# New Evidence Fuels Antarctic Ice Debate

*Geologists argue that the Antarctic ice sheet may have appeared earlier than most paleoceanographers suppose*

Twenty-four million cubic kilometers of ice covering an entire continent cannot be ignored by earth scientists. In spite of its geographical isolation, the Antarctic ice sheet is intimately linked to the circulation of the ocean, the climate of the earth, and even the depth of the world's seas. Yet the origin and age of this massive and influential geologic feature remain controversial.

Geologists searching the 2 percent of the continent not covered by today's ice have found only fragmentary evidence about the origin of the ice sheet. Oceanographers studying the effects of the ice on the ocean have found a more complete record in marine sediments, but its interpretation is not entirely straightforward. In the absence of overwhelming evidence from either the ocean or the Antarctic continent, a debate has developed between many oceanographers, who favor an age of about 14 million years for the main ice sheet, and some continental geologists, who suspect that a good deal of ice existed millions of years earlier.

The latest evidence from the Antarctic continent itself has been found in the area of the Dry Valleys, the ice-free valleys on the opposite side of the Transantarctic Mountains from the main ice mass in East Antarctica. George Denton, Michael Prentice, Davida Kellogg, and Thomas Kellogg of the University of Maine at Orono are using these mountains as a "dipstick" to measure the changing thickness of the ice during the past 20 million years.

In the Quartermain, Asgard, and Olympus ranges that separate the Dry Valleys, the Maine group has found signs of an ice sheet so much more massive than today's that it twice overrode the Transantarctic Mountains. There are two separate records of ice movement there, they say. Ice from a local ice sheet must have gouged out the Dry Valleys themselves. At the same time, small mountain glaciers carved the ranges between the Dry Valleys into typical alpine glacial terrain—bowl-shaped gouges in mountainsides; thin, separated ridges; and pyramidal peaks resembling the Matterhorn. Later, when a continental ice sheet submerged the highest mountain peaks beneath at least 500 meters of ice, glacial erosion modified these features. The overriding ice severely eroded less resistant rock, grinding out smooth, steep slopes on the upstream side of ridges and gentler slopes on the downstream side. The result is called a stoss-and-lee form.

The overriding ice sheet did not follow the same path as the ice that formed the Dry Valleys, the Maine group says. They know this because the ice left several kinds of direction indications: strings of boulders trailing away from the peaks from which they had broken; the asymmetric erosion of the stoss-and-lee forms; subglacial ripples from meltwater flow; and, in one isolated instance, glacial striations on bedrock. All point in the same southwest-to-northeast direction across the trend of the Dry Valleys.

The ice sheet crossed the Dry Valleys obliquely, the Maine researchers say, because a large mass of ice in West Antarctica deflected it across the normal drainage pattern. That happened twice, the earliest episode or series of episodes occurring sometime before 9 to 15 million years ago. They base these dates on the presence of two particular species of diatom microfossils found in ancient fjord sediments in one of the Dry Valleys.

The presence of a large mass of ice in West Antarctica sometime before 9 to 15 million years ago conflicts with the findings of some oceanographers. By splicing together a record from marine sediments, Paul Ciesielski and his colleagues at the University of Georgia concluded that the smaller West Antarctic ice sheet formed no earlier than 9 million years ago and quite possibly later (*Science*, 24 July 1981, p. 427). They emphasized the apparent effects that the ice, especially the West Antarctic ice shelves of the Ross and Weddell seas, would have had on the sea floor. These included reduced sedimentation in the Ross Sea, more distant deposition in the ocean of glacial debris carried by icebergs, and increased bottom erosion by deep-ocean currents originating near the Weddell ice shelf. In addition, John Mercer of Ohio State University has been unable to find evidence of glaciation in nearby South America older than 5 to 7 million years, suggesting that West Antarctica did not become extensively glaciated until then.

The overriding of the Transantarctic Mountains sometime before 9 to 15 million years ago does not necessarily conflict with the oceanographic evidence for the appearance of the larger East Antarctic ice sheet 14 million years ago, but Denton and his group see a problem with that date. They have a hard time imagining how the ice could have accomplished all of the observed erosion in the time allowed by the marine record. If most of the erosion occurred during the earliest episode, as appears to have been the case, and if the Transantarctic Mountains have risen only 400 meters, as they estimate, then there could have been a great deal of ice. "It is highly likely that an extensive overriding ice sheet existed prior to 10 to 14 million years ago," they say.

Antarctic geologists have found other evidence on the continent suggesting that significant amounts of ice appeared before 14 million years ago. Edmund Stump, Michael Sheridan, and Scott Borg of Arizona State University in Tempe and John Sutter of the U.S. Geological Survey in Reston, Virginia, have dated samples from the remote rock outcrops of Sheridan Bluff and Mount Early at the head of Scott Glacier. Mount Early is an outlier at the southern tip of the Transantarctic Mountains, on the very edge of the present-day ice sheet and only 500 kilometers from the pole. At both sites, they found lavas that had erupted beneath ice, as evidenced by the presence of hyaloclastites, pillow lavas, and pillow breccias. These are the quick-frozen forms of lava known to form beneath glaciers, as observed in Iceland.

Potassium-argon dating of the subaerially erupted lavas immediately above these lavas showed that the subglacial eruptions must have occurred more than $18.32 \pm 0.35$ million years ago (Sheridan Bluff) and more than $15.86 \pm 0.30$ million years ago (Mount Early). A perennial problem in such potassium-argon dating is the need to choose samples that contain all of the argon-40 produced by the slow decay of potassium-39 and no additional argon. Stump and his group chose to date only subaerially erupted lava in order to avoid this problem, which often crops up in the analysis of


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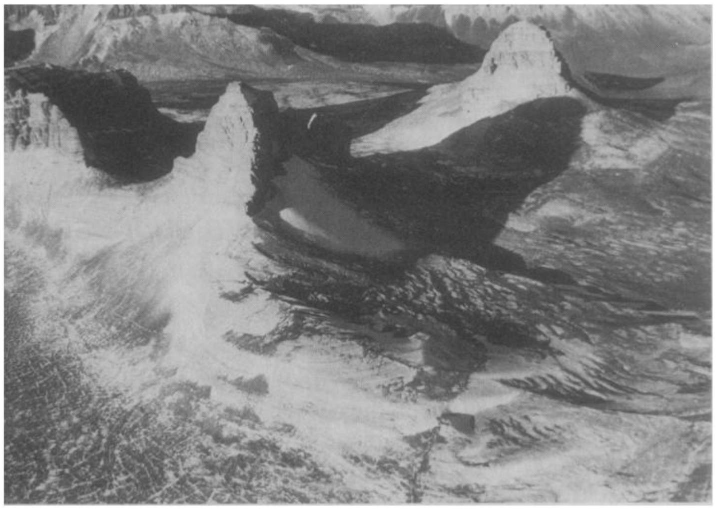

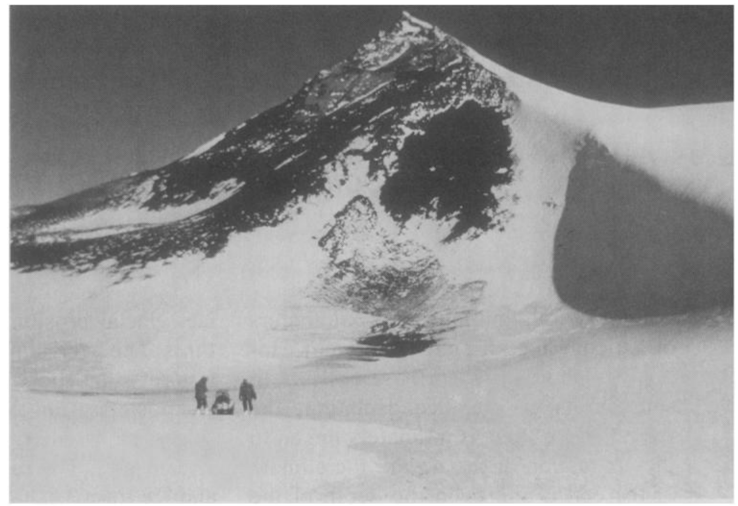

***Remnants of an icy past*** George Denton Edmund Stump

*(Left) The steep slope to the left and the gentler, rippled slope to the right were formed by a large ice sheet overriding the rock of the Olympus Range that was earlier shaped by local glaciers. The two pyramidal glacial horns survive from the time of that earlier glaciation. The ripples are debris shaped by subglacial meltwater. (Right) Light hyaloclastites in the upper section of the rock face and dark pillow basalts below were erupted beneath ice about 16 million years ago.*

subglacially erupted lavas. They also performed a check, the argon-40/argon-39 age spectrum experiment, to determine whether any geologic processes had tampered with the argon content of their samples. The results indicated that none had.

Stump and his colleagues conclude that the subglacially erupted lavas at Mount Early, at least, emerged from the crust beneath a major ice sheet, not a small glacier confined between valley walls. In light of the mountain's isolated position, "the data from upper Scott Glacier suggest the presence of the East Antarctic ice sheet in that area since Early Miocene time [16 to 22.5 million years ago]," the group reported.

Potassium-argon dating of lavas in another area of Antarctica tends to support the existence of significant ice even earlier. Wesley Le Masurier of the University of Colorado in Denver and David Rex of the University of Leeds have recently revised previously reported dates for hyaloclastites from volcanoes in Marie Byrd Land. These volcanoes poke through the ice of West Antarctica across the Ross Ice Shelf from the Transantarctic Mountains, 1500 kilometers from the pole.

Unlike Stump's group, Le Masurier and Rex had no choice but to date the hyaloclastites themselves, because the Marie Byrd Land volcanoes appear to be nothing but huge piles of hyaloclastites. When Le Masurier first attempted to date a variety of samples, the extreme ages that he found, up to 42 million years, provoked considerable skepticism about the suitability of the samples. He and Rex have now selected samples that are apparently free of the glassy or altered rock that can retain excess argon and cause false, older ages.

Even with suspect samples eliminated, Le Masurier and Rex found three volcanoes whose potassium-argon ages are greater than 14 million years, the oldest having an age of 27 million years. Unfortunately, they have not yet checked the integrity of the samples by applying the argon-40/argon-39 test, as many dating specialists would like to see. Le Masurier believes that the dates require the existence of a great deal of ice in West Antarctica well before 14 million years ago. Erosion of the soft rock of the volcanoes has left too much hyaloclastite in place over too large an area for the ice to have been a thin, local ice sheet, he says.

Many oceanographers have reservations about the evidence for early ice on East Antarctica. "Until [the continental data] are strongly constrained, I have to remain skeptical," says James Kennett of the University of Rhode Island. He favors the oceanographic evidence that suggests that most of the East Antarctic ice sheet appeared about 14 million years ago. Although there is a variety of marine evidence, the crux of the marine argument involves stable oxygen isotope data. When isotopically lighter ice accumulates on Antarctica, seawater becomes isotopically heavier as a result. Microfauna in the ocean that draw oxygen from seawater for their calcium carbonate tests record this isotopic shift when their tests become part of the sediment.

Most recently, Fay Woodruff and Robert Douglas of the University of Southern California and Samuel Savin of Case Western Reserve University have interpreted the record of one such isotopic shift as representing a "transition from a relatively unglaciated world to one similar to today's." That happened, they say, between 16.5 and 13 million years ago, with the greatest change occurring between approximately 14.8 and 14 million years ago. This is the most broadly held interpretation among oceanographers. Others have doubts about the sudden appearance of the Antarctic ice sheet. Some wonder whether allowance can be made for the effect of changing seawater temperature on the isotopic composition of carbonate tests. If the role of temperature has been underestimated, the isotopic shift 14 million years ago may have resulted from an increase in the size of an ice sheet that was already there.

There is a possibility of reconciling at least some of the apparent discrepancies between the continental and marine records. Woodruff, Douglas, and Savin noted that between about 15 and 14 million years ago the isotopic record fluctuated wildly between glacial and nonglacial conditions before settling into the glacial mode for good. It appears to these researchers that the fluctuations may have been controlled by the Milankovitch orbital variations that have influenced climate for at least the past 8 million years (*Science*, 4 September 1981, p. 1095). Nicholas Shackleton of Cambridge University now reports that he has found similar rapid fluctuations in a high-resolution study of 16-million-year-old sediments. Such high-frequency variability might allow the reconciliation of the presence of ice sheets with a low-resolution isotopic record that suggests a minimum of ice.

—Richard A. Kerr