Before Pangaea—What?

Earth scientists are busily gathering the meager bits of surviving evidence to piece together the course of continental drift over the millennia before the last great supercontinent, Pangaea, broke up 200 million years ago.

by Louise A. Purrett

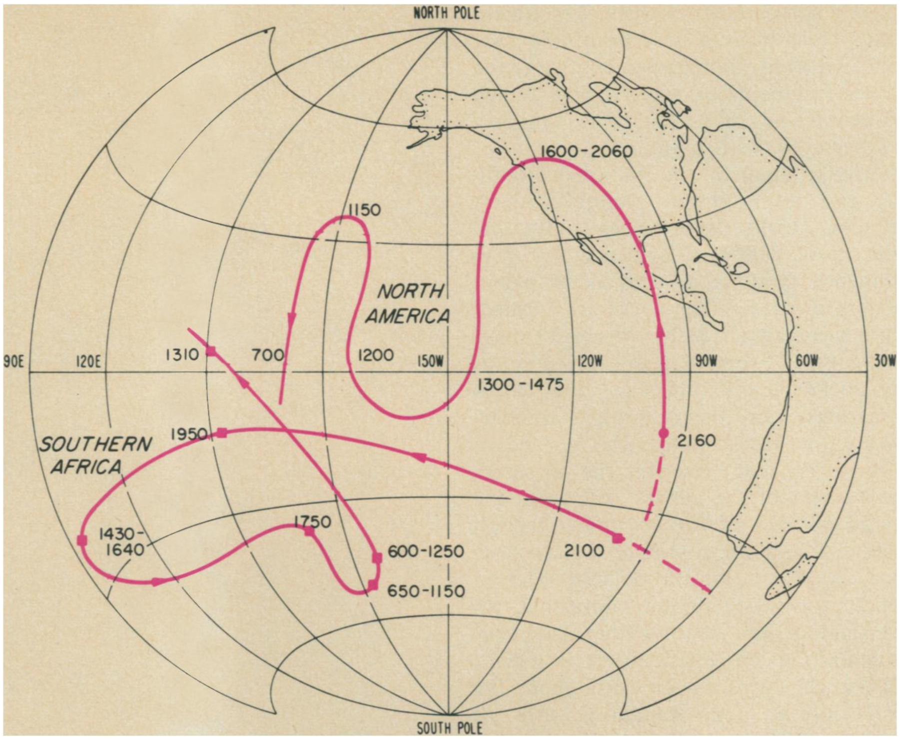
The continents as we know them resulted when the protocontinent Pangaea broke apart and its fragments made the long slow journey to their present positions. The process took about 200 million years. But the earth's crust is an estimated 4.5 billion years old.

Against this enormous cloth of time, 200 million years is but a scrap. While many geophysicists are immersed in the details of the processes of continental drift and plate tectonics during the past 200 million years, others have turned to the perplexing problem of what went on during the billions of years before Pangaea went to pieces.

The problem is perplexing chiefly because the evidence is scattered and scarce. The geological record for the past few hundred million years is quite complete, but a scientist peering into the past finds less and less data the farther back he tries to go. Subsequent events have often confused or obliterated the record. Rocks that can be reliably dated as more than 2 billion years old occupy less than one percent of the surface area of the earth, though they span more than half its age. The situation is even more discouraging on the ocean floors. Most existing oceanic crust was generated during the present episode of drift. The oldest rock so far recovered from an ocean basin is only 160 million years old. This means also that one of the most useful techniques for tracing drift—magnetic lineations on the ocean floor generated by sea-

Hurley's "continental nuclei" may prove to be compatible with theories on Precambrian drift.

Hurley/Science



Spall/Nature

Relative movements of the magnetic pole 600 million to 2,160 million years ago suggest that Africa and North America once drifted independently.

floor spreading—cannot be applied to pre-Pangaea events.

What evidence there is has given rise to two general theories about events prior to 200 million years ago. One view holds that continental drift is a catastrophic event and that Pangaea was the primeval crustal mass that abided intact through the eons until its relatively recent fragmentation. The other view, held by most geophysicists, is that Pangaea was only the latest in a series of "Pangaeas" that were the culminations of episodes or cycles of drift.

One of the scientists who originally held the first view was Patrick M. Hurley of the Massachusetts Institute of Technology. He plotted all available data for rock ages on maps of the continents and then juggled these maps into the probable arrangement of continents in Pangaea. He found that on the reconstructed map of Pangaea, the regions with rocks older than 1.7 billion years fall into two coherent groups spanning present continental boundaries. One group takes in adjacent parts of Africa, South America and Australia; the other covers North America, Greenland and Europe. Hurley concluded that the continents developed around these ancient nuclei and "these two regions were always essentially intact prior to the last great drift episode."

This was in 1969. But, says Hurley, "a lot of water goes under the dam very quickly in this field." Though the age data he presented earlier still hold, he says, his interpretation has altered. "We're now working on pre-Mesozoic drift in a large way."

One of the things that changed his mind, he explains, was his study of Pan-African belts of deformation. In reconstructions of Pangaea, these belts extend into South America. In a recent paper in EARTH AND PLANETARY SCIENCE LETTERS, he discussed how the belts may have been formed in situ by upwelling of mantle materials and then how they may have formed by continental drift mechanisms. He concluded that the characteristics of the Pan-African belts can be explained by both hypotheses and that final resolution of the problem must await more data.

Most geologists agree that Hurley's findings do not preclude earlier episodes of drift. There is, in contrast, considerable evidence in favor of the cycle theory. For one, geologists are finding, in the interiors of present continents, what appear to be sutures where earlier continental masses came together. Such sutures often take the form of mountain belts, and they contain sediments and rocks of the type found on ocean floors. Many mountain chains were apparently formed by collisions between continents. The Himalayas are thought to be the result of India's collision with mainland Asia some 60 million years ago. Some older mountain chains may be remnants of earlier drift and collision.

John F. Dewey of the State University of New York at Albany and John M. Bird of Cornell University believe the Appalachians may be a case in point and have found ocean floor materials in these mountains to support their view (SN: 8/15/70, p. 143). They hypothesize that in late Precambrian times (before 600 million years ago) a continent composed of what is now North America and Africa began to split apart and an ocean developed between them. The continents reached a maximum separation at about 500 million years ago. Then the intervening ocean contracted again and the continents collided, creating the Appalachians. Bird and Dewey believe the Urals may have formed in a similar fashion.

Geologists are finding similar sutures elsewhere. John Stewart of the U.S. Geological Survey found a sinuous belt extending from Alaska to northern Mexico which has all the earmarks of an extinct continental margin that he believes developed as a result of a continental separation about 850 million years ago.

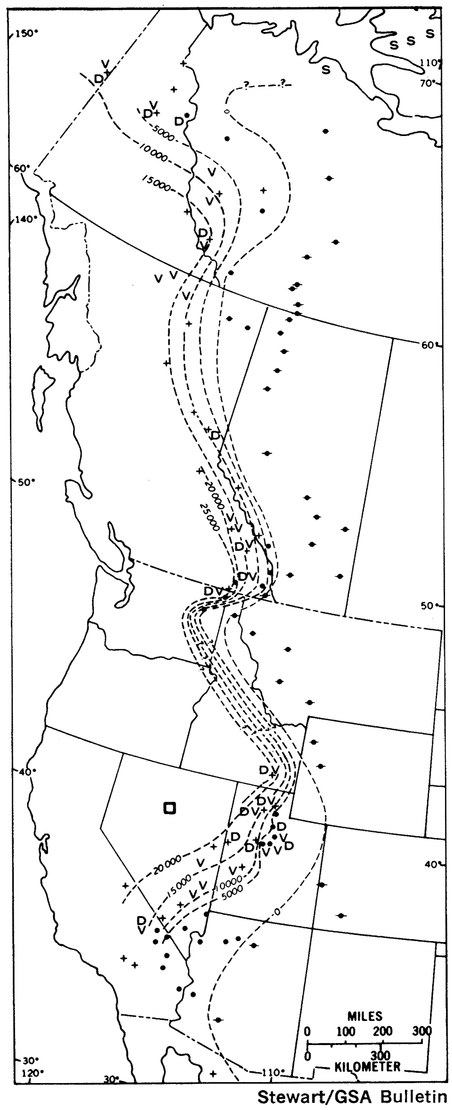
There are several sutures bordering the Canadian Shield, a section of ancient and stable crust. One, running in a north-south direction between the Shield and the Great Slave province to the west, is a "beautiful suture," says Dewey. These sutures are all about the same age and Dewey says it looks like the Canadian Shield may be completely surrounded by them. The Shield may have been a protocontinent that once drifted independently from the other fragments of what is now North America, he says. Africa is similarly crisscrossed with sutures.

Henry Spall of the National Oceanic and Atmospheric Administration's Boulder, Colo., laboratories thinks that the most definitive evidence for pre-Pangaea continental drift is in paleomagnetic data. When rocks are formed, they are magnetized by the earth's magnetic field. From magnetic orientations of rocks of different ages, the paleomagnetist can construct polar wandering paths, tracks across the surface of the earth that describe the apparent movement of the earth's pole from the point of view of the continent, though actually it is the continent that is moving. By comparing the polar wandering paths for two different continents, investigators can see whether the continents traveled separately or as a unit. If Pangaea was a unit throughout the Precambrian, polar wandering paths for all the continents during that period would coincide.

Unfortunately, there is relatively little paleomagnetic data for the Precambrian. Some 1,400 past pole positions have been determined. But most of them were from rocks younger than 500 million years. Only about 200 ("a drop in the present bucket," says Spall) apply to the Precambrian. Further, most of the data are from Africa, Europe and North America. No Precambrian pole paths have been drawn for any of the other continents, though paleomagnetic work is in progress in South America and Australia. Spall estimates that polar wandering paths for these continents should be developed within the next few years.

What paleomagnetic evidence there is supports the idea of Precambrian continental drift. Spall has compared the Precambrian pole paths for North America and South Africa and found them to be very different. The South African path, reconstructed for the period between 600 million and 1.95 billion years ago, has a large loop in it. The North American path for 700 million to 2.16 billion years ago shows no evidence of a loop. Spall tentatively concludes that southern Africa and North America drifted independently during the Precambrian. He can make no conclusions about Africa as a whole, he explains, because most of the data are from Rhodesia and the Transvaal and the crustal plates that now comprise Africa may or may not have been together in the Precambrian.

More recently, Spall has added to his comparisons a pole path for Europe for the period from about 500 million to 2 billion years ago. This path differs



Stewart/GSA Bulletin

A continental margin in N. America?

from both the North American and South African paths for the same period.

These three types of evidence of Precambrian drift—paleomagnetic, structural and rock ages—will eventually have to be tied together. Spall believes the best approach is for scientists using each technique to go as far as they can along their separate paths and then try to put it all together later. He notes that Hurley's age data, which now seem to conflict with the theory of Precambrian drift may eventually fall in place with the other findings. Perhaps reconstruction of an earlier Pangaea will also produce coherent groupings of the oldest rocks. In fact, the coherent group Hurley found spanning the southern continents may turn out to be correct; polar wandering paths for most of these continents have yet to be constructed.

Most earth scientists agree that there was continental drift prior to the formation and breakup of Pangaea. Most also agree that there was more than one "Pangaea"—amalgamations of most or all of the drifting continents. Logic alone predicts that this would happen, says Dewey. Over billions of years, "if you take plates moving at two centimeters per year and move them about randomly you're going to get Pangaeas." Bird agrees. He estimates that there were probably at least three previous Pangaeas.

Spall goes further. From the magnetic evidence, he has noted that there were periods when polar shift was more rapid than at other times. The rapid shifts perhaps denote initiation of a drift cycle. Using three other lines of evidence, he is suggesting that there were at least three, and perhaps four, Precambrian cycles of drift, beginning with fragmentation of a supercontinent and perhaps culminating in rejoining of the fragments. The periods of amalgamation would be marked by mountain building. Spall tentatively puts the beginnings of the Precambrian cycles at 2.6 billion, 2.0 billion and 1.1 billion to 1.2 billion years ago. He thinks there may have been a fourth cycle between 1.2 billion and 2.0 billion years ago.

Spall emphasizes that the fragmentation-drift-suturing is a continuous process. Rather than a simultaneous joining together of all continents and an equally simultaneous fragmentation, there would be periods when most continents were in the process of joining together or of splitting apart.

So it now appears that continental drift was going on at least as far back as 2 billion years ago. But this still accounts for less than half the earth's history. Rocks older than 2 billion years are rare indeed, but those that have been found, according to Dewey and Bird, suggest that some process other than plate tectonics was at work during the earliest eons. "There was a big change 2 billion years ago," says Bird. "There was an entirely different style of deformation." No one is sure just yet what that style was, but it now appears that the crust was hotter, thinner and more mobile than it is now; there was more volcanism, and masses of material were smaller. Areas of crustal spreading were much broader than the midocean cracks of the present-day tectonic world. It may be, suggests Dewey, that it wasn't until about 2 billion years ago that the earth's crust became rigid enough to crack into plates. Bird believes that study of these early processes may tell something about the evolution of the mantle.

Segments of the outlines of what happened on the earth before Pangaea are gradually being sketched in. Many earth scientists are now concentrating on the problem, but there's a vast span of time to cover and much data yet to collect. As Spall puts it, "There's enough there to keep us busy for some time to come." □