Log of Leg 76

The second of two parts

The end of a suspenseful week aboard deep sea drilling ship Glomar Challenger

BY SUSAN WEST

A 94-foot-long stand of pipe is lifted up the derrick of the Challenger *before being swung into place and added to the drill string.*

Between Nov. 22 and Dec. 1, 1980, Science News *joined the 76th voyage of the* Glomar Challenger, *the research drilling vessel for the 12-year-old Deep Sea Drilling Project (*DSDP*). As described in part one (SN: 1/24/81, p. 60), the ship was well on its way to reaching the oldest sediments in the ocean, although problems had slowed progress and the science crew was dejected by the possibility of not striking their goal by the scheduled end of the cruise. When we left off, the crew had successfully guided the 3-mile-long drill string back into the 5-inch hole on the seafloor for the fifth time; the scientists were eagerly awaiting the arrival of the next core on the drill rig floor.*

Monday, Nov. 24

Though quick—about 49 minutes—last night's re-entry into the drill hole was not without problems, we learn this morning. The soft muds in the upper part of the hole had washed away, leaving "shelves" of less-erodible limestone on which the drill pipe caught as it traveled down the nearly 1,400-m hole to where it could start drilling again. "They had to keep banging the pipe down the hole to get it in," recounts one of the roughnecks on the drill crew. "Then the drill bit plugged—actually the holes in the bit that let water circulate down the pipe into the hole and wash the drill cuttings away. So we weren't washing the hole and were building up pressure."

Co-chief scientist Bob Sheridan, just finishing the midnight to noon shift, is discouraged. It's getting more and more difficult to infect the other scientists with the excitement he feels about reaching basement and to persuade them to put aside commitments to join the extension of this cruise — the "mini-leg" that will complete the drilling. The mood is compounded by the fact that because of the difficulties of re-entry, no core has yet been cut and retrieved. Already up to date on their scientific reports and other duties, the science crew has little to do. With towels and novels, most head for the "beach," the bow of the ship where the constant racket of the derrick and drone of the thrusters is minimal. It's the first sunny, warm day in a while.

* * *

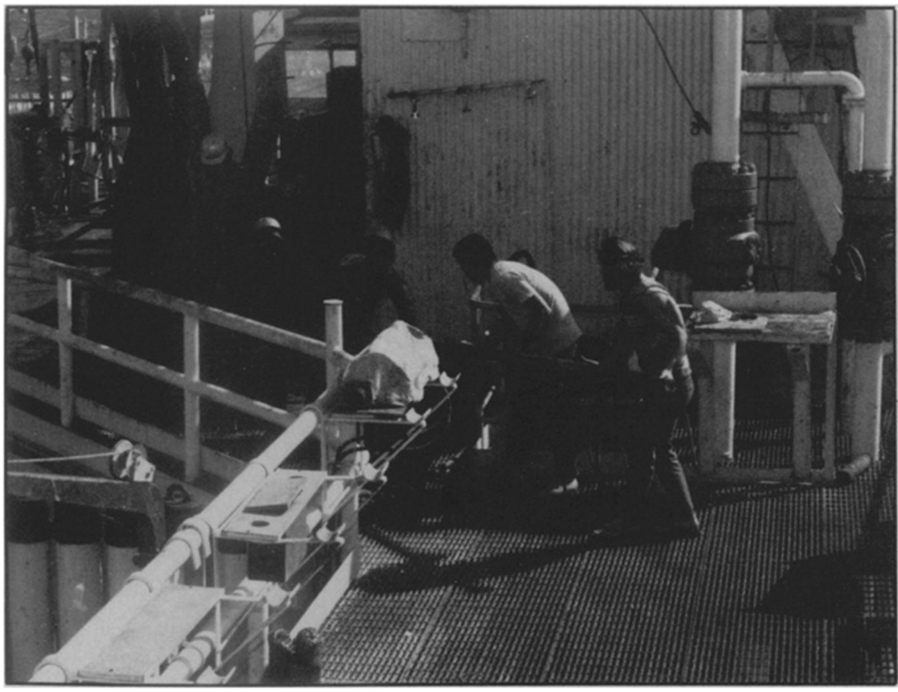
At last a core is up; it's about 5 p.m. The core barrel, measuring about 10 m, is drawn up the inside of the drill pipe, a trip that takes about one and a half hours at this depth. The core emerges on the derrick floor in a 6.6-cm-diameter plastic tube like a dripping, unwieldy deep sea worm. It is immediately cut into 1.5-m sections, numbered in sequence and carried to the core laboratory.

There, like a patient just admitted to a hospital emergency room, the core is swiftly subjected to a battery of tests. Indeed, the technicians have taken on the efficiency of a medivac team, automatically carrying out the routine treatment given each of the thousands of similar cores retrieved by the *Challenger* during the past dozen years. Mud from the ends of the core is smeared onto slides and immediately examined for microfossils that will give a first estimate of the age of the sample. Still in its plastic liner, the core is then weighed, bombarded with gamma rays that reveal its density and liquid content, and tested for thermal conductivity, sonic velocity and other "physical properties." Next it is split lengthwise, plastic tube and all, by a buzz saw. One half becomes the "working" half, destined for the ravages of sampling, poking and probing, while the other becomes the "archive" half, photographed and later preserved in one of two storage facilities in the United States.

The sedimentologists pounce on the archive half, quickly describing its color, texture and structure before the freshly exposed muds are altered by oxygen and the change in pressure. The descriptions are straightforward: yellowish, grayish-green or bluish-gray; silty, ooze or chalk; burrowed or laminated. Each change in shade or structure speaks of a unique source and of unique climatic and oceanic conditions.

From the working half of the core come samples for microscope studies of grain size, for chemical analysis of carbon and carbonate and water content, for X-ray mineralogy, paleomagnetism and microfossil dating. The laboratory, abandoned these few days, is suddenly swarming with blue-jeaned and tee-shirted scientists muttering over the five-and-a-half-meter core and grasping a handful of toothpicks bearing an identifying crest. Under the coaxing of Steve Asquith, the curatorial representative, each contemplates, stabs a banner in the sections from which he or she wants a sample and adjourns to the science lounge for a seminar.

Seminar? Out here in the middle of the ocean? Actually, says co-chief scientist Felix Gradstein, this is one of the most valuable aspects of the DSDP — that it allows, even forces, cross-disciplinary ex-



Burnette Hamlin/DSDP

Nine-meter plastic sleeve containing core is pulled from the core barrel.

changes. Scientists from the different specialities of geology meet about as frequently as rhinoceroses and eels and often communicate as poorly. The problems attacked on each leg of the DSDP, Gradstein explains, require a multidisciplinary approach and constant communication to assess the progress and to plan the next moves of the leg. This seminar is a summary, in part for the benefit of those who just came on board, of the findings of the leg so far. When each scientist has had a turn explaining the results of his or her studies, Sheridan turns to the subject most on everyone's mind — how far can they drill before returning to port?

With typical optimism, Sheridan gives a "good news, bad news" analysis of the situation. The drill bit is now at 1,400 m, he explains, and the object is basement at 1,740 m. That will probably not be reached in time, but they will cross horizon D and that's never been done before. Horizon D is an arbitrary name assigned to a major seismic reflection boundary — a line that shows up on charts produced by bouncing seismic waves off the ocean sediments and that marks a major transition from one type of rock to another. Such reflectors, which are worldwide phenomena, are used as universal age markers for sediments. Fixing an age to horizon D, not previously sampled, is a major goal of this cruise.

An age will be assigned to the reflector using a painstakingly constructed timescale. The evolutionary changes in the microfossils found in the sediments are correlated to a timescale for the same rocks constructed by radiometric dating (see part one). Next, the rate at which the sediments accumulated is determined by comparing the amount of sediments deposited between the appropriate points on the timescale. Then, a scale that relates the age of the sediments to their depth is constructed, taking into account the amount that they have compacted due to cooling and the weight of overlying sediments and water. Thus, using this "backstripping" technique, the age of horizon D will be determined. Already, results from this leg have upgraded the probable age of the basement rocks by 50 million years.

When they strike horizon D, Sheridan is saying, "we will be in the oldest sediments. We may not be able to core them, but we will be in them." What lies below horizon D is unknown, he continues. It is likely the rocks will be carbonate — limestones — but they could be chert — a very hard siliceous rock — and that could slow drilling.

* * *

Back in the laboratory, another core has come up and the mood has changed radically. Though it's 10 o'clock at night, the entire science crew is merrily slicing, describing, scraping and poking the cores, more enthralled than mothers with new babies.

Gradstein exclaims and holds up a bit of rock. There, an antediluvian ammonite is perfectly preserved, its enduring spiral remarkably fresh. Its preservation is an important clue to the depth of the ancient ocean, he explains. The ammonite's shell is composed of aragonite; below a certain depth — called the aragonite compensation depth (ACD) — the rate of aragonite dissolution exceeds the rate of aragonite input in the form of aragonite-containing organisms. The preserved ammonite means these sediments were deposited in water much deeper than 2,500 to 3,500 m but above the ACD, Gradstein explains.

"We are going into the unknown," he says. "It's really spectacular when you think we are seeing about 160 million years of rock. We had been through all these white limestones and now all these red clays. It's like if you stood in the Grand Canyon and looked up. You would see all this unknown rock below us, red clay above us, topped by white limestone, topped by a tumble of Miocene — 20 million years old — rock and a real jumble of shallow water mixed with deep water fossils. It's like we're cutting our own, much deeper, Grand Canyon."

Tuesday, Nov. 25

The *Challenger*'s four-mile-long arm has passed through the zone of red shales and is now laboriously digging through limestone. The cores are less frequent: 1:10 a.m., 5 a.m., 11:15 a.m. The brief exhilaration is gone.

In the paleontology laboratory, Peter Roth is poking at the flamboyantly ornamental remains of microscopic organisms called nannofossils. When he no longer sees a certain pineapple-shaped fossil, he will be satisfied that the drilling is solidly into Jurassic sediments.

These miniature, elaborate forms are the basis of the geologist's ruler, the timescale. The work is tedious, not given to streamlining by computer. "You have to have 300 to 400 shapes in mind, memorized," says Roth. "So it's a major investment of time and not something you give up easily. Few people are training in it now, though. There's really only a few nannofossil people. What happens when we get hit by trucks?"

* * *

Jim Ogg, shipboard paleomagnetist, is explaining how he uses the ubiquitous microfossil-based timescale. When he takes samples — 2.5-cm-diameter boreholes that leave the working half of the core looking like Swiss cheese — he is looking for magnetite, grains of iron that retain the direction of the ancient magnetic field. He then attaches an age to that field direction by identifying microfossils in the sample and finding their age on the established microfossil-radiometric timescale. Then comes the crucial part.

When basalt — volcanic rock — is formed at a seafloor spreading center such as the Mid Atlantic Ridge, it too retains a "memory" of the earth's ancient magnetic field. As it moves away from the ridge it is flanked by other basaltic rock that also retains magnetic memories, though of a time when the field had a different direction. These rock-recorded variations in magnetic field are called magnetic anomalies. If their age is known and if their distance from the spreading center is known, then the spreading rate at that time — the rate at which the ocean was forming and the continents were separating — can be determined.

So Ogg tries to match the magnetic anomalies recorded in the sediments to those recorded in the seafloor, which then gives him an age for the seafloor anomalies, which *then* allows him to calculate the spreading rates of the opening ocean. On this leg, he explains, the ages of the anomalies called M25 to M28 are critical. Previous indirect studies have given M25, for example, such a variety of ages that Jurassic period spreading rates for the Atlantic range from 1.5 cm per year to 3.76 cm per year. The ages of the anomalies and resulting spreading rates are the crux of the theory Sheridan described earlier that links periods of fast spreading with the eruption of molten material from the core-mantle boundary. This is the first time the necessary cores will be obtained to calculate — not just extrapolate — the rate at which the Jurassic ocean opened.

Wednesday, Nov. 26

Darker limestone is coming up now. Ogg points out a burrow where millions of years ago some creature wiggled through fresh, soft sediments. It's pseudopod shaped, surrounded by a "reduction halo" like a Kirlian image where the creature's chemistry changed the color of the rock.

The limestone is coarser now than it was at shallower depths. Gradstein picks up a chunk and explains that the coarse grains mean that turbidity currents swept particles along the bottom of the sea and the coarse heavy stuff dropped out first. The continental shelf was probably so far away, the water such and such a depth, the currents scoured like this, the climate like so, the ocean probably this temperature he continues, staring through a magnifying glass at the rock as if he can see this scene in its uniformly blank face. In a way, he really can — a whole primordial scene in a two-inch piece of limestone.

Rumors are flying that the pipe may be pulled early; drilling is going badly. Last night, operations manager Glen Foss showed me how the weight on the pipe was fluctuating wildly from 0 to 50,000 pounds. Drill foreman Mac Stilwell was just shaking his head. He has only two clues—the weight indicator and the speed of the rotating pipe — to tell him how the drilling is going. Those things, plus a lot of experience, tell him what to do. The weight on the pipe should be steady at about 20,000 to 30,000 pounds, Foss explained. But whenever Stilwell tried to run the pipe down, the weight indicator swung crazily. It's as though a current were lifting the pipe in and out of the hole, Foss said.

That incident bode ill, and today the cores are getting progressively smaller, down to about one-third the normal recovery. Nobody's saying much of anything. "Think about it," marine technician Richard Myers says of the scientists, "these guys have one shot and one shot only to get what they want. They know they have to get everything they can while they're out here and so they really scramble around working for it. Now they might not be able to make it. No wonder they're depressed."

Thursday, Nov. 27

The drill bit may now be punching through the rocks of horizon D, although just what rock types lie on either side of the transition is unclear. Most of the rock is still limestone with some claystone, which means the paleontologists are having a tough time finding anything to put an age on the cores. The harder and more altered the rock, the more difficult it is to find the delicate remains of the fossils. The paleontologists are stuck at 145 million years, and they are relying on a single type of nannofossil for that date. The fossils that might give good dates are dinoflagellates, but the proper equipment is not on board. The dinoflagellate specialist, Dan Habib, plans to do his analysis in his laboratory at Queens College and wire the results to the crew of the mini-leg.

Michel Moullade is boiling, washing and sifting a sample of clay to look for foraminifera. "It's very unusual to have a group like this working together," he says. "When Peter [Roth] stops finding something he can date, I begin finding things and then we can compare. It's also very unusual because of the pressure—we have to do it. We have to make our analyses immediately and write our reports without chewing over the results — that's not the way we are used to working. That's probably the most valuable part of the DSDP."

* * *

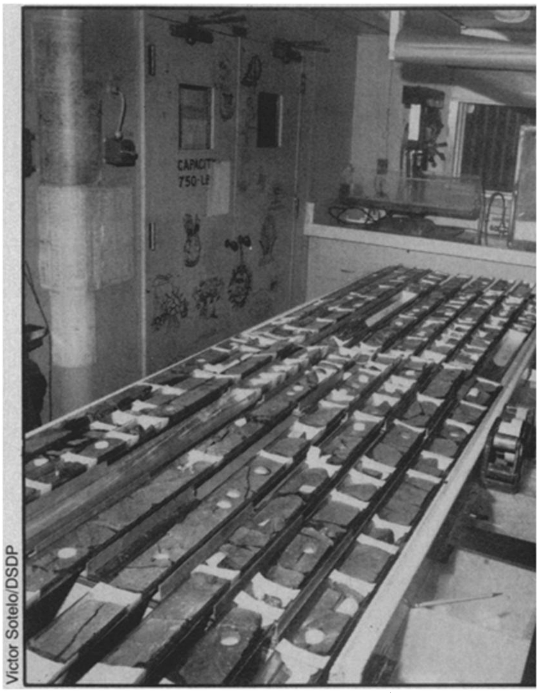
In the galley, the roughnecks are voting on which of the paper turkeys taped to the walls is best-looking.

Friday, Nov. 28

Slowly, but regularly, the cores are still coming — midnight, 4 a.m., 8:50 a.m. More and more limestone, little pillars of limestone, just as gray as the rainswept day outside. Core number 120 comes up only 1 m long. The plastic tube is filled with gravel-like cuttings, nothing that even resembles a core. People walk over to it, look at it, turn and walk away.

It's very difficult to get good dates from the types of rock that have been coming up because of the lack of fossils, Gradstein explains, but they appear to be about 145 million years old. This age is about 20 million years younger than the scientists expected, and it means that the Jurassic ocean was opening at a very fast rate. "It fits even better than we thought," he says, "but the facts are very incomplete."

Sheridan is musing over the idea of timescales, the implicit mission of this cruise, of most geology. "The timescale was constructed just by observation of macro-scale things, like clams, that were the result of shoreline changes," he says. "We now know those observations of shoreline changes — the ups and downs — are the result of tectonic changes. So the scale was set up and the periods were divided according to similar things that were found in different places. If all those observations had been gathered and scientists waited until now to put some kind of scale on it, I wonder how different the scale would look. Might be a good exam question for my students. I don't know, I suppose it wouldn't be too different. Certain disputed divisions might be settled differently....



Victor Sotelo/DSDP

White plugs mark where scientists have taken samples from drill cores for study.

"Dealing with those millions of years doesn't really bother me. It makes me look differently at things. More passive in a way. Geologists see things as part of a whole, see things as part of something that's been going on a long time.... It really is a systems analysis which gives a way of looking at the natural world, of organizing it into systems and using them."

Saturday, Nov. 29

The last core of Leg 76 came up at 15 minutes after midnight. It's just a midget of a core, only 0.6 m long, composed of limestone and siliceous mudstone from 1,581 m to 1,590 m below seafloor. The roughnecks are straining to pull up the miles of drill pipe; they set speed records when it's the last pipe-tripping of a leg. Lots of time and film is being spent on the core.

"I'm satisfied," says Sheridan, smiling into the sun. "We are in the oldest sediments." Gradstein is more expansive: "We can now say the Atlantic opened 153 million years ago, not 180 million years ago as everybody has thought."

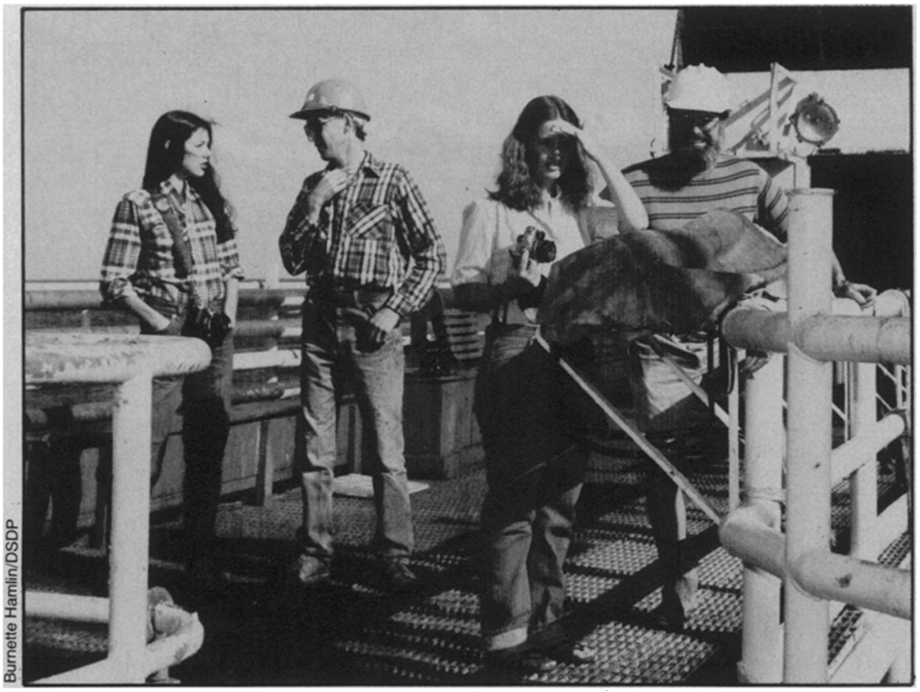
The drill bit arrives on deck about 2:30 p.m., the wobbly cones showing the wear of 52 hours' drilling time. After a thorough inspection of the bit and lots more picture-taking, the scientists make for their desks: Their final report must be complete by the time the *Challenger* docks in Ft. Lauderdale.

The ship is underway by 6:06 p.m., cutting through waves that twinkle with phosphorescent microorganisms.

West

Dan Habib (right) and co-chief scientist Bob Sheridan examine samples of 150-million-year-old sediments.

Burnette Hamlin/DSDP



Waiting for the end: (from left) Susan West of SCIENCE NEWS, *co-chief scientist Felix Gradstein, organic geochemist Everly Keenan and co-chief scientist Bob Sheridan.*

Sunday, Nov. 30

In the evening, when only the final thrashings of paperwork remain, the science staff meets for a summary of the cruise. Reduced to a bit of jargon and dry sentences, the often-excruciating weeks are recounted. There is a general agreement that the bottom of the hole is unlike anything ever seen before by the DSDP, but that it must be investigated more carefully. Though wary, paleontologists Roth and Moullade agree that the presence of the nannofossil *Stephanolithion bigotii* very likely makes the sediments 145 million to 150 million years old, just barely Jurassic age. Only further investigations and sediments from the mini-leg will fix this date, they say.

Even so, concludes Sheridan, the implication of all their data is that the Atlantic opened possibly 155 million years ago. "The data seem in general to support Ogg's contention of a Jurassic spreading rate of 3.76 cm per year in this part of the Atlantic. That's 300 percent higher than present and 100 percent higher than previously believed. Magnetic anomaly 25 is now 143 million years old."

The hole is still about 1,000 m shy of where the scientists believe the ocean basement lies, but all signs point to success. They have obtained continuous cores down to Jurassic sediments; the mini-leg will have no problem reaching basement. They have drilled through horizon D, through M25, and found that those important markers are significantly younger than anyone thought. The Atlantic opened about 20 million to 30 million years later than scientists believed from earlier studies, Africa and North America ripping apart at a much faster clip than ever imagined.

The written report concludes: "A correlation of times of rapid seafloor spreading with times of magnetic quiet intervals, relative eustatic highstands [sea level rises] and shallow CCD [calcium carbonate compensation depth] is supported by the information obtained so far." All of which, it continues, support the theory of pulsation tectonics — periods of rapid tectonic activity due to the eruption of hot mantle material from the core-mantle boundary. "The important thing is that this hypothesis of pulsation tectonics, which originates in the core of the earth, has a first order impact on the controls of the paleooceanographic environment. ... Paleobathymetry changes occur with global spreading rate changes, new oceans open with plume eruptions of hot spots, and sea levels rise and fall as mid ocean ridges grow faster or slower, and finally the very chemical composition of the world's oceans is influenced."

* * *

Somehow it's all a bit anticlimactic. No trumpets, no eurekas, just bits and pieces of different evidence that accumulated independently and that fit together consistently. No reactions of surprise or delight, just a group of scientists sitting together in a room, nodding their satisfaction.

Epilog

The mini-leg left Ft. Lauderdale on Dec. 5 and returned Dec. 21. Only four members of the Leg 76 crew — Gradstein, Sheridan, Ogg and sedimentologist John Kostecki — were able to witness the long-awaited end of the hole. Surprisingly, the drill bit struck basement after only two days of drilling; it lay at 1,636 m beneath the seafloor, far shallower than the anticipated 1,740 m. Sheridan explained that the depth of basement had been predicted based on seismic reflection surveys, which depend on the types of sediments and the way they transmit seismic waves and so are open to some interpretation. He added, however, that the actual depth was within the range of prediction. Even so, said Gradstein, they were "flabbergasted" to find they were in basalt so quickly. They continued coring to a depth of 1,666 m below seafloor, making site 534 the second deepest hole ever drilled by the DSDP, and logged all but the bottom part of the hole.

They found two important things, Gradstein reports. First, based on a single type of nannofossil, the minimum age of basement is believed to be 155 million years. While the scientists are awaiting supporting evidence for that date from post-cruise analysis of other microfossils, Gradstein said that the sediments contain the complete sequence of fossils known to have evolved since the critical nannofossil, a find that gives the scientists confidence in the 155 million year date. Second, the last sediments consist of dark, organic-rich shales, a signal to a geologist of low-oxygen conditions. This indicates, says Gradstein, that for 10 million to 15 million years after it began to open, the circulation in the bottom of the Atlantic was sluggish and restricted. This find may eventually interest oil companies in the region, he adds.

All of this is further support of Sheridan's theory of pulsation tectonics; he has already presented the preliminary evidence at one scientific meeting where it received a good response. "Once we put it all together, we will have sorted out quite a piece of Atlantic history," says Gradstein. "Eighty one days at sea ... it was worth it but it was hard." ☐