sequence of this gene doesn't match that of any of the previously described glutamate receptors," Michaelis concedes. Nevertheless, he argues that the activity of the encoded protein is consistent with what is known about the receptor they're seeking. "At this stage, I think our receptor matches quite well the known literature on NMDA receptors."

Precisely the same claim, however, is made by Nakanishi and his colleagues. "Our receptor has the function of the NMDA receptor. I am satisfied that our results are consistent with the predictions for this receptor," he says. When Nakanishi put his receptor protein through its paces, it performed as expected: It allowed the passage of calcium ions, it responded to the same drugs as the native receptor and was unresponsive to those that the native receptor would not respond to.

Furthermore, the structure of the single protein found by the Kyoto group is similar to other glutamate receptor proteins—including the kainate receptors. Like those other known receptors, says Nakanishi, the protein they have found has four segments crossing the membrane, and the portion of the molecule that sticks out of the cell is especially large.

"Nakanishi's [method] generated a clone that had virtually all of the properties of an NMDA receptor."

—Mark Mayer

For Mayer and others who think the Japanese are running on the right track, the clincher is that the receptor found by the Kyoto team is co-activated by the amino acid glycine, which, says Mayer, is a "hallmark of the NMDA receptor. We do know from Nakanishi's work that a single receptor subunit when combined with more of the same will make a functional receptor."

But the final determination of which group really has the receptor can be worked out only by performing more functional studies on protein chemistry. That work is now under way in the Nakanishi and Michaelis laboratories, and, given the recent publication, will likely be pursued in many other labs as well. "When these sequences come out, people will try to reclone it instantly," says Stevens. And the biochemical work done in those labs on the two clones will provide the late result in this longest-running of gene-cloning horseraces.■ MICHELLE HOFFMAN

Ancient Rocks, Rhythms in Mud, a Tipsy Venus

The Geological Society of America's annual meeting, held 21 through 24 October in San Diego, drew 6000 geologists and spanned planets' worth of news—the earliest plate tectonics on Earth, the latest revision of the geologic timescale, the gregarious volcanoes of Venus. Here are findings that captivated all who heard of them.

Pushing Plate Tectonics Back a Billion Years

According to the conventional wisdom in geology, plate tectonics—the jostling of great sheets of rock that now shapes much of the earth's surface—didn't get started until at least 2 billion years after the planet's formation. Rocks older than that just looked too different from those being produced by plate tectonics today. But at the meeting a group of Japanese scientists argued that plate tectonics was already under way almost 4 billion years ago, less than a billion years after the planet's formation. The evidence, they say—the debris of an ancient continental collision—is there for all to see on the west coast of Greenland.

That's going to be a lot for some geologists to swallow. In the 20 years since earth scientists convinced themselves that the planet's surface is a jigsaw puzzle of moving plates, the agreed starting point for the process has been pushed back—from 250 million years ago to perhaps 2.5 billion years ago—as geologists grow more adept at recognizing the signature of plate tectonics despite the ravages of time (*Science*, 20 December 1985, p. 1364).

Some geologists said they could see plate tectonics at work in even older rocks, from the Archean eon, but many researchers could not and have refused to go that far. After all, theorists had an explanation for the absence of plate tectonics before 2.5 billion years ago. At the end of their geologic lifetimes, plates sink back into the planet's interior; before 2.5 billion years ago, said the theorists, Earth's surface layers were simply too hot and buoyant to do so.

"We needed direct evidence of plate tectonics" to resolve any doubts, says Shigenori Maruyama of the University of Japan at Komaba, "and we found it at Isua." What Maruyama and his colleagues thought they saw among the 3.8-billion-year-old rocks at that well-studied field site near the southwest coast of Greenland were abundant signs of ocean crust that had been formed and transported by plate tectonic processes.

Although metamorphosed by burial deep beneath the surface in the interim, the classic components of the upper ocean crust were recognizable, according to Maruyama. From the top down, there were sediments, pillow-shaped mounds of lava that only form under water, and the silica-poor rocks that typically form in the magma chambers beneath the mid-ocean ridges of the recent past. These rocks thus gave every sign of having formed at an ancient mid-ocean ridge, says Maruyama; plate motions must then have carried the newborn crust away until it collided with an ancient continent.

That's just the process that has built much of the crust of modern-day island arcs like Japan. Indeed, Maruyama credits the discovery to his group's familiarity with such accreted ocean crust in Japan. Because they are younger, those rocks served as a good training ground for recognizing similarly produced rocks in Greenland despite 4 billion years of change, he says.

"This is a very innovative and exciting interpretation," says geologist Samuel Bowring of the Massachusetts Institute of Technology. Given earlier geologic, geochemical, and geochronological evidence, Bowring was already inclined to push plate tectonics back into the Archean. In the light of the new results, he says, "the burden of proof should be with those who say things were different in the Archean." The rocks of Isua will no doubt be at the center of that debate.

Ocean Mud Pins Down a Million Years of Time

The pace of the past million years of earth history just slowed down a little, thanks in large part to the persistence of a handful of paleoceanographers. Based on a record of Earth's clock-like nodding and wobbling preserved in deep-sea sediments, they have been arguing that the traditional date for a key event in the past million years, derived from the steady decay of radioactive isotopes, is off by as much as 50,000 years. Now, new radiometric dates presented at the meeting confirm the paleoceanographers' timescale.

Traditionally, radiometric dating is the standard of precision and accuracy for telling geologic time. But during the 1980s some radiometric daters began to worry about the age they had determined for a primary benchmark of the conventional timescale—the Brunhes-Matuyama magnetic reversal, a flip-flop of Earth's magnetic field. By measuring how much radioactive potassium-40 had decayed into argon-40 in volcanic rocks that had solidified at the time of the reversal, researchers had dated it at 730,000 years. But some daters eventually became suspicious that they might not be extracting all the argon from the rock. That would mean their age for the Brunhes-Matuyama reversal was too young by some undetermined amount.

Meanwhile, in the early 1980s, paleoceanographers began putting together their own timescale based on Earth's orbital variations, a then obscure phenomenon never before used to measure time. These periodic oscillations of the planet's axis at regular periods of 23,000, 41,000, and 100,000 years cause climate changes—the most dramatic of which are the ice ages—that leave their signature in ocean sediments in the form of variations in oxygen isotope composition. The paleoceanographers' idea was to count the number of less-than-perfectly preserved astronomical cycles in the sedimentary record in order to date other events that have also left their mark in the sediments.

The Brunhes-Matuyama reversal is one such event. In the first effort to count the sedimentary cycles back to the reversal, the Spectral Mapping (SPECMAP) group headed by John Imbrie of Brown University developed a sophisticated "objective" approach for extracting astronomical cycles from the isotope variations. Out came a date of 734,000 years—a comforting match to the radiometric age of 730,000 years (*Science*, 9 September 1983, p. 1041). But not everyone was content with the SPECMAP timescale.

Robert Johnson of Minnetonka, Minnesota, an engineer and, in Imbrie's words, "an intelligent amateur" in the field of astronomical cycles, thought he could make a better match between sedimentary cycles and orbital variations. His solution: Fit in an additional one and a half 40,000-year cycles after the Brunhes-Matuyama reversal, making it 790,000 years old. Imbrie rejected Johnson's fit as statistically invalid. But last year Nicholas Shackleton of Cambridge University, who had been a SPECMAP member, followed Johnson's lead while using the longer, higher quality sedimentary records recovered by ocean drilling during the past decade. "His hunch was right," says Shackleton. The new astronomical timescale placed the Brunhes-Matuyama at 780,000 years.

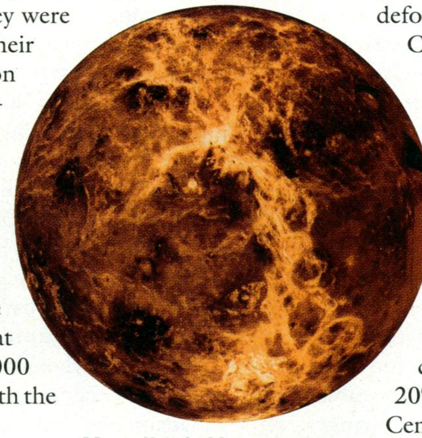
Faced with that challenge, radiometric daters redoubled their efforts. Ajoy Baksi of Louisiana State University and his colleagues dated Hawaiian volcanic rocks formed during the reversal using the improved version of potassium-argon dating—called argon-40-argon-39 dating—which does not suffer from incomplete argon extraction. At the meeting, Baksi reported an age of 780,000 ± 7000 years. Glen Izett and John Obradovich of the U.S. Geological Survey in Denver hadn't even heard of Shackleton's results—he had published them in the *Transactions of the Royal Society of Edinburgh*—but they were still trying to refine their earlier potassium-argon ages. Using a laser-fusion version of the argon-argon method, they dated volcanic rocks bracketing the reversal in California and New Mexico. Their best date for the reversal, as reported at the meeting, is 790,000 years, another match with the astronomical date.

With that triumph under their belts, the paleoceanographers are now pressing on, extending their timescale beyond the past million years. Five thousand meters of high-quality cores just recovered from the equatorial Pacific on Leg 138 of the Ocean Drilling Program promise a record of orbital variations in the form of color and density variations—properties easier to trace than oxygen isotope composition. Shackleton looks for an extension of the astronomical timescale back 5 million to 10 million years. At that rate, the sedimentary cycles could end up muddying a few more radiometric dates.

Magellan Finds a Flock of Venusian Volcanoes

If patterns on the surface of a planet can betray the unseen workings of its interior, Venus has given planetary scientists a heavy hint. The Magellan spacecraft has now mapped 80% of the planet's surface, and the images it has returned to Earth show that volcanic activity is concentrated in a splotch of volcanoes and lava flows 10,000 kilometers across, centered on the equator. The cluster may imply the existence of a great upwelling of hot rock deep below the volcanoes. It may even explain why the planet's equator is where it is today.

The pattern emerged from planetary scientists' efforts to make sense of Magellan's 12-month harvest of data: radar images so detailed they could reveal a Rose Bowl-sized feature on the surface. Within the Magellan data analysis program, the task of cataloguing volcanic features fell mainly to Larry S. Crumpler and Jayne Aubele of Brown University. In their survey they included kinds of features familiar from Earth, such as volcanoes, lava floods, and lava channels. But they also catalogued exotic Venusian markings such as coronae, arachnoids, and novae, thought to be caused by upwelling magma that has cracked and deformed the surface. All told, Crumpler and Aubele counted more than 1400 volcanic centers.


NASA/JPL

Magellan's Venus. *Volcanoes cluster on the equator at the far right side.*

When the researchers plotted the locations of their volcanic centers on a global map of Venus, a striking pattern emerged. More than half of the centers fell within a roughly circular cluster that occupies only 20% of the planet's surface. Centered on the equator between the eastern end of the highland of Aphrodite Terra and the volcanic center Beta Regio, the cluster has a density of volcanic centers two to three times greater than found elsewhere on the planet.

Venus thus joins Mars and Earth in having at least one broad concentration of volcanic activity. Mars has its smaller but higher-elevation Tharsis region with several volcanic centers, and Earth has two clusters of volcanic hot spots, one centered on Africa and the other in the Pacific. Although the Pacific cluster has been linked to a single "superplume" of rising heat-softened rock (*Science*, 15 February, p. 746), Crumpler imagines a different style for Venus: a broad zone of upwelling rock composed of many smaller plumes, like a cluster of thunderheads on a summer afternoon.

Whatever its origins, the volcanic cluster may have done more than dimple Venus's surface with craters and lava flows, suggests Crumpler. Originally, the volcanic centers may have formed far from the equator, but the added mass they deposited on the planet's surface may have slowly tipped Venus over until the cluster arrived at the equator, the most stable position for a mass concentration on a rotating body. Now that would be a mighty volcano. ■ RICHARD A. KERR