INTRODUCTORY OCEANOGRAPHY 5TH EDITION

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HAROLD V. THURMAN

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Fifth Edition

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Mount San Antonio College

Merrill Publishing Company
A Bell & Howell Information Company
Columbus Toronto London Melbourne

PREFACE

In the first edition of this text, my stated objective was to "help the student develop an appreciation for the oceans through an understanding of their physical and biological processes." I had not, however, presented this very worthwhile goal with any great sense of urgency.

But by the second edition, the 1973 oil embargo conducted by the OPEC nations created strong concern about the development of potential oil reserves lying beneath the continental margin. In a more pressing tone, I discussed the investigation of non-polluting, renewable energy sources such as ocean winds, currents, waves, tides, and temperature differences. Political activities were aimed at clearing the way for the mining of manganese nodules from the deep-ocean floor and the establishment of a 200-mile Exclusive Economic Zone by more and more nations. I pointed out that the Third United Nations Conference on Law of the Sea had been meeting at least once a year since 1973 in an effort to provide a solution to all of these problems. I increased coverage of renewable energy resources of the marine environment in the chapters dealing with physical motions of the ocean and added a chapter to cover in greater depth the problems of the Law of the Sea, fisheries, mariculture, minerals, marine pollution, and ocean research. My objective had intensified from "appreciation" to "understanding" so that we could make sound decisions to proceed with the development of the oceans.

In the third and fourth editions, I continued a comprehensive and intelligible discussion of the concepts necessary for a broad understanding of the physical and biological phenomena of the oceans. I wanted to provide an up-to-date picture of the problems arising from the development of marine resources as well as the degree of progress being achieved toward their solutions.

At present, most of the problem areas mentioned are still with us. A good many of the problems continue to elude solution because of their entanglement in the political confrontation existing between the developing and developed nations of the world. Thus, if we are to take a positive position relative to the possible solution of the problems discussed, we can do so only in the knowledge that there exists a relatively high level of public awareness and understanding of them.

My primary goal with this fifth edition—as it has been with all previous revisions—is to impart the new knowledge about the oceans and our means of studying them. Of course, we cannot cover this new information in depth. But the text does attempt to show clearly the essential concepts involved and explain their significance.

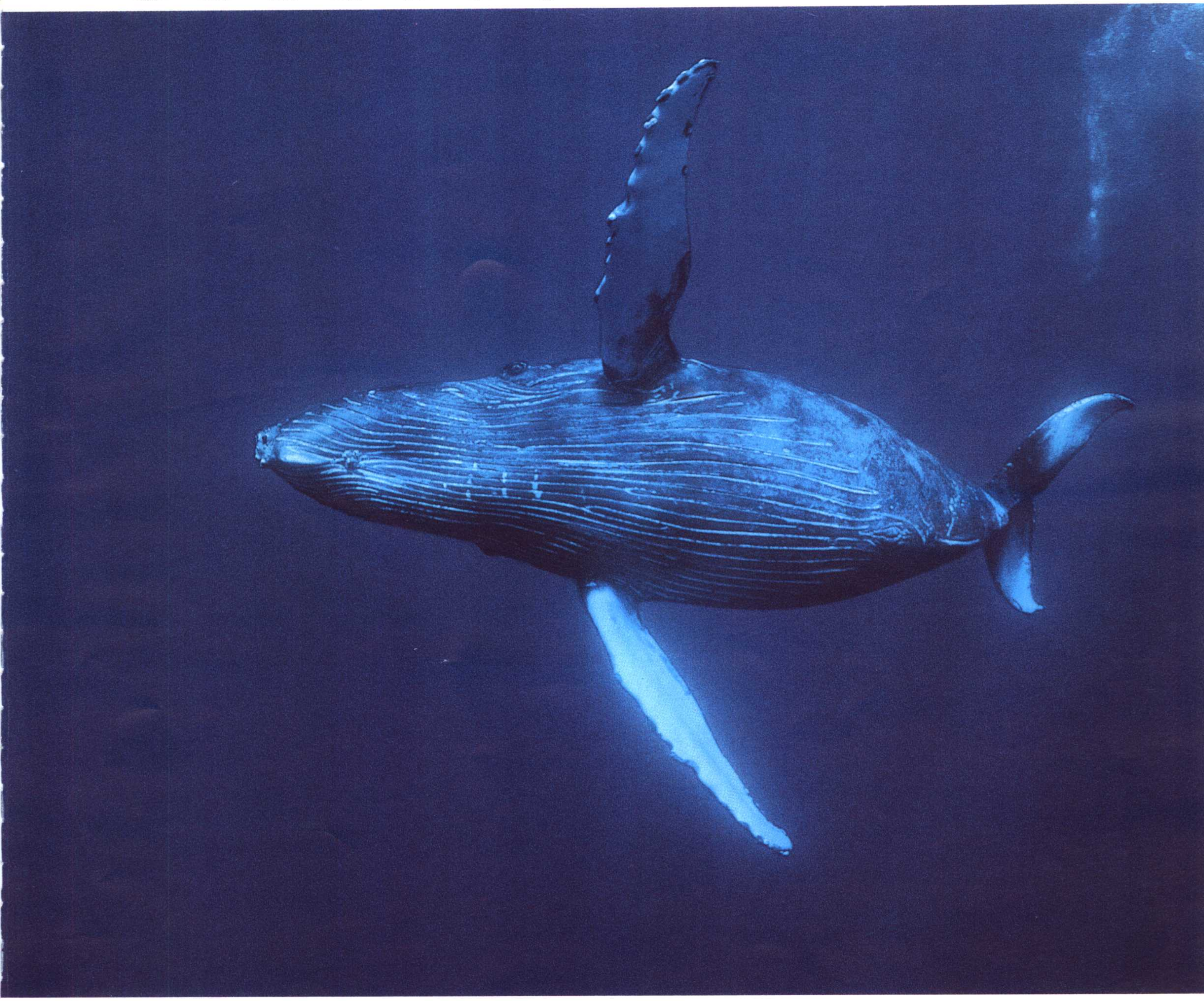
Most of the new information has been incorporated into the general text, but there are eight new features to complement the eighteen of the previous edition. These features explore recent discoveries to promote students' appreciation of the oceans and how we learn about them. The features range from interviews with experts in salmon ranching and deep-ocean benthos to overviews of complex phenomena such as the Southern Oscillation–El Niño system, ophiolites, and remote satellite and underwater observation.

I have made a special effort to reorganize the presentation based on suggestions from readers. The discussion of basic chemistry has been moved from chapter 6, "Properties of Water," to chapter 2, "The Origin of the Earth, Its Oceans, and Life in the Oceans." In its new location, this discussion can help give students some basic understanding of chemistry before they take on the chemical considerations discussed in regard to the origin of life in the oceans. In addition, the discussion of isostasy has been moved from chapter 4, "The Origin of Ocean Basins: Theory of Global Plate Tectonics," to chapter 3, "Marine Provinces." This was suggested because the subject seems to be more related to the fundamental difference between continents and ocean basins than to the plate tectonic process. To assist students in developing their knowledge of word roots, I have added an appendix on roots, prefixes, and suffixes. Improvements in the readability of the text have been made throughout the book.

A major focus of this revision is the improvement of illustrations. Many of the line illustrations have been redrawn, and captions have been improved to make them more useful to the students. The color insert sections have been expanded, and the plates have been arranged to follow four central themes: an introductory overview, marine geology, physical oceanography, and marine biology. Most of the images are new, and they have been carefully integrated into a narrative that explains the significance of each as it relates to the central theme. Both this narrative approach and the placement of the inserts at appropriate locations in the text provide the student with a context for understanding the relevance of each photograph to the specific subject matter.

We anticipate that these changes will be helpful and believe the book will meet the needs of more teachers and students of introductory oceanography than ever before.

I would like to extend a special thank-you for the valuable suggestions made by those professors who reviewed the manuscript for the fifth edition of *Introductory Oceanography:* Ernest Angino, University of Kansas; James Conkin, University of Louisville; William T. Fox, Williams College; David M. Karl, University of Hawaii, C. Ernest Knowles, North Carolina State University; Ted Loder, University of New Hampshire; James M. McWhorter, Miami Dade Community College; Larry L. Malinconico, Southern Illinois University; Edward D. Stroup, University of Hawaii; and Mel Zucker, Skyline College.



We humans are drawn to the ocean by our attraction to our close relatives, whales and other marine mammals, living at its surface. The humpback whale has aroused an especially large amount of interest with its "songs" and spectacular breaching behavior.

Some of the whales, all of which are marvelously streamlined, make remarkably deep dives and flawlessly track prey in water that is totally dark.

Sperm whales are known to dive to depths in excess of 2 km (1.2 mi). They are aided in making these long, deep, dives by a much greater volume of blood per unit of body mass than other mammals.

Many whales, including the sperm whale, locate and track their prey in the deep, dark waters by using echolocation—bouncing sound waves off the prey.

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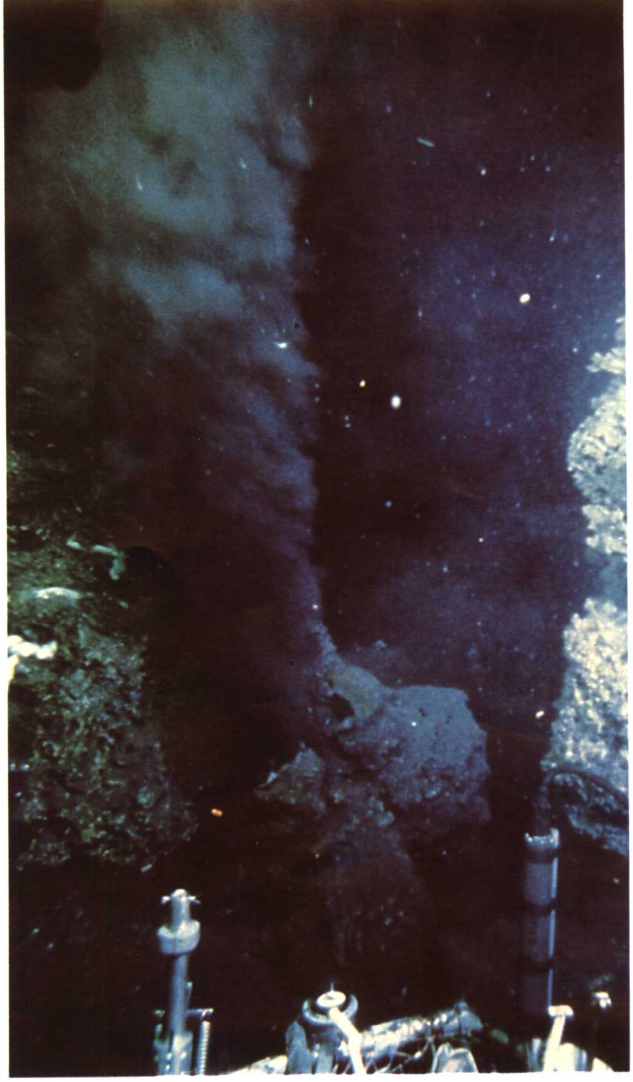
PLATE 2

A



B

But we also are driven to learn more of our distant relatives, invertebrates, that inhabit the ocean to its greatest depths. Of particular interest are relatively large bottom-dwelling animals living in association with hot-water springs found along the rift valleys near the axes of submarine mountain ranges. These animals are independent of the micro-scopic plant life that lives in the sunlit waters and supports the vast majority of marine animals.

These vent communities are supported by bacteria that produce food in total darkness by extracting chemical energy from the hydrogen sulfide gas that is dissolved in the vent water.

The first of these vent communities was discovered in 1977. Off the coast of Ecuador and near the equator, they were recorded by a photographic sled towed through the region of a temperature anomaly at the ocean floor. This initial find was in a rift valley at the axis of a submarine mountain range—the Galapagos Rift.

The more prominent members of this deep assemblage are large tube worms living in tubes over 1 m (3.3 ft) long, as well as clams and mussels up to 25 cm (9 in) long. None of these larger animals possess guts, and they may receive most of their nutrition from a symbiotic relationship with the chemosynthetic bacteria living within their tissue.

Other members of the hydrothermal vent communities may filter the bacteria from the water or graze on bacterial mats growing on the rocky ocean floor.

Subsequent investigations have located vents called black smokers that spew out dark clouds of metallic compounds at temperatures of more than 300°C (572°F) and biological communities associated with numerous hydrothermal vents in the Pacific and Atlantic oceans.

Cold-water seeps have also been found to support biological communities based on a basic bacterial food supply. The cold-water communities have all been located near the margins of continents. They are known to exist at the base of the Florida Escarpment in the Gulf of Mexico, off the coast of Oregon, and near Japan.

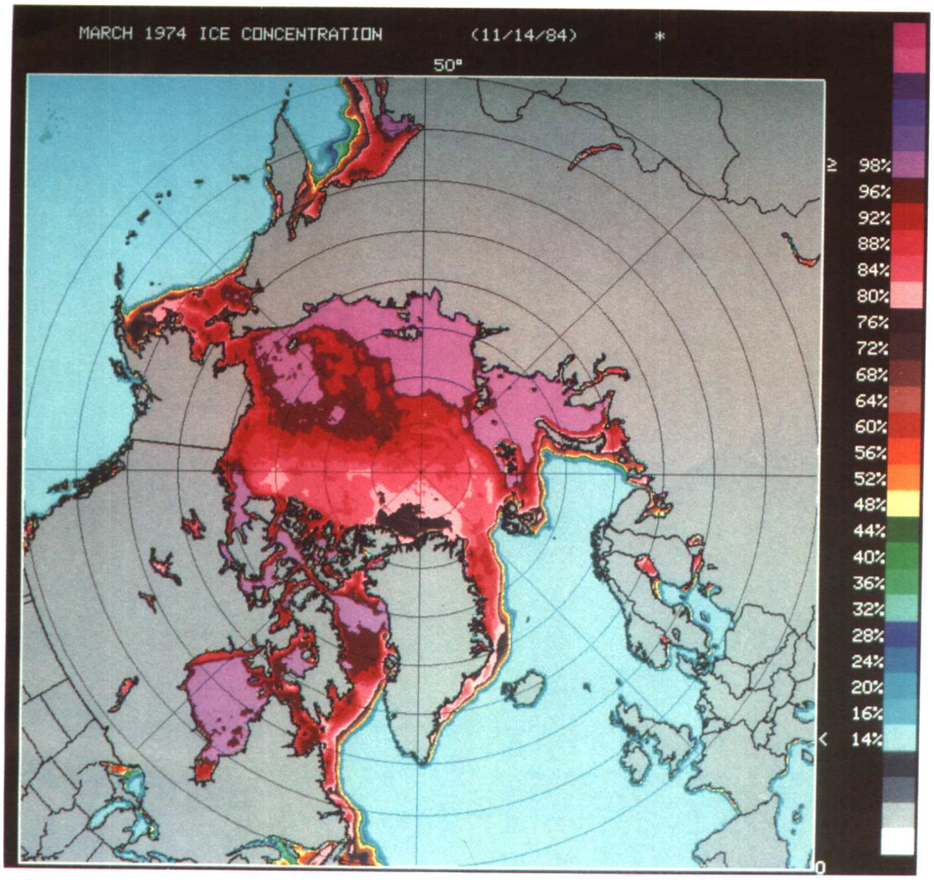
Seeping hydrocarbons support a biological community on the continental slope off the coast of Louisiana.

In addition to the unusual biological phenomena associated with the hydrothermal vents, these emissions precipitate metallic deposits that may be the ultimate source of metal-rich ores mined on the continents.

After the metal deposits form at the axes of the submarine mountain ranges, they are transported away by a slowly moving ocean floor. Eventually, the ocean floor may encounter a continent and descend beneath it. During this process, the metallic compounds are distilled out of the oceanic rocks and emplaced in the overlying rocks of the continent.

PLATE 3

PLATE 4



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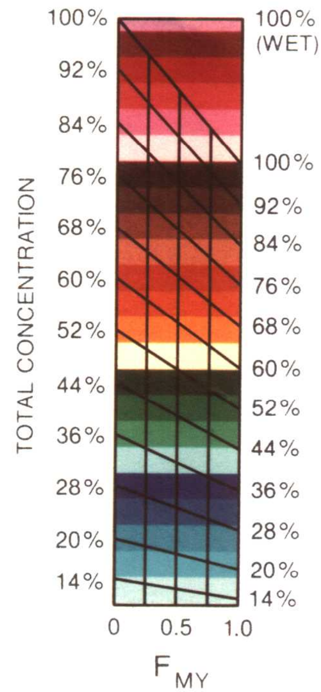

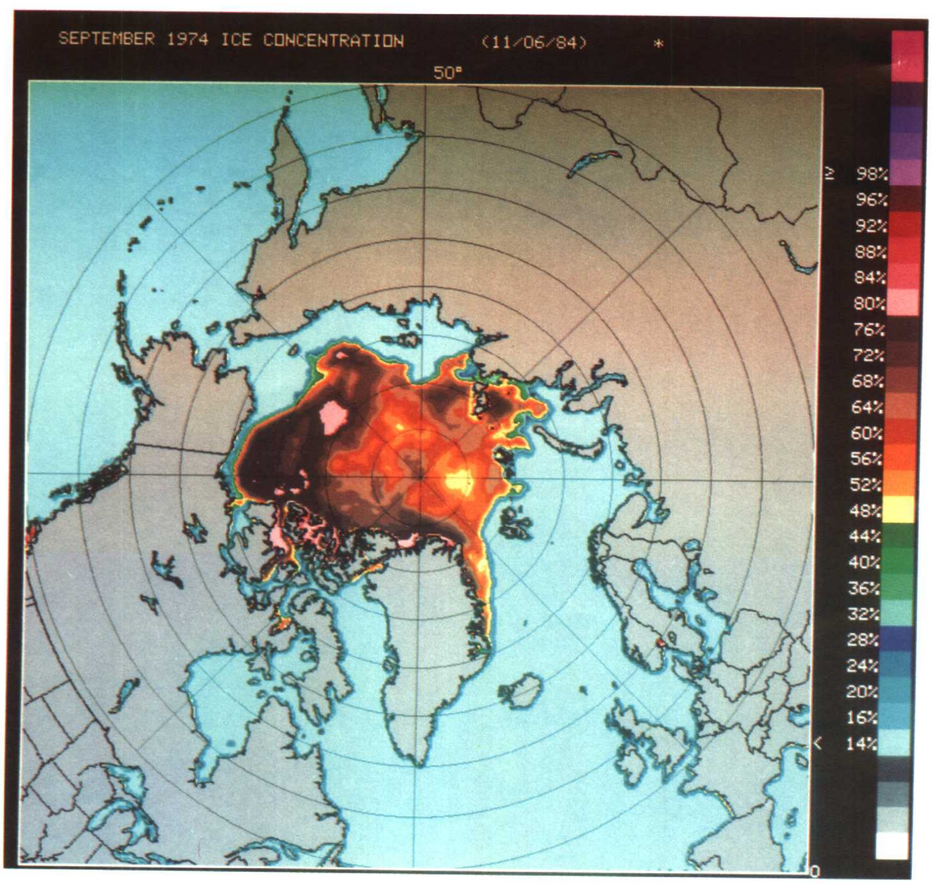

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During recent years, much attention has been directed at the polar oceans, where sea ice covers great expanses of ocean surface each winter and melts away in summer months. The seaward edge of this ice is a zone of intense biological activity.

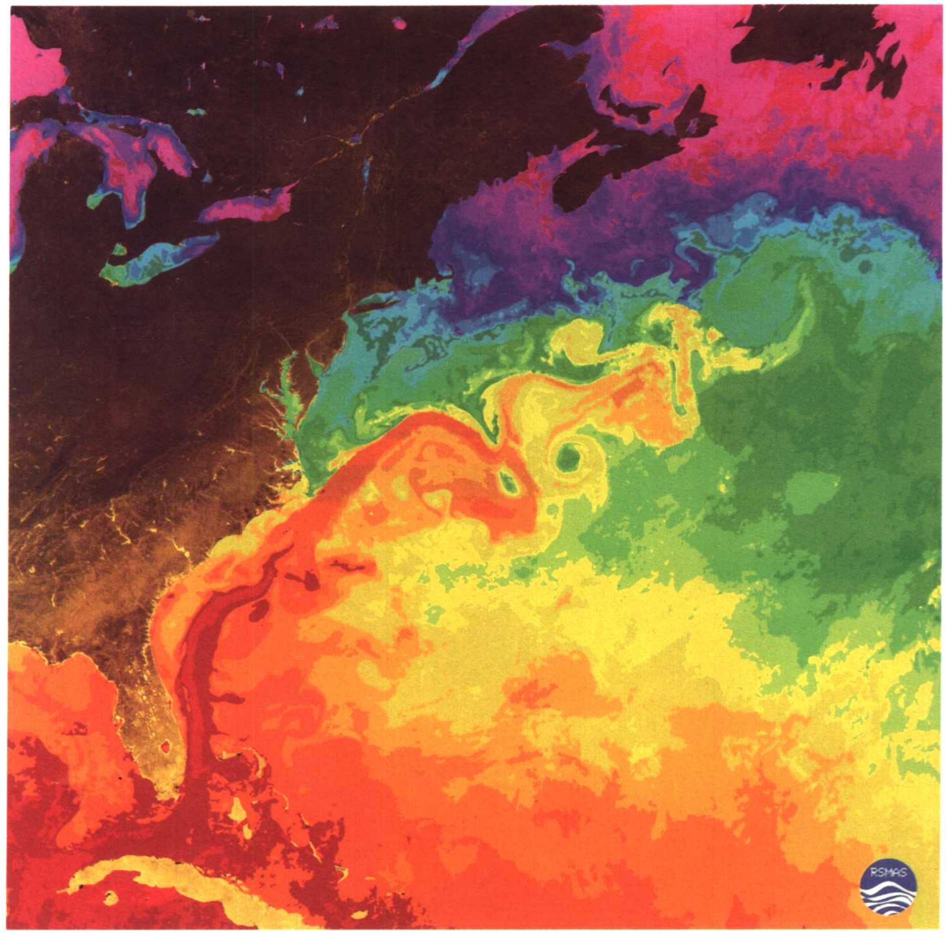
A permanent polar ice accumulation exists in the Arctic Ocean. During the winter, sea ice in the form of pack ice forms on the open sea to extend the polar ice to the south. Fast ice also forms along the shores to the south. Each summer the pack ice and fast ice melt away.

These 1974 images showing percent of sea-ice concentration are accurate to within 15% for first-year sea ice (pack ice and fast ice) and 25% for multiyear ice (polar ice cap). The scales of ice concentration along the right margins of each image are for first-year ice. The scale above can be used for first-year ice (left side) or multiyear ice (right side). The images were developed from the ESMR (Electrically Scanning Microwave Radiometer) aboard the Nimbus *5 satellite.*

Sea-surface temperature data gathered by a NOAA satellite was processed to produce this false-color image of the northwest Atlantic Ocean. The warm Gulf Stream waters are shown as orange and red. The colder nearshore waters are blue and purple. Warm water from south of the Gulf Stream is transferred to the north as warm core rings (yellow) surrounded by cooler (blue and green) water. Cold nearshore water spins off to the south of the Gulf Stream as cold core rings (green) surrounded by warmer (yellow and red) water.

The rings form when meanders close to trap warm or cold water within them. The warm rings contain shallow, bowl-shaped masses of warm water about 1 km (0.62 mi) deep with diameters of about 100 km (62 mi). The cold rings have cones of cold water that extend to the ocean floor. They may be more than 500 km (310 mi) across at the surface. The diameter of the cone increases with depth.

PLATE 5



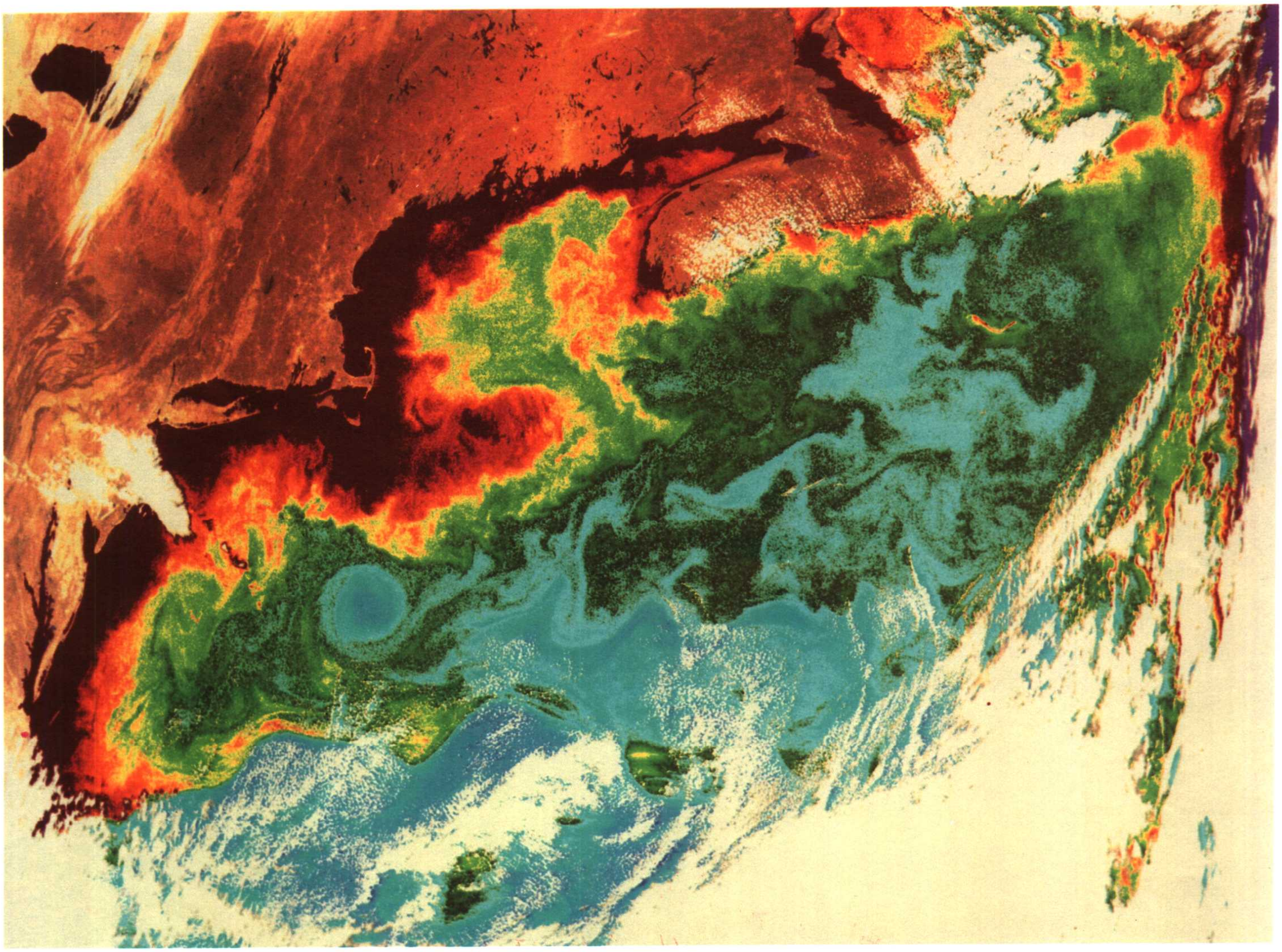


PLATE 6

In shallow coastal waters, where biological activity reaches its greatest development, there is a correlation between decreased temperature of surface water and high levels of microscopic plant production. Remote sensing by satellites may eventually make it possible to develop a global view of this relationship.

This false-color image of chlorophyll pigment concentration in the northwest Atlantic Ocean shows the low level of biological productivity of the Gulf Stream in blue. Increasing levels of productivity are shown as green, yellow, red, and dark red.

A striking feature of this image is the low level of productivity indicated by the blue color of the warm core ring south of Cape Cod. Note that it is surrounded by more productive green nearshore water. The white is cloud cover.

Coral reefs serve as biological oases in the relatively unproductive tropical ocean. The coral reef environment includes a great variety of marine life with the most colorful and varied marine communities found in the oceans. Here we see the tentacles of coral polyps extended to remove microscopic food particles from ocean water.

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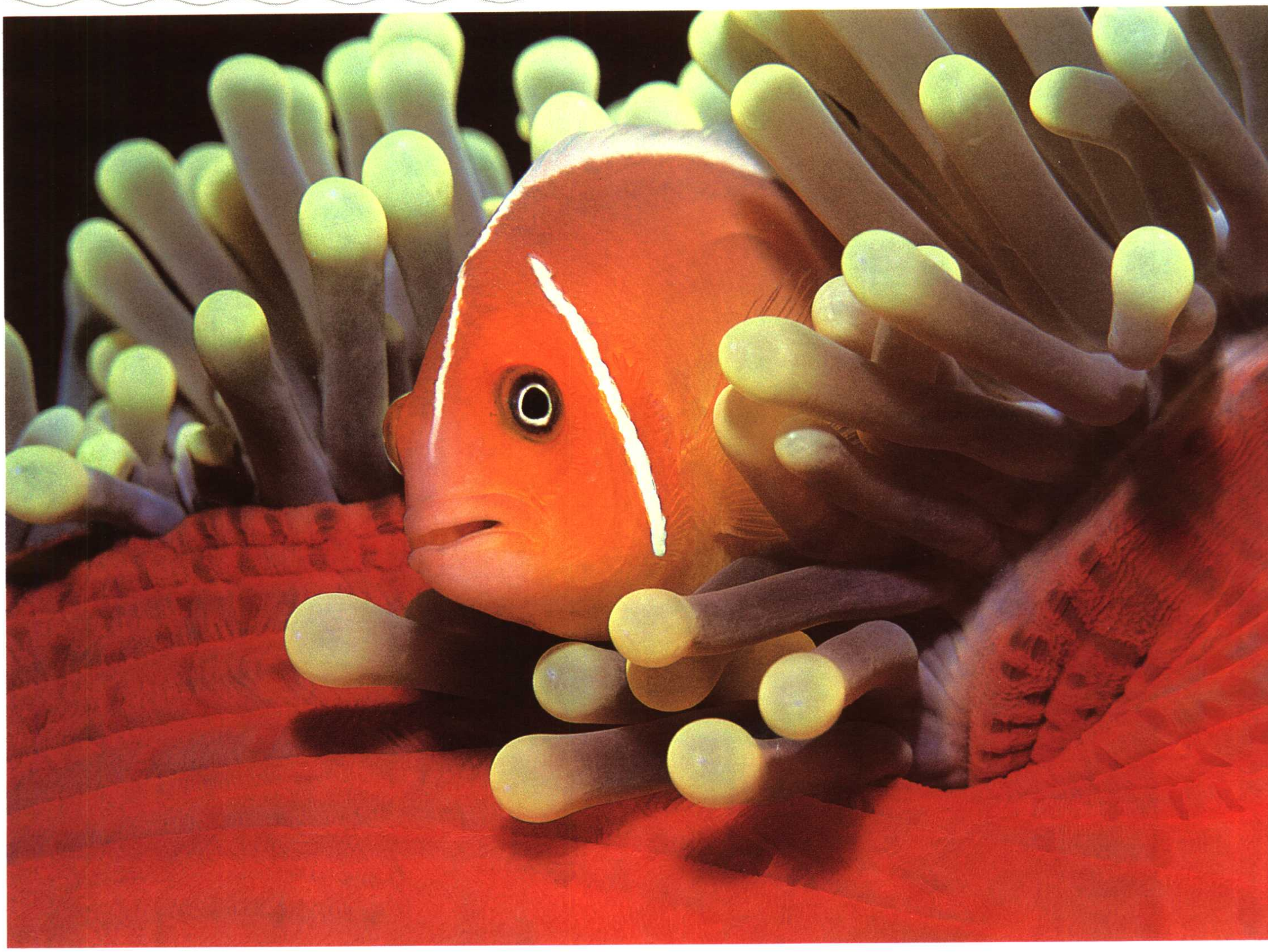

Coral reefs are found only in warm water, and reef-building corals have microscopic algae living in their tissues to aid them in secreting the calcium carbonate structure that supports them.

However, more than half of the limestone of coral reefs is produced by calcium carbonate-secreting algae that thrive in the nutrient-rich waters of the reef. Actually, the plant mass of a coral reef is three times as great as the animal mass.

The clown fish, which lives unharmed among the stinging tentacles of the sea anemone, may pay for this protection by bringing food to the anemone. This symbiotic relationship that benefits both participants is called mutualism. Two other types of symbiotic relationships that may be found in coral reefs and the ocean as a whole are commensalism and parasitism. In commensalism, one organism benefits while the other is unaffected. Parasitism involves the benefit to one at the expense of the other.

One of the most striking features of the coral reef is the great variety of brilliantly colored fish. The reason for such an audacious display of color has not been discovered. But for whatever reason it exists, no visual experience on this planet will ever produce the thrill and wonderment of one's first view of this display.

From the peak of Mt. Everest to the bottom of the Challenger Deep in the Marianas Trench, the maximum relief of the earth's surface is over 20 km (12.5 mi).

Because the continental crust is less dense than the ocean crust, the continents rise above the ocean surface with an average elevation above sea level of 840 m, or just over .5 mi. The average depth of the oceans is 3865 m (2.5 mi).

Seventy-one percent of the earth's surface is covered by ocean water.

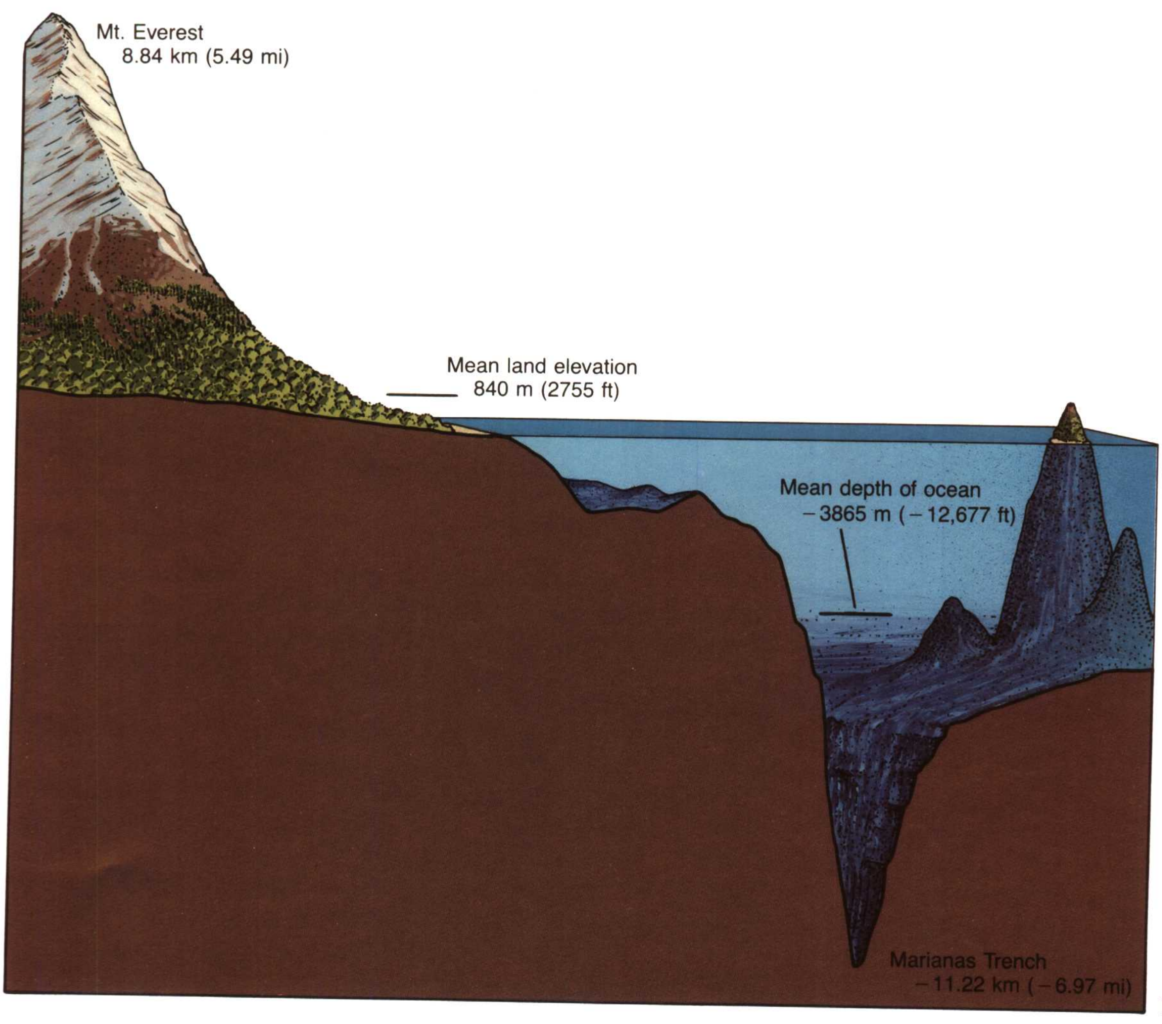

PLATE 9

PLATE 10

Key

1 Eurasian Plate
2 North American Plate
3 Philippine Plate
4 Pacific Plate
5 Juan de Fuca Plate
6 Cocos Plate
7 Caribbean Plate
8 South American Plate
9 African Plate
10 Indo-Australian Plate
11 Nazca Plate
12 Scotia Plate
13 Antarctic Plate
14 Arabian Plate
15 San Andreas Fault
16 East African Rift Valley

Convergent boundaries
Divergent boundaries
Transform fault boundaries
Direction of plate movement

This relief is directly related to the interactions of a dozen or so lithospheric plates that form at the axes of submarine mountain ranges (divergent boundaries) and dive back into the earth's interior beneath deep-ocean trenches (convergent boundaries). The divergent plate boundaries are offset by transform faults, along which the plates slide past one another in opposite directions.

The plates move at rates ranging from 1.5 cm (0.8 in) per year for the American plates to more than 10 cm (5.4 in) per year for the Pacific Plate.

Sixty-five thousand kilometers (40,000 mi) of oceanic mountain ranges called oceanic ridges and rises mark the divergent plate boundaries and transform fault plate boundaries and meander through the oceans. In places, they invade the land, producing such features as the San Andreas Fault in California and the East African Rift valley.

Convergent plate boundaries are associated with ocean trench–volcanic island arc systems like the Aleutian Islands. The Peru-Chile Trench and adjacent volcanic belt of the western Andes Mountains are elements of an ocean trench–continental volcanic arc system that also marks a convergent plate boundary. Folded mountain ranges such as the Himalayas and Alps are also manifestations of plate convergence.

New lithosphere is added to the plates by volcanic processes operating at the divergent plate boundaries. This volcanism is fed from chambers of molten rock or magma located only a few kilometers beneath the ocean floor. Another source of volcanism, represented by a stationary plume of magma that may rise from depths of over 2000 km (1200 mi), is called a hot spot.

Hot spots may be responsible for such continental volcanic features as Yellowstone National Park's hot springs, and there is much evidence of marine hot spots.

The island of Iceland is a large volcanic feature located on a divergent plate boundary or spreading center called the Mid-Atlantic Ridge. While most of the Mid-Atlantic Ridge is more than 2 km (1.2 mi) beneath the ocean surface, the additional lava produced by the hot spot has helped Iceland rise to the surface as a volcanic island.

The Hawaiian Islands–Emperor Seamount chain in the North Pacific Ocean was produced by a hot spot that is far from a divergent plate boundary. This hot spot has been in existence for more than 70 million years. Its present location is beneath the southeastern shore of the Island of Hawaii—the only volcanically active island in the chain. As the Pacific Plate moved in a west-northwest direction over the hot spot, it burned through the lithosphere to produce a series of volcanic islands and seamounts, which are volcanoes that did not become large enough to become islands. The oldest seamount in the chain is located just south of the western end of the Aleutian Islands, and it is over 70 million years old. Moving south along the chain toward the Hawaiian Islands, the volcanic peaks become progressively younger. The island of Kauai is the oldest major Hawaiian island, and it began to form 5.5 million years ago. The island Hawaii began to form only .75 million years ago.

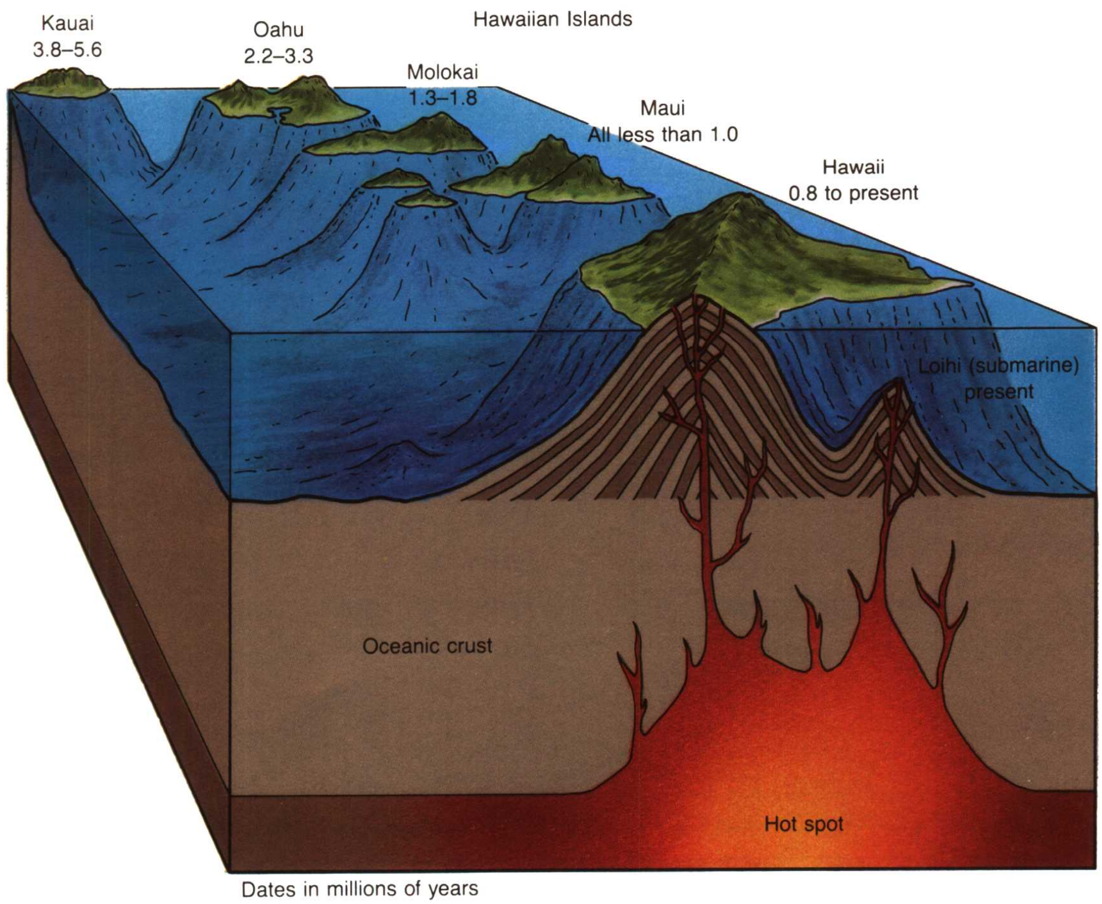

PLATE 11

Painted by Tanguy de Rémur.

Plate boundaries are readily visible on a bathymetric map of the ocean floor. The youngest ocean floor is found at the axes of the long chains of mountains that run through the ocean basins. The ocean floor gradually deepens toward the trenches, where the oldest ocean floor is subducting back into the mantle.

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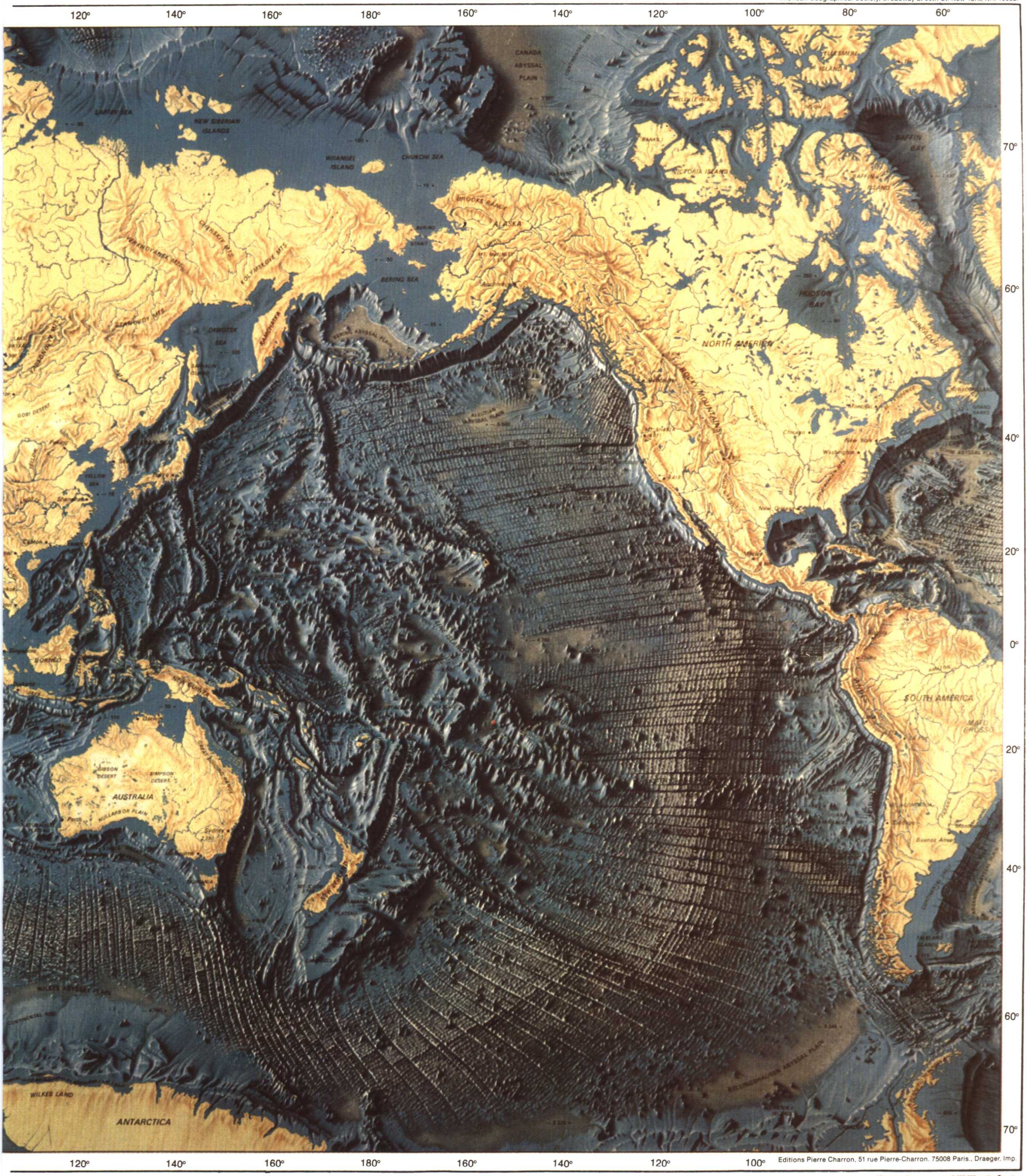

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Mercator Projection 1 [illegible] at the Equator
Depth and Elevations in Meters.

PLATE 12

THE FLOOR OF THE OCEANS

Based on Bathymetric studies by
Bruce C. Heezen and Marie Tharp
of the Lamont Doherty Geological Observatory
Columbia University Palisades, New York, 10964

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