The Gully

Upon Wegener's return in 1908 from the Danmark expedition to Greenland, he accepted a position as lecturer in astronomy and meteorology at the University of Marburg. Wegener found it difficult to confine himself to the library sections on the fields he lectured in. He liked to browse, and one day in 1911 he found a paper reporting on the similarity of fossil plant and animal species from either side of the Atlantic. That seemed interesting, so he responded as a curious man – but not a respectable scientist who knew his field and stayed in it – would. He began looking for other instances of similar biota separated by vast oceans. How did that happen?

Explanations in vogue at the time favored long (and long-gone) land bridges linking the various continents and providing a migration route for plants and animals (presumably Atlantis would have served as, or been located on, one of these bridges). Since little was known of the topography of the ocean floor, there was no ready way to disprove the hypothesis. What struck Wegener, though, was the similarity in shape between the Atlantic coastlines of Africa and South America. He wasn't the first to notice – it is said Sir Francis Bacon commented on "conformable instances" as early as 1620 – but he was the first to consider the idea that the continents had been joined at one time and had drifted apart.

He knew his colleagues would have a great laugh at that idea. Instead of keeping quiet, however, he began gathering all the evidence he could marshal in support of his theory. Quite a lot was already on hand: similar animal and plant species, fossils and geological strata found in widely separate locations, like marsupials in both South America and Australia and extensions of the Appalachian Mountains in Scotland, and fossils from climates totally unlike the climates in which the fossils are found, like fossils of tropical plants found on Antarctica and on islands in the Arctic Ocean.

Wegener wrote his first paper proposing continental drift in 1912. Further development of the idea was interrupted by the Koch expedition to Greenland (when he and Koch crossed the icecap), and by the outbreak of World War I. Wegener's combat career may have been cut short by a gunshot wound in the neck, but the convalescence afterward gave him time to nurture his ideas. In 1915 he published a book, "On the Origin of Continents and Oceans," that presented his theory in detail.

Wegener's argument was simple: until about 300 million years ago, all the continents were united to form one supercontinent, Pangaea. Beginning at about 150 million years ago, Pangaea began breaking up and the fragments drifted apart, eventually becoming the continents we recognize today. Wegener produced maps of how he thought the continents had been assembled or disassembled at various stages in time. He presented the geological, geographical, climatological and paleontological evidence in support of his theory, and he argued why other theories could not work.

For example, one hypothesis on the origin of mountain ranges stated that as the Earth cooled from it's molten state in the beginning, it shrank in diameter. As the Earth shrank, it wrinkled, the wrinkles becoming mountains. The cooling and shrinking would take a long time, however. In the 1800s Lord Kelvin (of Kelvin temperature scale fame) showed that the Earth was too hot to be as old as required for the process to occur. Wegener pointed out that decay of radioactive elements deep inside the Earth supplied the heat that Lord Kelvin had described, adding to evidence against the cooling and contraction hypothesis.

One problem (besides his audience) with Wegener's theory was that he did not have a convincing mechanism to drive this drift. His earliest vision was that the continents were analogous to icebergs floating on top of a deeper layer (which made up the ocean floor) in the Earth. He conceived of convection currents deep inside the Earth that pushed continents along. Since he had little data from the ocean floor (and died before the *Meteor* expedition data became available), he could not conceive of rift valleys and tectonic plates as the modern theory envisions. Still, Wegener grasped the basic fact that the continents were once joined and have drifted apart and collided over the eons.

Wegener met a hostile reaction to his theory. Many felt that he should have stuck to astronomy and meteorology. Some of the attacks stepped outside the boundaries of polite scientific discourse. His theory was called "utter, damned rot!" by the president of the American Philosophical Society. At a 1926 symposium on his theory organized by the American Association of Petroleum Geologists – at which Wegener presented a paper – one prominent participant wondered aloud if geology could still be called a science when it let theories like continental drift "run wild."

Wegener was a tenacious man. The more his theory was criticized, the harder he worked to gather evidence to support it. In 1929 he published the fourth edition of "The Origin of Continents and Oceans." But after his death on the Greenland icecap in 1930 only a few devotees kept the faith – and they were often regarded as crackpots. Every respectable Earth scientist knew that Wegener's theory was beneath contempt.

Maurice Ewing and Bruce Heezen were among the respectable. But Marie Tharp, who had little use for the conventions of the day, didn't feel bound to abide by prevailing thought. And she was set to shock the staid scientists of her day when she began to plot profiles of the mountains that lie underneath the surface of the North Atlantic Ocean.

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Scientists had known for decades that there was some kind of rise in the North Atlantic. Matthew Fontaine Maury, working with only 200 widely scattered soundings (depth measurements) marked it as a plateau on his 1854 map of the North Atlantic floor. Charles Wyville Thompson, on the *HMS Challenger* expedition, used a more dense network of soundings and temperature measurements to confirm that a broad rise lay in the middle of the North Atlantic. The sounding data from the *Meteor* expedition showed, however, that the rise was not broad and gentle, but narrow and extremely rugged. The results of the *Meteor* expedition would have revealed that the ridge system extended into the South Atlantic, but, because of World War II, the data had not been thoroughly analyzed by the time Heezen asked Tharp to begin plotting depth profiles of the North Atlantic.

Tharp was working exclusively for Heezen by 1952 when she took up the task. Heezen had originally joined Ewing's research group at Columbia University to study the undersea mountains of the North Atlantic and figure out which way they ran. After compiling soundings from several research cruises on board ships like Woods Hole Oceanographic Institution's *Atlantis*, Heezen hoped to have enough data to come up with part of the solution. He and Tharp had plenty of data for the initial task. As late as the 1930s, a collection of a few hundred soundings on a cruise was thought to be enormous. But with technological advances and Ewing's drive and direction, tens of thousands of depth measurements in the North Atlantic had been acquired during the period from 1946 to 1952. Most of the data were obtained on cruises of the *Atlantis*. The Navy's *USS Stewart* was another important source of data.

In 1911, Reginald Fessenden made the traditional rope-and-sinker method of obtaining soundings obsolete. The American developed a method to determine depth by measuring the amount of time it took to obtain a sound echo from the ocean floor. Originally, researchers would set off a sound – by striking the hull of a ship with a hammer, for example. A radio operator would start a stopwatch when he heard the strike and stop it when he heard the echo. The operator would record the time that elapsed between the two events. A scientist could then multiply the interval by the speed of sound in water (generally 800 fathoms per second) and thus obtain an uncorrected estimate of the distance traveled by the sound wave from the ship to the bottom and back. Half of that distance would be the depth.

Fessenden's method was improved upon in the 1930s and during World War II so that, by the middle of the century, sound waves had completely replaced ropes and weights as a means to measure depth. Soundings could be obtained much more easily and quickly – on a more-or-less nonstop basis with the continuous echo sounder – but the increased volume of data demanded a lot of labor of a mental, rather than physical, sort.

The continuous echo sounder would send out an electronic ping at a regular interval, and a microphone inside the hull of the ship would pick up the echo from the bottom. As a ping was sent out, a stylus would be set in motion downward across a continuously spooled strip of four-inch-wide paper. When the echo returned the stylus would mark the paper by burning it with an electric spark, thus recording the depth much like an electrocardiogram records heartbeats today. The resulting trace was a profile of the ocean floor along the ship's course. The early echo sounders used by Ewing recorded depths at a scale of one inch to 1000 fathoms. Since one fathom is equal to six feet, the strips of paper could accommodate depths over a range of 24,000 feet.

The early echo sounders on board ships like the *Atlantis* had one major flaw – they were entirely dependent on the ships' overdrawn electrical systems. If someone opened the refrigerator, for example, the electricity often went out and no echo would be recorded. Thus, as far as the sounder was concerned, bottomless pits were found every time someone went raiding the refrigerator for a soda or sandwich.

If all the crew had to do was to make sure the stylus continued to work and the spooler never ran out of paper, the job at sea would have been easy. But there was much more to it. A scientist held watch in the lab whenever the sounder was operating. On a ship run by Ewing, that meant someone was on duty 24 hours a day, typically on eight-hour watches with eight hours off.

The scientist on watch would usually be sitting in a lab below deck. In the case of the *Atlantis*, it was known as the lower lab – space on the deck was called the upper lab – because there was little room on the two-masted yawl. The small, cramped, cluttered room often had no portholes or windows, so he (only men were allowed to go to sea on a Ewing ship) could not look out and see the comforting horizon as his stomach turned with the pitching and rolling of a small ship in a big ocean. Most crew members adjusted to the motions of the ship after two or three days. Some, though, repeatedly lost the battle to control their stomach, running to the rail several times on any given watch to throw up. Most of the time the scientist was trapped, swaying with the motion of the ship and watching the recorder, marking down time intervals and course changes on the strip of recording paper, making sure the equipment kept working, and making especially sure that the crew didn't overlook any feature on the ocean floor that deserved more detailed study.

At times the lab would be frenetic with crowded, adrenalin-driven activity. Someone might be repairing equipment, analyzing a sediment core taken form the ocean bottom, or watching the instruments, keeping themselves awake with coffee from the galley. A group might be arguing over the interpretation of newly acquired data. Some might be relating to others the news from home. But no one would be talking about something silly like what kind of chance the Dodgers had against the Yankees – for time on ships was at a premium and they had to concentrate on getting as much data as possible. The chief scientist like Ewing or Heezen might walk through, making the rounds of the research groups to learn how they thought the cruise was progressing. At other times, usually late nights and early mornings, the lab would be quiet, the scientist on watch being the only one awake. Heezen, when he was chief scientist, frequently stole catnaps on an unoccupied bench, ready to come alive if awakened by someone with a problem or a potentially interesting discovery. Ewing would sleep in his stateroom, but he expected to be awakened if something came up. Anyone who tried to be nice and let him sleep would be rewarded with anger rather than gratitude.

Over the abyssal plains, the ocean floor was as flat and boring as the plains of West Texas are to a long-haul trucker. The depth measurements changed little for interminably long periods of time, leaving the scientist on watch with little to do but mark down times on the recording strips in military style – 2300, 2315, 2330, and so on. But eventually the stylus would mark the paper a little higher. The next time, the mark would be higher still. The scientist grew more alert, waiting for the next echo to tell him if this is just a slight rise or striking ocean-floor topography worthy of more investigation. A sea mount, for example, is defined as a feature that rose at least 500 fathoms above the surrounding plain. Sometimes it would be obvious that the feature was a sea mount and warranted detailed study. Other times, the rise would come up somewhat – say, about 300 fathoms as an example – before dropping again. Either the feature wasn't a sea mount and wasn't worth spending much time on, or it was the flank of a sea mount that deserved more attention. The scientist on watch would consult with the officer on duty. They often decided to backtrack across the area on a slightly different course to get a more detailed view of the feature. If nothing more was found, the ship would return to its original course. Otherwise, they would call the chief scientist to plan a detailed survey.

While the scientists worried about the depths, the ship's captain and first mate worried about navigation, making sure the course was correctly plotted on their nautical charts. Once a day, they would take the depth records from the continuous echo sounder and plot the data on an overlay of the navigational charts, usually working at a scale of 1:1,000,000 (one inch on the map represents 1 million inches, or 14 nautical miles, on the ocean floor). Rather than plot every sounding, Heezen cut their work load by having them plot the depths only at peaks, troughs, changes in slope angle along the ocean floor and course changes of the ship. Despite the simplification, the officers had hundreds of measurements to transcribe each day. The officers did the work by hand. Despite the motions of the ship, they read the depths off the profiles, with 24,000 feet compressed to a four-inch-wide strip, and wrote them down on the overlay in neat handwriting so precise it often looked as if it had been typed. The ship's officers knew an illegible number did no one any good. One would read, the other would write; hundreds of measurements a day would be transcribed in this fashion.

Such was the routine, 24 hours a day, seven days a week, for however many weeks they were at sea. Ewing demanded that it work that way and, being a hands-on leader demanding more from himself than from anyone else, made it work that way. Running a research ship was expensive, often costing tens of thousands of dollars per cruise, and he made sure that he got his money's worth of data every time. It was a hard life to be at sea with Ewing, but life was no easier on shore afterward. Once the ship reached port, the chief scientist, whether it be Ewing, Heezen or someone else, packed the data in a suitcase and hand-carried it to either Woods Hole, Columbia University or, by 1952, to Lamont Geological Observatory. The data were far too valuable to entrust to any courier. At the lab, the real work began.

Marie Tharp and her research assistant, Hester Haring, went to work at drafting tables in a room on the second floor of Lamont Hall. First, Haring would replot the sounding data using the charts compiled by the ship's captain and first mate. Then she and Tharp plotted profiles of the topography along the ship's course. The profiles had to be drawn in a consistent manner. The horizontal scale was 40 miles to the inch. The depths were plotted at a vertical scale of 1 inch to 1000 fathoms. The west end of the profile had to be on the left, the east end on the right. Of course, the depth values had to be correct, too. Any mistakes and someone like Tharp or Heezen would angrily scrawl a message like, "Plotted Backwards!" on the profile and have it redrawn. Tharp or Heezen would then compare the depths on the profiles with the original sounding record.

Eventually, after the drawing, checking, correcting, redrawing, rechecking, etc., was done, Tharp was left with a hodgepodge of disjointed, if not disconnected, profiles of sections of the North Atlantic floor. Plotted on a map, the ships' tracks looked like a web woven by a disturbed spider – the eccentricities in the paths often caused by the ships' sometimes unsuccessful attempts to dodge storms. The web's rays radiated out from Bermuda, where most of the research vessels took on supplies and water. Heezen asked Tharp to order the chaos and make six more or less parallel profiles of the North Atlantic.

Tharp took copies of the profiles and cut them up into sections. Next, she arranged them in proper order from west to east. Where tracks crossed one another, like when a southeastward track cut across a northeastward one, she rearranged them so that two more northerly arms formed one transect while the two southerly arms formed another transect more or less parallel to the first. Eventually, Tharp reassembled the jumbled tracks into six transects.

As Tharp plotted the more northern profiles, she noticed a large valley at the center of the Mid-Atlantic Ridge. Although the valley wasn't as prominent in the three southern profiles, it was still there, typically 1000 fathoms (6,000 feet) deep and nine to 30 miles wide – as deep as the Grand Canyon, but much wider. In the six weeks it took her to prepare the profiles, Tharp became convinced that she was looking at a rift valley and told Heezen so.

Heezen did not want to hear the news. A rift valley meant the Earth's crust was spreading apart, and that might mean the continents on either side of the Atlantic were getting farther and farther away from each other. If they were, it might mean that there was something to Alfred Wegener's crackpot idea. Speaking out in favor of Wegener's theory would be an act of professional suicide.

Heezen looked at Tharp's profiles. No matter how hard he tried, the valley would not disappear. He groaned, and said, "It can't be. It looks too much like continental drift."

Heezen was skeptical of Tharp's interpretation of the data, but she knew what she saw, and was determined to bring Heezen around to her way of thinking.

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At about the same time, Bell Laboratories asked Heezen to map the locations of breaks in transatlantic telephone and telegraph cables. Bell was planning to lay more cables, and wanted to know if mid-ocean earthquakes were responsible for the damage. Heezen hired Howard Foster, a recent, deaf, graduate of the Boston School of Fine Arts to plot the locations of recorded earthquakes around the world. Another group was put to work plotting the locations of cable breaks.

Heezen was adamant that all oceanographic data be plotted at the same scale. His instructions paid off when Tharp, working at a drafting table next to Foster, noticed that the earthquakes Foster plotted were roughly in the same region as her rift valley. There was some difference, but the earthquake data were subject to a certain amount of error because of the limited seismic network used in recording the locations of the epicenters. Heezen wasn't impressed with the matchup at first, but when he took into account the probable error in locating the earthquakes, he realized that the location of Tharp's rift valley coincided with the location of seismic activity, which coincided with the cable breaks.

By now, almost a year after Tharp pointed out the rift valley, Heezen no longer dismissed her interpretation of the depth profiles as “girl talk.” With the three types of data they were plotting, the conclusion was obvious.

She was right.

Ewing also began to get interested at this point. He’d heard of this “gully,” as they called it, and he would pop into their lab from time to time and ask, “How’s the gully coming?” It was coming along just fine. Using sounding data from the *Meteor* expedition, Tharp had extended the Mid-Atlantic Ridge and rift valley into the South Atlantic. Data from other expeditions revealed similar features in the Indian Ocean, Arabian Sea, Red Sea and Gulf of Aden. A U.S. Navy expedition found a large north-south ridge system in the eastern Pacific.

While Tharp and Haring busied themselves with sounding data, Foster was plotting tens of thousands of earthquakes around the world. The pattern held. 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.

In 1956 Ewing and Heezen reported the results of the work at a meeting of the American Geophysical Union. The title of the paper was, simply, “The Mid Atlantic Ridge Seismic Belt.” Only the abstract from their paper was published. Small as it was, as economical as the language was, the abstract was to have a tremendous effect on the Earth science establishment.

> “The Atlantic belt of earthquake epicenters follows the crest of the Mid-Atlantic Ridge and its prolongations into the Arctic and Indian Oceans with a precision which becomes more apparent with the improvement of our knowledge of the topography and of

epicenter locations. These are all shallow shocks. Their apparent departure from the narrow crest of the ridge seldom exceeds the probable error of location. The crest is 30 to 60 miles wide, very rough, and on a typical section shows several peaks at depths of about 800 to 1100 fathoms. There is usually also a conspicuous median depression reaching depths of about 2300 fathoms. This is interpreted as an active oceanic rift zone which continues through the African rift valleys."

Ewing and Heezen acknowledged that they saw a rift. Did they know what its existence meant?