BELFAST GEOLOGISTS' SOCIETY

ALFRED WEGENER - THE AFTERMATH

A LECTURE DELIVERED

BY

J. S. LOUGHRIDGE, B.Sc., M.D., F.R.C.S.

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PREFACE

The Belfast Geologist's Society has enjoyed a long and close association with James S Loughridge. That a man of such eminence in his own profession could find time to attend our winter lectures, follow our summer field excursions and enjoy the occasion of an annual dinner has been a constant source of pride; that such a man could become one of our closest friends will remain a treasured memory with all of us.

The honour of Vice-President which the Society conferred on him in 1968 was fully repaid when in 1972-73 he honoured us in turn by accepting the duties and responsibilities of President. More than any one of us he realised the need to weld amateur and professional interests in geology and set the example from his own experience and knowledge across the fields of medical, biological, archaeological and earth sciences. His friendship with such notable geologists as James Phemister broadened our horizons (as far as the Shetlands!) and made possible those memorable excursions with the Glasgow Geologist's Society.

Among all his interests, two topics remained paramount- "The Origins of Man" and "The Life and Work of Alfred Wegener". No one could be better qualified to review the fossil record of his own species- his Presidential address on November 3rd 1972 left us in no doubt as to the scale and direction of this evolutionary trend. But as he watched the progress of the earth sciences through the past two decades, he must, in his great admiration for Alfred Wegener, have been overwhelmed with joy to see the originality and insight of the Continental Drift hypothesis vindicated in the growth of Plate Tectonics.

James Loughridge's last lecture to the Society - " Wegener - The Aftermath " based on a wealth of reading and personal record proved so unique in its content that it is offered here in this first monograph of the Belfast Geologist's Society.

ALFRED WEGENER - THE AFTERMATH

1. Wegener

Alfred Wegener was born in Berlin in 1880, where his father was in charge of an evangelical church. His early specialization was planetary astronomy, and he obtained his doctorate in 1905 for tables of the planetary motions; he was then 25 years old. After a long and futile search for a Professorship in German universities, he was finally made a Professor of Meteorology and Geophysics in the University of Graz in Austria.

Wegener was described as a man of medium height, slim and wiry, whose most noticeable features were his forehead, and a stern mouth under a powerful straight nose. While still young, he enjoyed the general respect of professional colleagues on both sides of the Atlantic. When only 26 he went to Greenland as meteorologist to the great Danish expedition under Erichson in 1906-08, and proved to be a research student of distinction. After a period of fruitful work in Germany in meteorology, he went again to Greenland in 1912 with the Dane, Captain Koch, and wintered on the inland ice, which had never been done before.

The theory that the continents were not fixed but had drifted with respect to one another was first propounded by Wegener in his 1912 address to the Frankfurt-am-Main Geological Association. But his further research on the idea was interrupted first by the Greenland expedition and then by the outbreak of the 1914-18 war. He became a young reserve lieutenant in the 3rd Regiment of Queen Elizabeth Grenadier Guards of the German Army, was wounded in the arm and hospitalised. His recovery was swift, but no sooner had he returned to the front than a wound in the neck put him out of action for the rest of the war. His prolonged convalescence enabled him to do further research, and it was as a result of this that in 1915 there appeared on the horizon a little cloud, "like a man's hand", herald of one of the most profound revolutions in man's understanding of nature. I refer to a small book, The Origin of Continents and Oceans, a book which I consider puts the author on the same prominent platform as Isaac Newton and Charles Darwin.

Wegener was not the first to speculate on continental drift. As soon as exploration had produced reasonably accurate maps of the continents, the striking fit of some opposing coastlines became evident, notably the way in which the bulge of Brazil conforms to the bight of Africa on the opposite side of the Atlantic. Geology in the 17th and 18th centuries was dominated by the idea of the Biblical flood as a major force in shaping the earth's surface. It was a geology based on the belief that past catastrophes had caused sudden and radical changes. German theologians and the explorer Alexander von Humboldt in 1800 and even Sir George Darwin all accepted the catastrophic idea, but by the beginning of the 20th century this concept gave way to that of "uniformitarianism".

However, it was Wegener who first tried to muster the evidence for continental drift, and in so doing he anticipated present-day thinking based on highly diverse fields of science - meteorology, geology, oceanography, seismology and palaeontology - which bring into focus what is actually happening in the earth's crust and mantle.

A number of seemingly disparate discoveries were brought together to form the revolutionary concept of "continental drift", the current theory of which is that the continents are in motion with respect to one another, and are carried by the creeping movements of gigantic

plates of the earth's crust clashing with one another from time to time to produce the great mountain ranges. The manner in which these extraordinary discoveries were made is one of the great scientific detective-stories of all time. It casts new light on the topography of every corner of the earth, from the Alps to the Appalachians, from the San Andreas Fault of California to the volcanoes of Japan.

Had Wegener lived to a ripe old age, he would in the end have seen much of his theory vindicated.

Wegener argued in his book that in the Carboniferous period all the continents were united to form one great continent called Pangaea. Antarctica, Australia, India and Africa separated in the Jurassic period; in the Cretaceous, Africa and South America separated like two pieces of a cracked ice-flow; finally, Scandinavia separated from Greenland and Canada at the start of the Pleistocene. The mountains of the west coast of America from the Andes to Alaska were formed, he said, by the pressure of great blocks of the continent pushed west. The snowy mountains of New Guinea were pushed up by the northward drive of Australia, and the Himalayas arose from the northward pressure of India.

Wegener rejected the theory of shrinkage of the earth which went back to Sir Isaac Newton, and pointed to the discovery of radioactivity and the heat and energy it generated.

There were zoological problems to consider. The lemurs, the most primitive of the primates, are found only in the island of Madagascar, in nearby East Africa, and across the ocean in Ceylon and India. The hippopotamus is found in Africa and Madagascar. How could it, a habitant of muddy streams, cross 250 miles of open sea to Madagascar?

Then again, in botany, the fossil leaves of Glossopteris are found in India, Australia, South America, and also in the coal seams of Antarctica.

Wegener also found matching features on opposing sides of the North Atlantic. Thus, the Caledonian mountain system of Norway and northern Scotland has features in common with North Newfoundland and the Appalachian chain of north-east America.

Finally, Wegener cited evidence of great climatic changes, of fossil palm trees in Spitzbergen and coal in Antarctica, and at the same time deposits left by melting ice-sheets in South Africa. Large gypsum deposits in Texas and Kansas during the Permian period indicate the same hot arid climate as in Permian Europe.

In 1926, after the third edition of Wegener's book had appeared, the American Association of Petroleum Geologists organised a symposium on the issue. Though a few spoke in favour of "drift", the big guns of American geology were totally against Wegener. Thirty years later Longwell criticised the ridiculing of Wegener's idea. He said: "We know too little about the earth to indulge in such final judgment. In my view the hypothesis of continental drift has not failed so utterly that it deserves the death sentence."

Just after the 1926 symposium, to which he also was a contributor, Wegener tried to strengthen his arguments with astronomical proof of measurement, because the first observations seemed to show that Greenland and the U.S.A. were drifting west at a rate of 35 metres a year. (Today these positioning methods have been replaced by laser beams - without, so far as I know, determining direct evidence for drift.) The main body of geologists (with a few notable exceptions in the Southern

hemisphere) just could not accept the idea of the drifting of great barges of rock. Nevertheless, Wegener had made a major contribution. He had mustered the help of every field of science.

Wegener's theory has led to the greatest revolution ever to occur in man's understanding of the planet on which he lives. Although its roots lay in the past century, it has only come to fruition in the past two decades.

The Last Expedition

In 1930 Wegener crossed Greenland by a route of 600 miles. A short summary of his expedition gives some idea of his determination and grit, at a time when he was no longer a young man.

The chief goal was to set up an observatory in the middle of Greenland, in the area known as Eis-Mitte, and to carry out weather observations throughout the long polar night. Wegener left Denmark for Greenland on 1st April 1930, picking up 25 Icelandic ponies on the way. On 4th May 1930 the Danish Government ship reached Um-a-Nak Bay to find the fjord still completely blocked by thick sea-ice. The expedition had to wait for six weeks until the sea-ice broke up. This occurred on 17th June, and from June till November every effort was made to transport, over a distance of 250 miles, the great mass of material required to equip Eis-Mitte for the winter. It was a fearful physical toil, under which even the strongest members of the party sometimes collapsed. Wegener was described as being everywhere - now he was lending a hand in making a road over the moraine, now conducting a column of Greenlanders to repair a causeway on the glacier, now calling by boat on a coastal settlement to get dried fish as dog-food, or scanty Greenland grass for the ponies. His colleagues, Sorge and Georgi, had gone straight to Eis-Mitte from the east coast of Greenland. Here they carried out their famous measurements. Eis-Mitte was found to be 9000 feet above sea-level, resting on an ice thickness of about 6000 feet.

The main part of the expedition was fitted out with Icelandic ponies, dogs, and propeller-driven sledges. But the plans went wrong. Ice and storms delayed the unloading of supplies. The advance party including Sorge and Georgi had built a temporary station at Eis-Mitte by digging a large pit in the snow. Observations were then carried out before the arrival of the prefabricated hut and the supplies for wintering out. Desperate, after the agonising series of delays referred to above, Wegener, with the rest of the party, set out from the west coast towards the end of September 1930, with 15 sledges carrying 4000 lb. of supplies, sufficient to keep two men at Eis-Mitte during the winter. The party consisted of 13 Greenlanders, Wegener and Loewe. After trekking 100 miles through new snow, driving winds and extreme cold, all but one (Rasmus) of the Greenlanders turned back. The bulk of the supplies, including Christmas parcels, a gramophone and some scientific instruments, had then to be cached in the snow to leave the three remaining men a load they could mangge to carry.

Meanwhile, morale at Eis-Mitte was sagging. Georgi had just written to his wife: "We feel ourselves abandoned. Wintering here in the middle of Greenland is indeed no trifle. We are very depressed." Next morning, 30th October, the depression vanished, for, lying in their sleeping bags - they had turned off their heater to conserve fuel - they heard a sleigh on the snow surface above them. They scrambled out to find a Greenlander, bulky in his heavy clothes, standing grinning beside a dog-sleigh, with Wegener and Loewe close behind. Georgi said: "A marvellous performance in a temperature of minus 66°!" Wegener was

fit, but Loewe's feet were so frost-bitten that he could not return. Even with their dogs worn out, Wegener started out with Rasmus to return to the coast. Three men stayed behind, with fuel short and rations skimpy for two. They survived, but Wegener and the Greenlander never reached the coast. The coastal camp became alarmed at their non-return and alerted the British Arctic Air Expedition under Gino Watkins. Next summer Wegener's body was found on the trail; he was thought not to have frozen to death but to have died from a heart attack; he had just passed his 50th birthday.

Three important results may be put to the credit of Wegener's expedition:-

1. They measured the thickness of the ice-cap and made it to be 6000 feet - sufficient, if it melted, to cause all the oceans of the world to rise about 18 feet and therefore to swamp extensive coastal plains and certain towns, including London and Belfast.
2. The meteorology showed local wind circulation to be much more complicated than a simple system of glacial anticyclone.
3. The expedition's work led to improvements in storm warnings and in weather forecasts generally for Atlantic shipping and air traffic.

2. The Aftermath

Since Wegener's time, research work and advances in knowledge have been along three lines:-

1. Residual rock magnetism and the recognition of magnetic stripes on the sea floor. These discoveries were made significant by the time-table of magnetic reversals erected on them.
2. Drilling of the earth's crust, which started with the Mohole project (abandoned before completion).

3. The Deep Sea Drilling Project, which emerged from the failure of the Mohole programme, and was to become one of the most successful scientific enterprises of this century.

In the 1950s, Hess, Professor of Geology at Princeton, attached much importance to the recent discovery of long rifts in the floor of the Pacific. (Later, as Chairman of the Space Science Board, he was responsible for the space programme of the U.S.A., though his chief interest lay in the opposite direction - down rather than up.) Hess's crucial role in the development of new concepts in ocean-floor geology in the 1960s began when he recognised the full importance of the undersea research work carried out by F.A. Vening Meinesz before the war. Meinesz, a Dutch geophysicist, had made several long submarine journeys to test local variations in the earth's gravity by using the oscillations of a pendulum when the submarine was stationary on the sea bottom. Near the East Indies he had found a zone of markedly weakened gravity. The zone was 100 miles wide and 5000 miles long, and followed the sequence of trenches that parallels the island arc of the East Indies on their southern flank, curving north with the trend of the chain to pass west of New Guinea and then up the east coast of the Philippines. A similar gravity anomaly was discovered following the trenches on the oceanic side of Japan, and another in the West Indies. By the 1950s these trenches were recognised as one of the most remarkable features of the earth's surface, and the zones of weak gravity were to give Hess and others one of their strongest clues to sub-oceanic processes.

The trenches are scattered round the rim of the Pacific Ocean, forming long gashes which penetrate deeper below sea level than Everest rises above it. They lie to the seaward side of an arc of volcanic islands or a coastal mountain chain like the Andes, which also includes volcanic provinces. The suggestion was that the upthrust of the islands or mountains and the downthrust of the trenches is all part of the same process.

As the water pressure on the trench floors is about eight tons per square inch, they may prove physically impossible to visit. However, sounding of the trench floors produced a remarkable result in that samples recovered even from the deepest trenches resemble in many ways deposits laid down in shallow water.

Benioff plotted all the earthquakes in South America for 36 years from 1906 to 1942, and found they delineated a sloping zone nearly 3000 miles long, on the western edge of the continent. This zone started at a relatively shallow depth under the trench that skirts the coast; but under the Andes and further east it extended down to more than 400 miles.

These sloping regions, known as Benioff zones, slope down under the continents at about 45 degrees. Volcanic eruptions occur over that part of the slope where earthquakes are taking place at depths of up to 60 miles. It is tempting to speculate that the quakes occur between a descending ocean plate and the over-riding continental block.

As recently as 1935, the British Association set up a committee to collect information and appointed Edward Bullard of Cambridge University as one of their experimenters. He studied the sea floor in contrast to the continental rocks heated by their rich inclusion of radioactive elements. The sea floor everywhere was found to consist of basalt and below it the "basic" rock from which basalt had been derived - a rock containing even less radioactivity. After the war, Bullard was appointed Director of Naval Operation Research in Britain and had to stop his work at the Scripps Institution of Oceanography, leaving a graduate student to continue. Heat-flow measurements were made at sites in the Pacific and Atlantic oceans, and the rate proved remarkably high, though variable from place to place, in the mid-Atlantic region. Bullard explained this high heat-flow by convection currents in the mantle rising beneath the oceans and sinking under the continents.

This evidence was used by Hess to form a comprehensive picture of the movements of the sea floor which Wegener had failed to make. It has set the stage for the now general acceptance of the modern theory of mobile plates. As the convection currents rose under the mid-ocean ridges, new crust formed and moved towards the continents riding on top of the convection cell, only to vanish with it beneath the continental plate. This motion explained the thin blanket of sediments found on the sea floor, so thin that it could not represent more than 200-300 million years of deposition. Sediments were thinnest at the rising-point and thickened towards the periphery of the ocean basins; thus almost no sediment is found over the mid-Atlantic ridge.

It was largely the nuclear weapons race which led to a confirmation of Gutenberg's proposal of 1926. Reporting evidence for a deeper layer about 100 miles down in which earthquake waves travelled at a rate 6% slower than in the layers above, he postulated that with heat and pressure the mantle changed from a crystalline to a vitreous state, became more plastic and therefore more amenable to flow. So Gutenberg believed that continental drift was a possibility - not a very popular idea in the 1920s.

Just before the nuclear tests were banned by treaty, 500 seismic stations were established, spread over the south-east half of Montana. In 1970 the recorded observations made it clear that there is, in fact, a layer of less rigidity about 50 to 150 miles below the surface. The upper rigid layer is called the Lithosphere, and the lower weaker layer the Asthenosphere. The discovery of the Asthenosphere won new converts to the concept of drift. Tuzo Wilson of the University of Toronto saw it as a lubricating layer on which the continents and the sea floor could

move. He was the first to point out that if ocean islands and guyots were formed on a ridge and then rode away from it on a "conveyor belt", then the islands near the ridge should be younger than those further away.

Residual Magnetism

This has been found in pottery, old and new, classical, prehistoric and even neolithic. When hot at the time of firing, the magnetic particles of the clay were free to re-orientate themselves with the lines of force of the earth's magnetic field. On cooling, the magnetic particles were locked in place as frozen dip needles.

Magnetic grains settling in a fluid medium are also free to align themselves with the earth's magnetic field. The varved clays of New England offer a year-by-year picture of magnetic directions. Between 15000 B.C. and 9000 B.C. the magnetic north drifted back and forth to either side of true north.

Lava also acts as a fluid medium. Iceland, California, Oregon, the Aleutians, Hawaii and Japan have all experienced intermittent eruptions for years, piling lava-layer on lava-layer. The resulting magnetic memory is preserved indefinitely. Early studies of such trapped magnetism showed slight wandering of the magnetic poles. A study of rock magnetism converted P.M.S.Blackett in 1946 to become a "drifter" - the first of the Nobel laureates to do so.

Blackett succeeded the Braggs, father and son, as Professor of Physics in the University of Manchester. Chapman, also on the Faculty at Manchester and a world authority on earth magnetism, met Wegener in Norway, at a conference of Norwegian and German weathermen, and was excited by his theory of drifting continents. On returning home he so impressed Bragg that the latter wrote to Wegener for an account of his theory.

Bragg had this translated into English and presented it to the Manchester Literary and Philosophical Society. Bragg said that the geological members were furious, and literally "foamed at the mouth". - "Words cannot describe their utter scorn of anything so ridiculous" as this theory of Wegener's, which now, in our own time, is accepted by so many geologists as basically correct.

Blackett returned to his study of residual magnetism in old rocks, and his students spread over Great Britain and to the remote parts of the world to collect specimens. The placement of each sample was carefully noted before it was extracted from its parent formation. The former orientation of magnetic lines of force could be determined in terms of declination and dip. One of the first indications of changed geography was found when the "compass needles" laid down in England during the Triassic period, 200 million years ago, pointed not to the magnetic pole in its present position but to the north-west, proving a clockwise rotation of the rocks since then.

A protégé of Blackett, one who was to become the chief advocate of the drift theory, was S.K.Runcorn, a native of Lancashire, who studied the lava flows in Oregon, scrambling down the sides of the Grand Canyon and collecting samples from top to bottom. From these and other specimens, Runcorn was able to construct the path of the North Magnetic Pole over several hundred million years.

Runcorn, the great protagonist of the idea of polar wandering, met Hess in Atlantic City at a meeting of the American Association of Petroleum Geologists. As a result of their discussions it was seen that the idea of sea-floor spreading could be incorporated into Runcorn's overall theory; it had thus found a vociferous advocate.

By 1960 it was evident to Blackett's group that rapid changes in magnetic latitude had occurred. Thus, Europe and North America were near the magnetic equator some 300 million years ago. Australia appeared to have moved in latitude in a somewhat complicated way. India had moved farther and faster than any other continent, from a position south of Australia, 150 million years ago, across the equator to its present position.

Another aspect of earth's magnetism demonstrated sea-floor spreading in a manner that even the most determined sceptic could not ignore. A long-standing puzzle had been the 1909 discovery by Bernhard Brunhes that some ancient lava-flows in the Massif Central carried a magnetic polarity exactly opposite to that of rock layers just above and just below. Then in the year 1929 a Japanese, Matuyama, found that many rocks laid down more than 700 000 years ago were also reversely magnetised. So it was appreciated that rocks laid down over a long span of time seemed to be divided into formations with normal and reversed polarity.

This new evidence led to a major investigation of earth magnetism by the U.S. Geological Survey. The idea of magnetic field reversals seemed at first so preposterous, they felt, that one immediately suspected a misinterpretation of the physical evidence; and they commented that "..after centuries of research the earth's magnetic field remains the best described and least understood of all planetary phenomena". However, they concluded that the earth's field does flip over from time to time.

The present orientation of the earth's magnetic field has been found in rocks formed over the past 700 000 years, and is called, in honour of the Frenchman, the Brunhes Epoch. The Matuyama Epoch, named after the Japanese geophysicist, of reversed polarity, ran for 1.75 million years before the Brunhes and itself succeeded the Gauss Epoch of normal polarity. A similar timetable of reversals, 16 in all, was identified in samples taken from the floor of the Pacific; the magnetic epochs ranging in duration from ½ to 1 million years. Because of this irregularity they were able to provide a master code for the ocean floor, just like tree rings in dendrochronology. Help in establishing a relationship between magnetic reversals and sea-floor spreading came unexpectedly from the U.S. Navy, which during World War II developed a device for detecting submarines known as M.A.D. (Magnetic Airborne Detector). So, in the year 1962, the British Research Frigate, H.M.S. Owen, was used at Bullard's initiative in the Indian Ocean to make an intensive magnetic survey on an area 50 miles wide covering the Carlsberg Ridge. It was found that the magnetism on one of the sea mounts on the floor of the Indian Ocean was reversed. The indication was that the sea mount was a volcanic feature formed during a period when the earth's magnetism was reversed.

If this was the case, and if the theory of sea-floor spreading recently proposed by Hess were correct, it meant that material erupting along a mid-ocean ridge, as it cooled, would become imprinted with the polarity of the earth's magnetism in effect at that time. After this ridge had been split and pushed to either side by more material erupting along the ridge, this newly formed floor would also capture the current magnetism; and if the field by then had reversed itself the polarity of the imprinted magnetism would also be reversed. The effect of this process, after a succession of reversals, would be to produce a series of sea-floor bands parallel to the ridge and alternating in their magnetic polarity.

It was realised that if long magnetic bands were being manufactured on the ridge and then split and forced aside to form a new band, the resulting magnetic pattern should be symmetrical on either side of the ridge. Such a pattern was proved to exist across the Juan de Fuca and Rekjanes ridges. By 1968 the main features of spreading patterns had been recorded for half the world's oceans, and 171 magnetic reversals had been charted for the past 60 million years.

The Drilling Programmes

Efforts to penetrate the crust of the earth started in earnest in 1956 - an earlier Mohole project had been abandoned - with the drilling of several hundred holes deep in the ocean floor. It provided strong confirmation for the hypothesis of sea-floor spreading.

Darwin had expressed the hope that borings would be made of Pacific and Indian Ocean atolls to find the basalt beneath the coral and so prove his theory of formation by submergence of the central volcanic cone to 1000 m. or more. The first drilling at Bikini Atoll followed the first atomic tests of 1947. The hole was abandoned, still in coral, at a depth of 800 m. Ladd of the U.S. Geological Survey and Lill of the British Office of Naval Research continued this attempt at Eniwetok Atoll. In the early 1950s, Ladd had inscribed "Basalt or Bust" on the walls of his shack. They finally brought up basalt from a depth of 1287 m.

The National Science Foundation allowed the modest sum of 30000 U.S. dollars for a feasibility study on a further programme of drilling. Then a political motive for the Mohole emerged. It was a period of intense Cold War rivalry, brought to a climax when the Soviet Union blazed the way into space. This prodded the U.S. into a race to land men on the moon, a race the Russians took no part in; nor did they join the race to reach the Moho. Considering the millions of dollars going into the moon programme and spent on the atomic bomb, the Mohole cost could not be considered exorbitant. It was argued that ".. the ocean's bottom is at least as important as the moon's behind". Four oil-companies - Continental, Union of California, Shell and Superior - banded together to form a group ("Cuss"), bought a war-surplus navy barge, called it Cussi, and built on it a 30 m. high derrick for drilling. The ship was anchored over the drill-hole by winch-controlled mooring lines attached to large anchored buoys. These were aided by four huge diesel outboard engines, one at each corner of Cussi. After drilling several test holes in relatively shallow water off San Diego, the barge was towed to a position 40 miles east of Guadeloupe Island, off the coast of Mexico, where the sea is two miles deep. Here, one drill-hole penetrated 200 m. into the sea floor and brought up two cores of basalt, one of them 3 m. long. It was at this stage that the Mohole project, launched initially on a wave of scientific enthusiasm, ran into a morass of political and administrative controversy. The wags started to call it the Nohole project. In August 1966 Congress killed the project finally. Mohole was dead. Yet from the ashes of Mohole was to emerge the most successful scientific enterprise of the century, one that was to contribute more to the history of the oceans than all the expeditions to date. It began inconspicuously with two years of manoeuvres and counter-manoeuvres among the Oceanographic Institutions and their leaders on both coasts of America. Thus the oceanographers from Miami, Lamont, Woods Hole and Princeton formed a committee to explore the possibility of chartering a drilling ship.

By 1965 the "dynamic positioning" of drill ships to keep them over a hole in deep water had been adapted to oil exploration vessels; one such was the Glomar Challenger, which was manoeuvred by means of propellers placed transversely through its bows. With the Mohole dead, the U.S. Government was prepared to be more generous, and it signed a 12-million-dollar

contract for a programme of drilling in the Pacific and Atlantic oceans.

To lower a drill several kilometres to the ocean floor, it was necessary to screw together 300 sections of pipe, each 29 m. long. These pipes were housed on a pipe rack on the forward deck of the ship and hoisted up as required inside the derrick. When the string of pipes was assembled, a motor called a "power sub" was attached to its upper end to turn the entire length of pipe and the drill bit at its lower end. As the drill began to turn, an enormous block and tackle brought weight on to the bit and retained enough of the weight to keep the pipe from buckling. The block rode down as the drill penetrated until a new pipe section had to be added. The whole process was carried out with military precision, but accidents sometimes happened. On one occasion the crew were working through the night, hauling up the pipe section by section. With 12000 feet of pipe dangling from the great floodlit derrick, a clamp suddenly broke free, and the pipe was torn apart. Benson, one of the scientific leaders of the expedition, came on deck just in time to hear the shrieking rupture of the metal and to see the jagged upper end of the pipe sink downwards, whirling in ever-widening circles that came alarmingly close to decapitating one of the crew. The 12000 feet of pipe sank beyond retrieval to the bottom, but as the ship carried 20000 feet of pipe on her deck she was able to continue without returning to port.

A major difference from drilling on land is the need to provide for the heaving of the ship on the sea surface. This wave motion would lift the drill from the rock and let it drop with a hammer action if it were not for an ingenious shock-absorbing device of telescopic pipe sections just above the bit: these allow for a few feet of up-and-down motion and yet, with long interlocking teeth, continue to impart rotation to the bit. The bit itself, nine inches in diameter, bored a hole sufficiently large to allow the five-inch drill pipe to pump down fluid and flush out the chips of rock as drilling proceeded.

Most important of all was the coring system that retrieved sections of sediment or rock as the drill bored down. By the end of 1973, the total length of all the Glomar Challenger core sections came to more than 57 kilometres.

Drilling was not easy. They encountered layers of chert which wore the bits, even those studded with 500 to 800 carats of tiny diamonds, to scrap metal within a few feet; and the flinty chips jammed the telescoping "bumper subs" until, with every passing wave, the bit pounded mercilessly on the rock bottom of the hole, causing further damage. On dry land it would have been easy to change the bit, but on board ship there was no way of re-entering a hole once the bit had been hauled out.

Yet, in spite of all the handicaps and technical difficulties, the Glomar Challenger began to revolutionise many aspects of marine geology. The scientists aboard reported that the "sea floor of the South Atlantic had been spreading at a constant rate for the past 67 million years". Points on opposite sides of the ridge - and hence Africa and South America - were moving apart at a rate of 4 cm. per year.

Little did those riding the Glomar Challenger in the summer of 1970 as she sailed past Gibraltar into the Mediterranean suspect that beneath them there could once have been a waterfall grander than any on earth today. The first evidence came on, or near, the basin of the Balearic Islands. Stuck in the teeth of the drill bit were fragments of gypsum. Further drilling revealed a far-flung series of beds of evaporites. Today, such layers are precipitated from shallow, salty seas and lakes on sun-baked deserts, especially if flat and near the coast, where they can be occasi-

onally flooded at high tide. The indications were of evaporite beds a few kilometres thick; yet calculations gave only a thickness of 25 m. if the Mediterranean were assumed to have dried out only once. The only explanation was that the rocky ridge of the Strait of Gibraltar had acted as a flood-gate that opened and closed repeatedly during the late Miocene and flooded the Mediterranean area each time anew. East of Gibraltar, a sharp drop in the ocean floor marked a scarp of great height.

Retrieval of open-sea sediments from earlier levels beneath the Mediterranean indicated that there had been an open connection between the Mediterranean and the Indian Ocean, permitting the passage of cold bottom water from the Atlantic to the Indian Ocean. The Mediterranean was at that time part of a great body of water known as the Tethys Sea.

The Tethys Sea was reduced in size by the pressure of the African plate, which by northward movement generated the Alps, the Caucasus, and the Zagros Mountains of Iran. This process cut the link with the Indian Ocean, and pushed the Gibraltar slab of rock into a configuration that made it susceptible of opening and closing. When closed the inflow of water from the Rhône and the Nile was insufficient to make up the loss by evaporation; the sea then dried out even to the bottom of its 3 km. deep basins. Even today, rainfall and rivers do not balance the loss due to evaporation, and so, if the Strait of Gibraltar were to close, the sea would conceivably dry up, in perhaps 1000 years.

When challenged about their concept of the desiccation of the Mediterranean followed by catastrophic flooding, the scientists replied: "The idea that an ocean basin the size of the Mediterranean could actually dry up and leave a big hole thousands of metres below sea level seems preposterous indeed, and we were reluctant to adopt such an outrageous hypothesis -

until we were overwhelmed by many lines of evidence."

A conference in New York set in motion a chain of events destined to bring support to these ideas from a member of the Geological Institute of the Soviet Academy of Sciences. In the course of construction of the Aswan Dam, a series of holes, 15 in number, were drilled into the bottom of the river Nile. These revealed that under the flat bottom of the present-day river bed, a canyon some 600 feet deep had been carved out of the bedrock and later filled with sediment. The lowest part of this canyon was a narrow gorge with almost vertical walls; the infilling sediment was full of marine fossils of Pliocene age. Therefore the Nile flowed into a Mediterranean 1000 feet lower than today, and the rapid filling sent salt water up the Nile canyon. Further evidence came from French scientists in connection with the Lower Rhône. Deep wells sunk as far north as Lyon, 200 miles upstream from the Mediterranean, penetrated marine deposits at the bottom of an ancient buried channel. The drying-out of the Mediterranean basin could possibly explain the radical change in Central European climate in the late Miocene, when ".. the Vienna woods were changed into steppes, and when palms grew in Switzerland".

A similar role was played in oceanic history by the isthmus of Panama. Just prior to the end of the Cretaceous, the period of extinction of the dinosaurs, this gate was closed by a land connection between North and South America. During the Eocene, when dog-sized horses roamed the United States, this gate was wide open, and water flowed freely between the oceans. The result in the Caribbean was the rapid accumulation of sediment rich in silica shells - largely from radiolaria. In the Miocene this gate began to close again, and closure was complete in the late Pliocene.

This new land bridge of Panama enabled mammals, which now dominate the

land, to migrate between the Americas. The closure of the isthmus had a profound effect on the ocean currents. Prior to closure, a great equatorial current could flow round much of the earth's circumference. After closure, circular systems started to flow in the two oceans, the Gulf Stream being part of the new Atlantic system. This would have altered the storm paths and brought warm humid air to central Canada and northern Europe. This would have meant heavier winter snows - and, where the accumulation was greater than the summer melt, an ice-age.

Though there may still be some discoveries to come from the Deep Sea Drilling Project, it may be said that probably no other expedition of any kind has collected such a volume of specimens and so much new information. It has rolled back the pages of history to the time when each ocean was born, and shown that they are all no older than the age of the dinosaurs. "The drilling marks the start of an era in geology."

By the start of 1974, a total of 469 holes had been drilled at 319 sites, and by its ocean journeys the <u>Glomar Challenger</u> was helping to weave the scientific world together. Scientific institutions in a number of countries were taking part in planning future goals for the project. Notable is the Soviet Union, which has made an unprecedented commitment to contribute each year one million dollars towards the project. This is indeed a far cry from the early days of Mohole, when the Cold War rivalry was uppermost. Though the soundings have not been as deep as envisaged for Mohole, the penetrative drilling of <u>Glomar Challenger</u> has been far more widespread, and has been hailed as of major economic importance following discoveries of what promise to be vast mineral and oil resources.

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While most of the activity that is pushing the oceans apart and steadily altering the world's geography is submarine, there are two regions where it can be observed at first hand. One of these is Iceland, where a section of the mid-Atlantic ridge has risen from the sea. The other is the Afar Triangle, at the southern end of the Red Sea. Arid and incredibly hot, this latter place is probably as close to the proverbial concept of Hades as anywhere on earth.

The Red Sea is 1200 miles long and 150 miles wide. Part of the Afar Triangle is apparently a portion of the Red Sea floor, uplifted as dry land. Wegener, in his early discussion on continental drift, picked out this triangle as of special interest. He noticed that its low-lying terrain is composed of recent lava beds, and he considered it to be a region of broadening in a rift which runs northwards to form the Red Sea. This idea was suggested to him by the course of the coastlines on either side of the Red Sea, whose otherwise accurate parallel edges are spoiled by the projecting Afar Triangle. If one cuts this triangle off, the opposite corner of Arabia fits perfectly into the gap.

When Schmitt, the Harvard-trained geologist, looked back at the receding earth, on his way to the moon, he told the flight controller in Houston: "I did not grow up with the idea of drifting continents, but I tell you, when you look at the way the pieces of the north-east African continent fit together, separated by a narrow gulf, you could almost make a believer of anybody." Even back in 1930, a French archaeologist and theologian who had explored the Afar Triangle wrote: "If there is any truth in the concept of continental rupture, it is in specific and clearly-defined regions such as the South Red Sea that there lies the opportunity to put it to the test and finally accept or definitely reject it."

The first hint that something out of the ordinary was afoot in the Red Sea had come in 1880, when a Russian survey ship took samples of deep water.

Off the sacred city of Mecca, the water recovered from a depth of 600 m. was considerably warmer than water at the surface. The Red Sea communicates with the world's oceans only through the narrow and shallow strait of Bab-el-Mandeb; the Red Sea reaches a depth of 9000 feet, whereas the strait is only 400 feet deep.

In 1969, the British research ship Discovery extracted water from a deep trough in the Red Sea. It was at a temperature of 110° Fahrenheit and contained 256 parts of salt per 1000 parts water. This is eight times the normal salinity, and only 13 parts per 1000 less than the saltiest water known in nature, that at the bottom of the Dead Sea. A black ooze was also hauled up that looked like tar and was too hot to touch. It contained shell-debris from the nearby coast, and was brightly coloured with metallic compounds, mainly oxides and sulphides of iron, manganese, zinc and copper.

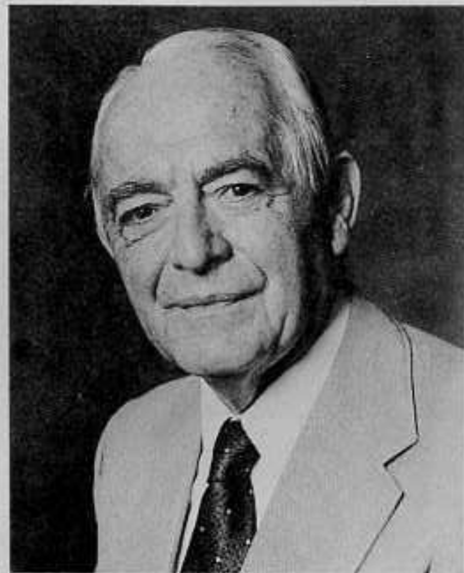
Twenty months after the discovery of this hot pool, temperature-readings for the bottom layer were found to be 1° F. hotter than before. Further readings were taken, and these indicated an enormous invasion of hot water into the pool. Heat-flow from the earth's interior into what is now called Discovery Deep is higher than at any other known point in the world's oceans: 79 microcalories per square centimetre per second. Drilling along the centre line of the Red Sea by the Glomar Challenger proved 14 m. of metal-rich sediment above basalt. There was then little doubt that the metals were a by-product of the rifting and sea-floor spreading process.

Iceland, in contrast to the Afar region, is the most volcanic place on earth above water. Most of the activity is concentrated in a central zone which bisects the island. This zone is a continuation of the mid-Atlantic ridge along the length of the submarine Rekjanes ridge. The lava in the island's central rift zone is magnetised parallel to the present-day magnetic field. It is flanked on either side by reversely polarised rock of the Matuyama Epoch, and these zones are flanked in turn by rock of the Gauss Epoch of earlier normal polarity.

As soon as the theory of sea-floor spreading became known, a scientist from Reykjavik and one from Imperial College London undertook a study of the ages and distribution of Icelandic volcanic intrusions to see if they supported or contradicted the concept. Everywhere they worked they found confirmation. Volcanic rock had been generated along a central zone some six miles wide at a fairly uniform rate since the formation of the oldest rocks on the island 12 to 16 million years ago. The location of the older rocks at the extreme east and west of the island could be explained by a spreading action that carried them steadily away from the central zone until they are now 250 miles apart. One feature of Iceland is the large number of dykes - 1000 of them in 33 miles. Their cumulative thickness is two miles; that is, they have increased the earth's crust by this amount.

The Icelandic findings, the evidence for spreading in dry land rather than submarine geology, helped to convince the last sceptics, except Sir Harold Jeffreys, who explained the fossil dinosaur found in Antarctica by a land bridge, and regarded the new volcano in Iceland as nothing surprising.

James S. Loughridge.



James Loughridge