Venus, the surface roils and churns so quickly that solid crust does not have a chance to form. On geologically static planets like the Moon, geology was a game that was played only once, very quickly after the planet was formed, and then was gone forever. NASA's *Apollo* missions showed very clearly that the only geological action now on the moon comes from the eternal impact of dust particles captured by its indifferent gravity as well as the occasional apocalyptic arrival of an impacting asteroid or planetoid.

Only Earth, as far as we know, has the compromise necessary to produce continents—the internal fires burn quickly enough to bring magma to the surface and, as it spreads away from the mid-ocean ridges, it has the necessary time to cool. It is then recycled back into the interior of the planet at the ocean margins where, like a sinking slab of toffee, it is returned to a molten state. This mass of molten continent still, however, retains enough homogeneity to be returned more or less as a unit at the mid-ocean ridges eons later as the rock cycle continues. Then it starts the same process all over again. With each iteration—each distillation—the chemical composition of the heated magma changes, becoming lighter and lighter, so that in time these great slabs of rock ride higher in the magma ocean than the oceanic crust. The continents are like the ships of the Victorian navy, patiently constructed to ride the oceans of the inner planet.

Looked at this way, with the advantage of a century and a half of geological research that *Challenger's* Scientifics could not have imagined, we can see that as our iron-and-wood corvette made her way across the Channel and out into the storm-racked Bay of Biscay she had not even started her long voyage of discovery. Her officers, bluejackets, and Scientifics were finally at sea, yet from the perspective of geology they had not yet even left the continents. The true silent landscape still lay before them.

The Desert Under the Sea

Lisbon, Portugal, January 3, 1873, 38° 44′ N, 09° 08′ W to Gibraltar, Mediterranean Sea, January 18, 1873, 36° 09′ N, 05° 21′ W

THE LOST EMPIRE

On January 3, 1873 *Challenger* entered Lisbon Roads on the river Tagus, arriving at the city of Lisbon at midday. On either side of her rose hills covered with vineyards and the gently rotating white sails of the windmills used for crushing grapes. Before she was allowed to anchor, the Portuguese admiral's boat came alongside and interrogated Captain Nares closely: "The name of this ship, sir? It's purpose, your armament, hands on board, any sickness?" Despite their exhaustion, the *Challenger's* crew were both amused and infuriated by what they saw as continental officiousness. Who did they think they were, addressing a vessel of Queen Victoria's empire that way?

The men of the *Challenger* expedition were a product of an "empire on which the sun would never set." In word, thought, and deed they were colonialists steeped in unconscious prejudice. Young Joe Matkin observed that the Portuguese seamen looked dirty and that even their flagship was not as good as his own modest *Challenger*. William Spry observed smugly that although the churches, gardens, and palaces scattered about were worth a visit, the full tide of Portugal's prosperity had receded with their empire 300 years earlier. Yes, the Portuguese had been great explorers; after all was it not Vasco de Gama who sailed to the Cape of Good Hope and then visited India? Other Portuguese explorers had conquered the Maldives, established industries in Ceylon, the Moluccas, Sumatra, and other places on "the Eastern Archipelago." The Portuguese had established early trade links with China and Japan, connections that the British Empire had been able to forge only recently. Indeed, in the early sixteenth century no flag but that of Portugal flew along the whole length of the African coast and no ship dared anchor in any harbor from Gibraltar to Abyssinia, Ormuz to Siam, without the permission of the Portuguese. In the sixteenth century, England could not have disputed the possession of an inch of ground with Portugal for a week, but who ruled India now?

The rot, according to Spry, set in 1557 when misgovernment, tyranny, the Jesuits, and the Inquisition strangled the rising fortunes of the Portuguese. Now Portugal was stripped of nearly all its colonies, a shadow of what she had been. "England," concluded Spry, "now wears the mantle Portugal in her blindness and bigotry let fall."

Yet after a few days in Lisbon, the men of *Challenger* found the place growing on them. Despite the pervasive smell of garlic on the local breath, which particularly disgusted Matkin, they had to allow that fruit and fish were fresh, plentiful, and cheap and made a welcome change from the monotony of shipboard rations. Culturally, too, there was much to admire in Lisbon. Herbert Swire enjoyed a visit to the opera while Matkin and a mate told of bullfights, theatre, and a masquerade ball where even the lowliest rating could dance with a countess. And could it be that the Portuguese were not so ignorant after all? Just before departure, the King of Portugal, an enthusiastic natural historian, paid a visit to the ship, where Nares and Wyville Thomson, impressed with the king's knowledge of biology, took great delight in introducing him to *Challenger's* laboratories.

After being detained in Lisbon for two days longer than planned because of bad weather, on January 12, *Challenger* made all plain sail for the most southerly of Victoria's possessions in Europe, Gibraltar.

NIGHT OF THE LIVING DEAD

Challenger's Scientifics might have had no inkling of the true nature of continental shelves yet they did make some significant discoveries on this leg of the voyage. Soon after leaving Lisbon, in water 2,000 fathoms (6,000 feet, a little more than a mile) deep, they dredged a sea lily. Technically, sea lilies are known as crinoids and are a member of the same phylum as starfish and sea urchins although they look very different, having many articulated arms connected to a long stalk that anchors the animal to the seabed. Arms and stalk are covered with hard plates of lime (calcium carbonate). The crinoids have a long and illustrious fossil record and were exceptionally abundant in the Jurassic period at the height of the dinosaur's reign.

The Scientifics' recovery of the crinoid was significant because it proved that the *Challenger* expedition was fulfilling one of its primary roles: testing Darwin's theory that the bottom of the ocean was a haven for life forms found on land only as fossils. Darwin's theory of "descent with modification" stated that the variation among offspring (produced through genetic recombination, a mechanism at that time not fully understood) was then worked on by the process of natural selection. "Natural selection" was a term that Darwin coined to indicate the winnowing of unsuccessful body types and chracteristics through early mortality while better-adapted types developed into successful species. This "differential reproductive success" is another way of saying that better-adapted organisms leave more offspring behind. These offspring, too, leave more offspring behind and so on. The process continues *ad infinitum* as the successful species out-competes less well-adapted forms. This process fuels an eternal struggle to optimize an organism to its environment, with the implication that a successful species will eventually be perfectly adapted to its environment. In the language of ecology, it will have successfully and completely occupied an ecological niche.

Because the environment itself has continually changed over geological time, the floras and faunas of Earth have had to continually change too. Successful adaptation is like trying to score a goal while the goalposts are constantly moved. But the Victorians believed that on the unchanging ocean floor—the silent landscape—organisms would not have been forced to evolve beyond the form best fitted to that environment millennia ago and, therefore, that the animals of the deep would be evolutionary throwbacks, living fossils. This idea also highlighted another of the Scientifics' preconceptions: namely that the ocean floor is the most ancient place on Earth. Both of these ideas would eventually be shown to be wrong, but it would be the *Challenger* expedition itself that would overturn the "evolutionary throwback" notion.

But when they dredged up the sea lily, the *Challenger* crew were simply elated to have found what they thought was the proof of Mr. Darwin's theory, that the ocean floor was indeed a dark, ancient, and unchanging place, populated by the living dead. To the crew, this success seemed like a long overdue good omen for the rest of the voyage.

THE ECHO OF AN IDEA

Sounding and dredging were the two techniques at the heart of *Challenger's* enterprise; sounding to measure the depth of the ocean over which the ship passed and dredging to bring up material for study. Today these seem incredibly primitive, just throwing a string over the side of a boat. But in fact they represented the cutting edge of Victorian remote sensing technology. The sounding principle had reached its highest form of development in 1853, just 19 years before *Challenger* sailed, through the efforts of one John Mercer Brooke. Brooke had developed a method that solved the two main problems of sounding with a line: He used twine rather than hemp rope, so that its weight would not continue to pull more of the line overboard after it hit bottom; and he used a weight to keep the twine as vertical as possible so that inaccuracies due to the curvature of the line as the ship moved would be all but eliminated. In fact the weight was quite sophisticated. It was an iron ball connected to a rod-like apparatus that allowed the ball to be detached and the twine pulled up without snapping. A further innovation was a device on the rod assembly that took a sample to prove that the sounder had hit bottom. This system was later used successfully by the U.S. Navy to take soundings right across the Atlantic Ocean.

Despite the fact that occasional soundings in the vastness of the Atlantic were totally inadequate to generate a true picture of the subsurface topography, in 1854 the director of the U.S. Navy Depot of Charts and Instruments, Matthew Maury, published the first "chart" of the undersea geography of the Atlantic. It successfully showed the steepening where the continental slope began and also hinted at the presence of a plateau in the middle of the Atlantic—a feature that was soon to assume overwhelming importance to science. This feature Maury named the "Dolphin Rise" after the ship that had carried Brooke's cutting-edge sounding gear. But physical sounding with a line never had much of a chance as a means of mapping the silent landscape—better eyes were needed. Strangely enough, when they finally arrived, in the early twentieth century after *Titanic's* epochal encounter with an iceberg, it was through a technique, echo sounding, which had been developed at the start of the same era that had spawned the *Challenger* expedition.

In 1838 Charles Bonneycastle, a young professor at the University of Virginia, was interested in an experiment with sound and water that had been performed 12 years before by the Swiss mathematician Jean Daniel Colladon. Colladon and an assistant had measured the time needed for sound to travel through water by striking a submerged bell and releasing a flare at the same time. From this, Colladon calculated that sound traveled underwater at almost a mile per second—four times faster than the speed of sound in air. It was this idea that Bonneycastle used 12 years later when he tried to estimate the depth of the ocean floor using sound. A team of sailors from the U.S. Navy brig *Washington* detonated a mine while a little way off Bonneycastle sat with the narrow end of a flared tin pipe in his ear. He heard the sound of the detonation and a fraction of a second later another, smaller explosion which he took to be the echo of the main blast off the seafloor. Using Colladon's estimate of the speed of sound in seawater, Bonneycastle was able to calculate the depth of the ocean at that place: about 160 fathoms (960 feet). But when he checked his estimate using a sounding line he found that the actual depth there was only about 540 feet. Discouraged, he abandoned his attempts and for the rest of the nineteenth century the echo-sounding technique was forgotten.

It took the tragedies of *Titanic* and *Lusitania* in the early twentieth century to renew interest in echo sounding as a way to detect unseen obstacles at sea. By then the Submarine Signal Company of Boston, Massachusetts had for some years been manufacturing underwater bells that could be attached to ships and microphones that picked up their peals. In this way two ships that were out of visual range could detect each other's presence.

One of the company's more innovative employees, Reginald A. Fessenden, took this approach a step further and developed a bell so loud that its *reflected* echo from an underwater hazard was audible without amplification. The bell was actually a large metal membrane warped by the action of electrical current. It was so effective that on field trials off the Grand Banks of Newfoundland officers eating in the ship's mess could hear the echo of the device reflected from an iceberg two miles away and, crucially, also from the ocean floor, one mile straight down. The Fessenden Oscillator became the sound source used by U.S. Navy physicist Harvey C. Hayes to develop, a few years later, the first true echo sounder. It was Hayes who overcame the final problem of echo sounding: measuring the time interval between the transmitted and received sound pulses with sufficient accuracy. This measurement was crucial, because a time error of only half-a-second translated into a depth error of more than a thousand feet. His technique was to "center" the sound, that is, to vary the outgoing pulse frequency until it coincided exactly with the incoming echo. To accomplish this the operator used a set of headphones, one earpiece registering the outgoing pulse, the other, the incoming echo. When the two noises coincided exactly the distance to the seafloor was simply the time difference multiplied by the speed of sound in seawater, 0.9 miles per second. To find the time difference the operator detuned the device by varying the frequency control—speeding up or slowing down the succession of pulses—until once again the two sound pulses coincided. The time-distance equation could now be solved using basic algebra and the echo sounder—or depth fathometer—was born.

It was now possible to make almost continuous measurements of the ocean depth along a ship's track, and Hayes himself was the first to do this in 1922 while sailing between Newport, Virginia and Gibraltar aboard the USS *Stewart*. During the single week that he was at sea he managed to take more than 900 soundings—more than *Challenger* had managed in its entire four-year voyage. From then on, the development of the fathometer was continuous, initially embracing automated pen recorders to graph changing submarine topography and then being integrated with solid-state electronics and computers. This integration ultimately gave rise to a technique that came to dominate the world of underwater warfare—sonar (the term stands for SOound NAvigation and Ranging—but it is certain that this acronym was created retrospectively. It is likely that the original term was coined simply because to early operators it was perceived to be "something like radar").

The impetus for developing sonar was the limitation that the Hayes Fathometer (and its other variants developed in the years after the First World War) could reconstruct only the topography of the seabed directly underneath a ship's track. The fathometer's output is a one-dimensional line and the ocean floor is a two-dimensional surface. An additional problem was that the width of the line was not clearly defined—the sonar "ping" spreads on its way down to the ocean floor as well as on its way back up, resulting in a depth estimate that is an amalgam of the topography beneath the ship.

To get around these difficulties, Harold Farr and Paul Froelich, of the Harris Anti-Submarine Warfare division of the General Instruments Corporation of Massachusetts, developed multibeam sonar. Their technique depends on the use of interference patterns, the physical phenomenon whereby light or sound waves, when passed through a diffraction grating, either disappear by canceling each other out or augment each other. Stringing a row of several sonar transmitters beneath a ship in an array from bow to stern makes the sound waves fan out, mapping the seafloor beneath and on either side, but from back to front they cancel each other out. This "insonification" phenomenon results in a stripe of sonar pings coming back to the receivers for miles to port and starboard but not from fore and aft.

The real genius of Farr's and Froelich's invention, though, was to string the array of *receivers* at right angles to the transmitter array. A signal originating from directly beneath the ship would reach all the receivers at once but a signal originating from, say, far to port would reach the port side of the receiver array first and then progressively along each receiver until it reached the starboard-most one. In this way, Farr and Froelich were able to calculate not only the delay between an outgoing signal and its arrival back at the receiver, but the tiny time differences between its reception along the elements of the array. From these results they would then calculate not only the distance to the echo source but also its angle underwater. At last a tool had been devised that could accurately measure the depth of features on the seafloor on either side of a ship as it moved forward. With electronic integration, this swathe or line on either side could be easily turned into a map of the surface of the seafloor.

Multibeam sonar was given to the U.S. military early in the 1960s and they immediately did what the military always do with an innovation—they classified it Top Secret. But after 30 years even the U.S. Navy could see that, following the collapse of the Cold War, there was not much point sitting on an invention that would finally allow us to visualize the 70 percent of our planet that

remained almost completely unknown and so they allowed a commercial version called Sea-Beam sonar to be developed. But this instrument is a pale reflection of the full-blooded military version, having only about a third as many sensors as multibeam sonar. Nevertheless, Sea-Beam sonar, combined with accurate satellite navigation, finally allows us to map the topography of the silent landscape and it is this development, as we shall see, that has confirmed one of the most extraordinary discoveries of *Challenger's* voyage, the mid-ocean ridges.

But multibeam sonar was as remote and incomprehensible to the crew of HMS *Challenger* as the dark side of the moon. They had to be content with their sounding lines of piano wire. Their methods of physically retrieving samples from the ocean floor were similarly primitive. Their dredge was an iron frame that held open the mouth of a bag made of finely woven material. It was connected to the ship by one-inch-diameter hemp ropes with a drag so fierce that it typically took more than three hours to lower the dredge to a depth of 2,000 fathoms. Once the dredge was on the bottom, the ship stayed on station all day, hauling the dredge slowly along under steam power. To prevent the dredging line from snapping, a special "accumulator" made from gutta percha (india rubber) ropes connected the line to the supporting mast. The accumulator absorbed severe variations in tension and protected the mast. Transits between dredging sites had to be done under sail in order to conserve fuel. After the day's dredging, the haul was lifted from the depths by the ship's tiny 12-horsepower donkey engine; then the eager scientists fell upon the day's pickings and worked far into the night in their odorous laboratories, describing and cataloguing their findings. But they discovered that their dredge hauls were disappointingly puny and they soon abandoned it in favor of an ordinary beam trawl. This was a heavy length of wood, like a railway sleeper, to which a lead-weighted net was attached at either end. Being larger and more flexible than the iron dredge, this produced much greater results.

GATEWAY STATION

Gibraltar, Mediterranean Sea, January 18, 1873, 36° 09′ N, 05° 21′ W

In the early hours of January 18, 1873 *Challenger* entered the Mediterranean Sea through the Straits of Gibraltar, slipping quietly past the Pillars of Hercules as a huge gibbous moon climbed silently into the sky from behind the summit of the rock. Herbert Swire was on deck to watch their arrival, woken from an uneasy sleep by the realization that *Challenger* would soon be braving the deep waters of the Atlantic as it finally left the familiar seas of Europe behind. The first leg of their long journey was behind them, the proving leg where they had tested their new technology of dredging and sounding. There was much to be proud of. They had used the "Fox Dipping Circle" to make numerous observations of the strength of the earth's magnetic field. They had used thermally sensitive "galvanic wires" deployed overboard to confirm Wyville Thomson's theory that the deep waters were divided into great discrete masses that moved slowly but with massive momentum about the globe. They had discovered, too, that the muddy bottom of the European continental shelf extended from shore at least 31 miles before dropping steeply into the Atlantic abyss, and they had brought on board a great variety of living organisms dredged from the bottom.

As well as the crinoid that had caused so much excitement among the Scientifics, they had collected a Venus Flower Basket (to which the Scientifics, with their penchant for dog Latin, insisted on referring as *Euplectella*), a conical tube only 2 inches wide at the top, with walls made up of a delicate tracery of tissue that resembled spun glass. Previously, this strange organism had been known only from the deep waters around the Philippines. Together with spectacular finds of strange and grotesque deepwater fish previously unknown to science, their eyes almost blown out of their heads by the thin pressure of the sunlit world, these *Euplectella* confirmed in the minds of *Challenger's* Scientifics that Mr. Darwin had to be correct: the seafloor was a haven for species previously thought to be extinct. The silent landscape was a living portal into the history of life.

By now the portents and ill omens that had dogged the start of their journey were receding quickly into memory. To a man, the crew was pleased to be at Gibraltar. It was, after all, home from home for the citizens of Victoria's empire, the gateway to the east and to the jewel in the crown, as well as the refueling station for voyages to America and the colonies of Africa and the antipodes. The Treaty of Utrecht had ceded Gibraltar to England in 1713 and, as William Spry observed with his customary imperial conceit, it was only since then that Gibraltar's greatest features had been added. These features included the mile-long network of galleries that lined the rock and the honeycomb of tunnels that afforded the garrison protection and access to all points of the compass from which they might be threatened. Joe Matkin noted with amazement that Gibraltar was one of the most heavily armed outposts of the empire. There were no fewer than 1,873 guns on the rock—a surfeit of armament precisely matching the year of their visit. The Channel Fleet, an impressive array of the ironclads *Minotaur*, *Agincourt*, *Sultan*, *Hercules*, *Bellerophon*, and *Lively*, rode at anchor in the Inner Mole, where Swire was keen to catch up with his former shipmates. But the fleet sailed for Madeira later that afternoon, slipping their moorings and steaming Indian-file into the Mediterranean before turning for the straits and the west. Swire consoled himself with the thought that *Challenger* would catch up with them again in Madeira or Tenerife.

And there was much to enjoy. All hands agreed that the view from the signal station at the summit of the rock was magnificent. It was 1,300 feet above sea level and a hard climb along a narrow path, but the effort was amply rewarded by the sight of the glittering waters of the Mediterranean stretching away to the east and the rich ochres and blues of the Spanish hills beyond the cluster of small villages across the bay. To the south, on the other side of the straits, was the imposing dome of Apes Hill and even from the signal station they could see the monkeys clambering among the rocks. Beyond that, fading into the haze was the vast secret bulk of Africa, the source of so much of the empire's wealth. As they stood there, they all felt it, a feeling so intense that it made the hairs on the back of their neck stand up, that particular pride at being an Englishman in the year 1873. It was the height of empire—and it could never fall.

William Spry noted the security arrangements with approval. The daily opening of the gates was carried out with a sense of ceremony appropriate to a lonely British outpost on the periphery of Europe. Immediately after sunrise the Sergeant of the Guard collected the heavy bunch of gate keys from the Governor's house and, accompanied by troops with rifles and fixed bayonets, proceeded to open each gate in turn and lower its drawbridge. Throughout the day the motley collection of nationalities—Englishmen, Spaniards, Portuguese, Turks, Moors, and Jews—that made up the garrison came and went, the Spaniards with compulsory visas, until, at sunset, the ceremony was repeated in reverse, the Sergeant accompanied by his armed guards pulling up the drawbridges and closing and locking the massive gates before returning the keys to the Governor. At night Gibraltar became again a little piece of England, secure from the infidel who waited just on the other side of the gates.

The naval dockyard was small but beautifully equipped, with at least 10,000 tons of coal on hand at any time. An excellent library was immediately placed at the disposal of the crew. It was updated daily with newspapers, periodicals, and telegrams from home. The gardens of Gibraltar afforded many pleasant walks among beautiful surroundings, the colors of fuchsia, oleander, and orange groves mixing with those of Spanish broom, subtropical cacti, and dwarf palm.

But there was work to be done here, too. The Scientifics were excited to discover a large deposit of bones, shells, and teeth in the

cave of St. Martin halfway up the southeastern face of the rock and speculated that they might be the remnants of animals that had lived there during the last great glacial age. Samples were taken for further work on board the ship. While they were at Gibraltar, the naval men made a new survey of the Mole, rated the chronometers, and calibrated their compasses. The distance to Malta was calculated too, by measuring the time taken for an electrical impulse to transit the newly laid telegraph cable between the two colonies, and found to be exactly 1,000 miles. Coincidentally, the ship in Malta that assisted in this measurement was the *Shearwater*, the same sloop that Wyville Thomson and William Carpenter had used for their survey of the Mediterranean in 1870. The disappointment of that mission was at least partly responsible for the decision that *Challenger* would not enter any further into the Mediterranean, thereby missing one of the most extraordinary stories that the silent landscape has to tell.

THE DESERT UNDER THE SEA

That story had to wait another hundred years for new technology as well as a new ship. The new technology was seismic shooting and the new ship was the spiritual successor to, as well as the namesake of the original *Challenger*, the drilling vessel *GLOMAR* (*GLO*bal *MAR*ine) *Challenger*.

At about the same time that multibeam sonar was invented, scientists were developing another method of seafloor imaging using sound—seismic shooting. Seismic shooting was pioneered by the American geophysicist Maurice "Doc" Ewing, the founder of the Lamont-Doherty Geological Observatory in Palisades, New York, an institution that became the home of marine geology in the United States. Ewing's idea was to use dynamite to create an explosion so powerful that the sound waves were not just reflected back from the ocean floor but penetrated it and were then reflected back by subsurface features. With suitably positioned detectors, the time taken for the echo of the explosion to return to the surface indicated the hardness of the sedimentary layers beneath. The American research vessel *Chain*, operating out of the Woods Hole Oceanographic Institution in the late 1950s, used this technique while surveying in the Mediterranean. In the course of that cruise, seismic shooting revealed the presence of a hard layer—an acoustic reflector or sound-reflecting layer—deep within the sediments of the Mediterranean seafloor. This M-reflector, as *Chain's* senior scientist Brackett Hersey named it (M for Mediterranean), was quite clearly something that had been laid down with the sediments of the seafloor because it followed perfectly the contours of the hard rock basement of the Mediterranean.

Although sonar gave a clue that something strange had happened in the Mediterranean, a physical investigation of the nature of the hard layer was still very far off. Because the M-reflector was buried under 2 kilometers of sediment, the only way to reach it was by drilling and that meant using a drilling ship. Only one vessel was suited for the job, the research vessel of the Deep Sea Drilling Project, the *GLOMAR Challenger*. The origins of the Deep Sea Drilling Project are complex and will be dealt with in the final chapter of this volume, when we consider the implications and heritage of the original *Challenger* expedition. However, since we cannot leave the Mediterranean region without discussing its secret history we must anticipate ourselves slightly and tell the story of the day the Mediterranean became a desert.

In late August 1970, the *GLOMAR Challenger*, after 12 successful cruises around the Atlantic, entered the Mediterranean Sea for the first time. Interest in the Mediterranean was intense for two reasons: first, because the new theory of plate tectonics predicted that the proto-Mediterranean must once have been a wider ocean—named Tethys after the world-girdling ocean of Greek mythology—which had gradually narrowed as the African plate moved northward into Europe; and second, because scientists still wanted to know what the enigmatic M-layer was. Indeed Bill Ryan, one of the *GLOMAR Challenger's* two chief scientists on its Mediterranean cruise, had been with Brackett Hersey aboard the *Chain* when the M-layer was discovered. But by the evening of August 24, 1970, Ryan and the other chief scientist aboard the *GLOMAR Challenger*, Ken Hsu, were becoming discouraged. They had drilled down to the M-layer and all that they had managed to retrieve was a handful of gravel. Late that night, as they sat mournfully in the deserted paleontology lab, Hsu watched in growing amazement as Ryan washed and rinsed the gravels that they had retrieved, dried them on a hotplate, and started gluing them to the cover of a brown manila folder.

But as he watched, Hsu gradually became aware of the reason for his colleague's apparently compulsive preoccupation. Ryan was performing a form of low-tech grain-size analysis; he was ordering the sediment grains according to their size in order to better understand the forces that had laid them down. When he was finished, both scientists could see that the larger grains were fully 7 millimeters across; genuinely gravel sized and not at all something that either had expected to find in the deep ocean. Gravels are normally deposited by fast-flowing rivers and as they are too large to be moved by the slow-flowing currents of the deep ocean, they tend to settle out close to the mouths of estuaries. Among the gravels there were shiny crystals of the mineral gypsum, the residue left behind when seawater evaporates. Today gypsum forms on the shores of arid coasts and is also found in rock outcrops on land that were formed under conditions of intense evaporation; it belongs to a class of minerals known as evaporites. No one expected to find gypsum in a deep-sea deposit, much less in association with gravel-sized grains. At its current position the *GLOMAR Challenger* was drilling on the flank of a submerged volcano, but it was clear that the volcano could not have provided these pea-sized gravels unless it had once been exposed to weather and subjected to erosion by streams running down its sides.

Then the paleontologists on board began telling Hsu and Ryan that the species of foraminifera—tiny single-celled creatures that leave a hard shell of chalk—that they were retrieving belonged to contemporary species that are usually found only in shallow coastal lagoons. In the deep waters where they were now drilling this was a very strange finding. But these "forams" had another unusual feature: They were dwarfs. When dwarf faunas are found in the fossil record, they are invariably associated with times of environmental stress. To Hsu there could be only one explanation for the gypsum, gravel, and stressed foram fauna at the bottom of a hole drilled in 3 kilometers of water: The Mediterranean basin had once been a desert.

Hsu was able to piece together the story. At some point in the past, the supply of seawater from the Atlantic Ocean through the Straits of Gibraltar had stopped. As it dried out, the Mediterranean basin gradually changed into a giant salt lake, like the Dead Sea but a hundred times larger. As the desiccation continued the remaining brine became progressively saltier in the harsh Mediterranean sun, stressing the foraminifera and other deep-dwelling creatures that lived there and turning each new generation into a progressively more stunted shadow of its ancestors. Finally, the Mediterranean bottom had been laid bare and the submarine volcano near which the ship currently floated became a mountain, rising high above a barren treeless landscape. Its oozes and sediments were baked hard by the sun and eventually eroded into gravel by the streams running down its flanks. Finally the Straits of Gibraltar had opened again and the Atlantic had come cascading into the 3-kilometer-deep ocean basin in a torrent that dwarfed even the Victoria Falls on the Nile.

Ryan was skeptical, and who could blame him? Hsu had fabricated this extraordinary story in the course of a few days on the basis of three lines of evidence that, on their own, were extremely flimsy. But Hsu was not discouraged. He pointed out to Ryan that the M-layer itself could well be additional supporting evidence for the desiccation of the Mediterranean. Did not the M-layer follow the Med's basement topography perfectly? Did not the seismic data

show unequivocally that sediments must underlie, as well as overlie, the layer? The M-layer must, therefore have been deposited when the basin topography of the Med had already been formed. It was the hard relic of the ancient saltpan.

A couple of holes later they found more supporting evidence for Hsu's theory. At Hole 124 they discovered rocks that Hsu, with characteristic bravado, named the "Pillars of Atlantis." These cores were composed of the mineral anhydrite and contained a type of fossil known as stromatolite. Anhydrite is found only on arid coastal flats in a dry environment known as sabhka. Stromatolites are hard, limey, fist-sized fossils secreted by billions of tiny, filamentous, blue-green algae. These tiny bacteria-shaped objects, which have no true nucleus, live today in shallow salty pools at the edges of oceans, for example on the margins of Shark Bay in Western Australia. As the tide comes and goes, they trap limey muds between the layers of cells that eventually become lithified—turn into rock—and what was once a gelatinous mass of primitive cells becomes a large hard mound. Stromatolites are one of the oldest fossils in the geological record. They have been found in rocks that are 3.5 *billion* years old (about 80 percent as old as Earth itself). But the point is that the stromatolites are *always* found in shallow waters. They need sunlight to power the process by which they derive their nutrition: photosynthesis.

Ryan began to waver. The presence of anhydrite and stromatolite in this core was indeed strong confirming evidence. This left the remaining crucial question—when? Not all members of the crew became converts to Hsu's apocalyptic vision and indeed, when the ship eventually returned to Lisbon after 60 days at sea, only three people were willing to put their names to the paper that proposed the desiccation idea: Hsu, Ryan (who had finally been persuaded by the weight of evidence), and the foram paleontologist on board, Maria-Bianca Cita. Cita's contribution to the desiccation idea was most notably the dating of the event. She pointed out that many of the lands rimming the Mediterranean—Italy, Spain, Portugal, and several of the North African states—have extensive deposits of salt. When dated using land fossils, all of these deposits were found to be of the same age, defining a short-lived but discrete period at the top of the Miocene epoch named (after the location of the biggest salt deposit at Messina in Sicily) the Messinian. The forams that Cita analyzed on the cruise had all been of Messinian age and thus pinpointed the age of the M-layer very precisely between 5 and 6 million years old. More than a century before, English geologist Sir Charles Lyell had differentiated between the Miocene and the Pliocene epochs of Earth history on the basis of two radically different fossil assemblages, the changeover occurring within this narrow Messinian stage.

In the late 1960s and early 1970s deep-sea drilling technology was still very new, and strangely, one of the most difficult rock types to retrieve was soft salt. Its solubility meant that it was almost invariably dissolved away by the circulating sea water used to keep the drill bit cool and lubricated. Amazingly, at the very last hole they drilled before their return to Lisbon and against all the odds, the scientific party retrieved a cylinder of salt. It was from the Messinian stage. The enigmatic M-layer could now be finally understood: it was indeed the layer of evaporite that defined the end of the Messinian salinity crisis.

When the ship docked in Lisbon, the crew was unprepared for the publicity that was beginning to surround Hsu's big idea. It had already made the front pages of dailies around the world and the co-chiefs of the expedition were bombarded with requests for interviews. The idea that the huge Mediterranean Sea had once been as dry as a garden pond after a long hot summer had caught the public imagination. It was good publicity too for the Deep Sea Drilling Project, whose success in proving the plate tectonic theory had made the headlines only a year before.

Hsu soon found that the scientific literature was dotted with many other clues to the desiccation idea. For example, previous seismic surveys revealed strange elongated trenches under the Mediterranean seafloor. Some geologists speculated that these trenches were river channels that had submerged when a chunk of the earth's crust had sunk, but only one person, a young French scientist, thought that they might be the remains of river beds incised into the edges of the Mediterranean when that sea had dried out millennia ago and the rivers draining Europe and North Africa had cut down to its bottom.

Still more impressive was evidence from the mouths of the Rhone and the Nile rivers. At the end of the nineteenth century the remnants of a deep gorge had been found beneath the Rhone. This gorge had been filled in with sediments during the Pliocene Epoch and then overlain by contemporary sands and gravels. Further exploration showed that this fossilized gorge extended 200 kilometers from Lyon to La Camargue, practically to the shores of the Mediterranean, where its bedrock base was now a kilometer below present-day sea level. The conclusion was inescapable: The mighty Rhone had once been even mightier, cutting down through a thousand meters of granite to deliver its cargo of water to the desiccated floor of the Miocene Mediterranean.

Similarly, Soviet geologists, surveying prior to the construction of the Aswan Dam, had drilled several boreholes into the floor of the Nile Valley and to their amazement had discovered another deep narrow gorge similarly filled with Pliocene sediments. It was the mirror image—on the southern margin of the Mediterranean—of what had been found beneath the Rhone: a deep channel where the waters of the Nile had once flowed into the Mediterranean with much greater ferocity than today. Other buried gorges have since been discovered in Algeria, Israel, Syria, and other countries, all adding silent support to this most amazing of tall sea tales.

But the biggest irony of all came when Hsu discovered that one Herbert George Wells, too, had believed that the Mediterranean was once a desert. H. G. Wells studied geology under Vincent Illing at Imperial College in London before the First World War. Finding Lyell's account of the faunal crisis separating the Miocene and Pliocene epochs in the library one day, Wells later used it as the basis for one of his science fiction novellas (*The Grisly Folk*, 1921) in which he speculated that the Mediterranean had once been a massive, dried-out hole separating Europe and Africa.

Whoever said that truth is stranger than fiction?

The Restless Earth

Gibraltar, Mediterranean Sea, January 23, 1873, 36° 09′ N, 05° 21′ W to Station 19, Western Atlantic, March 3, 1873, 19° 30′ N, 57° 35′ W

ATLANTIC TRANSECT

HMS *Challenger* left Gibraltar on January 23, 1873, and finally headed out into the true unknown, the deep Atlantic Ocean. As the continental shelf dropped away beneath her, and the fans of mud from the rivers of Northern Europe gave way to the unchanging vastness of the Atlantic abyssal plain, the crew settled into a routine of sounding and dredging operations that would govern all their days for the rest of the voyage. The ship's company rose at 4 A.M. and, on standing orders from *Challenger's* two staff surgeons, swabbed the decks with copious quantities of seawater. The emphasis on hygiene, like the daily ration of lime juice and the improvements in discipline were all part of the navy's new recognition of the importance of morale. And although the bluejackets might complain at the extra work involved in the daily swabbing of the decks, they, too, recognized its importance and so they did it well. Legends of the navy only 60 years before, when impressment was still the norm and men did not see their families for years on end, as well as the terrible privations suffered by sailors during the Crimean War, were still too fresh for the new sail-and-steam navy not to appreciate the reforms.