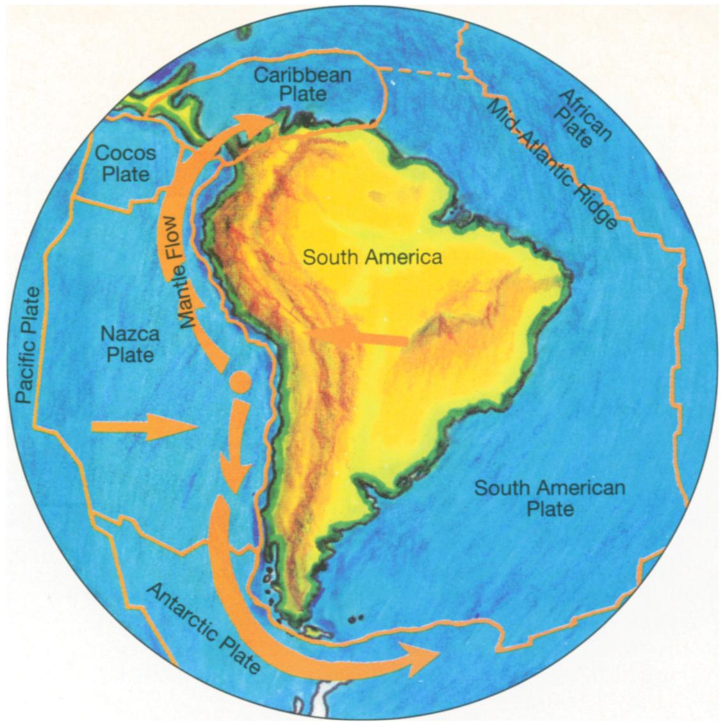
Raising the Andes

The view beneath South America shows some surprises

By RICHARD MONASTERSKY



What moves South America? The standard theory holds that the creation of new ocean crust at the mid-Atlantic Ridge pushes the South American plate westward. But new evidence suggests that South America gets dragged toward the Pacific by mantle currents moving beneath the plate.

Seen from space, the curved hook of the Andes Mountains looks a bit like a walking cane ready to head westward on a jaunt across the Pacific Ocean. If you could peer outward from the center of Earth, however, a different pattern would emerge: The same arcing shape would turn into a continent-size question mark.

The question that needs answering is why the Andes exist at all, contend geophysicists Raymond M. Russo and Paul G. Silver, who claim that the classical theory of plate tectonics offers no explanation.

World-class mountain ranges are formed, in theory, only when two continents run into each other, as India and Asia are doing today. That continental shoving match has over the last 40 million years compressed the landscape as though it were an accordion, raising up the Himalayas and the Tibetan plateau. Similarly, the Andes show massive compression in places and possess a high plateau like Tibet's.

But whereas India is plowing into Asia, South America has no continental opponent to push against. So what forces have erected the Andes, the highest peaks in the Western Hemisphere, ask Russo and Silver, former colleagues at the Carnegie Institution of Washington, D.C. (Russo has since moved to the University of Montpellier II in France.)

Instead of focusing their attention on the tectonic plates covering Earth's surface, the two scientists used seismic waves to look deeper into the planet, probing the hidden reaches of the mantle. Their findings led to a far-reaching theory that seeks to explain not only the Andes, but also the Rocky Mountains and a host of other peculiar features on Earth.

"If it's true for South America, then it's probably true for North America. And if it's true for North America, then it's probably true for the rest of the Atlantic as well," Silver told a meeting of the American Geophysical Union (AGU) in Baltimore in May.

He and Russo did not start out with such grand ambitions. Their theory arose only after they noticed something unusual about the earthquake waves passing beneath South America.

The two researchers were trying to track the movement of mantle rock a few hundred kilometers under the western edge of the continent. Although the mantle is solid, the high pressure and temperatures deep inside Earth cause rock to flow slowly, like a soft plastic. Seismologists can discern the direction of mantle flow by looking for anisotropy—differences in the speed of earthquake waves depending on their direction and polarization. This technique works because rock crystals tend to align themselves in the direction of flow, changing the speed at which they transmit seismic waves.

Seismic wave studies thus gave the geophysicists a way to see through solid rock to the subterranean streams in the mantle underlying South America. Before starting their study, Russo and Silver had expected that mantle currents would mirror the movement of the tectonic plates on Earth's surface. One of these, a patch of the Pacific seafloor called the Nazca plate, slides eastward underneath South America at about 6 centimeters per year, in a process geophysicists call subduction. Meanwhile, South America moves westward at about half that speed.

According to theory, mantle currents should flow with the eastward-moving Nazca plate. But the seismic data collected by Russo and Silver pointed to a north-south movement instead. The region of the mantle beneath the Nazca plate apparently flows parallel to the west coast of South America, at right angles to the anticipated orientation.

To explain the discrepancy, Silver invokes what he calls the "bad-boat analogy." Think of a square-fronted boat trying to push its way through the sea. The awkward ship can advance only by forcing water to flow around its wide bow.

This is how Russo and Silver picture the undersides of South America. As the continent moves westward, it bulldozes through the mantle, forcing rock to flow parallel to the coastline until it can swing around the continent's northern and southern tips. Recent seismic data collected in Venezuela support this concept. There, the mantle appears to flow east-west, as if it were curving around the bulky northern end of South America.

Just as the bad boat might suffer some damage to its bow, so too does South America. Plowing through the mantle generates tremendous pressure along its western coastline, causing it to buckle.

Such stress helps explain why the Andes have formed in the absence of a continental collision, say Russo and Silver.

Other factors have also played a role in raising the Andes, note the researchers. Many of the peaks are volcanoes, fed by rock that melted off the sinking Nazca plate. Yet the volcanic process alone cannot explain the east-west compression of the mountain range, seen especially in the central Andes, contend Russo and Silver.

To test the bad-boat theory, Carnegie scientist L.P. Solheim used a computer model to simulate the motion of a wide continent through the mantle. At the AGU meeting, he argued that the model can explain many of the features of South America. Both simulated and real continents show the greatest damage midway along their leading edges, where mantle flow splits into two currents, one heading north and one south. The Andes reach their widest extent at this point, forming the high plateau known as the Altiplano. The coastline is even indented here, as though South America had wrapped itself around a telephone pole. The model also predicts that the northern and southern tips of the continent should curve eastward, as they do in South America.

"The actual shape of South America is close to what you would expect for an object moving through a fluid and getting deformed in the process," says Silver.

Looking north, Russo and Silver wonder if a similar process marked North America's history. The Rocky Mountains, they note, show a distinctive bend and widened midsection reminiscent of the Andes. Furthermore, during the time that the Rockies rose, about 100 million years ago, North America had a subduction zone off its west coast similar to the one along South America today.

If continents can plow through the mantle, what forces would drive them directly into an oncoming stream? Russo and Silver find a potential answer beneath the plates. They suggest that South America and North America are swept westward by a deep, wide mantle current originating beneath the Atlantic Ocean.

That suggestion, however, runs counter to the prevailing view among geophysicists, who believe that a deformable layer called the asthenosphere separates the surface plates from deep mantle flow. In this standard model, the forces that drive plates come not from below, but from the plates' front and back edges. Plates that sink into the mantle, such as the Nazca plate, are pulled along by their foundering front ends. Other plates, such as South America, receive a push from the rear as new crust forms at midocean ridges.

Last year, Randall M. Richardson of the University of Arizona in Tucson and his colleagues concluded that this ridge-push effect can account for the motion of South America and the height of the Andes. "You don't need anything special to hold up the Andes," says Richardson.

In another study of South America, Donna M. Jurdy of Northwestern University in Evanston, Ill., found that the conventional ridge-push force could account for most of the continent's motion. "I don't see any reason to call on anything else," says Jurdy.

Russo and Silver remain undaunted, however. "We can demonstrate unequivocally that the driving force for South America has to be the deep mantle flow," says Silver.

In fact, evidence to support their idea has popped up in an unexpected place, just a few doors down the hall from Silver's office. In a completely unrelated study, Carnegie seismologists John VanDecar and David E. James discovered signs that a deep mantle current has carried South America westward for the last 130 million years.

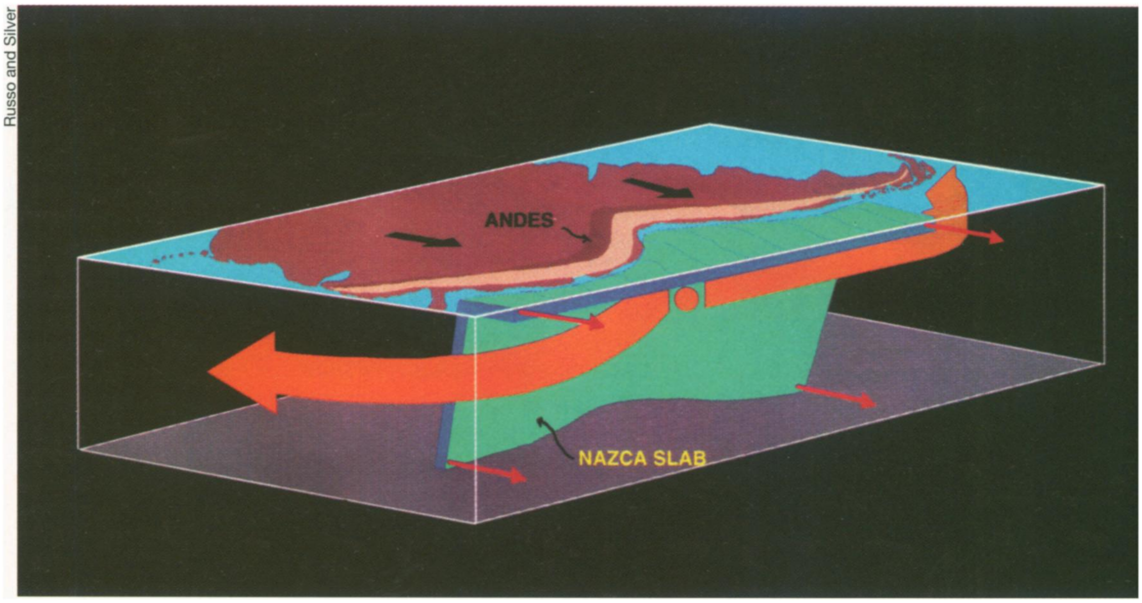
VanDecar, James, and their South American colleagues performed seismic tomography—a technique akin to the medical computerized axial tomography, or CAT scan—using earthquake waves recorded at sites in Brazil. Seismic tomography can identify deep-seated structures because density and temperature differences in the mantle alter the speed of seismic waves.

Tomographic images of the mantle underneath Brazil revealed that seismic waves slow down as they pass through a vertical column extending from a depth of 600 kilometers to about 200 km. The position of the structure hints at its origin: The column leads directly to the Paraná Basin in Brazil, where huge volumes of basalt erupted about 130 million years ago. VanDecar and his colleagues suggest the vertical feature represents the fossilized plume created by hot rock as it rose through the mantle toward the surface.

The presence of a relict plume conduit surprised the scientists. Since the time of the Paraná eruptions, the continent has moved some 3,000 km to the west, yet the eruptive source has remained fixed. The same plume of hot rock that fed Paraná now supplies eruptions at Tristan da Cunha in the middle of the South Atlantic.

The fossilized conduit has somehow managed to remain in place beneath South America over a long stretch of geologic time. The most likely explanation is that a deep mantle current has carried both the mantle shaft and the South American continent on a slow westward journey, the scientists told attendees of the AGU meeting.

The new findings will probably drive other scientists to focus their attention beneath South America for clues to the geologic forces directing its movement. "It's a perfect laboratory because it is just about the simplest continent you could imagine," says Silver. "So if we can resolve this problem for South America, then we can start to look at other continents, where the situation isn't so clear-cut." □



Russo and Silver

As South America moves westward, it plows through the mantle, forcing rock to flow out of the way. Orange arrows show how mantle currents carry rock north and south around the bow of South America. The force of pushing through the mantle has deformed the continent, particularly at the so-called stagnation point, where mantle currents must diverge to the north and south. The Nazca plate, or slab, is a portion of the Pacific Ocean floor currently sliding underneath South America.