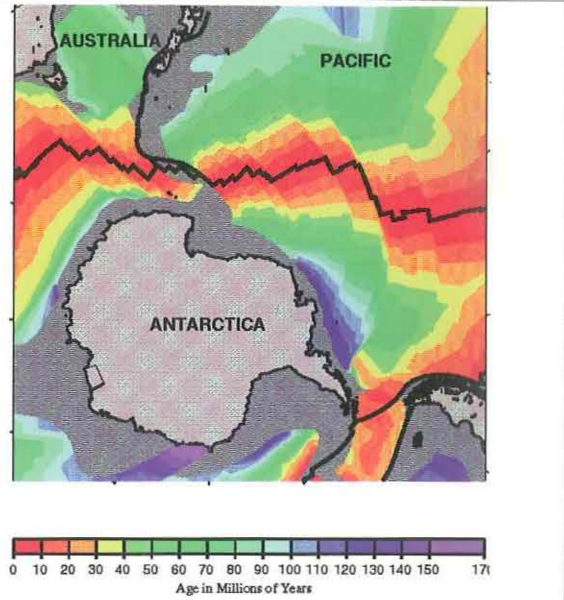
Right: This map of the age of the seafloor around Antarctica shows that, with the exception of some older floor around the Weddell Sea (the purple and dark blue at bottom), the continent is surrounded by young seafloor from spreading mid-ocean ridges (red). The gray parts are still a mystery.

Below: Mount Erebus, an active volcano near McMurdo Station, is thought to be the surface expression of a hot spot with its volcanic source deep in the Earth, below the tectonic plates. Relationships between this and other hot spots around the globe may give clues to how the plates have moved.



Geophysical Secrets Beneath Antarctic Waters

by Joann M. Stock

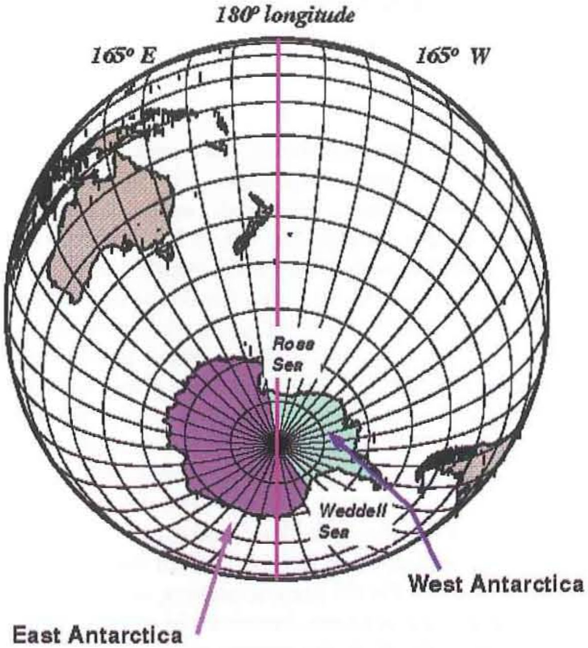
Few geophysical data have been collected around much of Antarctica because it's so out of the way. . . . So we went there ourselves.

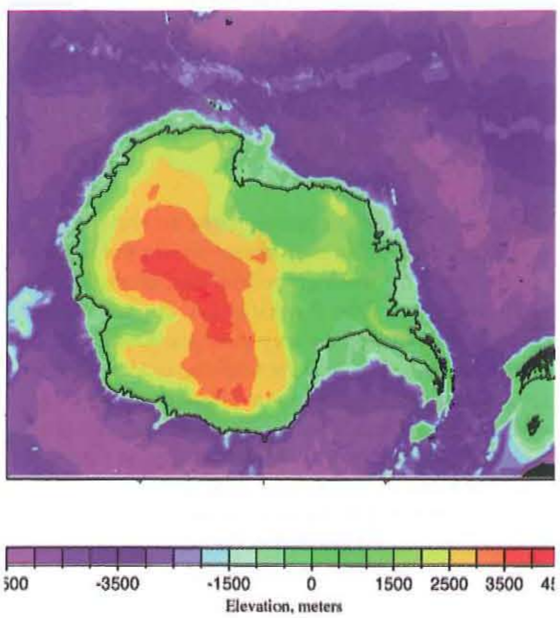
Cruising around Antarctica is a perk that a group of us from Caltech have enjoyed over the past few years. You might be curious about how we book one of these cruises. First of all, we write a proposal and send it to the National Science Foundation, which has an Office of Polar Programs and an Office of Marine Geology and Geophysics. If the proposal is approved, we're scheduled for time on board one of the NSF ships. We had proposed several projects to answer some nagging plate-tectonic questions about the history and evolution of the Antarctica plate, which may hold the key to understanding movement of some of the other plates and other global geophysical problems, such as relative motions among the hot spots.

The idea behind plate tectonics is that the surface of the Earth is composed of a number of relatively rigid plates that move with respect to one another at speeds of a few inches per year. The deformation—fault slip, earthquakes, mountain building, seafloor spreading—between the plates is concentrated along the plate boundaries, of which there are several different kinds. For instance, the Pacific plate is moving along the San Andreas fault system sideways relative to North America. In some places the plates are colliding, and in others the plates are moving apart. The latter describes the case we were interested in—where the Pacific and Australia plates are moving away from Antarctica. And the evidence of the movement lies at the bottom of the ocean, in the seafloor formed by the spreading ridges that mark these plate boundaries.

The ocean floor is younger close to the spreading ridges and gets older as it spreads away. The map above shows the age of the ocean floor: red is very young, grading through yellow and green into blue and purple, which is very old ocean floor. You'll notice that much of the area around the Antarctica plate is surrounded by very young regions that formed at mid-ocean ridges. There's a little bit of older seafloor in the Weddell Sea and a lot of gray representing the gaps in our knowledge—no one knows exactly what the age of the seafloor is in those places. In fact, for much of the region surrounding Antarctica, there is very little detailed information. There haven't been very many scientific expeditions here compared to other parts of the oceans. There's good reason for this, as we discovered.

The particular knowledge gap that we were trying to close in our own surveys concerns the development of the Antarctic plate. It was part of a larger group of continental blocks called Gondwanaland, which, more than a hundred million years ago, included Africa, South America, Australia, India, Antarctica divides into east and west fairly neatly along with the eastern and western hemispheres—but not exactly. The Transantarctic Mountains (the yellow-green band crossing through the center of Antarctica in the topographical map below) form the actual boundary between East Antarctica and West Antarctica for geologists. East Antarctica is much higher above sea level than the western half; the Transantarctic Rift System (the green basins to the right of the mountains) has undergone a lot of geological extension and has sunk below sea level.





Antarctica, and fragments of New Zealand. We can tell how fast the plates spread apart and in which direction by studying the seafloor, and what we find when we calculate the relative rates of motion along the plate boundaries, while these plates were separating, is that there had to be some other deformation somewhere. If these plates were rigid, you would expect that the motion across the spreading center, the convergence in one place and the extension in another, would add up to zero. But in fact, scientists who have reconstructed the positions of the plates over the last 70 million years have found that the motion doesn't add up correctly; there's some motion missing. This motion had to be either through Antarctica or through the Pacific plate, in the area of New Zealand. From what's known about New Zealand geology during that time, we don't think there was deformation going on there early in this period, between about 72 to 56 million years ago, so any extra deformation in that period had to be accounted for in what was thought of as a single, rigid Antarctica plate. And for the last 42 million years, the Pacific plate, Australia, and Antarctica have indeed behaved more or less as rigid plates.

Antarctica is surrounded by spreading ridges, and it's been growing in the sense of oceanic material being added to the edges of the continent as the ridges spread away from the center. This extra deformation might be accounted for within Antarctica or on the seafloor that is considered part of the Antarctica plate. New Zealand is the other possibility, before 42 million years ago. So our expeditions focused on surveying this region of the West Antarctica margin, between the Ross Sea and South America and between the Ross Sea and New Zealand, to try to figure out what really happened in the early history of plate formation.

What do we mean by "West" Antarctica if every direction from the South Pole is north? "West" is determined by longitude lines. The part of Antarctica that lies within longitudes that are within 180 degrees east of the Greenwich Meridian (south of the Indian Ocean, south of Africa, India, and Australia) is called East Antarctica. And West Antarctica is the part that lies in the western longitudes, or the western hemisphere, south of the Atlantic and Pacific Oceans and South America. What we actually consider the boundary between East and West Antarctica doesn't coincide exactly with the longitudes, but rather with a fundamental geological boundary that runs through the continent very roughly along the longitudinal divide. And we can tell from the topography that there is something very different going on in these two halves of the Antarctic continent. East Antarctica is fairly high above sea level, while West Antarctica is a lot lower in elevation. A fairly steep topographic gradient runs right along the boundary between the two parts of the continent, a boundary that also extends offshore into some of the region that we were surveying.

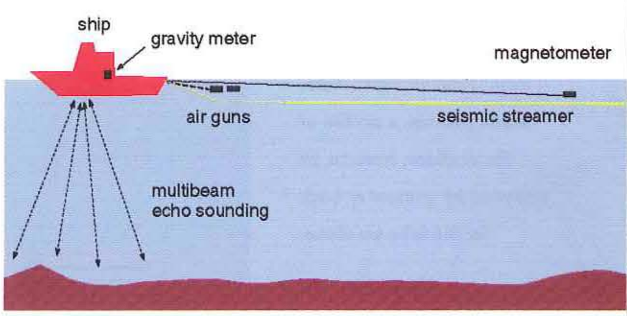
Members of the crew deploy the seismic streamer off the Nathaniel B. Palmer's rear deck, a precarious place to be in rougher weather than this. The ship also towed a magnetometer behind it, and mounted on the ship itself are a gravity meter and an array of instruments to map a three-dimensional swath of the seafloor beneath the ship (below).

Almost all of Antarctica is covered with glaciers, and it's hard to know what rocks are beneath them, although a few exposures of rock that poke up through the ice have given geologists some idea. We do know that East Antarctica is composed of much older rocks than most of West Antarctica. The major geological boundary between East and West Antarctica is a huge mountain range, the Transantarctic Mountains, next to a big basin—the large green areas on the right in the map on the opposite page. This adjacent area of West Antarctica, the zone called the Transantarctic Rift System, has suffered a lot of geological extension; it thinned out and sank below sea level. It may have suffered as much as a thousand kilometers of relative opening. Active volcanoes, including Mount Erebus near McMurdo Station, indicate that some tectonic activity is still going on here. Almost all of West Antarctica is below sea level and covered permanently with ice, and you can't get to the rocks at all. Even the surrounding seafloor is usually covered with sea ice, but if you can get close to it during the summer season, when the ice has retreated, you can study the seafloor using marine geophysical techniques.

The geophysical techniques sense what is on the seafloor, since we can't actually get down there and measure things directly. We're particularly interested in looking at features formed by a spreading center, or "ridge," between two tectonic plates, which leaves behind magnetic anomalies on the seafloor that we can measure with a magnetometer. It might also leave gravity anomalies that we could measure. If the ridge stops spreading and dies, it may leave a trace that we can see in the symmetry or the relief of the seafloor. And we also look for offsets in the spreading ridge system, called transform faults, whose extinct traces some distance away from the spreading center are called fracture zones. These track the direction of relative motion between the plates.

Few geophysical data have been collected around much of Antarctica because it's so out of the way. It's not on major shipping lanes, for example. So we went there ourselves. And we found out for ourselves *why* not many people go there. In addition to the problems of the sea ice, the weather can be very bad. We had 50-foot seas for a while, and some waves got up to 60 feet. I got very seasick, and spent much of the bad weather in my bunk. But the weather wasn't bad all the time.

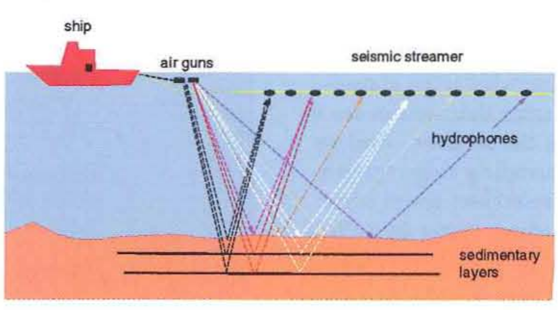
The 308-ft.-long Nathaniel B. Palmer is the kind of ship you need for work in Antarctica. It can break ice three feet thick at a speed of three knots, and it can deal with the difficult weather conditions. (The other ship we cruised on—the Maurice Ewing, run by the Lamont-Doherty Earth Observatory—is not an icebreaker, but we didn't need this capability every time.) The Nathaniel B. Palmer doesn't just do geophysics; it's a multidisciplinary ship, run year-round by the National Science Foundation, and is also involved in marine biology, oceanography, aquatic chemistry—you name it. The NSF tries to coordinate investigations, so often different groups of investigators who want to go to the same place for different reasons find themselves together on the ship. One year we shared the ship with two ocean engineers from MIT, who were building a remote-controlled submersible device that could swim around by



Above: The Nathaniel B. Palmer at dock. The picture of a 60-foot wave about to crash over the bow of the ship was taken from the bridge; the mast at far right on the ship can be seen against the wave for scale.

itself and make measurements under the sea ice; and another year we shared space with researchers from the National Oceanic and Atmospheric Administration who were collecting gas and water samples. Although these projects had no impact on the work that we were doing, sometimes we can actually use data that others have collected on cruises. For example, another group might be towing a magnetometer on a cruise that's primarily for some other purpose, and we can analyze the data for our own work.

The standard geophysical equipment we use on these cruises includes some instruments mounted on board and some towed behind the ship. We usually do tow a magnetometer behind the ship, as well as a seismic streamer. There's a gravity meter mounted on the ship and an array of transmitters and receivers for multibeam echo-sounding built into the hull; this allows us to map out a three-dimensional image of a swath of the seafloor beneath us. With the magnetometer we're looking for variations in the magnetic field that are related to changes in magnetization of the seafloor caused by symmetric seafloor spreading. These occur because Earth's magnetic field reverses through time, every million years or so, and when the lavas cool at the mid-ocean ridge, they acquire the magnetization of the field at that time. Then, if the field reverses, the next batch of lavas gets magnetized in the opposite direction. This creates patterns of magnetic anomalies that we can identify and date. We can match up these characteristic patterns with what we observe from the ship; this will tell us how old the seafloor is and allow us to map out which way the plates were spreading. But we need *a lot* of magnetic data to cover as much of the seafloor as possible, which is why we often combine our observations with the magnetic anomalies observed by previous cruises.



The seismic system's air guns bounce pulses off the seafloor and the sedimentary layers beneath, back up to hydrophone receivers along the 3,600 feet of cable towed behind the ship. Most of these data, which provide a profile of the seafloor, have to be analyzed by computer back in the labs on shore.

Our seismic system consists of air guns that bounce pressure pulses off the seafloor and also off sedimentary layers beneath the seafloor, essentially making seismic waves that travel through water and rock. The pulses are received by a series of hydrophones along the streamer, which we tow more than 12 ship lengths (on 3,600 ft. of cable) behind the ship. The seismic data give us a profile of the seafloor. We can also see details of the sedimentary layering below the bottom, which is important for helping us understand the timing of deformation, how deep the basins are, and so on. Analysis of these seismic data is very time-consuming and computer-intensive, so we do what we can on board, but have to save most of it for later when we're back in our labs.

We also tried to dredge rocks off the seafloor. First we have to pull in all the rest of the gear we're towing so that it doesn't get tangled up. Then we tow a chain-link dredge bucket on enough cable for it to reach the bottom. We drag it along for a while and then bring it back up, just hoping to get some rocks.

When we're deploying our equipment—the dredger and various instruments—off the ship's rear deck, we have to wear float suits that are full of foam. So if you are unfortunate enough to fall overboard, you wouldn't live very long in the icy water, but at least your body would float and the crew could find you. And when the back gate is actually open you have to have a rope tied around your waist, so you can't go very far if you're washed overboard. Other than that, however, Even in March (left), there's a lot of ice to navigate through around Antarctica, and by September, at winter's end, the continent is so completely surrounded by ice that no ship would be able to get through.

shipboard life is pretty cushy compared to some other kinds of field work. In the Mexican desert, for example [see *E&S* Fall 1993], you have to do your own cooking. There's no water, so you can't take showers. It's hot; there are rattlesnakes; your truck breaks down; you get lots of flat tires. . . .

But on ship there's much more infrastructure supporting you—technical support people as well as the ship's crew. (The Nathaniel B. Palmer carries a crew of 25 and about 37 scientists.) The crew members make their own fresh water from the sea water and they have plenty of it; you can have a hot shower any time you want one. They have laundry machines. They have someone else doing the cooking. We even have recreational activities. When the weather is good, you can go out and build snowmen on the helicopter deck. If the weather is not so good, but you can still stand up, you can play Ping-Pong in the cargo hold. We had a couple of Ping-Pong tournaments with the crew and gave out prizes of Caltech hats and T-shirts.

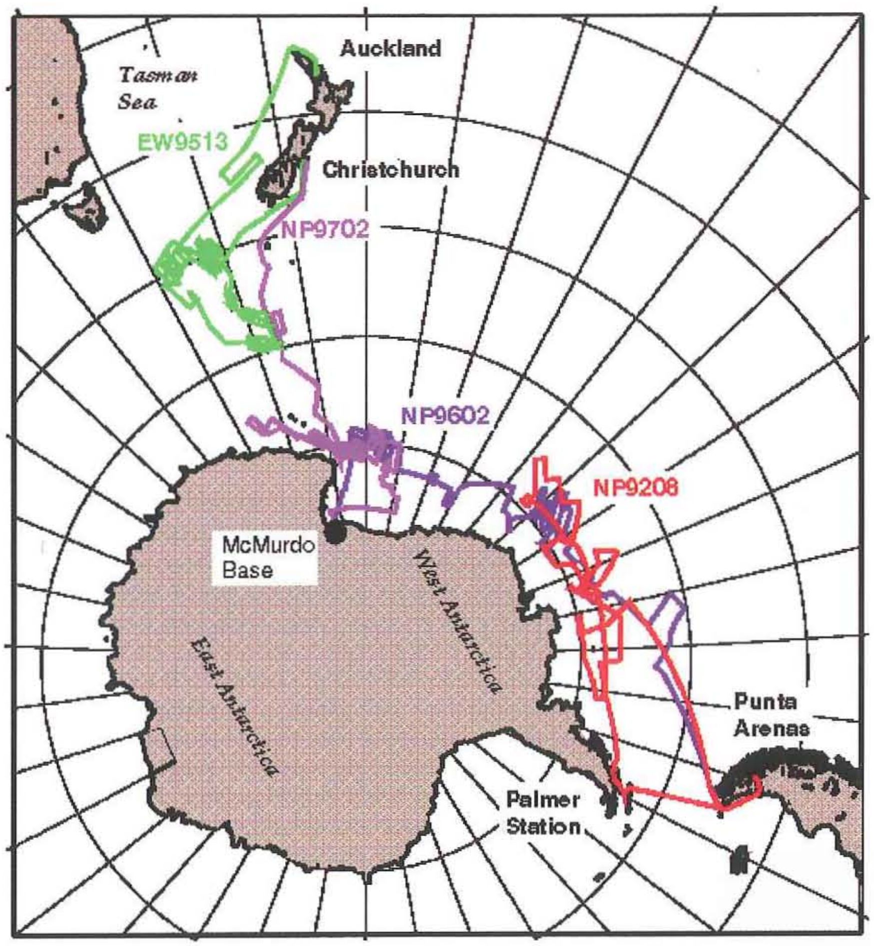
There are also comprehensive computer facilities, as well as lab space where you can lay out maps, make big color plots, and hold meetings to discuss the latest scientific results. Team members stand watch 24 hours a day, in 6-hour shifts, monitoring the computer screens and making sure that all the equipment is functioning and that we are registering all the data that we need to be collecting. As the data come in, they're constantly being analyzed and processed to the extent that we can do that on board. So if a problem with an instrument occurs, we can try to get it working again and not lose too much data. Sometimes in the southern oceans you might not really notice that you're working such weird hours—like midnight to 6 a.m.—because it stays light so long. On one of our cruises in December and January, it didn't get dark at all for four weeks; the sun doesn't set when you're that far south at that time of year.

As the Palmer cuts through the ice (below right), its wake quickly fills in again behind the ship. Ice *on* board ship, as this stairway shows, can be almost as dangerous as the stuff in the sea.

The time of year that we do this work is pretty important, because the sea ice surrounding Antarctica expands dramatically in the austral winter and then shrinks again in the austral summer. All the area we were surveying would have been chock-full of ice in September, and we wouldn't have been able to work there. In March it was a little better, but we still ended up plowing our way through ice, which was already building up again toward the end of the summer. Large icebergs aren't too much of a hazard because they can be seen on the radar and the ship can adjust course to avoid them. The problem situation is with ice three feet thick or more. As the prow of the ship physically breaks up the ice, big chunks of ice flow by the side of the ship and fill in the wake behind, often endangering our equipment. We tow most of the equipment below the surface, but the ice chunks also extend down some distance. So, whoever is in charge of each science watch spends a lot of time running up and down from the bridge, consulting with the captain and the mates about the ice, trying to decide if we need to pull the equipment out, if we should go a different way, or if we have to give up and turn around.

How do we decide on our course in the first

Wearing and carrying identical NSF-issued gear, Joann Stock (from bottom), Katrin Hafner, and Igor Sidorin, wait at the U.S. Navy station in the Christchurch, New Zealand, airport for the cargo plane to McMurdo Station. This was the February 1996 cruise, marked in blue on the map below.



The Caltech group participated in four Antarctic cruises between 1992 and 1997, three on the Nathaniel B. Palmer (NP) and one, around New Zealand, on the Maurice Ewing (EW). Two of the trips (red and blue) concentrated on the area off Marie Byrd Land, and the other two on the Ross Sea and Tasman Sea between Antarctica and New Zealand.

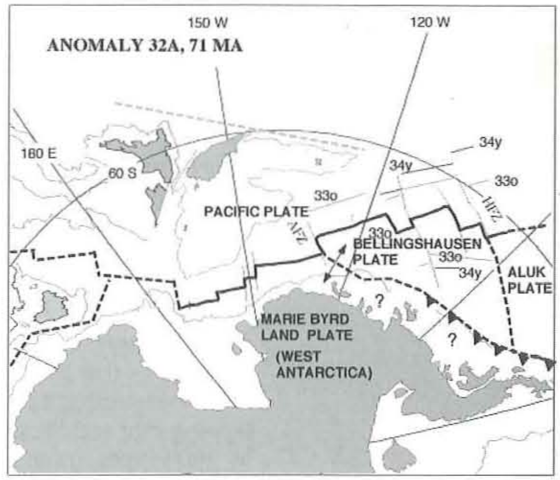
place? We use satellite gravity data to guide us in picking the ship tracks. Satellites measure the height of the sea surface by bouncing a radar signal off it. Even though the sea surface is pretty rough and ragged, if you average a number of observations in the same place, you come up with a smooth version of the potential surface of the ocean (the geoid). This tells you something about the topography of the ocean floor, because variations there cause gravity anomalies that affect the shape of the sea surface. Knowing the general position and shape of features on the ocean floor, even if not the exact details, is an immense help to us in deciding where to go. For example, there's a gravity anomaly in the Tasman Sea that corresponds to a ridge that stopped spreading 56 million years ago between Australia and New Zealand. (Such an event might be related to plate tectonics elsewhere; for example, some subduction zone stopping or starting somewhere else on Earth affects the mantle flow patterns and causes repercussions in the spreading system.) We could plan our ship track—that cruise was in late 1995 and early 1996 on the Ewing—to look at that ridge, making sure that we got data in the places that we wanted.

Our various cruises are shown on the map at left. In 1992–93, we went from Punta Arenas near the tip of Chile along the West Antarctica margin over to the Marie Byrd seamounts and back. We went on two cruises in 1995–96: one out of New Zealand to survey the South Tasman Sea, and the other from McMurdo going along the edge of West Antarctica and ending up in southern Chile. In February and March of 1997, we went from McMurdo up to New Zealand. In each case we were planning our tracks to cover specific areas of the seafloor that would answer our questions about plate tectonics, to look at the spreading ridges between plates, and to see where the fracture zones come into the continental margin, which will help us reconstruct the plate-tectonic history of the region from East Antarctica to Australia. We also looked at some enigmatic features of the seafloor that had never been surveyed and found some new and interesting things.

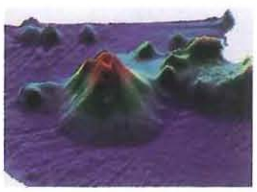
If you look at the tracks in detail, they look very erratic. There are little kinks where the ship had to turn into the waves so that not so much water would come crashing onto the back deck while the equipment was being deployed; and some funny squiggles where the ship kept turning to avoid big chunks of ice, or even icebergs. And sometimes, if we needed satellite access for e-mail or essential communications, we would have to turn east or west for a while because the satellites, which are sparse in the southern oceans in any case, are low on the horizon and our antenna couldn't pick them up if we were heading south. The little boxes along the tracks mark places where we were trying to establish exactly where a particular feature lay on the seafloor; for example, trying to fix the position of a fracture zone with our magnetic, gravity, and seismic measurements. Locating the fracture zone will help us match it back to its counterpart fracture zone near New Zealand, to determine the positions of the plates when the first rifting occurred. We already know where these fracture zones lie on the New Zealand side, but we didn't know exactly where they were in Antarctica.

In 1996 we also surveyed in a region where we thought, from our previous studies, that there might have been an old plate boundary within West Antarctica. This region is all now just part of the Antarctica plate, but we thought it might once have been two plates, and we wanted to try to confirm this. That has turned out to be the case, although the boundary is somewhat obscured by sea mounts—volcanoes that had erupted on the seafloor after spreading had occurred. They poke up through the seafloor and remove the evidence of the magnetic anomalies that had been there. Based on the ages that we determined for the Antarctica seafloor (isochron lines, or lines of constant age), we can see that something happened near the Marie Byrd seamounts to split it open. Much of this region was actually formed by seafloor spreading at some ridge that is now dead. Comparing this with a map of the whole South Pacific area, we were forced to conclude that these magnetic isochrons were formed by two separate spreading ridges and that there had been a third spreading ridge trending south toward West Antarctica from the triple junction of the three ridges. We ended up with a model (above) for the positions of the plates 71 million years ago, in which the Pacific plate was moving relative to another plate called the Bellingshausen plate, which was moving relative to West Antarctica. This is a very important result, because it tells us that if we want to know the position of the Pacific plate relative to Antarctica, we have to use the data from the region between the Campbell Plateau, near New Zealand, and Marie Byrd Land. They give us a different answer from what was done before, using the data farther to the northeast.

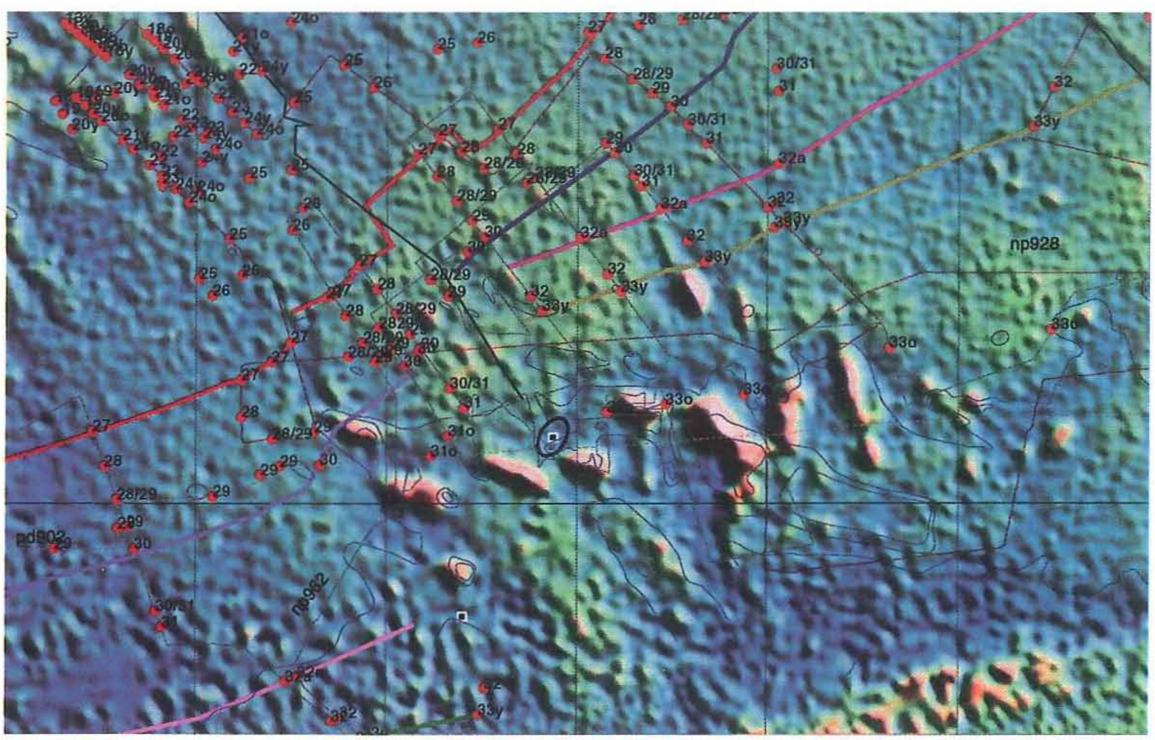
We also found another place with evidence of relative motion within a plate that formerly had been thought to be a single plate. It's the Adare Trough, which connects up to the West Antarctica



Right: Data collected off Marie Byrd Land in West Antarctica led the researchers to conclude that 71 million years ago three spreading ridges came together in a triple junction, where the Pacific and Antarctic plates came up against a third, the Bellingshausen plate.



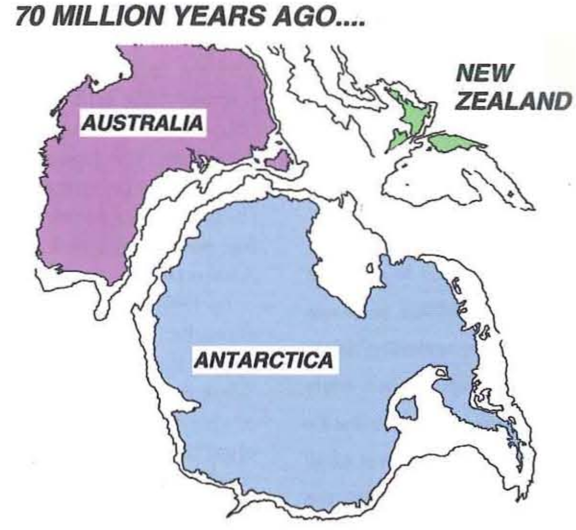
Above: One of the underwater volcanoes off Marie Byrd Land, imaged by the ship's multi-beam echo sounding system. The Caltech group tried to dredge rocks from this seamount with little luck.

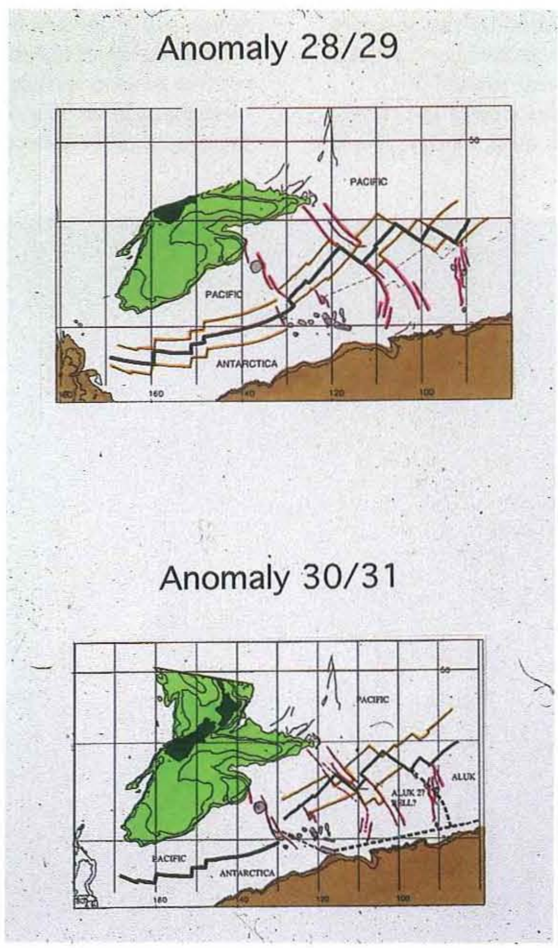


Right: Isochrons indicating seafloor age are superimposed on an image from gravity anomaly data around the Marie Byrd Land seamounts. The red line, marked 27, tracks seafloor that is 62 million years old; the blue line (30) is 67 million years old; purple (32) indicates 72 million years. These isochrons enable researchers to reconstruct spreading ridges on the seafloor.

ridge system and is part of a region that seems to have endured seafloor spreading between East and West Antarctica. It isn't very much motion, only about 150 or 200 kilometers, which probably all took place before roughly 35 million years ago. This is important to models of past plate motions because it allows us to place some constraints on how much relative motion there could have been between East and West Antarctica. Other models have proposed as much as a thousand kilometers of "missing" motion, but we don't see that—at least not in the last 70 million years. You can tell from the geology that there must have been some extension or stretching, and we try to close that out by lapping East and West Antarctica back together by 200 kilometers and then trying out various reconstructions of the plates. Our magnetic-anomaly data give us more constraints in fitting the different pieces of Antarctica back together, and we can tell which reconstructions will work and which will not.

Hot spots, which have been used as an alternative method of reconstructing plate positions, offer another possible constraint (Mount Erebus, which I mentioned earlier, may be a hot spot). Hot spots are thought to have some source of volcanism from beneath the plates, possibly deep in the Earth, in the mantle or at the core-mantle boundary. As a plate moves over a hot spot, it leaves behind a trail of volcanoes.



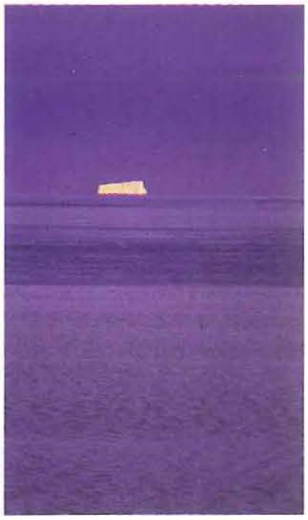


Right (above): About 70 million years ago, as Gondwandaland was continuing to break up, Australia and Antarctica were separating into continents opening up the Tasman Sea as they spread apart from the Pacific Plate and New Zealand. Right (below): A closer look at the isochrons around the Campbell Plateau region (light green) off New Zealand (dark green). Anomaly 28/29 indicates where the spreading was about 63–65 million years ago, while anomaly 30/31 shows its position 67–69 million years ago. The spreading ridge of the plate boundary (black line) can be reconstructed from these Campbell Plateau data, critical to determining the relative positions of the Pacific and Antarctic plates.

One example of a hot spot track is the Hawaiian chain of islands, which is part of a longer group of seamounts (underwater volcanoes) called the Hawaiian and Emperor seamounts. Since the ages of these submarine features are known, we can map the progression of the Pacific plate over the hot spot that gave rise to them. We can tell that the Pacific plate has to be moving northwest relative to some fixed hot spot because of the direction in which it's dragging the volcanoes. A number of hot spots are thought to exist on the Earth, and it has also been postulated that they are all fixed relative to one another—that there is some fixed reference frame deep in the mantle or at the core-mantle boundary where these hot spots originate. If this were so, you could apply it to help reconstruct the past positions of the plates.

But if you assume that the African hot spots formed a fixed reference frame relative to the others, and then reconstruct the Pacific plate relative to Antarctica and Africa, you find that this doesn't work. Using the data that we collected to get plate motions for Pacific–Antarctica–Africa, if we try to hold the Hawaiian hot spot fixed to the African hot spots, it doesn't reproduce the geometry of the Hawaiian seamount chain. This forces us to conclude that the hot spots must be moving relative to one another.

Others have argued that perhaps the Antarctica plate was really more than one plate, with a thousand kilometers of opening along the Transantarctic rift system. If these plate reconstructions of the Pacific plate or the African plate are all wrong, then perhaps the hot spots could constitute a fixed reference frame. We can conclude, however, from our new data in the Ross Sea that West Antarctica and East Antarctica were separate during the last 70 million years, but the amount of relative motion was less than has been postulated—a few hundred but not a thousand kilome-



Right: An iceberg catches the late afternoon light. Below, right: Happy to be on land again, after the Nathaniel B. Palmer docked in Lyttelton, New Zealand, last winter are (from left): Jane Heinemann, Magali Billen, Joann Stock, and Katrin Hafner.

ters. We know there's no easy way to reconcile these different hot spot traces. This strengthens the case for the hot spots to be in relative motion with respect to one another.

Why, you might ask, do we care about the position of the Pacific plate with respect to Antarctica? It's actually very important for a number of reasons, but, in particular, it helps us form a clearer picture of what's going on closer to home. For example, if we want to determine the relative position of the Pacific plate with respect to North America for some time in the past, we would reconstruct, by means of the spreading ridges, the position of the Pacific plate relative to Antarctica, Antarctica to Africa, and Africa to North America. But this model assumes that the Antarctic plate was entirely rigid, with no internal deformation between the east and west parts. Whether this is a valid assumption depends on the time we're looking at. The motion between the Pacific and North America plates is of importance to geologists trying to understand the history of the geologic evolution of western North America, where we see evidence of volcanism and deformation, which we are trying to link to the plate motions. The details of what was going on in the Antarctica plate provide a key to the other plate motions and, ultimately, to a better understanding of western North America.

Because our results help us figure out the amount of deformation in Antarctica, we can then reconstruct the position of the Pacific plate with respect to all the other plates. Once we can do this, we can then build other observations into our models—for example, the wandering of the Earth's magnetic pole. The Earth's magnetic pole coincides with the planet's spin axis, which has wandered a certain amount with respect to the plates or to the hot spots. The various models that assume that the hot spots are fixed, or are not fixed, give different pictures of how the magnetic pole has actually wandered over the past several million years. We haven't yet incorporated the results from our cruises into these kinds of models, but we expect they're going to be important. Our new data from the Antarctica plate will probably also help solve a disagreement, arising from plate reconstructions, about the Pacific plate's latitude relative to the Hawaiian hot spot.

Now our task will be to analyze all of these data we've collected. But in the meantime we're planning another cruise in May to gather still more data to help us reconstruct the Pacific plate relative to other plates. We won't need an ice-breaker this time, and there won't be any snowmen on the helicopter deck. We'll be surveying the seafloor around the Manihiki Plateau—sailing from American Samoa to Honolulu. □

Joann Stock delivered the Watson Lecture on which this article is based last March, shortly after returning from her latest journey to Antarctica. She travels a lot—her article in the Fall 1993 issue of E&S *described her field work in Baja California, which has been rifted away from the North American plate as the Pacific plate slides past. Since then Stock has continued to work in Baja California as well as Antarctica; she has also been granted tenure and had a daughter, Gabriella Wernicke, now going on 3. (Stock's husband is Professor of Geology Brian Wernicke.) Stock received her BS and MS in geophysics (1981) and her PhD in geology (1988) from MIT and has been associate professor of geology and geophysics at Caltech since 1992.*

Also involved in the Antarctica research were Steven Cande of the Scripps Institution of Oceanography; Carol Raymond of JPL; Dietmar Müller of Sydney University in Australia; and Robert Clayton, professor of geophysics at Caltech. Several Caltech grad students have also participated in these cruises: Tim Melbourne, Magali Billen, Jane Heinemann, Nathan Niemi, Igor Sidorin, and Judy Zachariasen, as well as undergrad Katy Quinn. Katrin Hafner, member of the professional staff, was also part of the group and took many of the photographs in this article. The work was supported by the National Science Foundation.