geneticist at the University of Minnesota, noticed that a patient who had this eye tumor also had a deletion on chromosome 13. Yunis and other geneticists were intrigued by this cancer because it is hereditary, it strikes young children between birth and age four, and those children who get retinoblastoma are hundreds of times more likely than normal to develop osteosarcoma, a bone cancer, when they are teenagers. (The exact frequency of osteosarcoma in retinoblastoma patients is not known.) The patient with the deletion in chromosome 13 provided the first hint of where the retinoblastoma gene might be located.

By 1974, geneticists had identified eight additional patients with a chromosome 13 deletion. But it was a discouraging search. Their techniques were far from sensitive and they could only spot the largest deletions. Between 1976 and 1980, they examined the chromosomes of 1200 retinoblastoma patients. Only 24 had noticeable deletions in chromosome 13.

Then Brenda Gallie and her colleagues at the University of Toronto noticed that the enzyme esterase D is coded for by a gene in the region of the putative retinoblastoma gene. This meant that researchers could look for retinoblastoma mutations by looking for normal variations in the nearby esterase gene. This technique enabled geneticists to identify chromosome 13 mutations in as many as one-third of all retinoblastoma patients who were studied.

Finally, Dryja and Webster Cavenee of the University of Cincinnati School of Medicine showed that nearly all retinoblastoma patients have mutations in the q14 band of chromosome 13. Then Dryja used chromosome walking techniques to isolate and map a 30-kilobase region of DNA in the q14 region. He found a fragment that is conserved in mouse and humans, suggesting that it constitutes a coding region. Finally, Friend and Weinberg looked for RNA transcripts in retinoblastoma cells from four patients and in normal retinal cells that hybridize to this conserved region. They report that a 4.7-kilobase RNA transcript from the normal retinal cells hybridizes to the DNA segment and that this transcript is missing in the retinoblastoma cells, indicating that the transcript may be the normal counterpart of the gene that is deleted or missing in retinoblastoma. They extended their analysis by making a cDNA copy of this RNA transcript and using it to screen four retinal cell lines, four retinoblastoma cell lines, and one osteosarcoma cell line. The cDNA probe hybridizes to a transcript in the retinal cells but not the retinoblastoma cells nor the osteosarcoma cells.

Now that they apparently have located the retinoblastoma gene, the researchers plan to add good copies of it to cells that have only mutant genes to see if the good copies restore normal growth. And they hope to learn what sort of protein the gene normally codes for. Now, says Friend, "we can do the experiments we always wanted to do." ■ GINA KOLATA

Plate Tectonics Is the Key to the Distant Past

Field geologists taking a closer look at 3-billion-year-old rocks are deciding that drifting plates formed them after all

GEOLOGIST Gregory Harper was intrigued. Here he was in the middle of Wyoming, sitting on rocks more than two and a half billion years old, more than half as old as the earth itself. Yet there was something familiar about these rocks of the Archean eon that reminded him of the rocks he had studied in northern California, a jumble of crust assembled only a few hundred million years ago.

According to conventional thinking, geologic processes quite unknown during the past billion years formed these exotic Archean crustal rocks in Wyoming's Wind River Mountains. The drifting and colliding of the continents evident in today's plate tectonics supposedly had nothing to do with this sort of rock, which constitutes the most ancient cores of the continents. But Harper eventually convinced himself otherwise. The familiar Archean rocks led him to propose that a nearly complete slice of ocean crust sits in the middle of Wyoming, ocean crust of the sort shoved up on the continents by drifting plates throughout the past billion years.

A growing number of geologists, apparently now a solid majority, have through one avenue or another arrived at the same conclusion as Harper—the present is the key to the past, no matter how distant that past. With only cosmetic differences in the end result, the same basic mechanics of crustal generation and destruction have shaped the surface of the earth from its early days until now. The division of geologic time, as well as geologic specialties, into epochs of unique behavior of the earth would appear to be unfounded.

Harper's claim of a beached slice of Archean ocean crust, called an ophiolite, is one of three being presented as evidence of modern-style plate tectonics in the Archean. Like the other two Archean ophiolite proponents, Harper was not trained as a specialist in the study of Archean rocks. He knew ophiolites from younger terranes, but he was not looking for them in Wyoming. He was only there to teach undergraduates at the University of Utah's annual summer field camp. What first caught his eye was a spot on a geologic map indicating a patch of rock a few hundred meters in diameter. It was labeled ultramafic, the type of dark rock found at the base of the oceanic crust and the uppermost mantle. "That's how you smell an ophiolite," says Harper, now at the State University of New York at Albany. "That's what got me going."

On close inspection, Harper found what he believes to be all but one of the components of a typical ophiolite of the past billion years—the mounded lava that flowed out onto the sea floor, the conduits or dykes of unique structure that carried magma to the sea floor where new crust was forming, and the ultramafic mineral crystals that fell to the floor of the underlying magma chamber. Missing was a piece of the uppermost mantle. That would be understandable, says Harper, if the higher temperatures of the Archean earth, temperatures that had been presumed to radically transform the behavior of the crust, merely raised the point at which the ophiolite was sliced off from the upper mantle to the lower crust.

The other two reported Archean ophiolites are related in a nongeologic way. For several years Maarten de Wit of the University of the Witwatersrand, Johannesburg, has been building a case for a 3.6-billion-year-old Archean ophiolite on the far northeastern border of South Africa. After showing it off to Herwart Helmstaedt of Queen's University, Kingston, Canada, during a week-long field trip, de Wit visited Helmstaedt's field site on the northern shores of Great Slave Lake in north-central Canada.

After being reassured by de Wit that his Archean rocks looked more like an ophiolite than those of many accepted ophiolites, Helmstaedt wrote up his fieldwork in support of the site being ocean crust.

All three of these claims will be controversial. Inevitably, rocks this old have been altered by being baked at high temperature and pressure and have often been sliced up, stretched out, and generally beaten up. And no one of the three clearly includes all four typical ophiolite components. This does not bother Helmstaedt, for one, who notes that there are many atypical ophiolites from the Phanerozoic, the most recent 590 million years of geologic time. Another frequent complaint is that the proponents often offer less than convincing examples of sheeted dykes, the uniquely patterned veins formed when magma repeatedly injects itself into vertical fissures where two ocean crustal plates are forming and pulling away from each other. Harper notes that, judging from the effects of high temperature and pressure on ophiolites in northern California, the unique patterning of Archean sheeted dykes will have been obscured in most cases, leaving nothing obvious but mounded lava flows, something ubiquitous in many Archean rocks.

All three geologists claiming discovery of Archean oceanic crust agree that there is a major problem of semantics involved in the ophiolite debate. There are rocks of Archean age, older than 2500 million years, that Archean geologists would call greenstone belts, after the greenish mineral chlorite typical of the belts. But, say the three Phanerozoic geologists, there are rocks just like these in character, structure, and origin that are of Phanerozoic age that include ophiolites. It is their experience with younger, indisputable ophiolites, they say, that lets them recognize the less complete, more altered ancient examples. Obviously, more reciprocal field visits between the two camps might help resolve the disputes.

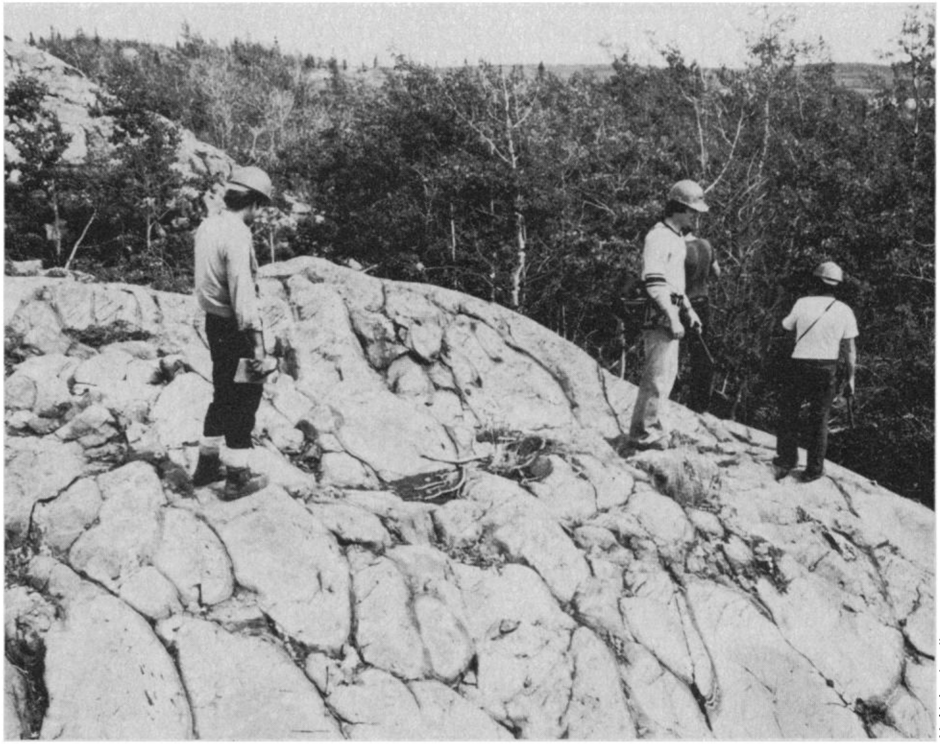
While the debate over possible slivers of ocean crust caught in greenstone belts continues, new fieldwork is transforming views of the greenstone belts themselves. A plate tectonic origin for them is gaining the upper hand. No longer do they seem to be 20-kilometer-thick piles of lava that welled up onto continents through stretched and thinned crust, only to sink later under their own weight. Instead, geologists are increasingly viewing a greenstone belt as a jumble of volcanic lavas, sediments, and injected magma. That is exactly what remains when continents collide and squeeze a volcanic arc like the Aleutian Islands or Japan between them. Scraps of ocean crust containing evidence of sea-floor spreading would thus be just one bit of the evidence that horizontal motion of plates, rather than simple ups and downs of the crust, dominated the Archean as it does the present.

There have been proponents of Archean plate tectonics since most geologists accepted Phanerozoic plate tectonics around 1969, but the shift from vertical to horizontal motion has not been easy for everyone. "Frankly, we were dubious," says David Mogk, an Archean geologist at Montana State University. "We resisted Phanerozoic plate tectonics for quite a while." What brought Mogk and his co-workers around was a variety of evidence from their own field sites in the Beartooth Mountains of southwest Montana, the northern extremity of the Archean terrane of the Wyoming Province.

For one thing, there is just too much volcanic rock in the Beartooths of the kind making up arcs like the Aleutians and the Andes. The only practical way to make that rock in those quantities, says Mogk, would be to have an oceanic plate dive or subduct into the mantle and generate magma that rose to the surface to form a volcanic arc, as happens today in subduction zones marked by deep-sea trenches and chains of volcanoes. Some rocks in the Beartooths had also been quickly buried 20 to 25 kilometers down. That is too deep for the rocks to have been buried in any way except by compression and the shoving of crustal slivers on top of one another, as happens today when volcanic arcs collide with continents. Mogk and his colleagues found abundant evidence of such compression in folded rock strata that were stretched and finally broken by the thrusting of one slab over another.

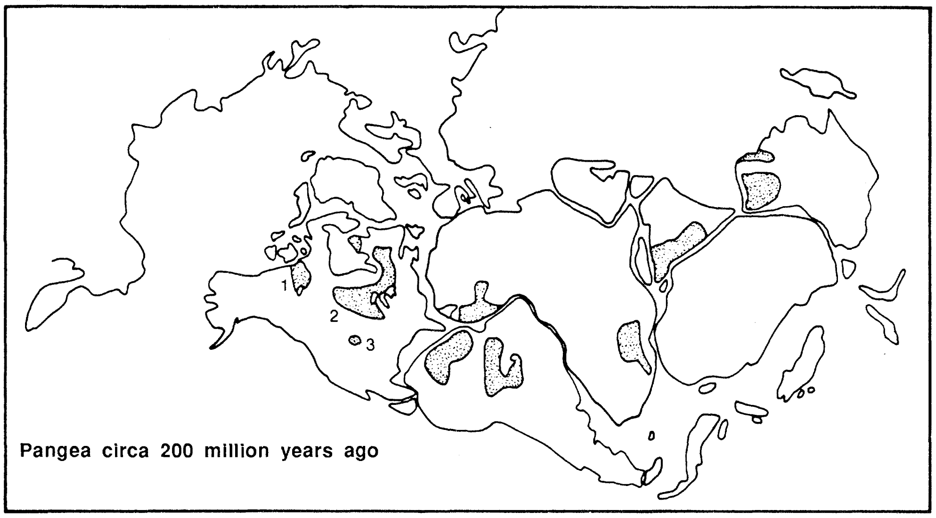
John Ludden and Claude Hubert of the University of Montreal have proposed a similar reinterpretation of the Abitibi greenstone belt just to the northeast of the Great Lakes. By conventional thinking, the Abitibi belt would be a 20-kilometer-deep sag in the crust filled with volcanic rock and sediment. But Ludden and Hubert see the three distinct types of Abitibi volcanic rock and the faults slicing through the belt as evidence that processes familiar from the Phanerozoic rocks of Japan and Sumatra created the belt. In their model, rifts where ocean crust formed dissected continental crust created by Andean-style, subduction-related volcanism. "That's what a greenstone belt looks like. You just close it up when it's all done," says Ludden, a petrologist who studied modern ocean crust until he teamed up with Hubert, a structural geologist who initially worked on the Phanerozoic Appalachian Mountains.

Central to much of the work used to reinterpret greenstone belts is the technique of uranium-lead dating of zircon crystals. In an exhaustive winnowing process, a 50-



H. Helmstaedt

A walk on 2.7-billion-year-old sea floor. *These geologists are standing on lavas that flowed onto the sea floor during the late Archean eon much as they do today at mid-ocean ridges. Quickly chilled on the outside by seawater, the lava forms mounded "pillows." Other rocks in the area of Yellowknife, Canada, suggest that then as now pillow lavas form the upper part of new ocean crust.*



Some of Archean geologists' favorite places. *These are some of the ancient terranes that make up the oldest parts of the continents. These contain greenstone belts, which are now thought to mark the closing of ocean basins, that were described at a recent workshop. Three terranes of particular interest to North American geologists are Slave Province (1). Superior Province (2), and the Wind River Mountains of Wyoming (3).*

kilogram rock sample yields 0.1-millimeter zircon crystals containing 0.5 nanogram of lead. The lead was not there when the zircon crystallized, only uranium that decays radioactively to lead at a known rate. Mass spectrometric analyses of the lead yield ages with an error of ±2 million years for rocks that are 3000 million years old.

Donald Davis, Fernando Corfu, and Thomas Krough of the Royal Ontario Museum in Toronto have been accumulating uranium-lead zircon dates to decipher the style of tectonics of the Archean Superior Province that lies north and west of the Great Lakes. Their model has taken a sudden turn toward plate tectonics. In an abstract written for a meeting last January on greenstone belts, the group wrote that "the bulk of the evidence presently available argues for a model in which greenstone belts were initiated by rifting of older silaic [continental] crust and the formation of narrow ocean basins. . . . Evidence for subduction in late Archean tectonic processes is missing." With commendable prudence, they added that their view was tentative and was "subject to the constraints of a constantly expanding data set."

The expansion of the Royal Ontario Museum's data set now points to a complete plate tectonic cycle consisting of rifting, ocean basin formation, closure of the basin, and a collision, says Davis. In the northern Wabigoon subprovince, they find 3-billion-year-old crust and evidence of 2.7-billion-year-old volcanic activity, but no activity during the intervening 300 million years. That would suggest, says Davis, that there was no subduction on that side of the basin, only volcanic activity at the final collision. To the south, there was continuous activity, suggesting subduction there while new ocean crust formed in mid-basin that subducted to the south.

The basin was sizable, not just a narrow crack like the Red Sea, because the zircons reveal no trace of contamination as magmas rose from the mantle, as happens if they have to pass through a narrow continental rift. Also, sediment zircons eroded from older crust only appeared near the time of the collision. Davis says that they also see signs in the north of a stacking of rock layers of different ages indicative of a collision that shoved one layer across another. Gary Beakhouse, who recently received his doctorate in Archean geology and is now at the Ontario Geological Survey, and Robert McNutt, his advisor at McMaster University, proposed a similar model for the north side of the basin more than a year ago on the basis of the geochemistry of the rocks and early zircon dating by the Royal Ontario Museum group.

Schemes explaining Archean subprovinces in terms of plate tectonics have proliferated to the extent that geologists are treating whole provinces, the most ancient cores of the continents, as products of horizontal plate motion. Paul Hoffman of the Geological Survey of Canada in Ottawa compares the Slave Province of northern Canada with southwest Japan, where subduction has plastered one volcanic island arc after another. Those additions of new crust have extended the coastline and its associated subduction seaward. That in turn moved the inland, subduction-related volcanism analogous to that at Mount St. Helens and the Cascades outward, reprocessing the accreted island arcs as it went. That, plus the sediments deposited in a deep-sea trench, is what Hoffman sees in the Slave Province.

Kenneth Card, also of the Geological Survey of Canada, paints a similar picture of the Superior Province, albeit a more complicated one. Card compares the Superior Province of the Archean to Japan and the Kamchatka Peninsula of the present northwest Pacific. The diversity of rocks within the province reflects the diversity of landforms in the North Pacific that could eventually accrete to its margins—not only young and old volcanic arcs, but also interarc basins, trenches, seamounts, submarine rises, and microcontinents. On the northwest Pacific's road to becoming thick, stable continental crust like that of the Superior Province, there will be still more injections of magma, plate collisions, uplifts, and erosion, Card says.

All in all, Archean geologists are sounding quite like their Phanerozoic colleagues who for more than 5 years have been dissecting the west coast of North America into scraps of crust accreted within the past few hundred million years. Thus, it would appear that from their very beginnings continents have been built up from the bits and pieces of plate tectonics.

Despite the continuity of plate tectonics over perhaps the past 3.8 billion years of the earth's 4.5-billion-year history, there do appear to be distinct differences in the products of plate tectonics over time. Some differences in the Archean would not be surprising given the higher temperature of the earth then, which resulted in a heat flow three times that of today. The prevalence in the Archean of the high-magnesium lava called komatiite and its near absence in modern rocks must certainly reflect higher temperatures where mantle rock partially melted to form the komatiite. But the significance of other apparent differences will no doubt be debated. The difficulty of identifying Archean ophiolites or sediments on stable continental margins, for example, may reflect their absence or simply the poor preservation and limited volume of Archean rocks. Extension of the modern geologic techniques applied to the Archean in recent years, plus increased interaction between those geologists studying relatively young rocks and ancient rocks, may soon resolve many of the questions about the earth's early days. ■ RICHARD A. KERR

ADDITIONAL READING

M. J. de Wit and L. D. Ashwal, Eds., *Workshop on Tectonic Evolution of Greenstone Belts* (*LPI Tech. Rep.* 86-10, Lunar and Planetary Institute, Houston, TX, 1986). Available from Library-Information Center, Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058–4399. Postage and handling fee for U.S. destinations is $3. Foreign requestors should contact LPI for a price quote.