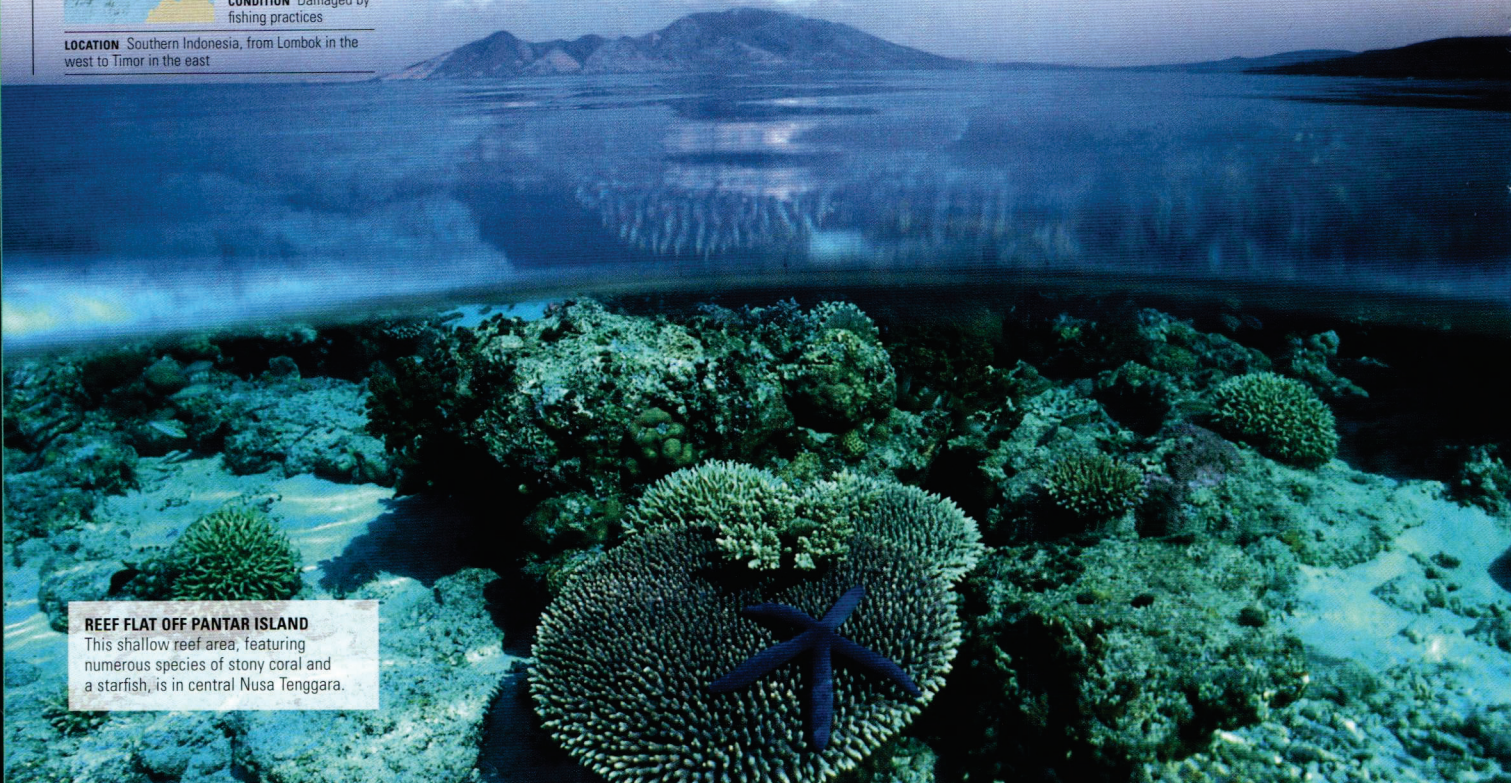
TYPE Fringing reefs, barrier reefs
AREA 2,000 square miles (5,000 square km)
CONDITION Damaged by fishing practices

LOCATION Southern Indonesia, from Lombok in the west to Timor in the east

Nusa Tenggara is a chain of around 500 coral-fringed islands in southern Indonesia. The northern islands are volcanic in origin, while the southern islands consist mainly of uplifted coral limestone. Many of the reefs have been only rarely explored. However, what surveys have been carried out

indicate an extremely high diversity of marine life in this region. For example, a single large reef can contain more than 1,200 species of fish (more than in all the seas in Europe combined), and 500 different species of reef-building coral. Common animals here include eagle rays, manta rays,

humphead parrotfish, and various species of octopuses and nudibranchs (sea slugs). Major threats to the reefs in Nusa Tenggara include pollution from land-based sources, sediment pollution from logging, removal of fish from the reefs for the aquarium trade, and reef destruction by blast fishing.

**REEF FLAT OFF PANTAR ISLAND**

This shallow reef area, featuring numerous species of stony coral and a starfish, is in central Nusa Tenggara.

PACIFIC OCEAN SOUTHWEST

Great Barrier Reef



TYPE Barrier reef
AREA 14,300 square miles (37,000 square km)
CONDITION Damaged by crown-of-thorns starfish; coral bleaching

LOCATION Parallel to Queensland coast, northeastern Australia

Australia's Great Barrier Reef, which stretches 1,250 miles (2,010 km), is the world's largest coral reef system. Often described as the largest structure ever made by living organisms, it in fact consists of some 3,000 individual reefs and small coral islands. Its outer edge ranges from 18 to 155 miles (30 to 250 km) from the mainland, and its biological diversity is high. The reef contains about 350 species of stony coral and many of soft coral. Its 1,500 species of fish range from gobies, the smallest fish on the reef, and 45 species of butterflyfish, to several shark species, including silvertip, hammerhead, and whale sharks. The reef is also home to 500 species of algae, 20 species of sea

REEF CHANNEL

In this view of a central area of the reef, a deep, meandering channel separates two reef platforms. The region's high tidal range drives strong currents through such channels.

snakes, and 4,000 species of mollusks. Damage to the reef over the past 30 years has resulted mainly from predation by the crown-of-thorns starfish and a mass coral bleaching event in 1998. In 1975, the Great Barrier Reef Marine Park was established, and in 1981 it was declared a UNESCO World Heritage site.

THE WORLD'S SMALLEST VERTEBRATE?

One of the tiniest residents of the Great Barrier Reef, at less than 1/2 in (just 7–8 mm) long from snout to tail, is the stout infantfish. When discovered in 2004, the infantfish was declared to be the world's smallest vertebrate species. That title has since been claimed for a slightly shorter species of Indonesian cyprinid. However, the infantfish is more slender and lighter than the cyprinid.



PACIFIC OCEAN SOUTHWEST

Marshall Islands



TYPE Atolls
AREA 2,400 square miles (6,200 square km)
CONDITION Generally good; some local degradation

LOCATION Micronesia, southwest of Hawaii, western Pacific

The Marshall Islands consist of 29 coral atolls and five small islands in the western Pacific. The atolls lie on top of ancient volcanic peaks that are thought to have erupted from the ocean floor 50–60 million years ago. They include Kwajalein, the largest atoll in the Pacific at 1,000 square miles (2,500 square km), and Bikini and Eniwetok atolls, which were used by the US for testing nuclear weapons between 1946 and 1962. Human pressures on these two remote, evacuated atolls have been minimal during the past 50 years, and marine life around them now thrives; for example, 250 species of coral and up to 1,000 species of fish have been recorded at Bikini.

MAJUORO ATOLL

As with many Pacific atolls, the rim of Majuro Atoll consists partly of shallow submerged reef and partly of small, low-lying islands.

PACIFIC OCEAN SOUTHWEST

Society Islands



TYPE Fringing reefs, barrier reefs, atolls
AREA 600 square miles (1,500 square km)
CONDITION Good, but significant local damage

LOCATION French Polynesia, northeast of New Zealand, south-central Pacific

The Society Islands comprise a chain of volcanic and coral islands in the South Pacific, including islands with barrier reefs (such as Rai'atea), islands with both fringing and barrier reefs (such as Tahiti), and atolls or near-atolls (such as Maupihaa and Maupiti). The reefs' biological diversity is moderate compared with the reefs of Southeast Asia, although more than 160 coral species, 800 species of reef fish, 1,000 species of mollusks, and 30 species of echinoderm have been

recorded. The reefs' health is generally good, but some reefs around the busy vacation destination islands of Tahiti, Moorea, and Bora-Bora have been severely affected by construction, sewage, and sediment runoff.



MOOREA

A wide fringing reef almost completely surrounds the shoreline of mountainous Moorea, part of which is visible in this view.

PACIFIC OCEAN CENTRAL

Hawaiian Archipelago



TYPE Fringing reefs, atolls, submerged reefs
AREA 450 square miles (1,180 square km)
CONDITION Generally good; some degradation

LOCATION North-central Pacific

The Hawaiian Archipelago consists of the exposed peaks of a huge undersea mountain range. These mountains have formed over tens of millions of years as the Pacific Plate moves

northwest over a hotspot in Earth's mantle. Coral reefs fringe some coastal areas of the younger, substantial islands at the southeastern end of the chain, such as Oahu and Molokai. To the northwest, located on the submerged summits of older, sunken islands, are several near-atolls (such as the French Frigate Shoals) and atolls (such as Midway Atoll). These reefs are highly isolated from all other coral reefs in the world, and although their overall biological diversity is relatively low, many new species have evolved on them. About a quarter of the animals and plants found in the Hawaiian Islands and a few nearby reefs are found nowhere else.

FRENCH FRIGATE SHOALS

Reef fish, including longfin bannerfish, milletseed butterflyfish, and bluestripe snappers, swim around a table coral.



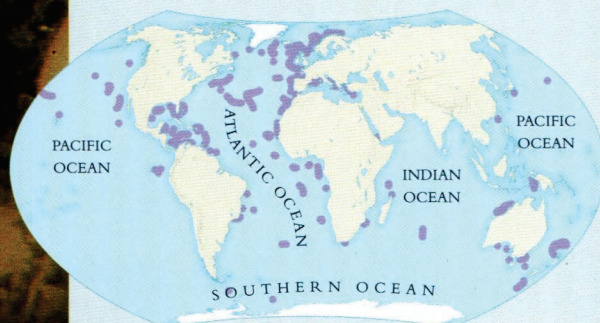
COLD-WATER REEFS

Deep-sea corals were first discovered in 1869, but it took the advent of sonar and deep-sea submersibles to reveal the size and abundance of the reefs that they build. Although less well studied than their tropical counterparts, these cold-water reefs are just as rich in life. The stony corals that form deep-water reefs flourish in water temperatures of 39–55°F (4–13°C). Unlike tropical corals, they can live in total darkness because they do not rely on zooxanthellae (p.153) living inside them to produce nourishment by photosynthesis in sunlight. Instead, they survive by filtering food from the water. Norwegian scientists have suggested recently that hydrocarbons (compounds of hydrogen and carbon, such as methane) seeping from the sea floor could provide an additional food source at some sites. Methane may provide energy for bacteria at the bottom of a food chain, which are then filtered from the water by the coral polyps.

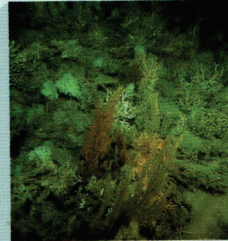
One of the biggest reefs—covering 38 square miles (100 square km)—was discovered during an oil-related survey of the Atlantic Frontier, northwest of Scotland, in 1998. *Lophelia pertusa* is the main reef-forming coral at these reefs, called the Darwin Mounds, which lie at a depth of 3,300 ft (1,000 m). *Lophelia* reefs occur at similar depths on many seamounts in the Atlantic, and also in shallow cold water such as in Norway's fjords. Several other coral species form cold-water reefs elsewhere in the world. For example, in the Pacific, the main reef species on seamounts and oceanic banks around Tasmania and New Zealand are *Goniocorella dumosa* and *Solenosmilia variabilis*. Over 1,300 species of animals have been recorded on deep-sea reefs, and they may be important nursery grounds for commercial fish species.

LOCATION OF DEEP-SEA REEFS

The map below shows the global distribution of cold-water reefs. Some of these reefs are small, while others cover up to 770 square miles (2,000 square km), although the map dots exaggerate their extent. The many reefs detected in the north Atlantic probably reflect the intensity of surveying there, particularly in the search for oil. More detailed surveys of other oceans are likely to reveal the existence of further deep-sea reefs.



LIFE IN COLD WATER

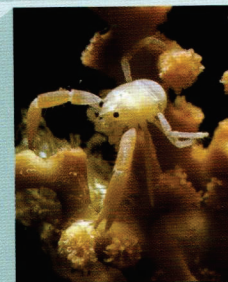


LOPHELIA REEF This *Lophelia* reef lies deep in the Atlantic off the west coast of Ireland, where it can be studied only by means of a submersible. Fortunately, *Lophelia* can also be viewed in water as shallow as 128 ft (39 m) in some Norwegian fjords.

DEEP-SEA CORALS

GONIOCORELLA CORAL

This deep-sea coral thicket is made mostly of *Goniocorella dumosa*, a species that is restricted to the Southern Hemisphere. It forms reefs at depths to 5,000 ft (1,500 m).



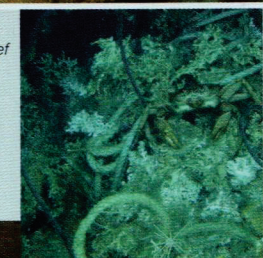
SQUAT LOBSTER This tiny squat lobster is sitting on *Madrepora oculata* coral polyps, 1,290 ft (390 m) down in the Bay of Biscay, north of Spain.

CHIROSTYLUS CRABS Many animals live among the coral. These long-limbed crabs are crawling over a black coral in the northeast Atlantic.

ASSOCIATED MARINE LIFE



DAMAGED REEF Fishing gear has snagged on this reef west of Ireland, tearing off chunks of living reef that could be up to 8,500 years old. In 2005, the European Union banned fishing near the Darwin Mounds.



THREATS FROM DEEP-SEA TRAWLING



TRAWL MARK Even before scientific surveys discovered them, many deep-water reefs had been severely damaged by trawls dragged across the sea bed to catch bottom-living fish. The scarred seabed shown here is at a depth of 2,900 ft (885 m).