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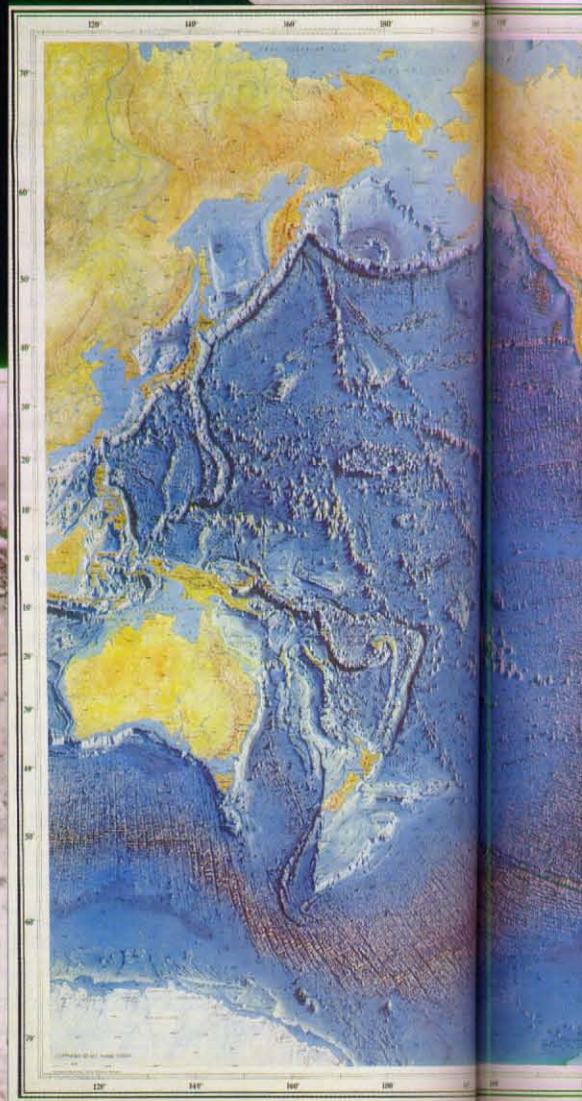
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Mountains under the Sea

Marie Tharp's maps of the ocean floor shed light on the theory of continental drift

BY DAVID M. LAWRENCE

Marie Tharp in 1978. World Ocean Floor panorama, which she created with Bruce C. Heezen the previous year, has become an icon of earth science.



The face of the deep oceans is hidden beneath a watery veil several miles thick. For millennia humans were tantalized by the mystery of what lay beneath the surface. Tales passed down from generation to generation told of estates of gods, lost continents, and fantastic civilizations. Some tried to do more than retell the inherited myths. Scores of scientists and mariners probed the sea, but limited methods and seemingly unlimited depths doomed their efforts. None were able to lift the veil and reveal what lay underneath. But Marie Tharp, in what was arguably one of the most quixotic quests in cartographic history, succeeded in illuminating the abyss.

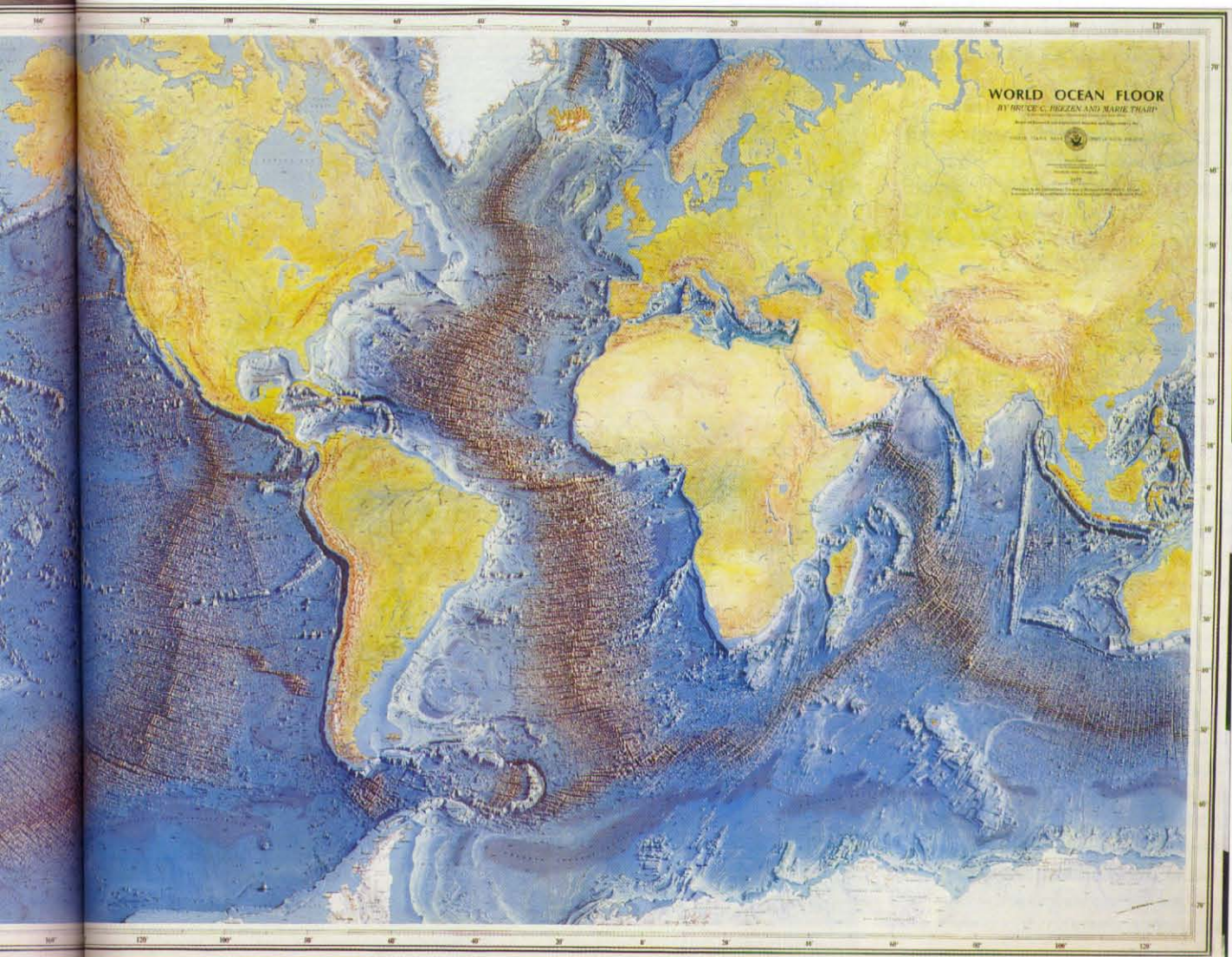
Tharp worked with Bruce Heezen, an oceanographer at Columbia University's Lamont Geological Observatory, on the

seemingly impossible task of mapping the world's ocean floors. Beginning in 1952 with a desire to learn the extent of a mountain range under the surface of the Atlantic Ocean, they began to chart a terrain no one could see, using data familiar to ancient mariners — soundings, or depth measurements. Even mappers of the moon had photographs to work with, but Tharp and Heezen persisted, sounding by sounding, seamount by seamount, basin by basin, ocean by ocean, until they produced the first detailed map of the world's ocean floor in 1977.

Heezen collected the data and planned the strategy, but Tharp did the bulk of the mapping work, using what amounted to millions of measurements, plotting thousands on sheets representing 1 degree latitude by 1 degree longitude, to visualize the lay of a terrain no human could set foot on. In the process she made a discovery that

helped to spark one of the greatest scientific revolutions in history, a finding that tore apart, then reassembled, our view of how the earth was — and continues to be — created. By recognizing and mapping the mid-oceanic rift valley, she paved the way for the acceptance of the theory of sea-floor spreading and continental drift.

"Her maps have made sea-floor spreading seem quite natural and almost obvious," says Mark Monmonier, professor of geography at Syracuse University and author of numerous works on cartography. "They really have been able to explain a phenomenon that a lot of people have found rather arcane and, in some cases, maybe improbable," Monmonier adds. "In other words, if you have a good illustration that is realistic, it can not only show how something operated, but basically present a convincing argument that that's the way it is."



©Marie Tharp, 1977

Marie the Mapper

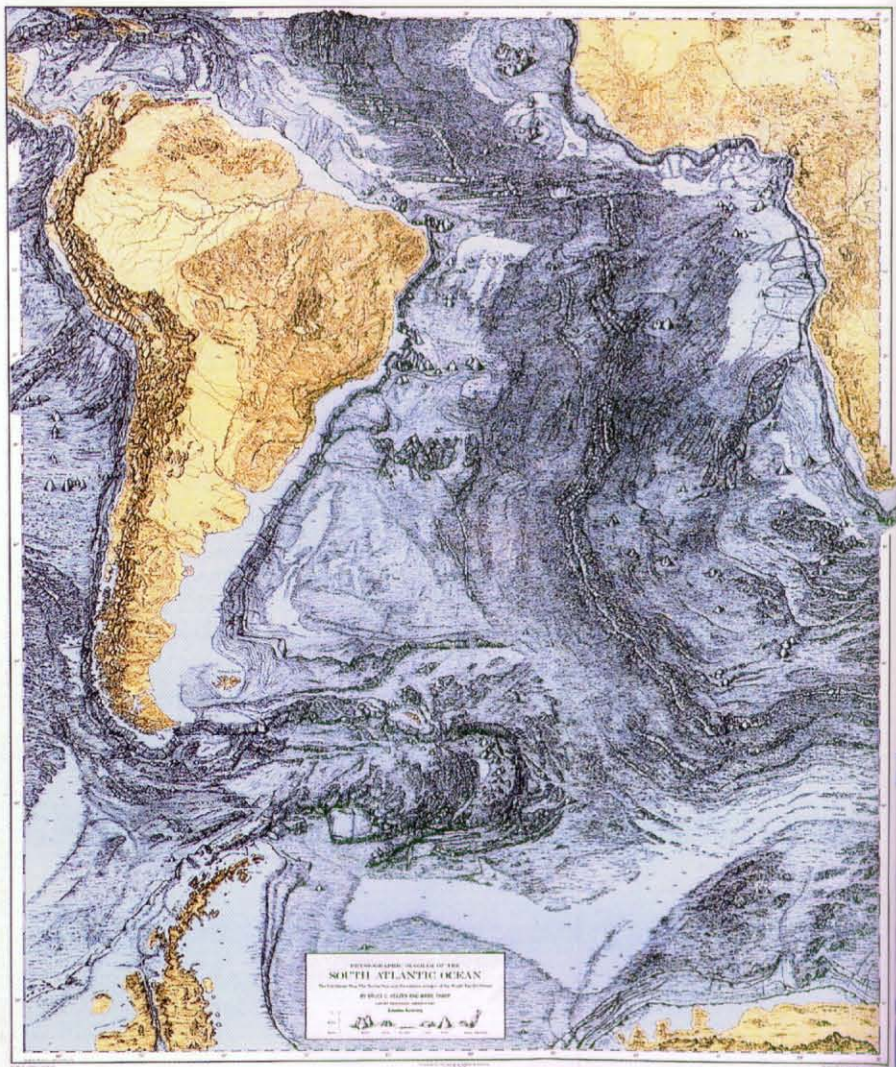
Tharp grew up immersed in mapping. Her father, William Edgar Tharp, was a soil surveyor for the U.S. Department of Agriculture who produced many of the bureau's soil classification maps and reports. But by the time Tharp graduated from Ohio University in 1943, with majors in English and music and four minors, a career spent mapping the ocean floor seemed unlikely. Then global events intervened.

"I never would have gotten the chance to study geology if it hadn't been for Pearl Harbor," Tharp says. "Girls were needed to fill the jobs left open because the guys were off fighting. A year after the war started, the geology department at the University of Michigan opened its doors to women. In 1943 about ten of us girls responded to one of their flyers, which promised a job in the petroleum industry if we got a degree in geology."

By 1944 Tharp had earned a master's degree and landed a job at the Stanolind Oil and Gas Co. in Tulsa, Oklahoma. She worked for Stanolind until 1948, obtaining a math degree from the University of Tulsa along the way, and then moved to New York City in search of a more interesting job. "I looked for work at the American Museum of Natural History," Tharp recalls, "but I decided I didn't want to work there after a paleontologist told me how it took two years to separate a fossil from the surrounding matrix. I couldn't imagine devoting so much time to something like that, so I tried Columbia to see if I could get a more interesting research job."

Because Tharp had a math degree, geology department staff thought she should talk to Maurice "Doc" Ewing, a new faculty member, who had come over from the Woods Hole Oceanographic Institution. Ewing was at sea, however, and Tharp had to wait three weeks before he returned. "When he heard about my background," Tharp says, "he was surprised and didn't know quite what to do with me. Finally he blurted out, 'Can you draft?'" Tharp had held a part-time drafting job at the University of Michigan, so Ewing hired her immediately. She began assisting his students, one with whom she would be associated for the next thirty years.

"Doc Ewing undertook a Sigma Xi lecture tour with the official purpose of



Tharp at Lamont in the early 1950s. The map of the South Atlantic Ocean floor, which she and Heezen completed in 1961 (above), spurred intense interest in the continental drift question. Tharp's maps and plottings are currently being catalogued by Gary North for the Library of Congress.

finding bright students to work in oceanography," Tharp says. "Actually, he was scouting for a group of technicians from wealthy families to whom he could offer adventure instead of pay." After one lecture, Bruce Heezen, then a junior at the University of Iowa, introduced himself to Ewing, who said, "Young man, would you like to go on an expedition to the Mid-Atlantic Ridge? There are some mountains out there, and we don't know which way they run."



Scientists previously had thought the ocean floor was a largely featureless plain, a dumping ground slowly filled by sediments eroding from the earth's surface. But soundings in the nineteenth and early twentieth centuries indicated that it was much more complex. Ewing lured Heezen to Columbia with the challenge of learning just how complex.

For ages soundings had been made using ropes or cables and weights such as cannonballs. Using data collected with that method, Matthew Fontaine Maury discovered, and Charles Wyville Thompson later confirmed, that some kind of rise existed in the center of the North Atlantic Ocean. Sounding data from Germany's Meteor expedition in the 1920s revealed that the rise, initially thought to be broad and gentle, was in fact narrow and steep. It became known as the Mid-Atlantic Ridge.

In 1911 Reginald Fessenden developed a method to measure depth by measuring the amount of time it took a sound echo to bounce back from the ocean floor. Ewing and J. Lamar Worzel, who worked with Ewing at Woods Hole and then followed him to Columbia, used Fessenden's method as the basis for developing the continuous echo sounder for the U.S. Navy during World War II. With the continuous echo sounder and an improved device — the precision depth recorder, developed at Columbia by Bernard Luskin in 1952 — soundings could be obtained around the clock and recorded on continuously spooled strips of paper while the host ship was underway.

Girl Talk

By 1952 Tharp was doing drafting work exclusively for Heezen. Ewing — who by then had founded the Lamont Geological

Observatory, later known as the Lamont-Doherty Geological Observatory, at Columbia — and his students had amassed thousands of soundings of the North Atlantic Ocean, and Heezen thought it was time to see what his topography looked like.

Tharp and another of Heezen's assistants, Hester Haring, used the soundings to plot profiles — i.e., cross-sections — of the sea floor along the ship's course. Both Tharp and Heezen ensured that the profiles were drawn at the proper horizontal and vertical scales, that the west end of the profile was to the left and the east end to the right, and that the depth measurements were correct. If there were any mistakes, the profile would have to be redrawn.

After the drawing, checking, correcting, redrawing, and rechecking, Tharp was left with a hodgepodge of disjointed and disconnected profiles of different sections of the North Atlantic floor. Plotted on a map the ship's tracks looked like an irregular spider's web, with most of the tracks centered on Bermuda, where the research vessels took on supplies and water. Others spiraled off into bizarre directions as the ships fled from the paths of storms.

After Tharp arranged and pieced together the profiles in proper order from west to east, she completed six more-or-less parallel transoceanic profiles. "I noticed immediately the general similarity in the shape of the ridge in each profile," Tharp says. "But when I compared the profiles, I was struck by the fact that the only consistent match-up was a V-shaped indentation in the center. The individual mountains didn't match up, but the cleft did, especially in the three northernmost profiles. I thought it might be a rift valley that cut into the ridge at its crest and continued all along its axis. When I showed what I found to Bruce, he groaned and said, 'It cannot be. It looks too much like continental drift.'"

The theory of continental drift was first advanced by German meteorologist Alfred Wegener in 1912. In one of the earliest and best examples of modern interdisciplinary science, Wegener amassed evidence from geography, geology, paleontology, and biology to propose that the continents were not fixed objects on the surface of the earth, but instead



were analogous to icebergs, floating and drifting on top of the molten rocks of the earth's mantle. Wegener proposed that about 200 million years ago a giant supercontinent, Pangaea, began to break up into smaller landmasses. As the new continents drifted apart, new oceans were created, among them the Atlantic, which formed when the Americas broke away from Europe and Africa.

Both Wegener and his theory were immediately attacked. Many scientists resented this meteorological interloper on their turf. Others were troubled by his lack of evidence — not that drift may have occurred, but of the mechanism that could drive it. One prominent American scientist pronounced the theory "Utter, damned rot!" At Lamont, where Ewing was a loud and powerful skeptic, speaking out in favor of the theory would be an act of professional suicide. Heezen himself tried to dismiss Tharp's rift valley as "girl talk."

But Tharp stood by her interpretation of the profiles. She had found a rift valley in the North Atlantic and knew it could be the seam separating North America from Europe. Continental drift was real. She began looking for additional data to confirm it.

Heezen and Ewing had earlier proved the existence of turbidity currents — slurries of sediment and water that behave as distinct streams within the ocean — and documented the speeds the currents could obtain, such as when they snapped transatlantic telegraph cables during the 1929 Grand Banks earthquake. Bell Laboratories was interested in laying new cables and — at about the same time Tharp was working on the six profiles — asked Heezen to help determine the best place to lay them.

Heezen hired Howard Foster, a deaf graduate of the Boston School of Fine Arts, to plot the location of recorded earthquakes in the oceans. Working at a table next to Tharp's, Foster began plotting temblors by hand. Heezen was adamant that all data — whether from soundings or from earthquakes — be plotted at the same scale. The approach made it easy to compare data from different sources, something that would pay dividends none of the scientists envisioned.

In the early 1950s seismic stations were scattered sparsely throughout the globe,

and as a result earthquake location data were not very accurate. The scatter in the positions of individual earthquake epicenters could be as much as several hundred miles, which Heezen complained "was absolutely abominable." When the scatter was taken into account, however, it was evident the earthquakes formed a nearly continuous line down the center of the Mid-Atlantic Ridge — right down Tharp's rift valley. At about the same time new data from other expeditions also revealed similar ridge features in the Indian Ocean, Arabian Sea, Red Sea, and the Gulf of Aden.

"The pattern we had noticed held," Tharp recalls about her sounding profiles and Foster's earthquake plottings. "Wherever there was a mid-oceanic ridge, there were earthquakes. When the Indian Ocean earthquake belt was shown to be continuous with the East African Rift Valley, there was but one conclusion: The mountain range with its central valley was more or less a continuous feature across the face of the earth."

What Tharp had stumbled on in the North Atlantic was the largest single feature on earth, a 40,000-mile-long ridge and rift system that extended throughout the world's oceans. Ewing and Heezen announced the discovery of the global rift system in 1956 at a meeting of the American Geophysical Union in Toronto.

Seeing Is Believing

Heezen and Tharp were unable to publish any detailed bathymetric charts based on their work, because the data were classified by the U.S. Navy. In 1952 they decided to make a physiographic map of the ocean floor as a way to get around the restrictions. Unlike contour maps, physiographic maps show the terrain as it would look from above if all the water were removed. Heezen knew most of the features of the western North Atlantic by then and produced the first diagram after about an hour of doodling. Although he asked Tharp to do it over, they were both pleased with the technique.

"It allowed us to capture the sea floor's many textured variations, contrasting the smoothness of the abyssal plains, for example, with the ruggedness of the mountains along the ridges," Tharp now says. "But we also had an ulterior motive. Detailed contour maps of the ocean floor

were classified by the U.S. Navy, so the physiographic diagrams gave us a way to publish our data. In retrospect, our choice of map style turned out to be significant, because it allowed a much wider audience to visualize the sea floor."

First, Tharp and her assistants — she eventually had several — would plot the profiles on a chart by hand. She and Heezen would interpret what they saw, using data from adjacent tracks to estimate the topographic trends in the areas where they had no data. After interpreting the entire chart, they would do it again. Then they would match the chart with adjoining charts, reinterpret the

Physiographic Diagram: Atlantic Ocean (1956, 1959) portrays the North Atlantic between 17 degrees and 50 degrees north latitude. Tharp and Heezen based the diagram on continuous echo-sounding traverses made by research vessels.



patterns, and plot a final chart. They would repeat the process, often changing their minds several times, until they were satisfied with their map for a given section of ocean floor.

Tharp was never overwhelmed by the mountains of data they had. She was daunted by what they lacked. "We'd use everything available, but there would be blank areas," she says. "I'd work up a blank area with what we could get. The biggest challenge was just to keep providing data for the blank areas and to upgrade the areas that we changed our minds on."

Heezen and Tharp first published their North Atlantic physiographic map in the Bell Telephone System's technical journal in 1956. The Geological Society of America reprinted the map in 1959. The popularity of the North Atlantic map led Heezen and Tharp to produce a South Atlantic map in 1961, which, because of the almost perfect conformity in shape among the Mid-Atlantic Ridge and the

South American and African coastlines, inspired a number of scientists to tackle the continental drift question. Heezen and Tharp didn't realize it at the time, but they were on their way to mapping the entire world.

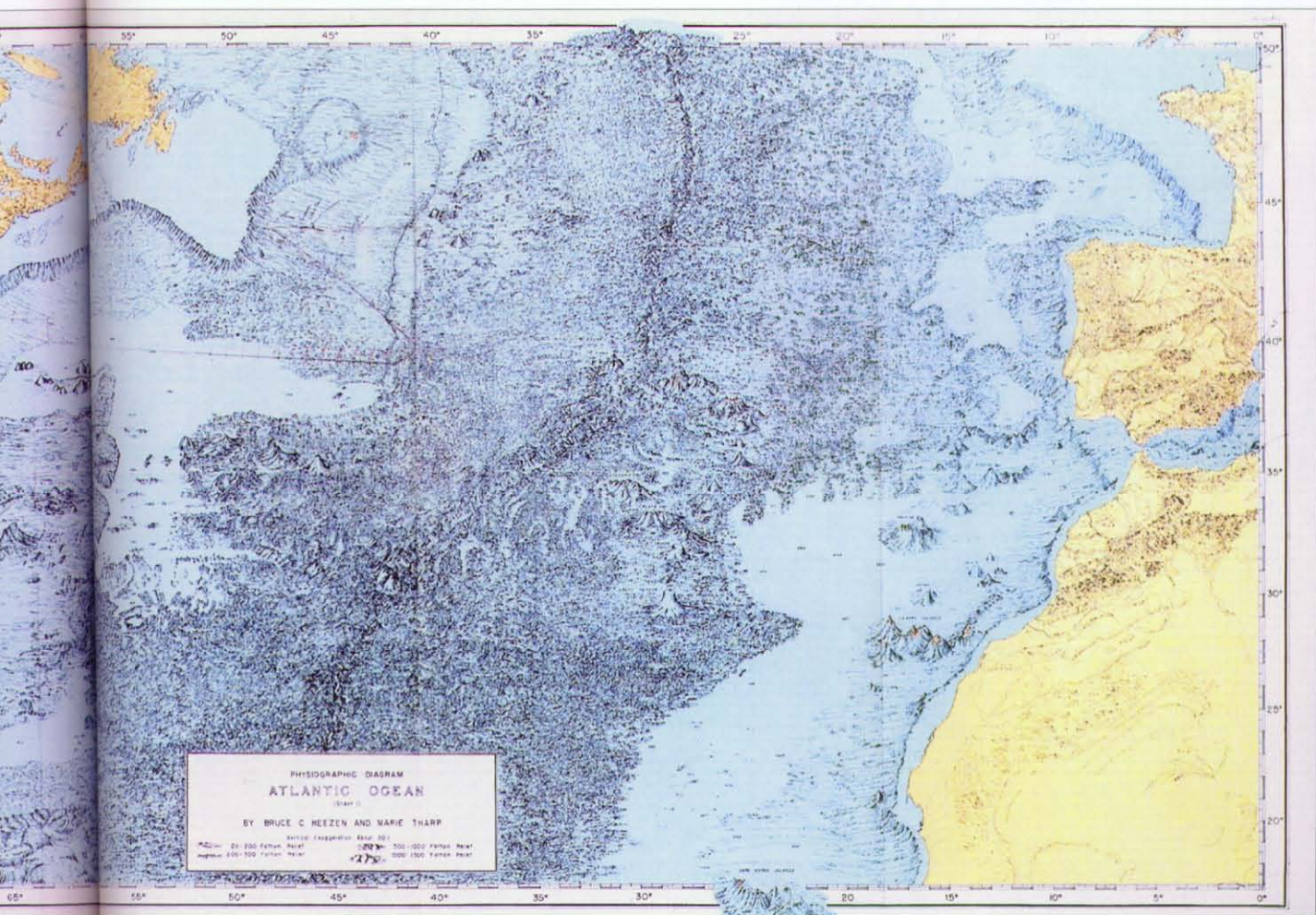
Heezen and Tharp next turned to the Indian Ocean to make a much-needed map, which was published in 1964, for the upcoming International Indian Ocean Expedition. *National Geographic* also wanted a map of the Indian Ocean to accompany an article on the expedition. But the magazine wanted something more like a painting than the pen-and-ink drawings Tharp had been producing.

National Geographic had recently become aware of an Austrian landscape painter, Heinrich Berann, who earned extra money by painting realistic alpine panoramas for advertisements promoting skiing for tourists. The magazine commissioned him to paint the Indian Ocean floor and hired Heezen and Tharp as con-

sultants. "We loved working with Heinrich," Tharp says. "His familiarity with painting the Alps translated beautifully to the sea floor." The Indian Ocean panorama was published in 1967. It proved to be such a success that *National Geographic* asked Tharp, Berann, and Heezen to continue with the rest of the world's oceans. Their final map for the magazine, depicting the Antarctic Ocean floor, was published in 1975.

The next step was obvious: to create a panorama of the entire ocean floor. In 1973 they submitted a proposal for the project to the Office of Naval Research. "To accomplish it, we had to simplify some of our previous work to accommodate the smaller scale called for by a world map," Tharp says. "At the same time we had to update our work to include the vast volume of data that had accumulated over the years."

The *World Ocean Floor* panorama was completed and published in 1977. The



panorama is more than a map of the world's ocean floor. It is a moving work of art that inspires in the viewer a sense of mystery and wonder, recalling the romantic days of the great explorers. Twenty-two years later, the map still has a powerful emotional impact, a warmth that is lacking in the more recent (and accurate) world ocean-floor maps generated by satellite data. It adorns the walls of offices and hallways of oceanographic and other research institutions around the world, a constant source of reference and inspiration. The masterwork by Tharp, Heezen, and Berann is possibly the closest thing Earth science has to iconography.

Tharp and Heezen teamed up with the artist Heinrich Berann to create this dramatic painting of the Indian Ocean floor, published in 1967, for *National Geographic*.

On 21 June 1977, three weeks after approving the final proofs and delivering them to the printer, Heezen died of a heart attack on board the U.S. Navy's research submarine *NR-1*. He was preparing for a dive to explore the Mid-Atlantic Rift off of Iceland.

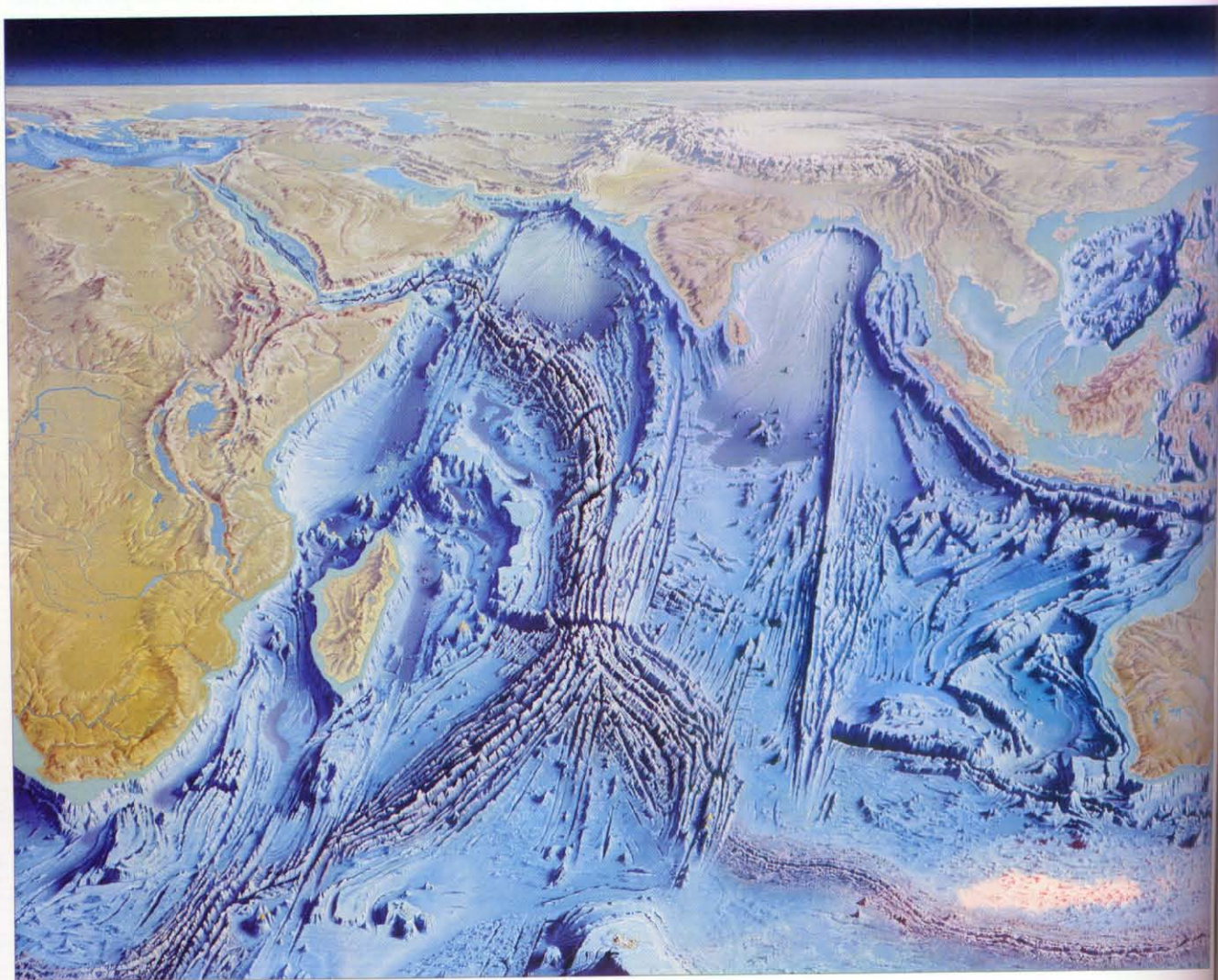
Until his death Tharp had worked in Heezen's shadow. She rarely got scientific recognition, such as credit as author or co-author of a research publication. Only recently — in the eighth decade of her life — has Tharp begun to receive long-overdue accolades.

In November 1997 the Library of Congress named her one of four individuals "who have made major contributions to the field of cartography." In March 1999 the Women's Committee of the Woods Hole Oceanographic Institution honored her with its Women Pioneers in Oceanography Award. Tharp doesn't

mind the belated honors. She was never after glory. "I have absolutely no resentments," she says. "I thought I was lucky to have a job that was so interesting. I just had the fun of putting the puzzle together. I had the whole world to figure out."

Tharp's maps awakened the scientific establishment to a view of the world that explains how tropical fossils can be found in Antarctica, why the ridge-and-valley section of the Appalachian Mountains is so folded, why California has so many earthquakes, and how the mighty Hudson River, along the shores of which Tharp lives, was formed.

"I think our maps contributed to a revolution in geological thinking, which in some ways compares to the Copernican revolution," Tharp says. "Scientists and the general public got their first relatively realistic image of a vast part of the planet



National Geographic Maps

that they could never see. The maps received wide coverage and were widely circulated. They brought the theory of continental drift within the realm of rational speculation. You could see the worldwide mid-ocean ridge and you could see that it coincided with earthquakes. The borders of the plates took shape, leading rapidly to the more comprehensive theory of plate tectonics."

The vision played a key role in giving Wegener's controversial theory of continental drift an aura of respectability. Harry Hess, a Princeton University geology professor, was inspired by Tharp and Heezen's work to develop the hypothesis of sea-floor spreading — the missing mechanism that could drive continental drift. After a 1957 talk by Heezen on the mid-oceanic rift system, he stood up and said they had "shaken the foundations of geology!"

David M. Lawrence, a journalist living in Mechanicsville, Virginia, is working on a book titled Upheaval from the Abyss: Ocean Floor Mapping and the Earth Science Revolution, due to be released by Rutgers University Press in 2001.

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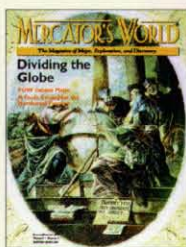
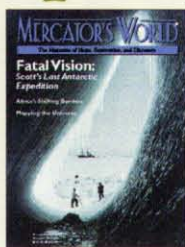
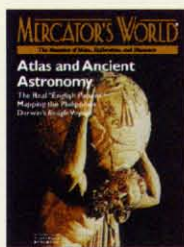
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