SPINNING THE SUPERCONTINENT CYCLE

Is the dance of the continents a minuet or a jitterbug? North America casts its own vote.

By RICHARD MONASTERSKY

Today, half a dozen hours in a jumbo jet separate North America and Africa, but 200 million years ago the two continents touched. Such is the power of plate tectonics – the system that drives Earth's continents slowly around the globe.

Actually, about 300 million years ago, all the continents on Earth had drifted together to form a huge supercontinent. Called Pangaea, this giant land mass lasted until 180 million years ago, when forces inside the Earth ripped the supercontinent apart, sending the individual continents drifting toward their present positions.

Has this kind of aggregation happened often, or was it chance? Since scientists accepted the theory of plate tectonics in the 1960s, many researchers have wondered whether the continents join together and separate in an orderly cycle, or crash about aimlessly like bumper cars at a carnival.

"In other words," asks geologist Paul F. Hoffman, "is the dance of the continents a minuet or a jitterbug?" Ultimately, this issue raises questions about the forces that drive plate motions and shape Earth's geography.

Earth scientists do not know how many times the continents may have arranged themselves into large land masses during the planet's long history. Because Pangaea developed in the relatively recent geologic past, researchers have found ample evidence to document its existence. Looking farther back in time, many believe a different supercontinent broke up 600 million years ago.

For times even earlier, the history of the plates dims. But in recent years, North American geologists have made great strides in describing the origins of their own continent. Now Hoffman, of the Geological Survey of Canada in Ottawa, has compiled a geologic history of North America's first billion years, and he says the continent offers intriguing evidence that one or more supercontinents developed in Earth's Precambrian time.

These speculations about early North America tie in directly with recent theoretical work about the growth of supercontinents. Plate tectonic theory holds that the Earth's surface is divided into a dozen or so large and small plates riding on a soft, plastic layer in the rocky mantle.

The engine that powers plate movement resides in Earth's mantle. Although the mantle is solid rock, intense pressure and high temperatures enable the rock to flow, albeit extremely slowly. Heat generated in the mantle and core creates convection currents that carry plumes of hot rock from inside the mantle toward Earth's surface and return cooler, denser material back toward the planet's center. At the top of the mantle, the convection currents flow parallel to the surface, exerting friction on the base of the plates that pulls the plates along.

In the early 1980s, seismologist Don L. Anderson of the California Institute of Technology in Pasadena proposed that supercontinents such as Pangaea could directly alter mantle convection by acting as thermal caps. Recent computer simulations by Michael Gurnis of the University of Michigan in Ann Arbor have enabled scientists to explore this idea more fully (SN: 6/11/88, p.378).

The computer models offer an explanation for why supercontinents form and then break apart. In the simulations, converging flow patterns in the mantle carry individual continents toward a common point above an area where mantle rock is sinking. Smashing together, the blocks bond to form a supercontinent that covers a substantial area.

Initially, the land mass grows above the mantle cold spot; but with time, the insulating power of the continental crust heats the covered mantle. Hot mantle rock starts to rise and gradually forms a huge ascending current under the middle of the land mass. Growing stronger and larger, this "superswell" exerts stress on the crust until the supercontinent finally rips apart along weak zones in the crust. The individual continents then slide off the superswell and move toward colder sinking regions in the mantle.

To Hoffman, these ideas about supercontinents offer an explanation for some perplexing events in North America's distant past.

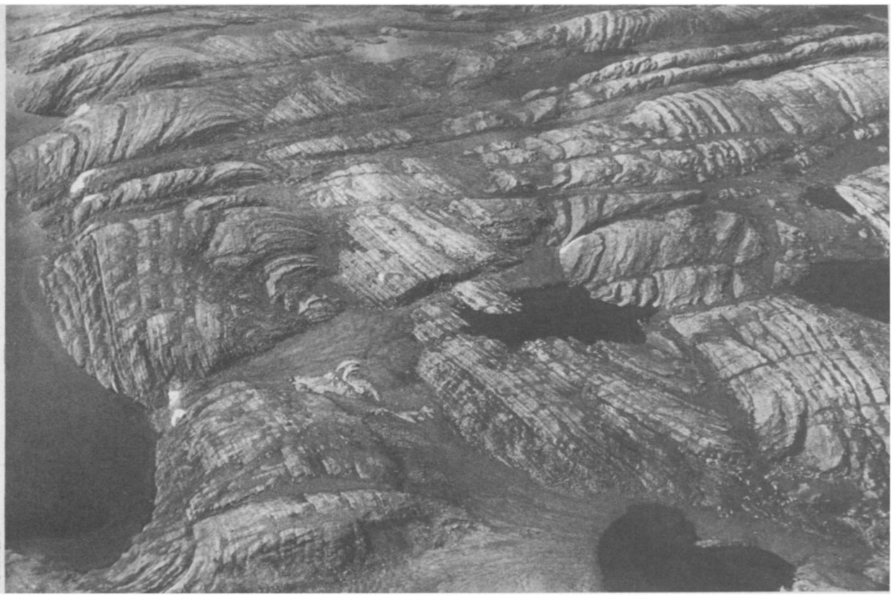
Hoffman spent the field seasons of the 1960s and 1970s chipping away at Precambrian rocks in desolate sections of Canada's Northwest Territories. More recently, he has spent his time indoors, attempting to synthesize all that's known about the development of the North America's stable interior – an area he has nicknamed "The United Plates of America."

The Precambrian is the dark, unexplored basement of earth science. Spanning the eons between the planet's genesis 4.6 billion years ago and the beginning of the Cambrian period 570 million years ago, the Precambrian encompasses more than 85 percent of Earth's history – but is its least understood phase. Recent advances, particularly techniques for dating rocks, are now helping scientists make sense out of this time.

In the February GEOLOGY, Hoffman describes how the Precambrian development of Laurentia – the name for ancestral North America – fits in neatly with theories about supercontinents and superswells.

One of the strange things about Laurentia's birth is that it happened so quickly, says Hoffman. Instead of developing over a billion years or more, with small chunks of crust crunching into each other in a piecemeal fashion, most of Laurentia evolved in a relatively brief span of 150 million years. This "crescendo of collisional activity" started 1.96 billion years ago and ended 1.81 billion years ago, Hoffman says. During that period, seven microcontinents collided to create the bulk of Laurentia. Although geologists do not know the size of the ancient continent, Hoffman says it included crust that now forms much of Greenland and Northern Europe as well as the interior of North America. Even after the microcontinent collisions ended, Laurentia continued to grow. Chains of young volcanic islands on oceanic plates swept toward the ancient continent and grafted onto it.

Then the building frenzy ceased and Laurentia entered a different period, lasting from around 1.6 billion to 1.3 billion years ago. This stage is marked by an enigmatic type of rock – red granites and rhyolites – appearing in a broad belt that stretches several thousand miles from southern California to Labrador. Granites and rhyolites are igneous – meaning they crystallized from molten rock – and share identical chemical compositions. While rhyolites form from magma that erupts at the surface, granites develop from magma that cools below ground.


Hoffman

These carbonate sediments in northwestern Canada formed as flat layers, but a collision between two microcontinents 1.9 billion years ago folded them. Evidence suggests this crash was part of a global series that created a supercontinent. Crosscutting basalt dikes formed 600 million years later when tectonic forces rifted pieces away from the continent, a process that stretched this region. Though these dikes belong to the same swarm shown on the cover, they make depressions here because they erode more easily than the carbonate "host" rock.

These silica-rich rocks are found in many spots around the world, but the Laurentian granites and rhyolites are different from most others. Perhaps their most obvious characteristic is their sheer volume. Currently, they reach above the surface only in parts of Missouri, Oklahoma and a few other locales. But drillholes across the continent have struck these rocks at depths of 1 or 2 kilometers.

"It's really quite amazing," says Marion E. Bickford, a specialist in Precambrian geology from the University of Kansas in Lawrence. In the center of the continent, he says, "essentially every drillhole that goes down, that's what you get."

For decades, these rocks have resisted attempts to explain their origins. Because they developed from melted portions of the lower crust, some kind of activity must have been heating the crust at the time, but scientists have had trouble explaining this heat.

Granites and rhyolites often form in two places: where plates collide and where tectonic forces stretch the crust. Collision doesn't explain the Laurentian rocks, because they show no sign of originating in an area that was being squeezed. Indeed, they are called "anorogenic," which means not related to mountain building.

For this reason, many researchers have suggested the rocks developed in an area of crustal stretching. Though better, this explanation falters as well, Hoffman says. Where crust is extended, as in Nevada, significant amounts of basaltic rocks from melted mantle material usually coexist with crustal granites and rhyolites. Yet geologists have found very little basaltic rock in North American anorogenic formations dating from 1.4 billion years ago.

Into this enigma enters Hoffman's theory. He suggests that if Laurentia were part of a supercontinent, then the anorogenic granites and rhyolites from this period would no longer present a problem.

Remember that a supercontinent heats the underlying mantle and causes a superswell to develop. According to Hoffman, the hot superswell material would melt the silica-rich lower crust. This molten rock would then rise toward the surface and create formations of granite and rhyolite.

A superswell would explain many puzzling characteristics of the anorogenic rocks, including why they developed over such a large area and why they formed in essentially unstressed crust. The upwelling would neither squeeze the crust nor stretch it initially.

Samuel A. Bowring at Washington University in St. Louis, who has studied the anorogenic Laurentian rocks, says Hoffman's idea has promise. "It is speculative, yes. But on the other hand, it's the first time anyone has been able to propose a very innovative solution to the problem of the anorogenic granites that has been around for 30 years," Bowring says.

J. Lawford Anderson at the University of Southern California in Los Angeles agrees with Hoffman. Working independently, Anderson has also arrived at the conclusion that a mantle superswell could have caused the anorogenic magmatism in Laurentia.

This idea received some unexpected support from a paper in the April GEOLOGY. Suzanne Mahlburg Kay from Cornell University in Ithaca, N.Y., and colleagues from Argentina and Chile report that the supercontinent Pangaea had extensive provinces of anorogenic granites and rhyolites quite similar to those found in Laurentia. The researchers say these formations occur through South America, Antarctica and East Australia, all of which were connected when the anorogenic rocks formed. The similarity suggests Pangaea may provide a modern example of a geologic event from a billion years earlier.

Aside from explaining the granites and rhyolites in North America, the supercontinent hypothesis also deciphers other aspects of Laurentian history, such as why this continent came together so quickly. Hoffman proposes that mantle convection swept the microcontinents and island arcs toward an area where cold mantle material was sinking.

If Laurentia was part of a supercontinent, then it had to break up sometime, and Hoffman says certain rock formations in North America indicate such activity. Cutting across Canada for more than 2,000 kilometers is a set of vertical basalt sheets called dikes. Basaltic rock often forms in regions where the crust has been thinned. This dike swarm, dated at 1.27 billion years ago, may chronicle the fragmentation of a Laurentian supercontinent, Hoffman says.

Having proposed this theory to explain the early development of North America, Hoffman is now trying to tear it apart. "Once a hypothesis has been proposed, one's duty is to try and find out what's wrong with it. So I would like to be the first to prove that the hypothesis doesn't work," he says. For this purpose, he has suggested several tests for the theory.

If Laurentia was part of a supercontinent that started forming 2 billion years ago, then other continents from that period should show histories similar to North America's. And indeed, there does seem to be a global pattern. Geologists have found that Australia had strikingly similar periods of mountain building and anorogenic magmatism. Information on South America is less complete, but Hoffman says events there appear to have matched those in Laurentia.

Since it is critical to know the times of these events, geologists need to obtain precise dates on Precambrian formations from around the world. One modern method, the uranium-lead isotope technique, allows researchers to determine the age of a 2-billion-year-old rock to within a few million years. But researchers outside North America and Australia have yet to use this technique extensively.

Geologists can also test Hoffman's hypothesis by examining the magnetic imprint in Precambrian rocks. Since the Earth's magnetic field stamps a pattern into certain rocks during their formation, this technique enables scientists to determine how continents have moved with respect to the planet's magnetic poles. If a supercontinent did exist about 1.6 billion to 1.3 billion years ago, then paleomagnetically derived positions should show the continents clustering together at that time.

Moreover, the paleomagnetic data should reveal that the continents travel in spurts rather then drift at the same speed. During supercontinent times, the plates should rest approximately over the equator. After breakup, they should move quickly to a new position, Hoffman says.

Scientists might also uncover signs of a supercontinent elsewhere, according to R. Damian Nance and Thomas R. Worsley of Ohio University in Athens and Judith B. Moody of J.B. Moody Associates in Columbus, Ohio. These researchers have proposed that geological records of sea levels and chemical isotopes can indicate whether the continents gathered together in the past.

One problem area in Hoffman's supercontinent theory is the denouement of the action. His hypothesis holds that a supercontinent grew quickly at about the time Laurentia developed, then entered a stable period of anorogenic magmatism, and finally split into pieces 1.3 billion years ago. But events between 1.2 billion and 1 billion years ago are a little confusing.

About 1.1 billion years ago, vast quantities of molten basalt poured out of a huge tear in the crust running from southeast Nebraska into the Lake Superior area. While this was happening, though, Laurentia seemingly collided with a large, unknown continent on its southern and eastern sides. Hoffman suggests the collision may have been part of the growth of a new supercontinent that lasted until about 600 million years ago.

Yet simultaneous rifting and collision seem to contradict the superswell model. Collisions supposedly occur when continents gather over a cold area in the mantle. But the midcontinent rift indicates Laurentia was sitting over hot mantle.

Hoffman says this is one of the main problems plaguing his theory, although there are ways of reconciling these two events. He raises the discrepancy to show that the supercontinent model has some weak points. "The real story will inevitably be more complex than the beguiling simplicity of the [superswell] theory," he says.

The idea that a supercontinent developed around 2 billion years ago is not new. It has drifted through the geological literature for several decades, even before scientists had fleshed out the theory of plate tectonics. Hoffman's contribution lies in synthesizing much of the knowledge about Laurentia and in attempting to explain how processes in the mantle might create the geology seen at the surface, Bickford says.

The supercontinent theory for Laurentia may not survive Hoffman's own scrutiny or the careful eyes of others. Yet geologists say it will stimulate more work on the Precambrian. Many are seeking to determine whether plate tectonics followed different rules during Earth's early eras.

The Precambrian, with its highly deformed rocks and its lack of fossils, has traditionally been overlooked by many earth scientists. But through the work of Hoffman and many others, this vast geologic time is now coming of age.

"Hoffman is basically bringing respect to the Precambrian," Bowring says. "A lot of people thought this time was hopeless in terms of deciphering whether supercontinents existed back then. His work has shown that it's anything but hopeless."

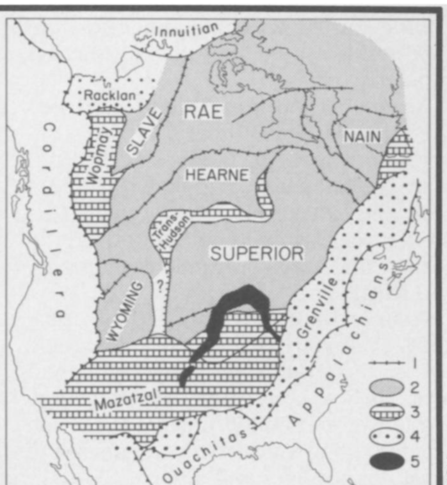
On a more speculative note, the theory of repeated supercontinents raises provocative issues whose ripples extend well beyond strict geology. "If correct, corollaries to the theory suggest the supercontinent cycle controls the global climate and, ultimately, probably the history of life itself," Hoffman says. Since the growth of supercontinents would alter rates of seafloor spreading and continental weathering, the cycle would influence the temperature of the planet by changing the amount of carbon dioxide in the atmosphere. □

A continental symphony

Ancestral North America's first billion years resemble a symphony in four movements, according to geologist Paul Hoffman. During the first movement, 2 billion to 1.8 billion years ago, seven microcontinents made of old crust (shaded) crashed together, forming a combined land mass that included Greenland (shown in the upper right) and portions of Northern Europe.

In the second, from 1.8 to 1.6 billion years ago, younger crust such as the Mazatzal region bonded onto the continent. At this point, North America may have connected with most of the other continents as part of a supercontinent.

Stability replaced the theme of collision in the third movement, from 1.6 billion to 1.3 billion years ago. Yet formations of distinctive granites and rhyolites, which developed most widely during this third period, signaled that stability could not last forever. The last movement, from 1.3 billion to 1 billion years ago, started off with rifting, which may have split the supercontinent apart. Then, between 1.2 billion and 1.1



Hoffman

billion years ago, proto-North America collided with an unknown land mass that thrust up mountains in a 5,000-kilometer-long belt called the Grenville orogeny. At the same time, massive flows of basalt flooded an opening rift (black) that split the midcontinent. The northernmost region of the ancient rift now sits under Lake Superior.

— *R. Monastersky*