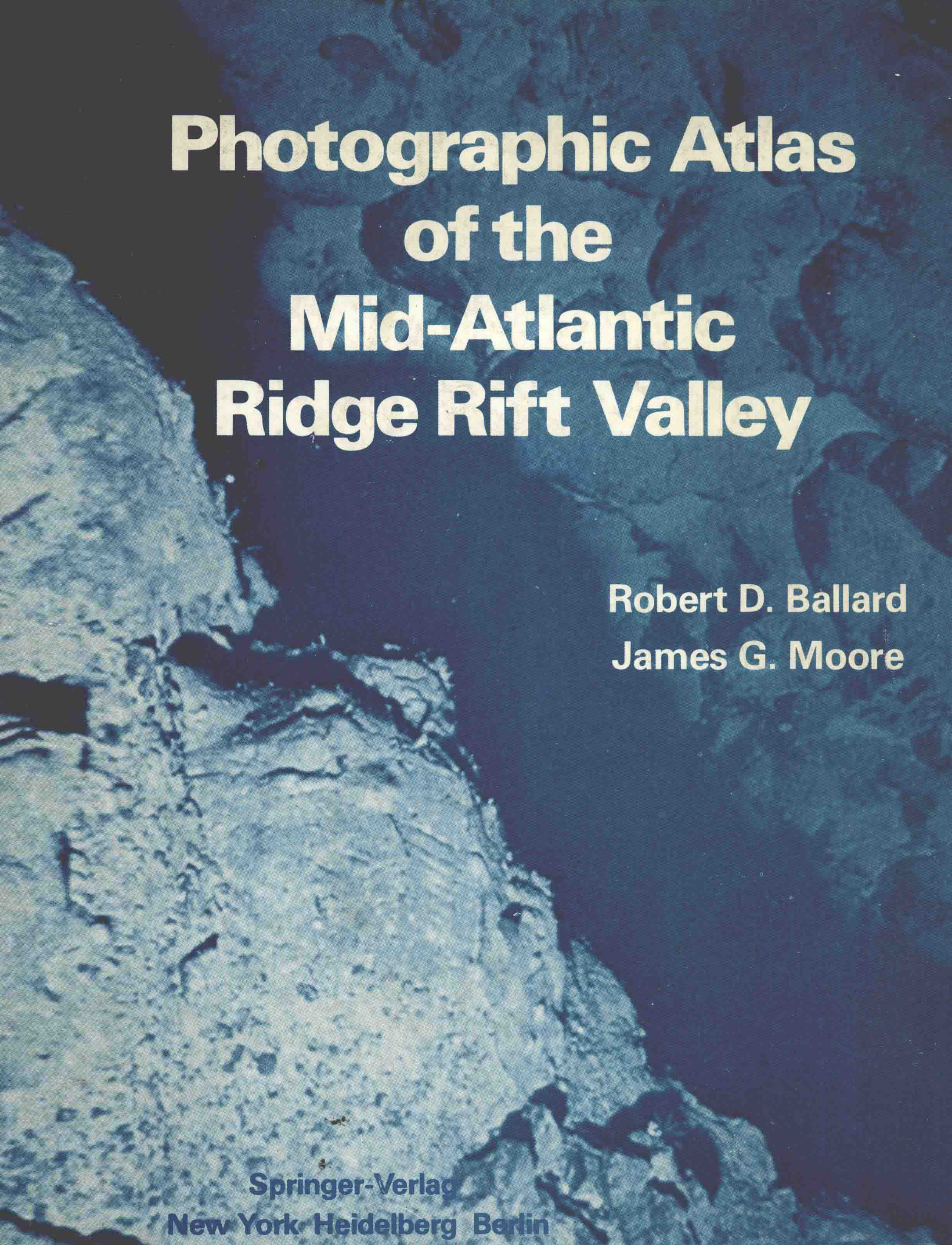

Photographic Atlas of the Mid-Atlantic Ridge Rift Valley

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Dedicated to the crews, scientists, engineers, and pilots who first demonstrated in Project FAMOUS that diving craft can safely perform detailed scientific studies of the deep ocean floor.

Foreword

The oceans are so large and our knowledge of them so limited that we sometimes think of the sea floor as a vast uniform wasteland. But modern oceanographic research is revealing that each part of the sea floor has its own characteristic features and is as distinct as the geologic and topographic provinces on land. The deep ocean floor holds the same fascination for us as unexplored mountain tops, jungles, or the surface of the moon and planets. And, since the oceans cover more than 70 percent of the earth's surface, the ocean floor holds the key to much of the history and evolution of our earth.

There are very few places in the depths of the ocean that have been explored and studied directly by man, and to which man can relate in the way he relates to the earth on land. The Mid-Atlantic Ridge rift valley, studied during Project FAMOUS, is one of these places. This location was chosen because it is typical of the zone in the central Atlantic where volcanic activity apparently creates all of the sea floor of that ocean. Consequently the region is of great importance to earth scientists. Here participating scientists systematically investigated large and small geologic features to learn their shape, properties, and origin. They used the most advanced techniques available from aircraft, surface ships, and submersibles which operated in water depths of nearly 3 kilometers. As part of these studies an extensive photographic record of bottom features was obtained. Some of these photos are reproduced in this book to give the reader a view of the sea floor and to help him understand the natural processes at work.

Robert Ballard is a geologist with extensive experience in submersible diving and James Moore, a volcanologist who has made many scuba dives in active volcanic terrain. Both were members of the American scientific diving team of the project. They, and their colleagues, have published nearly 100 papers on the scientific results of the program. However, these papers have reproduced only a few of the large volume of photographs that are now in the archives. We believe that the public at large as well as our scientific colleagues will benefit from the selected photographs in this volume.

Woods Hole
November, 1977

J. R. Heirtzler

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Acknowledgments

The photographs in this atlas were obtained through the combined cooperation of the American and French scientists, engineers, technicians, crews, and pilots associated with Project FAMOUS. The authors wish to express their sincere appreciation to this international group who worked long hours at sea during the four year period of the project.

We wish to particularly thank Drs. Jean-Louis Cheminee and Gilbert Bellaiche of the Centre National de la Recherche Scientifique and Walter Brundage of the U.S. Naval Research Laboratory for their assistance in the preparation and review of this atlas. FAMOUS was funded in the United States by the National Science Foundation and the National Oceanic and Atmospheric Administration with support from the Office of Naval Research, and the Naval Oceanographic Office. Chief scientist for the American phase of Project FAMOUS was Dr. James R. Heirtzler, Woods Hole Oceanographic Institution. The French program, operating under the government agency Centre National pour L'Exploitation des Oceans, CNEXO, was directed by Mr. Claude Riffaud and Dr. Xavier Le Pichon.

We also wish to thank Susan Christiansen and Irene Fisher for the sketches they made of various pillow and tectonic forms contained within this atlas.

Robert D. Ballard
James G. Moore

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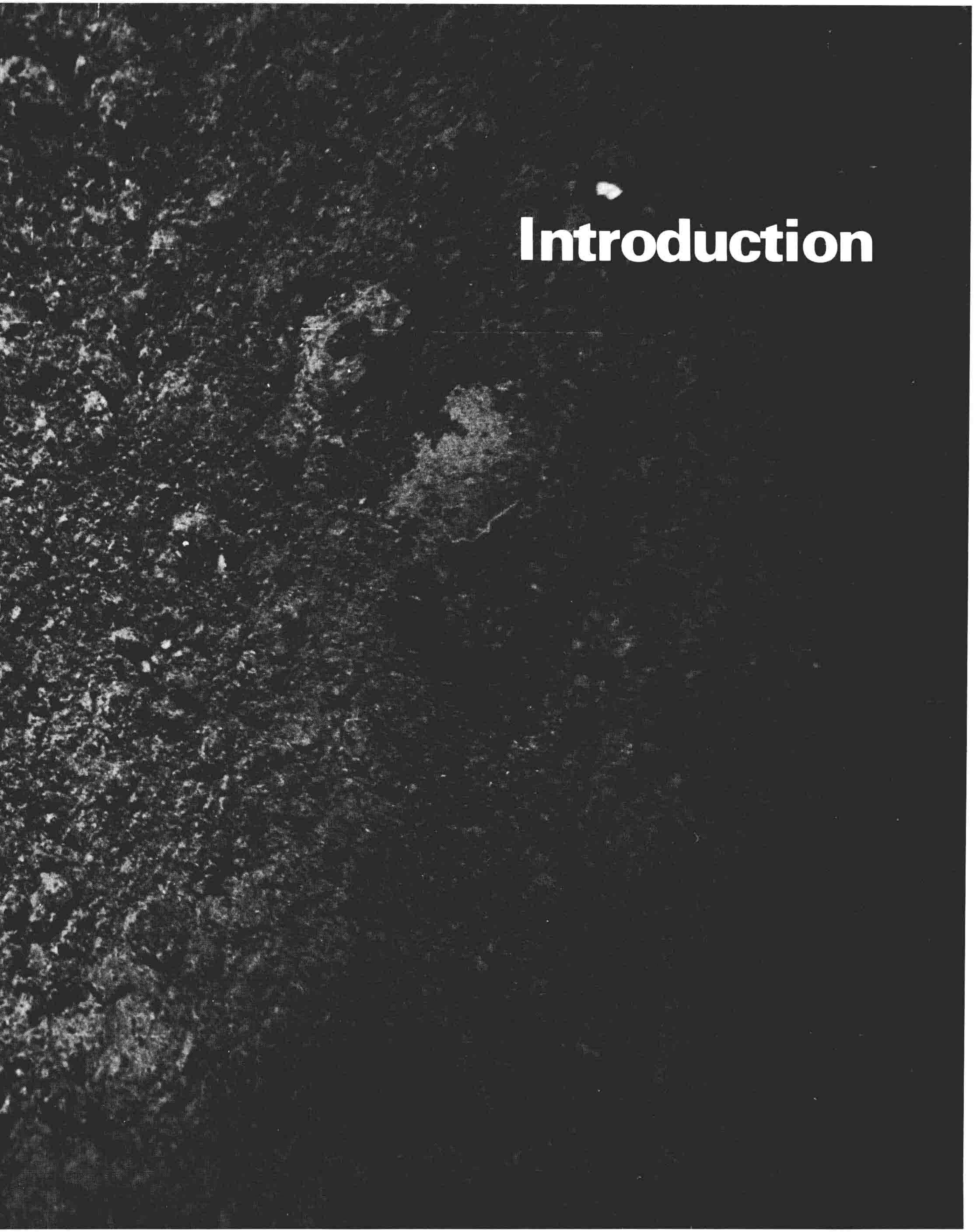
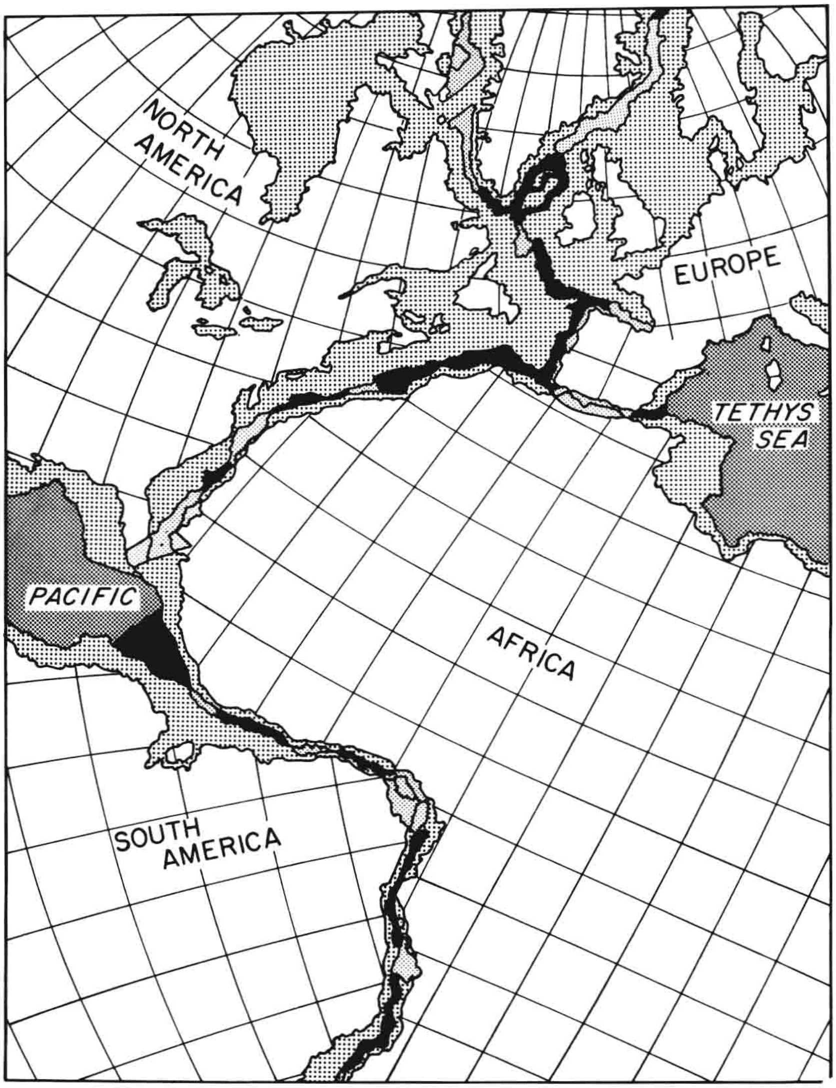
Introduction



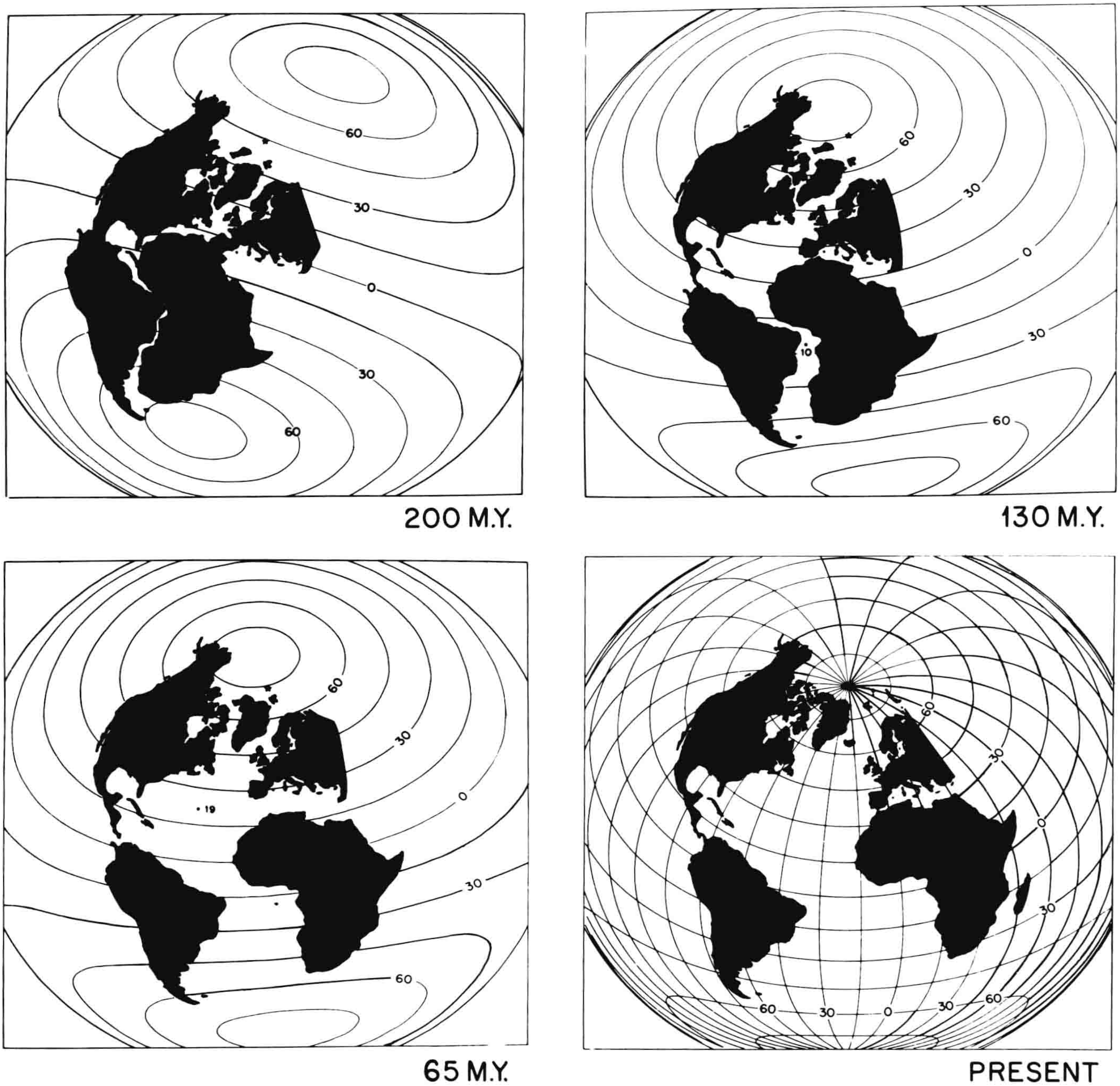
Approximately 200 million years ago, the continental nuclei of Europe, Africa, and the Americas began to separate as a result of dynamic processes taking place within the earth (Figure 1). As the land masses moved apart, a large crack or rift zone developed in the Earth's rigid outer layer, the lithosphere. In response to separation of the lithosphere along this zone of rifting, plastic material from the earth's interior rose toward the surface filling the void. Unlike the lighter granitic rock which forms the core of most continents, the rising material from the upper mantle crystallized to form basaltic and related denser rock. Since the lithosphere of the earth is floating on denser, more plastic deeper layers, this newly created basaltic rock initially equilibrated at a level lower than the lighter granitic continents nearby. The result was a depression, the Atlantic Ocean, situated between the separating continental masses. This depression was filled by the invading waters of the Tethys Sea (now Mediterranean) and Pacific Ocean which existed at that time.

Although the young Atlantic floor was lower than the adjacent continents, it still retained a great deal of its original heat, particularly adjacent to its site of formation at the spreading rift. As the new lithosphere was rafted outward from the rift, it slowly cooled and contracted. The youngest or most recently crystallized crust was swollen with heat, producing a welt in the form of a mountain range situated above the site of upwelling and rifting. As separation continued, the older crust was transported laterally farther and farther away from its original site of formation (Figure 2). In time it cooled and contracted, sinking to greater depths to form the deep ocean floor located between the continents and the younger mountain range in the center of the ocean.

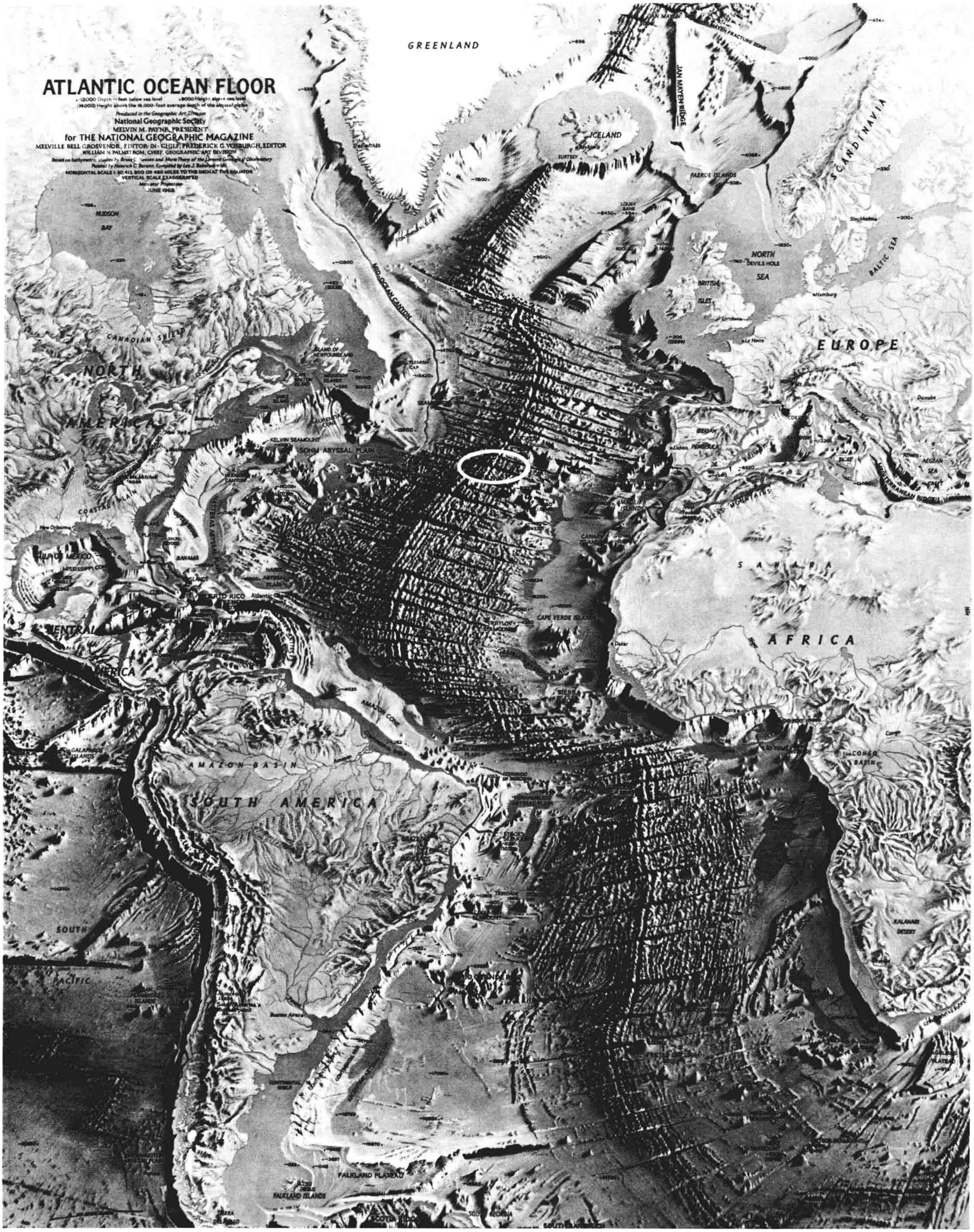
The process of separation in the Atlantic has been occurring at a relatively



1 A geometrical fit of the continental nuclei around the Atlantic Ocean which is thought to represent the rough outline of the supercontinent of Pangea which existed approximately 200 million years ago. This reconstruction was made by Bullard et al., 1965 using a least squares numerical method of fitting. The best fit was found to occur at the 500 fathom contour on the continental margins of the bordering land masses (lined pattern). The black areas correspond to voids in the fit whereas the small dotted pattern is where overlap occurs. It is along this boundary of separation that the Mid-Atlantic Ridge first came into existence.



2 Using Bullard et al. (1965) poles of rotation, Phillips and Forsyth (1972) generated a series of reconstructions showing the evolution of the Atlantic Ocean as we know it today. Their work suggests that the central Atlantic, Caribbean, and Gulf of Mexico began to form 200 million years ago while the South Atlantic first opened as late as 150 million years ago.



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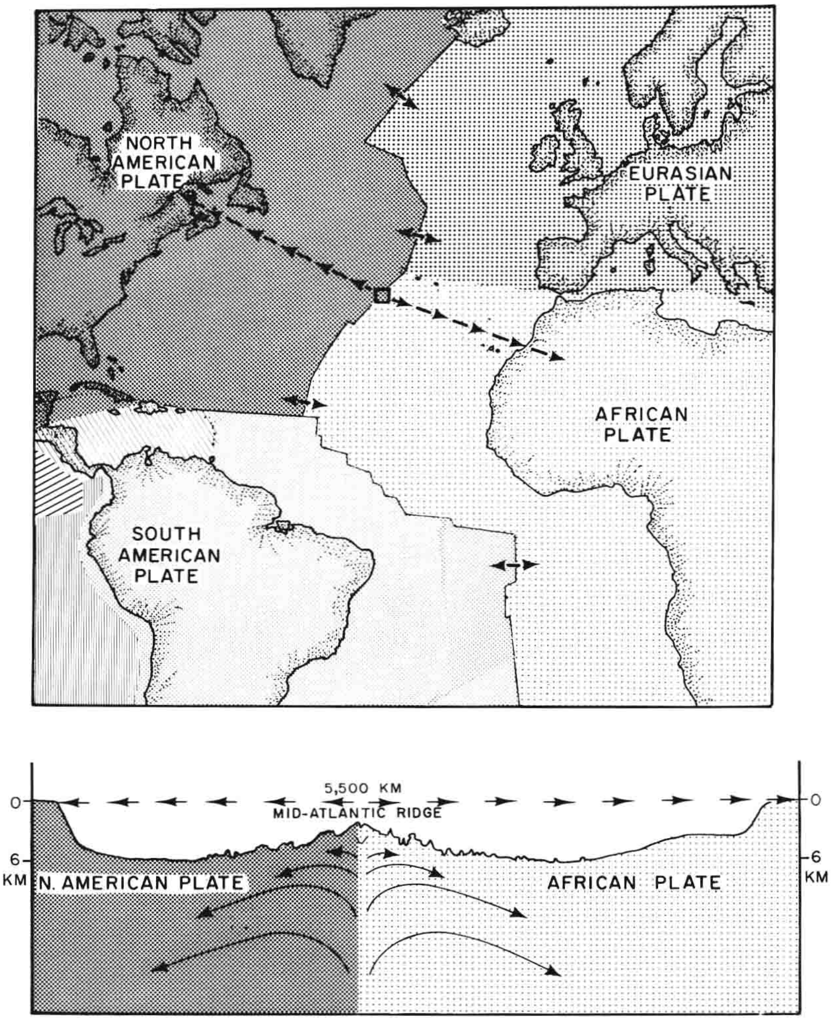
continuous rate for the intervening 180 million years. The central mountain range of freshly forming oceanic lithosphere of today is the Mid-Atlantic Ridge (Figure 3). Parallel to the crest of this mountain range and at its center is a deep rift valley, caused by the pulling away of two large lithospheric plates: the American plate which is moving west and the African plate which is moving east (Figure 4). The floor of this rift valley is mantled with very young basaltic lava flows which are fed from the upwelling hot mantle material.

As each episode of rifting or sea-floor spreading occurs, a portion of the plastic upper mantle material rises and because of reduced confining pressure undergoes partial melting. This partial melt rises towards the surface where it is probably stored temporarily in a shallow chamber. Finally a portion of the magma eventually flows out onto the sea floor as basaltic lava flows at a temperature of approximately 1,250°C. When this hot lava comes into contact with the cold seawater of the ocean floor, it is quickly cooled into a tangled mass of lobate flow tongues about the size and shape of pillows. Such "pillow lava" forms thicker master flow units which are commonly stacked on one another and build small, steep-sided volcanoes.

Immediately after formation this volcanic terrain is subjected to contractional cooling and the local tensional forces of sea-floor spreading. The newly formed crust is cracked and faulted as it is transported laterally to make room for the next intrusive and volcanic cycle.

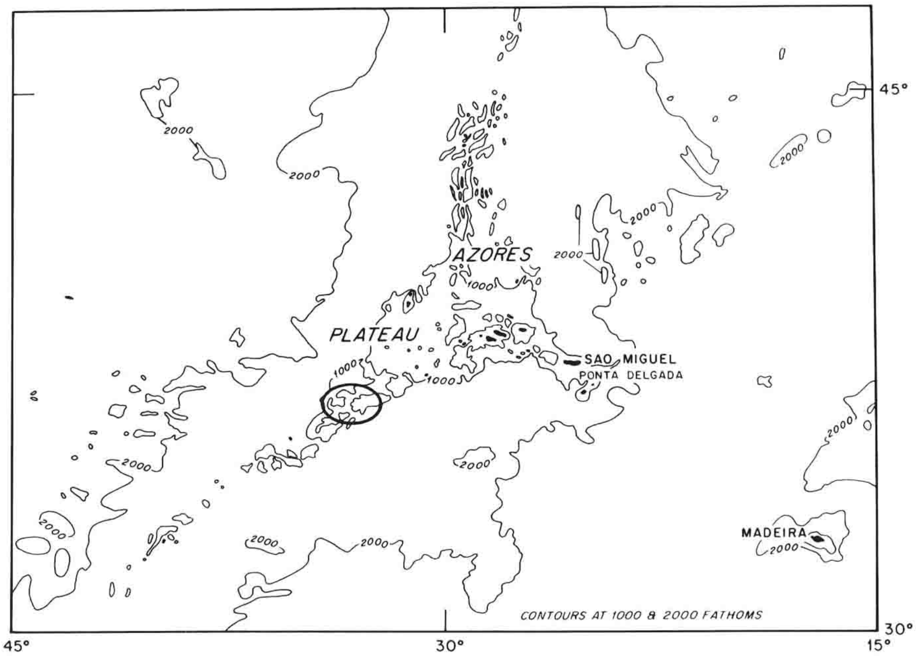
Such faulted volcanic terrain is the bedrock which underlies most of the world oceans. It represents the most common form of volcanic products on earth, but until recently was unavailable for systematic study. In 1972 a comprehensive marine field program called Project FAMOUS (French-American Mid-Ocean Undersea Study) was initiated to investigate the volcanic and tectonic processes taking place in the inner rift valley of the



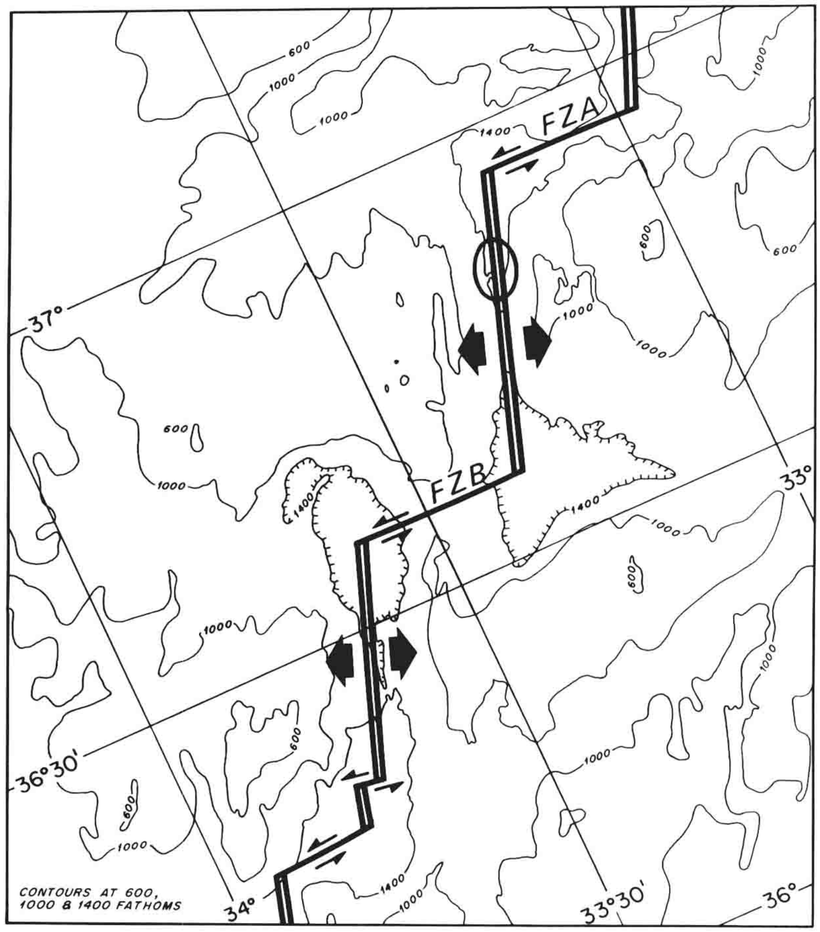
4 The top of the figure shows the crustal plates surrounding the Mid-Atlantic Ridge. The arrows denote the principal direction of relative plate motion and the small square is where the Project FAMOUS study was conducted. The lower portion of the figure is a generalized profile extending from the continental shelf of North America across the Mid-Atlantic Ridge rift valley to the continental shelf of northwest Africa.

3 Physiographic map of the Atlantic Ocean sea floor and surrounding land masses. Published and copyrighted by the National Geographic Society and based upon bathymetric studies by Bruce C. Heezen and Marie Tharp. Running down the center of the Atlantic is the Mid-Atlantic Ridge. The boundaries of the major plates meeting along this ridge line are marked by the rift valley extending along the crest of the mountain range. The small ellipse shows the region of the Mid-Atlantic Ridge where Project FAMOUS was conducted.

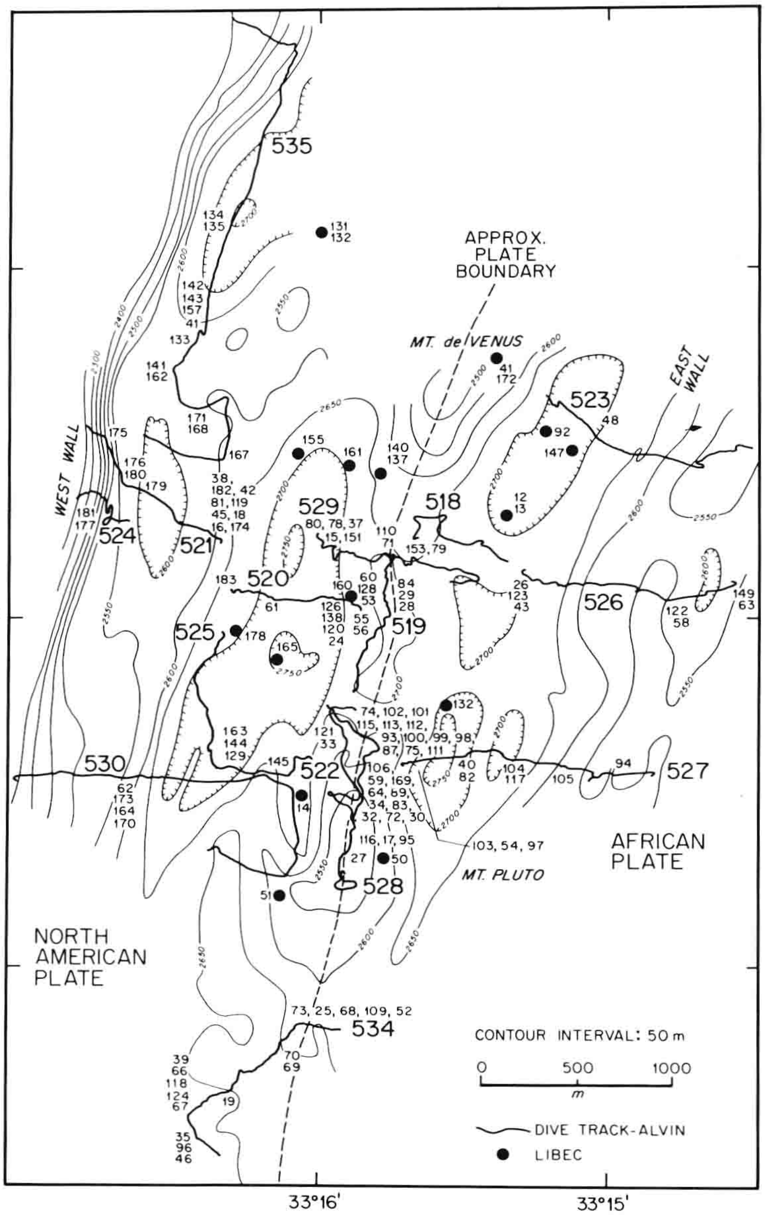
Mid-Atlantic Ridge (Heirtzler and LePichon, 1974). During the course of this four-year program, a unique series of bottom photographs was obtained. These photographs portray the original volcanic features as well as their subsequent modification by tectonic processes. Many of the photographs were obtained firsthand by scientists on the rift valley floor in small deep diving submersibles. The remainder were taken using surface-lowered remote camera units. Documentation and interpretation of observations, photographs, and samples have been published in a variety of journals. The purpose of this photographic atlas, however, is to present a visual aspect of the terrain and geological features occurring in the rift valley. Photographs of the various features are grouped together so as to emphasize the similarity or modification of important forms and structures. Since the principal emphasis of this atlas is on the oceanic crust exposed within the rift valley, little mention is given to the abundant marine life observed or areas where the sediment cover was thick enough to bury the bedrock surface.



5 The Project FAMOUS study area (ellipse) is situated on the southwestern portion of the Azores Plateau near the island of San Miguel which served as the base of operations for the program.



6 A further enlargement of the study area. The bathymetric data were obtained from a detailed series of maps compiled by the Naval Oceanographic Office (Phillips and Fleming, in press). At this scale it can be seen that the Mid-Atlantic Ridge consists of a series of short rift valley segments connected by intersecting fracture zones. The rift valley segments mark the boundary of plate separation (large arrows) while the fracture zones represent areas of faulting and crustal translation (small arrows). The ellipse is the area where the majority of the ALVIN dives were conducted.



7 The small-scale topography of the rift valley floor where the photographs in this atlas were taken. Mt. Venus, Mt. Pluto, and Mt. Uranus are volcanic highs extending down the axis of the valley and representing the area of recent volcanic activity. This central zone is flanked by the remainder of the floor which consists of older volcanic units. The valley itself is flanked by the east and west walls which consist of inward facing fault scarps. Large numbers are ALVIN dive numbers and small numbers indicate the approximate location of photo figures in this atlas.

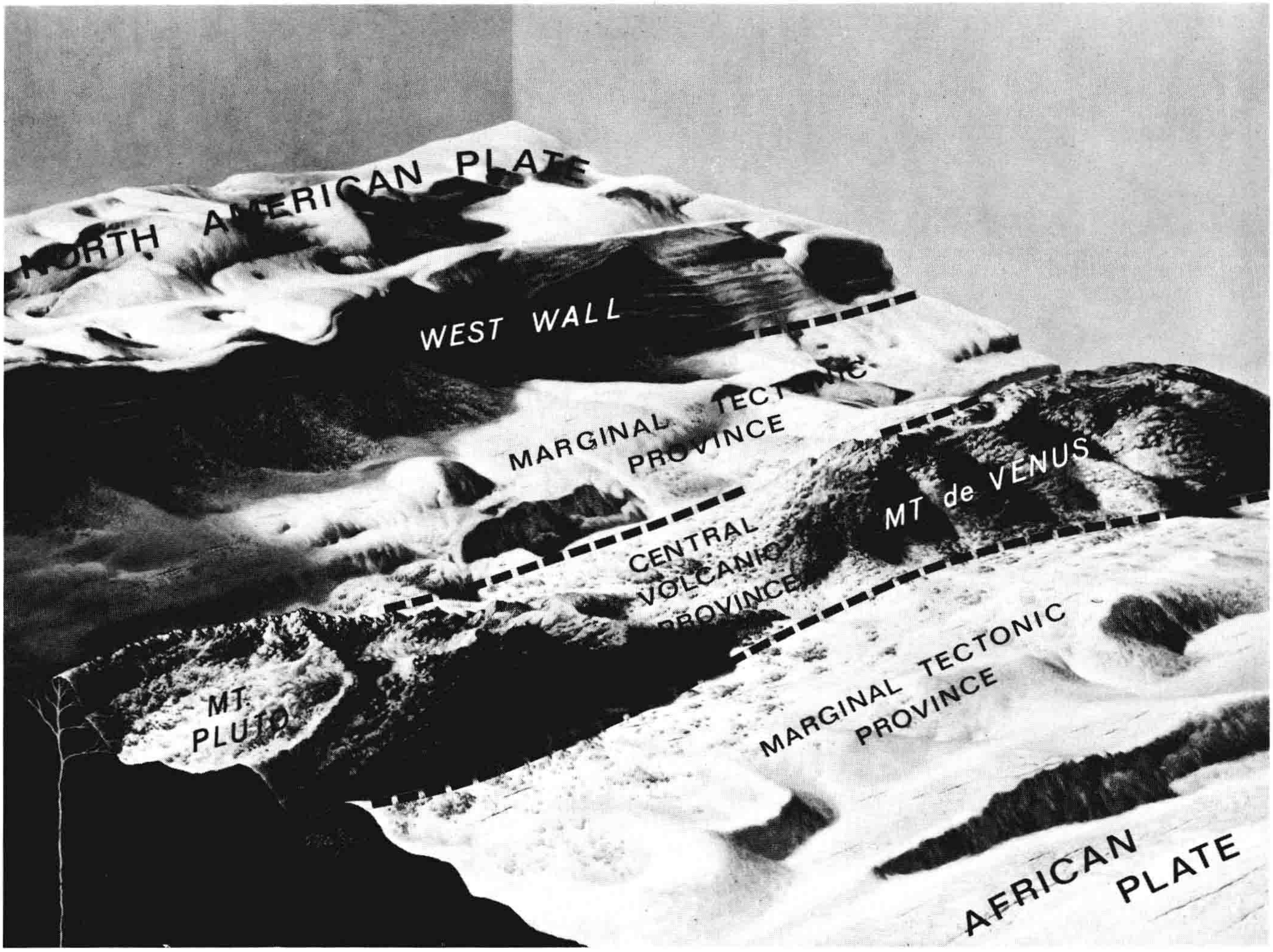
Geologic Setting

The Project FAMOUS study area is located along a portion of the Mid-Atlantic Ridge rift valley which intersects the southeastern margin of the Azores plateau (Figures 4 and 5). The area is situated some 720 km southwest of Ponta Delgada on the Azores island of San Miguel.

The rift valley does not extend continuously along the crest of the ridge, but instead is divided into a series of segments 20–45 km in length trending more nearly north-south (N29° E). The individual valley segments are offset by small horizontal-slip faults called transform faults which intersect the rift valley at approximately right angles (Figure 6). In general the inner valley can be subdivided into three geologic provinces (Figure 7). The first is a central zone of recent volcanic activity which outlines the present boundary between the two separating crustal plates (Figure 8). The most common features in this zone are young volcanic ridges which exhibit only recent faulting, faulting of small displacement which has not greatly modified the primary volcanic features. The second province includes the valley floor to either side of the central volcanoes. In this region the volcanic terrain is modified by small to intermediate scale fault scarps. Pelagic sediment a few meters thick has accumulated in the low-lying areas. The third province contains the east and west inner walls of the rift valley where vertical uplift is taking place on a major scale. It is on these fault scarps that the deeper internal layers of the oceanic crust are exposed.

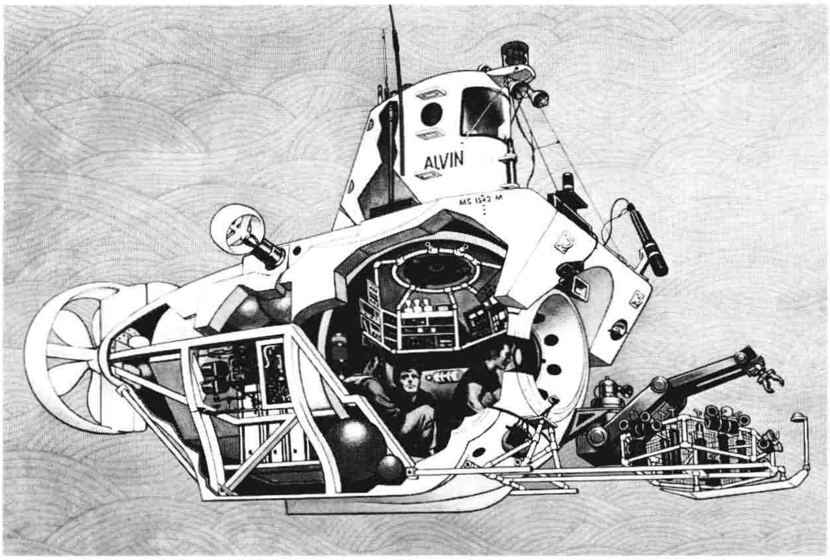
Photographic Techniques

The photographs shown in this atlas were taken using two techniques. The majority were obtained from the three-man submersible ALVIN (Figure 9). This



U.S. Navy submersible is operated by the Woods Hole Oceanographic Institution and has a diving limit of 3,650 meters (12,000 feet). The photographs were taken with both exterior cameras mounted on the submersible and internal cameras held by the scientists inside the pressure sphere and focused through its viewports. The external cameras are mounted on the brow of ALVIN and look forward. Pictures taken with these cameras can be distinguished from other photographs by the presence of the sample basket, a compass, and frequently a portion of a mechanical arm in the lower part of the frame (Figure 9). Scale in these photographs can be estimated from the fact that the water samplers on the sample basket have a length of 25

8 An artistic rendering of a portion of the rift valley shown in Figure 7. Using the detailed topography of the area an artist for the National Geographic Society rendered the sea floor relief based upon discussions with the various geologists who traversed the valley in ALVIN. Mt. Venus is shown on the right and Mt. Pluto on the left. The scarp in the background is the first major vertical step in the west wall. Copyright National Geographic Society.

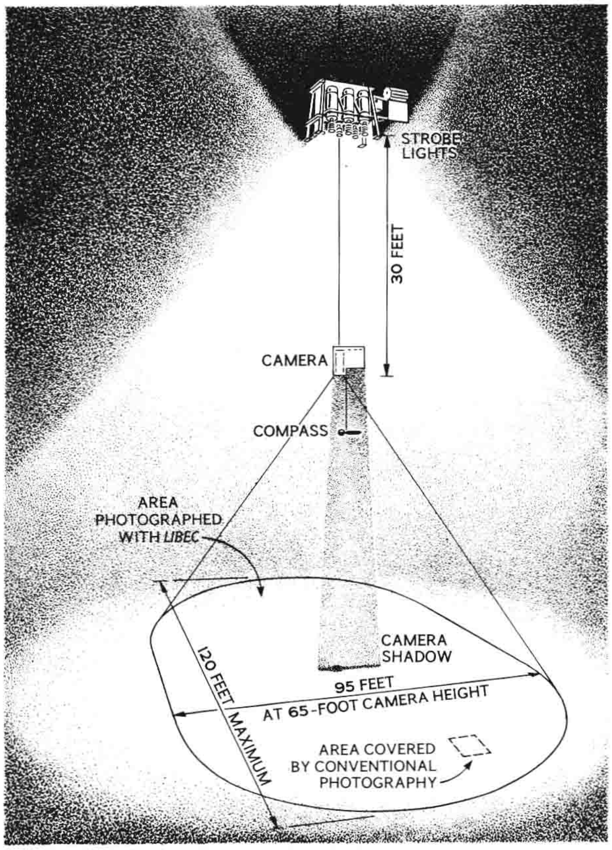


9 The major internal and external components of the submersible ALVIN which include a titanium alloy pressure sphere, mechanical arm, sample tray with tools, external television and still cameras with lights, and horizontal and vertical propulsion units. © 1975 National Geographic Society.

cm and a diameter of 10.5 cm. The external 35 mm cameras have a 50 mm focal length lens and are synchronized to a 200-watt strobe. Standard settings were shutter speed 1/25 second, and f-stop, 5.6. When the submersible is moving at 1/4 knot, 2 to 3 meters above the bottom, a shutter repetition rate of 10 seconds provides a series of photographs having 10–20 percent overlap. Some of the photographs in the atlas are crude mosaics constructed from such overlapping photographs. The mosaics have not been rectified and therefore contain some distortion.

The photographs taken by the scientists within the pressure sphere were made with NIKON 35 mm cameras having 24 and 43–83 mm zoom lens. The cameras were synchronized to an external 500 watt-s strobe. The highest quality pictures were taken at an f-stop of 5.6 within a distance of 1–3 meters from the viewport. The principal films used in all cameras were Plus-X and 2496 black and white shot at their normal ASA settings.

The majority of the remaining photographs shown in the atlas were taken by a surface-towed camera unit developed by the U.S. Navy called the LIBEC system (*LI*ght *BE*hind the *C*amera) (Figure 10). This 70 mm camera has a seawater focal length of 40.4 mm. The normal distance off the bottom was 12 meters, and each photograph covers an area approximately 22 meters across. Suspended beneath the camera and within its field of view is a compass which was used to orient the features observed relative to the axis of the valley.



10 Diagram of the LIght BEhind the Camera (LIBEC) system showing the electronic flash lamps with camera suspended beneath. The area of the bottom obtained in a photograph is shown as well as the average photographic coverage of conventional camera units (after Brundage and Cherkis, 1975). © 1975 National Geographic Society

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