How Far Did the West Wander?

Two new studies are renewing the controversy over how far chunks of the continent's west coast have traveled—and highlighting a rift between geologists and geophysicists

In geology, some questions have the durability of granite. Thirty years after earth scientists finally concluded that great tectonic plates drift about the planet, another battle about the dynamics of Earth's surface is still raging. The central issue in the debate is simple: Are chunks of western North America actually travelers from 3000 kilometers to the south, as many geophysicists contend, or have they only journeyed at most a few hundred kilometers northward, as most geologists think?

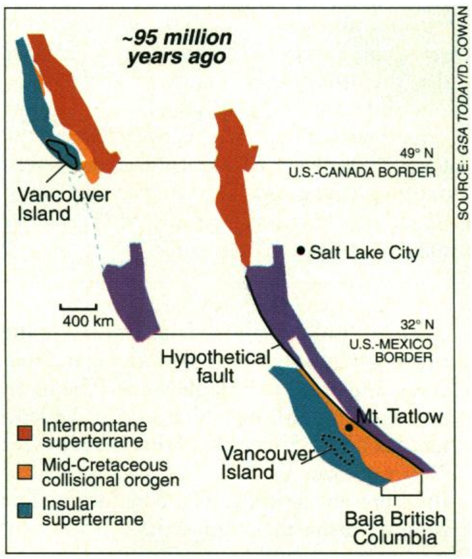
This time, the debate doesn't pit one philosophy of the Earth against another, as it did in the tectonics debate, where one side argued that Earth is static and the other countered that it is mobile. Both camps agree that these chunks of crust, or terranes, have moved from elsewhere to their present sites along the coast of British Columbia, southern Alaska, and perhaps parts of California, shunted about by plate tectonics.

What's in question are the details of their history, and who is better equipped to decipher that history: geologists, who do hands-on study of rocks in the field, or geophysicists, who analyze impalpable signals from rocks in the laboratory. Now the geophysicists have loosed their latest salvo in the battle over who has the best measure of tectonic motion, and they think it's a decisive blow.

In the 10 April issue of the *Journal of Geophysical Research*, Jane Wynne of the Geological Survey of Canada (GSC) in Sidney, British Columbia, and her colleagues present a study of the trace magnetism in the rocks near the British Columbia coast. The magnetism—a relic of Earth's ancient magnetic field frozen into the rocks when they formed about 95 million years ago—shows, they say, that the rocks formed at the latitude of present-day Baja California and later slipped northward 3000 kilometers along a giant fault like the present-day San Andreas. Designed to answer all the critics of the Baja–British Columbia hypothesis, this study is "bombproof," says Wynne.

"I think the battle's over," says paleomagnetist Myrl Beck of Western Washington University in Bellingham, who first proposed traveling terranes more than 20 years ago. Wynne and her colleagues "have dotted every i and crossed every t, some of them twice. I can't see how anyone can find fault with their work."

Don't bet on it. Geologists, along with some other paleomagnetists, are raising technical questions about the work and are starting to gather new evidence from rocks and fossils that suggests a nearby origin for the terranes. Perhaps the more stubborn obstacle to a consensus, however, remains what geologist Raymond Price of Queen's University in Kingston, Ontario, calls a "conceptual gulf." Geologists and geophysicists often see the world with different eyes (see box on p. 636). And when geologists walk the rocks of British Columbia they see "no room to get a big [San Andreas–type] fault through the area ... no room for the big-displacement interpretation," says Price. At the same time, geophysicists looking at their laboratory data "see no way around it."



Wanderer or longtime neighbor? In one scenario *(right)*, the crust of British Columbia migrated from 3000 kilometers south.

This huge fissure began opening in 1972, when Beck raised the possibility that, long before the San Andreas fault began slicing up the western edge of North America, longer faults might have let chunks of crust slide northward hundreds—or even thousands—of kilometers. Among geophysicists, the idea gradually caught on, says Beck: "Almost all of us found good reason to believe that northward transport [of terranes] on the order of several thousand kilometers was a fairly common occurrence." The key evidence came from paleomagnetism. At the equator, Earth's field is horizontal. At the poles, it is vertical. So, the farther north a rock forms—whether by cooling from magma or solidifying from sediment—the more inclined the magnetic field that it records should be.

Up and down the west coast of North America, such measurements revealed paleomagnetic inclinations shallower than those of rocks of the same age from the continent's interior, implying that coastal rocks had moved northward by up to 3000 kilometers. In one scenario, these terranes formed off the coast of northwest Mexico as islands or volcanic arcs, then drifted east, docking with the continent in a tectonic collision between about 100 and 80 million years ago. When plate motions shifted about 80 million years ago, they slid northward along a great fault or system of faults to their present location.

A faultless proposal?

Most geologists couldn't disagree more with this picture. "If, after 20 or 30 years of producing [geological] field maps," says geologist Peter Mustard of the GSC in Vancouver, "people can't put their fingers on faulting or a system of faults ... then you've got to say—well, where did the movement happen? It's a very well hidden fault if it did happen. The geophysicists say it's there, we just haven't found it yet, or they say it's been deformed so many times we can't see it any more. Most Canadian geologists are dubious about that."

Not that these geologists doubt the terranes have migrated to their present sites. Marked differences between parts of the continental edge and the interior suggest that some terranes, like those in western British Columbia, are "exotic." But geologists believe they probably formed offshore and docked near their present latitudes. The long-migration advocates have been misled, these geologists and a few paleomagnetists argue. As Beck puts it, these critics say "the geology is causing the paleomagnetics to lie."

Most of the rocks used in paleomagnetic studies in British Columbia formed during terrane docking when huge masses of magma rose and solidified within the crust to form structures called plutons. Paleomagnetists, for lack of any way to tell otherwise, have assumed that the orientation of the plutons hasn't changed since they formed, even as erosion removed the overlying rock and ocean plates continued to bang and scrape past the continent. "I think that's ludicrous," says geologist William McClelland of the University of California, Santa Barbara. "It's just unreasonable to think that's the case."

Finding Fault: Culture Clash in British Columbia

The argument in the earth science community over whether the rock beneath British Columbia formed nearby or 3000 kilometers away has just heated up. But the cultural divide between geologists and geophysicists that underlies that debate is a familiar theme in earth science.

"You don't have to go back very far to run into similar arguments, like the continental drift debates," notes paleomagnetist Robert Butler of the University of Arizona. "The predominant view among geologists was that continental drift was baloney. A fair number of paleomagnetists were saying 'We see evidence for it; we think it happened.' They were right in that case."

The jury's still out on who's right this time (see main text), but the lines between the two cultures are clearly drawn. "Geologists like something that they can all look at on a map or all go out and take a field trip to and say, 'Yes, here it is,' " says geologist Darrel Cowan of the University of Washington. And that's just what they don't see with the long-migration hypothesis, which is built not on what can be seen in the field but on laboratory measurements of the traces of Earth's magnetic field frozen into rock.

As geologist Peter Mustard of the Geological Survey of Canada (GSC) in Vancouver puts it, "We don't see the things you would expect to see" if British Columbia had slid up from the latitude of Baja California. "For one thing, we don't see the fault" along which British Columbia supposedly moved. "You have to wonder if there's something wrong with something [the paleomagnetics] that is basically a mathematical calculation, based on geophysics. ... There's a certain amount of magic involved."

Paleomagnetists and even a few geologists, however, are impatient with what they see as the conservatism of many geologists. "The fact that they haven't seen anything is not an argument," says paleomagnetist Jane Wynne of the GSC in Sidney, British Columbia, who has just come out with the strongest paleomagnetic case yet for the Baja–B.C. connection. "The absence of evidence is not proof." Cowan adds that his geologist colleagues "don't evaluate hypotheses the way we should—go out on a limb and make predictions" and then test those predictions.

In that respect, some geologists are now taking a new tack. They are collecting new kinds of direct evidence to test the Baja–British Columbia hypothesis or are looking at the rocks with new eyes. "We're finding whole sets of faults we didn't know existed" near the British Columbia coast, says Margaret Rusmore of Occidental College in Los Angeles, although she adds that the new faults cannot yet explain 3000 kilometers of slip.

But many of her colleagues are too skeptical of the paleomagnetic evidence to take the hypothesis seriously. "If you make extraordinary claims in science, you need extraordinary documentation," says geologist Jason Saleeby of the California Institute of Technology, "and most of the documentation based on paleomagnetism is not extraordinary."

British Columbia may or may not have moved northward, but earth scientists seem deadlocked. "I think it's up to geologists to disprove this," says paleomagnetist Wynne. Responds geologist James Monger of the GSC, "It's her problem just as much as ours."

–R.A.K.

And if geological processes did tilt the plutons, an originally steep magnetic inclination could now look shallow, causing the rocks to lie about where they had formed.

To convince their geological colleagues that they weren't being deceived, paleomagnetists needed some sort of geo-inclinometer that records and preserves the original orientation of the rocks. Two possibilities are sedimentary rocks and lavas, both of which form in horizontal layers. But nothing horizontal stays that way for millions of years in an active mountain belt. So Wynne and her colleagues—Edward Irving of the GSC in Sidney and Julie A. Maxson and Karen Kleinspehn of the University of Minnesota—made their measurements in obviously warped sedimentary and volcanic rock layers near Mount Tatlow in the Coast Mountains of southwest British Columbia, then corrected for the folding. In effect, they "unfolded" the rocks to determine the original orientation of the field.


JAMES W. HAGGART/GSC

A homebody? Fossils like this ammonite suggest British Columbia has stayed put.

The magnetic inclinations of the rocks as they rest today are scattered over a wide range. But when Wynne and her colleagues ran the clock backward, adjusting each measurement individually to compensate for the tilting of the rock, the wide-ranging inclinations converged to a single value. The inclinations averaged to $56.8° \pm 4.8°$ in the sediments and $51.5° \pm 8.0°$ in the volcanics, or 20° shallower than if they had formed at their present latitude. The conclusion: The Mount Tatlow rock formed 3000 ± 500 kilometers to the south.

Beck is impressed by the Mount Tatlow study, as are others who heard Wynne's talk last October at the annual Geological Society of America (GSA) meeting in Seattle, but there is sure to be criticism. "This is a serious piece of work," says paleomagnetist Robert Butler of the University of Arizona, a longtime critic of the Baja–British Columbia hypothesis. "They tried hard to get a message out of these rocks and resolve the issue, but the rocks are not untainted, you know."

Butler is referring to the hot, corrosive fluids released by fingers of magma that intruded parts of the formations. Wynne and company agree that volcanic fluids did alter one third of their rock as it was folding, creating new magnetic minerals with anomalous orientations. But Butler says that the process might have also altered and remagnetized the rock before it was folded, but after it had tilted as a single mass. That way, the "unfolded" rock would show consistent inclinations—but the inclination would not be a true indicator of the rock's original location.

Wynne and her colleagues saw that complaint coming and have some ready answers. For one, they doubt that any altered rock escaped their tests, pointing out that all rock with anomalous orientations also showed clear signs of alteration. And they say the microscopic appearance of the remaining samples, together with the high stability of their magnetic fields, suggest the rock was magnetized when it formed or shortly thereafter, and not by invading fluids.

Even if the Mount Tatlow study holds up, most proponents know they'll need more than one "bombproof" site to prove anything. But help may be on the way. At the GSA meeting last fall, paleomagnetist Scott Bogue of Occidental College in Los Angeles and his colleagues presented their results from an unusual pluton on Duke Island offshore of southeastern Alaska—a pluton that has layers. In the simplest scenario, the layers formed as crystals grew in the cooling magma and settled to the magma chamber floor. Some geologists say that's a dubious proposition. But if it's correct, the layers would provide a good marker of the pluton's original orientation. The results imply, Bogue says, that the Duke Island pluton formed 3400 ± 1300 kilometers to the south.

That finding "agrees almost exactly with results from the Coast Cascade Belt by us," notes Wynne. "If you had just that result to build this large-displacement case, you would be on weak ground, but it would be a remarkable coincidence if they went through all those machinations and still got a result that agreed with ours."

No common ground

This one-two punch has left the geologists unfazed—and ready with some counter-punches. At the GSA meeting, Mustard reported that he and his GSC colleagues studied the origin of 75-million-year-old sediment in the Nanaimo basin of southwest British Columbia. The sediment fans out to the west, showing that it had washed down from the east. As a result, its mineral grains should yield clues to where the terrane was docked 75 million years ago. If it lay next to Mexico, the zircon grains in the sediment should be about 1 billion years old, the most common age of the Mexican rocks that would have been eroded to supply the sediment. If British Columbia were instead about where it is now, the zircons washed in from the east would be more than 2 billion years old.

In fact, uranium-lead dating of the Nanaimo zircons showed them to be on the old side, Mustard reported. "Certainly the zircons we got are the ones you would expect to get from maybe 500 kilometers [to the south] or even up to 1000 kilometers, but nothing like 3000 kilometers."

Marine fossils in coastal rocks are also offering preliminary evidence against a distant origin for terranes. If the rocks originated far to the south, the mollusk fossils and radiolarian microfossils they contain should represent warmer-water species. But most of the 145- to 100-million-year-old fossils that James Haggart of the GSC in Vancouver and Elizabeth Carter of Portland State University in Oregon studied were characteristic of temperate and northern latitudes, suggesting the terrane has largely stayed put.

The geologists and their paleontologist allies say they won't stop there in their effort to counter the latest volley from the paleomagnetists. To Margaret Rusmore of Occidental College, this competitiveness is one of the beauties of the controversy. Rusmore, a structural geologist who works in British Columbia and is married to paleomagnetist Scott Bogue, sees the dispute from both sides: "It's amazing how riled up people can get about this at meetings. It's great; it's spurring a lot of good research, and eventually I think we'll come up with some sort of resolution."

Unless geologists and paleomagnetists change their stripes, however, that resolution will come only when both kinds of evidence finally agree. As geologist Vicki L. Hansen of Southern Methodist University notes, neither side is likely to change its standards of evidence: "It's kind of like religion."

–Richard A. Kerr

Additional Reading

D. S. Cowan, "Alternative hypotheses for the Mid-Cretaceous paleogeography of the western Cordillera," *GSA Today* **4**, 184 (1994).

OPHTHALMOLOGY

Envisioning an Artificial Retina

A speck in your eye usually obscures vision. But now researchers in Boston are trying to reverse the usual order of things. They've placed a speck of microelectronics in rabbits' eyes that might—eventually—have a vision-enhancing effect in humans, restoring sight to some blind people.

The speck is a tiny microchip that sits at the back of the eye, and it's designed to translate visual information into electric pulses that are sent to the brain. The device would be a partial substitute retina, a prosthesis for people who have lost the eye's light receptors—the retina's rod and cone cells—through diseases such as retinitis pigmentosa, which affects 1.2 million people worldwide, and age-related macular degeneration, the leading cause of blindness in the West.

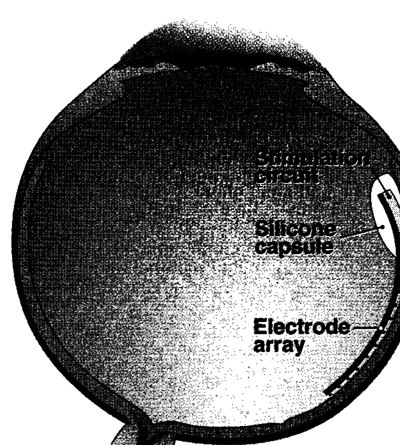
There are researchers who doubt this ambitious goal can be achieved. But in March, scientists on the Project for a Retinal Implant (PRI), a joint effort of the Massachusetts Eye and Ear Infirmary, the Massachusetts Institute of Technology (MIT), and Harvard Medical School, completed experiments that offered considerable encouragement. They finished a series of brief in vivo trials of prototype retinal implant components in rabbits. The test devices delivered tiny electrical currents to ganglion cells—the nerve bodies on the inside surface of the retina that feed into the optic nerve—and produced measurable activity in the visual cortex of the animals' brains.

These results, say some scientists who are following the research, reflect glimmers of the project's eventual success. "If they can create an effective interface and there are viable ganglion cells, they should be able to produce a partial retinal replacement," says Terry Hambrecht, a physician and electrical engineer who heads the Neural Prosthesis Program at the National Institute of Neurological Disorders and Stroke.

But those are still big "ifs," for even the PRI researchers acknowledge that the uncertainties at the interface between technology and human tissue are legion. "We're facing a number of very significant obstacles, one after the other," says Joseph Rizzo, a neuro-ophthalmologist at the Massachusetts Eye and Ear Infirmary and lead PRI investigator.

The problems fall into three main categories. First, researchers still have to determine how healthy ganglion cells are in the eyes of blind human beings. Second, the scientists need to develop an implantable chip that won't tear or poison the delicate retina. Finally, they must face the biggest problem of all: getting the chip to package visual information in a form the brain can use. And there are certainly researchers who don't believe these problems can be solved. Peter Schiller, a neurophysiologist at MIT, says he doubts any implant will be capable of mimicking retinal output well enough to produce anything resembling normal vision. In the face of such skepticism, the PRI team has not pursued large-scale funding, hoping to first bolster their case with small pilot projects.

What they hope to end up with is a prosthesis that includes a camera, mounted on eyeglasses, that captures visual images with an electronic analog to film known as a charge-coupled device. The device would digitize the images, and the information would be beamed via laser onto the retinal implant. Exploiting an attached electrode array, the chip would convert the laser pulses into a pattern of electric signals. In theory, these signals would then stimulate the nearest ganglion cells, which transmit the information to the optic nerve and the brain, enabling the wearer to perceive an image.



SOURCE: PRI

Implant in progress. This microchip assembly could substitute for a damaged retina.

This vision, however, depends on there being enough healthy ganglion cells remaining to transmit the information to the brain.