Mappers of the Deep

How two geologists plotted the Mid-Atlantic Ridge and made a discovery that revolutionized the earth sciences

Marie Tharp and Henry Frankel

Editor's Note: Only a few decades ago, most scientists ignored or rejected the ideas of continental drift and plate tectonics. Today, they accept these theories and use them to explain the earth's face, its movements, and its history. Continental drift, paleontologists now realize, has also played an immense role in the distribution of life on the planet.

Such great revolutions in scientific thought almost never arise from a single scientist, a single discovery, or even a single research facility. Yet discoveries do seem to emerge—by accident, by luck, and by different forms of genius—at a particular time and place. In this case, the place was the Lamont-Doherty Geological Observatory of Columbia University at Palisades, New York; the time was the early 1950s; the discovery was the unexpected length of the Mid-Atlantic Ridge and its surprising features; the major characters involved were Bruce Heezen and Marie Tharp. Heezen died in 1977. Marie Tharp discussed the events and supplied notes to science historian Henry Frankel, who coauthored this essay.

Soon after the end of World War II, an increasing number of geologists and geophysicists began investigating the sea floor. Within twenty-five years they turned it from an area about which scientists were ignorant into one of backyard familiarity. Little was known about the sea floor during the 1950s and 1960s but interest and support were strong, so oceanography was tremendously exciting, and the chances of making a major discovery were great. Bruce Heezen, then a graduate student in geology at Columbia University, and I, a graduate geologist, were working at Columbia's Lamont (now Lamont-Doherty) Geological Observatory when we made such a discovery—the central rift valley in the Mid-Atlantic Ridge.

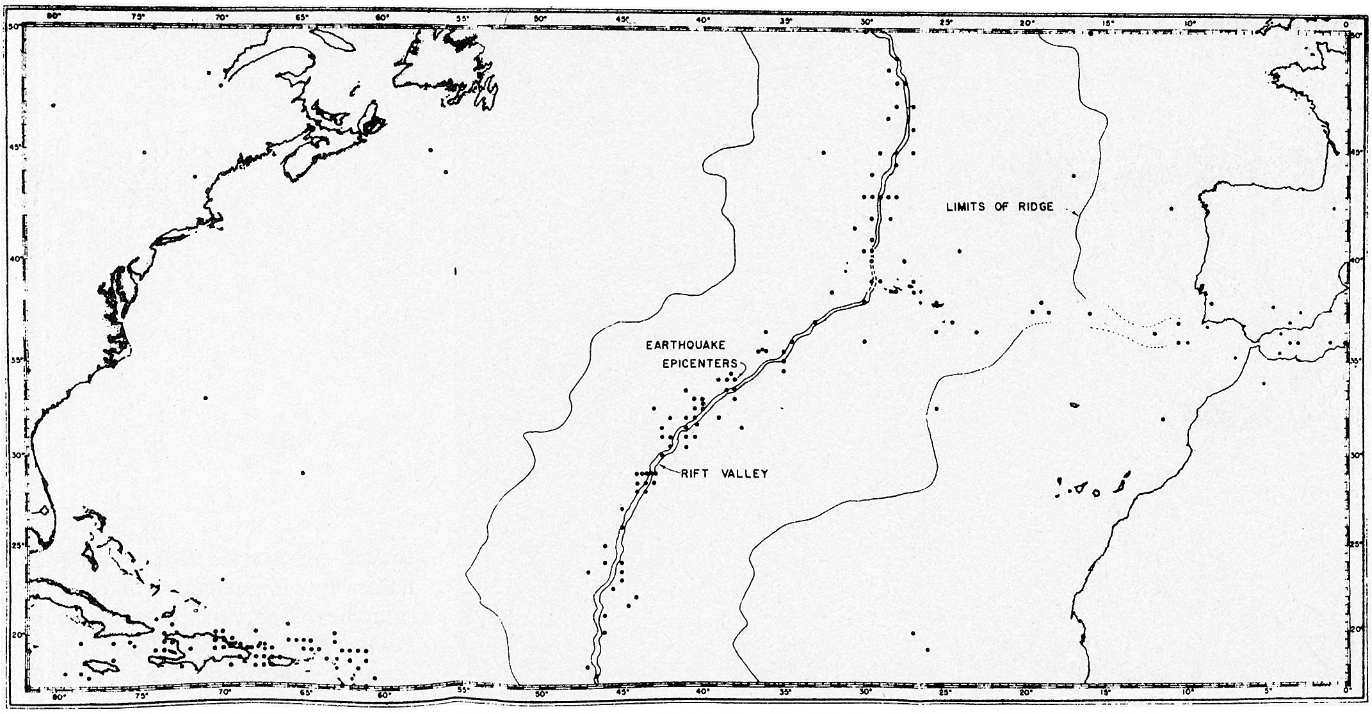
In 1952, I became convinced of the valley's existence along a segment of the ridge. Within about six months Bruce agreed and began to wonder about its significance. But it took four years before our discovery was published as an abstract by Maurice Ewing and Bruce. (Ewing at that time was the director of the Lamont Observatory.) Bruce and I had a great deal of fun during those years, and this is an account of how the discovery came about.

Fathoming of the deep sea did not begin until Matthew Fontaine Maury (1806–1873), the colorful and dynamic director of the U.S. Naval Depot of Charts and Instruments, produced, in 1854, a contour map of the North Atlantic on the basis of about 200 hemp and lead sinker soundings. He identified a higher middle ground in the North Atlantic, which he called the Dolphin Rise. This was the first identification of what later became known as the Mid-Atlantic Ridge.

In 1872, the British ship H.M.S. *Challenger* began a four-year research voyage. Charles Wyville Thomson (1830–1882), a professor of natural history at Edinburgh, headed the expedition. Thomson took soundings every 100 miles on several crossings of the Atlantic with a 200-pound lead sinker on a hemp line. He noticed a difference in the water temperature on either side of the Dolphin Rise and reasoned that it acted as a barrier to the flow of deep ocean currents. The tracks, or paths, he made extended the rise down through the South Atlantic. His soundings confirmed the existence of the plateau but could not differentiate between a mountainous ridge and a broad, smooth rise.

It was not until the German *Meteor* expedition (1925–1927), a water cruise that plotted currents, measured temperature and salinity, and took soundings every five to twenty miles, that the elevation in the mid-Atlantic was revealed as a rugged mountainous ridge running down the center third of the South Atlantic. The Germans made this determination through the use of the "stopwatch" method, which measures the lapsed time between an acoustical signal and its echo—the signal bounces off the ocean floor and returns to the ship as an echo.

Although the *Meteor* expedition received wide publicity in the popular press, and students of oceanography were excited about its findings, the detailed results of the cruise, published in German in several volumes, remained an untapped source of information for many years. Nobody, for example, ever bothered to connect all the "holes" found in the numerous sounding profiles along the crest of the ridge. If someone had made the connection, the central rift valley might have been discovered then



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Earthquake epicenters in the North Atlantic fall along the crest of the Mid-Atlantic Ridge. This was known as far back as 1944. What was not known then was that the ridge contained a rift valley—a fault created by earthquakes.

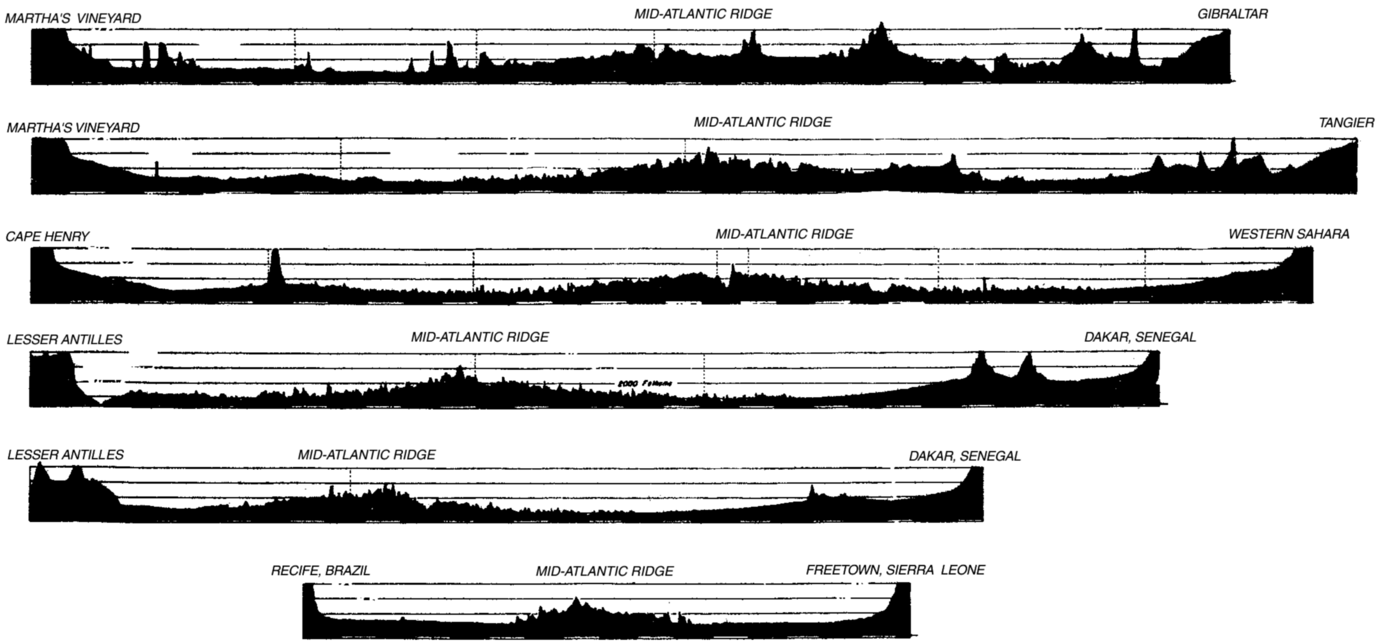
and there. But the *Meteor* expedition, being primarily concerned with sea water currents and the properties of temperature and salinity, did not bother with the ocean floor.

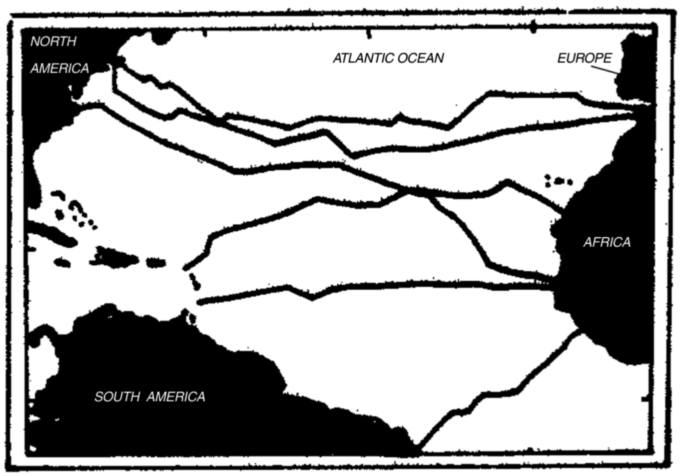
'In 1947, Ewing needed seagoing technicians to whom he could offer adventure in lieu of pay… if they were interested in geophysics and geology, all the better.'

In 1947, Maurice ("Doc") Ewing, then a newly appointed member of the Geology Department of Columbia University, undertook a Sigma XI lecture tour with the avowed purpose of finding bright graduate students to work in oceanography. Actually, what Doc really needed at the end of the 1940s, before funding became abundant, was a group of seagoing technicians from affluent families to whom he could offer a life of adventure in lieu of pay. Of course, if they were interested in geophysics and geology, all the better.

Ewing described taking seismic refraction profiles on the southern Bermuda Rise—these are cross sections through layers of sediment down to the sea floor, made by setting off bombs in the water behind a ship that is under way at full speed and timing the returning echo. The process involves short fuses and lots of explosives. After hearing Ewing's lecture on these perilous techniques, Bruce Heezen, who at that time was an undergraduate geology major at Iowa State University, came up to meet the speaker. Whereupon Doc Ewing 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." Bruce was somewhat startled. His professor Arthur Trowbridge said, "Of course he would like to go!" Bruce went, and spent the next thirty years working on problems connected with the sea floor. Over the next two years, Doc Ewing and Bruce participated in three expeditions to the Mid-Atlantic Ridge, each aboard the *Atlantis I*, the major oceanographic research vessel belonging to the Woods Hole Oceanographic Institution. The expeditions, jointly sponsored by Woods Hole, Columbia University, and the National Geographic Society, surveyed the ridge with an echo sounder that operated continuously while the ship traversed the ridge at random angles. The development of this nonstop echo sounder was extremely important, for it provided us with uninterrupted profiles—something that the *Meteor* expedition did not do. With this new technology, the amount of data in a profile no longer depended on how often the ship stopped at a station to take an echo sounding. But the device had one disconcerting drawback: it depended entirely on the ship's irregular and intermittent electric power, which went off whenever someone opened the ship's refrigerator. When that happened, no echo returned; instead, the sounder recorded measureless depths. At mealtimes the ocean floor became as bottomless as the crew's appetite.

In 1952, Bruce turned to the question of the topography of the Mid-Atlantic Ridge. I had gotten my job at Columbia University in 1948 by managing to know a little about a lot, after picking up a B.A. at Ohio University, a master's degree in ge-





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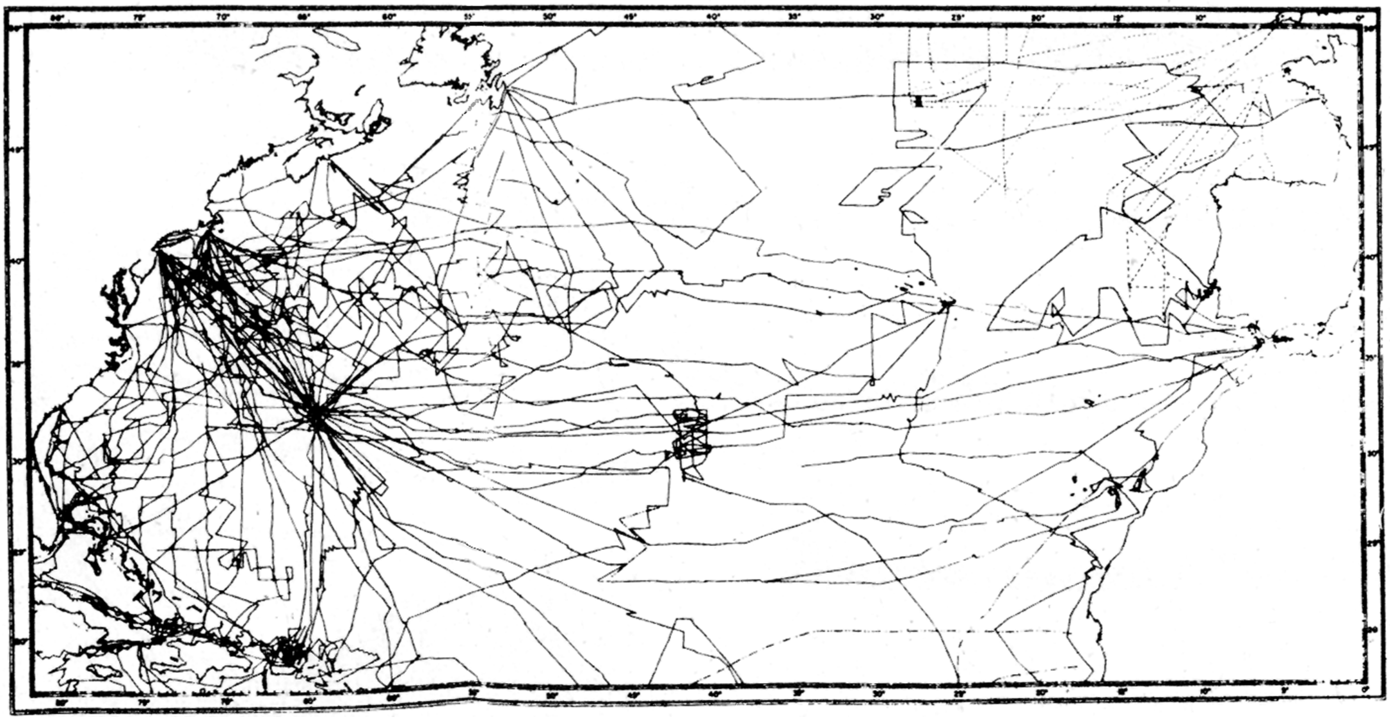
Tharp put together six profiles from early cruises. When superimposed one on another, a V-shaped indentation in their centers appeared to match up, suggesting that a valley ran along the length of the Mid-Atlantic Ridge. The inset shows the six profiles across the ocean; the heavy line in the center indicates the location of the rift valley.

ology at the University of Michigan, and a B.S. with a major in mathematics at the University of Tulsa. I was hired at Columbia by Doc Ewing, officially as a research assistant, but in practice I became a helper for graduate students and worked in the basement of Schermerhorn Hall. At first, I worked for anyone who needed me, but after a few years Bruce kept me so busy that I worked exclusively with him, drafting and plotting ocean profiles. He had interminable rows of sounding numbers plotted into graphs, or profiles, whose coordinates were depth and distance. The vertical coordinate was depth in fathoms (one fathom is six feet); the horizontal coordinate was distance in nautical miles (one nautical mile is 6,000 feet). I was supported to turn the rows of numbers into a set of highly detailed and complete profiles.

In 1952, after about six weeks of plotting, matching, and gluing, I completed six transatlantic profiles. I pieced together sections of data from eight cruises in order to make a more understandable set of west–east profiles from south to north in the North Atlantic. The ratio of the vertical to the horizontal coordinates was 40 to 1, and the continental margins, ocean basin floor, and Mid-Atlantic Ridge were shown between North America and Europe, South America and Africa.

Besides the general similarity in the shape of the ridge in each profile, I was struck by the fact that the only prominent matchup apparent when I compared the profiles was a V-shaped indentation located in the center of each. The individual mountains didn't match up, but the cleft did, especially in the three top, or northernmost, profiles of the North Atlantic. Thus it seemed to me that the V-shaped indentations represented cross sections of a valley that cut into the ridge at its crest and continued along its axis. Of course, I didn't know about the remainder of the ridge—the area beyond the most northerly and southerly profiles—and the V-shaped indentation was only obvious in the first three profiles.

I told Bruce what I thought and showed him the matchup in the position of the valley in the top three profiles and possible extensions into the other three. Bruce didn't think the matchup was so obvious. He groaned and said, "It cannot be. It looks too



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Composite chart of the tracks in the South Atlantic made by various research vessels. The heavy lines are tracks of the German ship Meteor.

much like continental drift." This was just about the worst thing he could have said, since at the time, he and almost everyone else at Lamont, and in the United States, thought continental drift was impossible. North American earth scientists considered it to be almost a form of scientific heresy, and to suggest that someone believed in it was comparable to saying there must be something wrong with him or her.

If there was such a thing as continental drift, it would have had a connection with a midocean rift valley. If drift did indeed exist, the valley would have been formed where new material came up from deep inside the earth, splitting the midocean ridge into two and pushing the sides apart. That, in turn, would move the continents resting on their various tectonic plates.

Some time after I had finished plotting the six profiles, I told Bruce my idea about the existence of a valley. Then one day we decided, quite suddenly, to make a physiographic diagram of the ocean floor. Unlike flat contour maps that do not bring out the three-dimensionality in pictorial form, physiographic diagrams look three-dimensional. They show the terrain as it would look from a low flying plane. After an hour or so of scribbling, Bruce produced our first physiographic diagram. By 1952, he had been on enough cruises to enable him to discover most of the features of the western Atlantic.

Although he was somewhat unhappy with the results of his efforts and asked me to do the diagram over, both of us were pleased with the technique. At that time, however, detailed contour maps of the ocean floor were classified by the U.S. Navy, so we had to find another way of presenting our data. Packaging our information in the form of physiographic diagrams not only solved our publication problem but also provided a much more natural picture of the sea floor. The diagrams allowed us, for example, to capture the sea floor's many textured variations, contrasting the smoothness of the abyssal plains with the ruggedness of the mountains along the ridges. In 1961, after contour maps of the sea floor were declassified, we decided to stick with our physiographic diagrams.

During the time I was working up the profiles and starting the physiographic diagram of the North Atlantic, Bruce was busy on another project. He and Ewing had confirmed the existence of turbidity currents and documented the great speeds these currents had attained when they caused the breakup of a series of transatlantic cables during the 1929 Great Banks earthquake. Bell Laboratories was contemplating laying new cables and wanted Bruce to determine the best place to lay them. Cables are costly to lay and maintain, and Bell Labs therefore thought the study worth supporting. It was, but primarily for reasons initially unknown to them or to us.

Bruce hired Howard Foster, a young, deaf graduate of the Boston School of Fine Arts who did all his work by hand (since the age of the computer had not yet arrived), to plot the location of recorded earthquakes in the Atlantic and other parts of the world. He plotted tens of thousands. The records weren't as accurate as our own topographical data, and Bruce complained that the scatter of one to several hundred miles in the positions of the plotted earthquake epicenters "was absolutely abominable" compared with our topographical data of the sea floor.

While I was at my map table plotting the position of the Mid-Atlantic Ridge and the alleged valley, a map of the same scale as mine, showing the position of the earthquakes, sat on an adjoining table—Bruce always insisted that all our oceanographic data be mapped at the same scale. He noticed that a line of epicenters from shallow-focus earthquakes ran down the center of the Mid-Atlantic Ridge. This, in itself, was nothing new, for we were aware that two seismologists, Beno Gutenberg and Charles F. Richter, had already noted in their widely read book, *Seismicity of the Earth* (published in 1944), that an active belt of shallow earthquakes "follows the Ridge very closely." (Richter, incidentally, devised the scale bearing his name that measures the magnitude of earthquakes.) But we found more: taking into account the inaccuracy of the plotted positions of the earthquake epicenters, Bruce saw that they fell within the valley. Because all our data were on maps of the same scale, the locations of the epicenters within the valley showed up when we superimposed the maps on a table lighted from below. At that point, I was completely convinced that the valley was real. We had a definite association of topography with seismicity. Although Bruce remained somewhat skeptical, he began to pursue the idea in earnest.

We also knew that Gutenberg and Richter had observed how the shallow earthquakes along the Mid-Atlantic Ridge extended into the Arctic Ocean; how the Carlsberg Ridge in the Indian Ocean and the Albatross Plateau in the Eastern Pacific, like the Mid-Atlantic Ridge, are associated with shallow-focus earthquakes; and how the epicenters of this earthquake belt along the Carlsberg Ridge extended through the Gulf of Aden into Africa along the East African Rift Valley. At this time there were many more recorded shallow earthquakes in the sea floor than there were deep-sea soundings, and many of the earthquakes had occurred along belts where no soundings had been made. This led Bruce to wonder if the isolated oceanic ridges might not all be part of one feature, a gigantic 40,000-mile-long Mid-Oceanic Ridge system.

Just as his predecessors had extrapolated the existence of the southern extension of the Mid-Atlantic Ridge from the differences in temperature between deep-sea currents on both sides of the Atlantic, Bruce reasoned that deep-sea soundings would reveal a ridge wherever shallow earthquakes had occurred. But he still wasn't ready to suppose that future deep-sea surroundings would also reveal that the shallow earthquakes occurred within the confines of a central valley running down the axis of this vast ridge system. He didn't accept that supposition until mid-1953, about eight months after I had finished working up the first set of six profiles.

Bruce keyed in on the terrestrial extension of the hypothesized oceanic-ridge system—the rift-valley system of the East African Plateau. He reasoned that since the system of rift valleys in east Africa appeared to be a landward extension of the oceanic-ridge system, he could learn about the oceanic part by studying the terrestrial. I made up profiles of some of the valleys in east Africa. Bruce noted the topographical similarities between the two sets of profiles: one across the ocean; the other across the land. He also saw that the belt of shallow earthquakes associated with the system of east African rift valleys stayed primarily within the confines of the valley walls. He decided to make the jump and endorse the existence of a central valley within the ridge itself that extended along the entire axis of the Mid-Oceanic Ridge system. As far as Bruce was concerned, the tightness of the analogy between the terrestrial and oceanic segments of the ridge system was the clincher. Before, even with the seismic data, he was not sure if the valley's presence on the original six profiles and other oceanic ones that we found was an accident or indicated a real feature of the ridge. Bruce stressed the importance of the analogy by calling the oceanic valley a rift valley, borrowing the term rift from the characterization of the African valleys as rift valleys. And with the "rift" designation came Bruce's suggestion that the central rift valley, whether in the oceanic or terrestrial part of the overall ridge system, was a huge tension crack in the earth's crust caused by a splitting apart of the earth's crust.

During the next few years we displayed our expanding knowledge of sea-floor topography on globes and maps. We prepared several globes showing the physiographic provinces of the oceans, the location of sediments, and the globe-encircling Mid-Oceanic Ridge system with its bisecting rift valley. By 1956 we finished our first detailed physiographic diagram of the North Atlantic. And like the cartographers of old, we put a large legend in the space where we had no data. I also wanted to include mermaids and shipwrecks, but Bruce would have none of it.

'Bruce brought along one of our globes with the rift valley outlined in bright red. The valley was at least on our globe, if nowhere else…'

Bruce told Ewing of our discovery soon after he accepted it himself. Doc was interested and would occasionally come around and ask me, "How is the gully coming?" But the knowledge of the existence of the rift valley remained within the confines of Lamont until February 1956, when Bruce first presented the idea at a symposium organized by Harry Hess, professor of geology at Princeton University, for the National Academy of Sciences. Bruce brought along one of our globes with the rift valley outlined in bright red. The valley was at least on our globe, if nowhere else, and hard to miss. Hess was impressed and invited Bruce to Princeton to elaborate on the discovery. The first published account of our find, the abstract already mentioned, did not appear until 1956 at an American Geophysical Union meeting in Toronto, at which Ewing and Bruce announced the discovery of a seismically active rift zone at the crest of the Mid-Atlantic Ridge and its extension into the Arctic and Indian oceans and African rift valleys. We also thought that the rift valley was associated with material that was highly magnetized.

Ewing and Bruce had begun taking magnetic measurements of the sea floor as early as 1948, when Ewing had Bruce tow an airborne magnetometer (an instrument for measuring magnetic forces) behind the *Atlantis I.* At first they were unable to associate any of the magnetic anomalies with a definite topographical feature, for among other things, there were questions about the reliability of the data. They thought, however, that the crest of the ridge might be associated with a large positive magnetic anomaly, but it was not until 1954 that Bruce was pretty sure the association was real. In 1957, after twenty additional crossings, Ewing, Bruce, and a graduate student at Lamont presented a paper at the AGU meeting in Toronto, at which the discovery of the rift valley was announced. In their presentation they reported that the presence of a large positive magnetic anomaly (material at the top of the ridge that was more highly magnetized than the material on its sides) was associated with the rift valley as a general pattern.

'Bruce and I got our first real look at the rift valley in 1959 in movies taken by Cousteau… the great black cliffs… sprinkled with white glob ooze, loomed up through the blue-green water.'

Bruce and I got our first real look at the rift valley in 1959 at the First International Oceanographic Congress. The meeting was held in New York, and Bruce gave a number of papers. Jacques Cousteau was there too. He snagged us one day and showed us the tracks of his research vessel *Calypso* plotted on our physiographic diagram. He hadn't believed in the valley until he crossed it himself. So he took movies with his camera mounted on a sled, the *Troika*, which he showed to a large evening audience as an unscheduled event at the congress. On his film, the great black cliffs of the rift valley, sprinkled with white glob ooze, loomed up through the blue-green water. I think that Cousteau's movies may have convinced a few doubters at a critical time that our rift valley was really there.

In the following years, we continued to construct a detailed physiographic diagram of the rest of the Atlantic Ocean. The *Meteor* profiles were our main source of data, which we supplemented with such other data on the South Atlantic as were available. Our diagram of the South Atlantic Ocean, published in 1961, showed the Mid-Atlantic Ridge in the central third of the ocean. The prominent rift valley, at the crest, is strikingly parallel to the coasts of South America and Africa. Upon the publication of our diagram, one of our Lamont buddies came up to us and said, "Now you can hardly avoid the conclusion that you guys believe in continental drift." Of course, he was right.

Continental drift and plate tectonics are now accepted theories rather than heresies. The connection between the central rift valley and the movement of continents has become legitimate. And by the early 1970s, in a complete reversal, the disbelievers were the ones who were thought to have something wrong with them.