that has happened since the splitting up of the commune property 6 years ago is a significant degree of economic differentiation between families, or "tentholds." Some families now own ten times as many animals as some other families. "This is very important to us," says Goldstein, "because it is a very live issue in the rest of China just now and here we have an opportunity to examine on a microlevel what led some people to succeed while others failed."

Beall's principal interest is in the physiological adaptation of the Phala to high altitude. "The textbook case is the Andean Indians," she says, "who have very high hemoglobin levels, barrel-shaped chests, and enormous lung volumes." Beall recently had an opportunity to study Tibetan-speaking populations in Nepal, but these people live at 1000 to 1500 meters lower than the Phala. With new data on 180 Phala people, the early indications from the Nepal results appear to be confirmed. "Although these Tibetan populations live at higher altitudes than the Andean Indians, the Tibetans have lower hemoglobin levels than would have been predicted, they don't have barrel-shaped chests, and their average lung volume is not as high."

Assuming the Phala have been living on the Tibetan plateau for a very long time, for which there is some archeological evidence that needs to be confirmed, these new results seem to imply that human adaptation to reduced oxygen levels at high altitude can take different directions.

Although there is a considerable degree of excitement about the newly available opportunity to carry out research in China in general and Tibet in particular, there are problems. "We are charged outrageously high costs for everything we need," one geologist told *Science*. "Our last expedition cost $200 a day for each member of the party, which is much higher than you'd expect virtually anywhere else in the world."

It has to be acknowledged that materials inevitably are more expensive in Tibet, simply because of the costs of getting them up to the high plateau. But it is also true that from the local trader to the highest official, there is often a tendency to charge foreign scientists what some consider to be exorbitant prices for everything from lavatory paper to vehicle hire. As a result the National Science Foundation recently protested at fees being levied by Chinese officials for U.S.-funded field trips.

As Adams says "patience and flexibility" are clearly going to be required while the Chinese and visiting scientists come to grips with the opportunities and responsibilities that flow from the new era of collaborative research efforts. ■ **ROGER LEWIN**

Ocean Drilling Details Steps to an Icy World

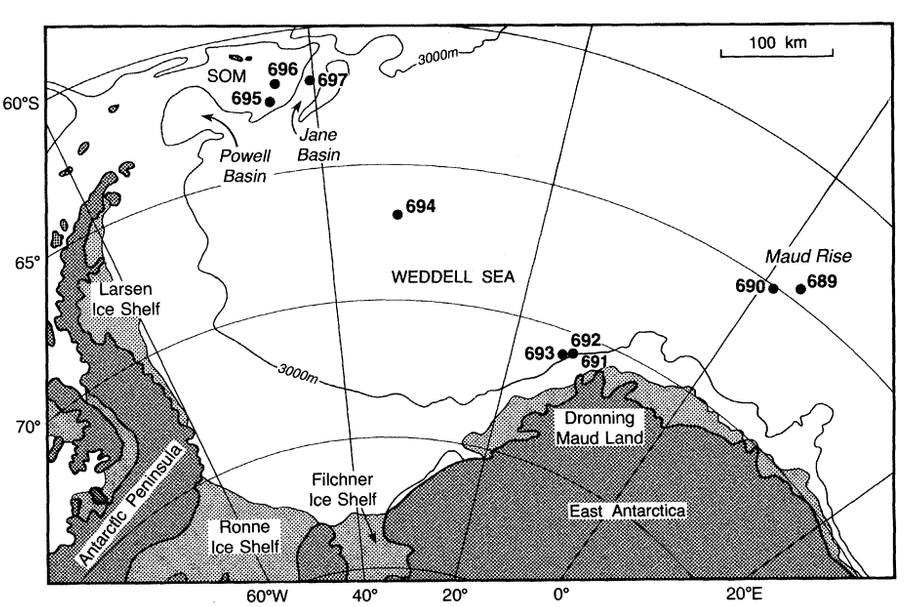
From the most southerly scientific ocean drilling in a decade, researchers are tracing Earth's jerky slide into glacial times

FOR 2 months early this year the deep-sea drilling ship JOIDES *Resolution* played tag with encroaching icebergs as it collected almost 2 kilometers of sediment cores from beneath the far southern sea floor near Antarctica. In those cores are clues to how 40 million years ago the Antarctic region, a pivotal cog in the global climate machine, began slipping step-by-step from a warm, ice-free climate into its present deep freeze in which it harbors 24 million cubic kilometers of ice.

Shipboard analyses of cores are already adding further support to the existence of an early ice-free East Antarctica (the continental landmass of Antarctica), the appearance of ice as early as 35 million years ago, and the durability of the smaller West Antarctic ice sheet that, contrary to recent fears, can stand up to a less frigid climate.

The Ocean Drilling Program's (ODP) strategy during its Leg 113 cruise in high southern latitudes was to follow close behind the breakup of summer sea ice as it progressed around the Weddell Sea, the embayment formed by East Antarctica and the Antarctic Peninsula, which is opposite the tip of South America. The strategy worked, with the help of an ice picket vessel that towed threatening icebergs off a collision course with the immobilized JOIDES *Resolution*. The ship recovered cores from 22 holes at nine sites that sampled sediments influenced by, depending on the location, the biological productivity of surface waters, East Antarctic climate, the production of cold, salty bottom water that flows as far north as New Jersey, and the glacial history of West Antarctica.

According to the initial reports from the shipboard party, there is every indication that Antarctica was unglaciated before about 40 million years ago. The variety of marine microfossils suggests that Antarctic waters were warm, the types and amount of clay are reasonable only if continental erosion oc-



Drill sites in the search for a climate history. *Although sea ice prohibits drilling at these sites except during a few months of the year, and even then poses a threat to the drill ship, the area of the Weddell Sea has a rich record of changing climate on land and in the sea. In addition, much of the water that flows through the deep sea and refreshes it first sinks from the surface of the surface of the Weddell Sea. The tip of South America would be just off the upper left corner of this map.*

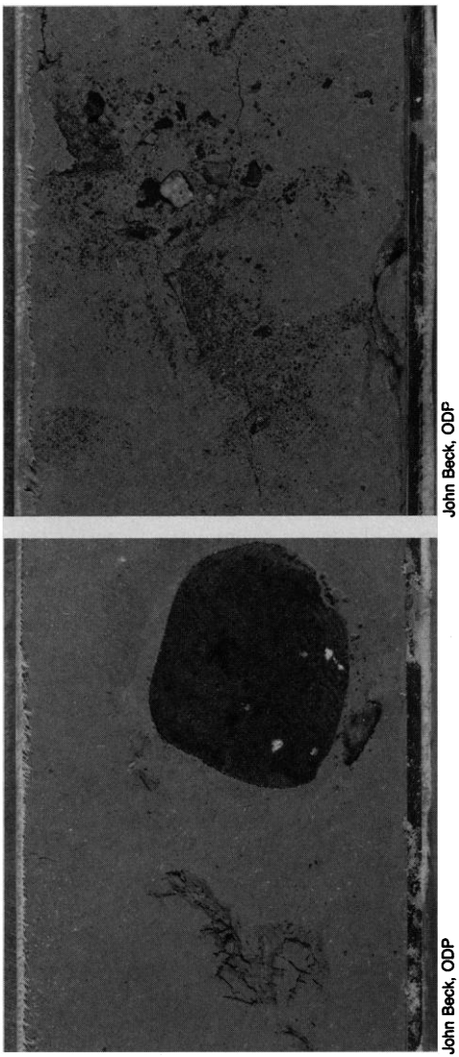
curred under warm, moist conditions, and the recovery of beech tree pollen and fern spores implies temperate forests, at least on the northern Antarctic Peninsula. These results "do not indicate the presence of any ice," says cochief scientist James Kennett of the University of Rhode Island, "not even any glaciation, much less ice sheets."

This evidence, some of which comes from as close as 100 kilometers from the continent, runs counter to suggestions by some researchers who invoke major ice sheets earlier than 40 million years ago. For example, Peter Vail of Rice University and his colleagues at Exxon Production Research Company see the waxing and waning of major ice sheets as the only way to explain the rapid sea level changes that they infer from their studies of continental shelf sediments. Others have cited signs of an ice-free Antarctica and suggested that Vail's sea level changes, if that is what they are, cannot be as rapid as they appear. These ODP results should only reinforce the latter argument.

About 37 million years ago the earth took a quick step toward a colder climate, and one result now appears to have been at least some ice on East Antarctica. "Our earliest evidence of ice is early Oligocene [about 35 million years ago]," says Kennett. "There was obviously some ice, but we can't say how much." The evidence consists of glacial dropstones or so-called ice-rafted debris. This is sand-size or larger rock frozen in ice on the land and dropped to the sea floor after the ice flows to the coast, forms icebergs, and melts. "There is not much of it," he says, "and it is near the continent, so you can't differentiate between local glaciers and a small ice sheet." Either situation could produce icebergs that drift that far before melting away.

A number of paleoceanographers had suggested in recent years that a substantial amount of ice, perhaps one-third to one-half of the present volume of the Antarctic ice sheet, existed well before the next major climate step, which was the formation of the present ice sheet about 13 million years ago. The debate has revolved around the cumulative effects of cooling and ice formation on the oxygen isotope composition of marine sediments. The physical evidence of ice-rafted debris settles the yes-or-no question of the presence of ice, but will not likely resolve the matter of ice volume.

Twenty million years after the first appearance of ice, the Antarctic climate took a double punch that left it in much the same state it is today. As expected, the recent drilling revealed a dramatic increase in ice-rafted debris that occurred about 13 million years ago, when the high landmass of East Antarctica clearly became covered by a massive ice sheet. But a few million years later, West Antarctica, which without its ice was an archipelago the size of the Philippines, became covered with ice as well. West Antarctic ice must have constituted only a small proportion of total Antarctic ice and may have waxed and waned long after its initial formation, according to preliminary results. But its formation has been linked to a shift in the ocean toward present conditions, including an increased flow of the the cold, salty water that forms in the Weddell Sea and sinks to flow along the bottom for thousands of kilometers.



Evidence of ice. *The sand, gravel, large stone in these sediment cores were picked up by glacial ice on East Antarctica that formed icebergs, melted, and dropped its load of debris about 100 kilometers off the coast. The large dropstone (below) is about 4 centimeters in diameter and was found in sediment that is about 30 million years old. The sand and gravel (above) is in 25-million-year-old sediment.*

Since about 4.8 million years ago, the West Antarctic ice sheet appears to have been a permanent fixture, Kennett says. That should be somewhat reassuring to glaciologists attempting to gauge its reaction to the greenhouse warming of at least a few degrees expected in the next century. Some had feared that any warming would destabilize the ice sheet and send it surging into the sea, drowning coastal cities with a sea level rise of several meters over a few decades. Kennett notes that at times during the past 5 million years the West Antarctic ice endured climates that globally were at least a couple of degrees warmer than at present. What might happen if the greenhouse warming reaches several times that amount, as models suggest could happen in polar regions, remains less certain.

The most recent step taken by Antarctic climate seems to have been in concert with events at the other end of the earth. About 2.4 million years ago, according to the ODP results, the production of diatoms in Antarctic surface waters decreased sharply, presumably when sea ice extended its reach northward and shaded the algae below. That also happens to be the agreed upon time of initiation of Northern Hemisphere glaciation. A link might be presumed between the two events. For example, physical changes in one hemisphere, such as the redirection of ocean circulation by drifting continents, might induce climate changes in that hemisphere, which in turn could alter the climate of the rest of the globe. Whatever the cause of the change 2.4 million years ago, says Kennett, "Obviously the globe went through another threshold."

The analysis of Leg 113 cores has only just begun. More precise dating and the measurement of isotopic composition will be of particular interest to paleoclimatologists. But there are also discoveries unrelated to climate. JOIDES *Resolution* managed to recover two cores containing the Cretaceous-Tertiary boundary without disturbing them during drilling. They are the highest latitude cores to bear on the controversy over the cause of the demise of the dinosaurs. And in one of the big surprises of the leg, a hole intended to begin in sediments less than 25 million years old instead encountered black, organic-rich mud more than 100 million years old. Unbeknownst to Leg 113 planners, invigorated currents at about the time of the 37-million-year cooling and earlier scoured away 60 million years worth of sedimentation.

JOIDES *Resolution* is now finishing Leg 114 in the sub-Antarctic South Atlantic. Combined with the results from future cruises in the Indian Ocean, these ODP legs should go a long way toward developing a picture of how Antarctica became Earth's deep freeze. ■ RICHARD A. KERR