Fits and Starts: What Regulates the Flow of Huge Ice Streams?

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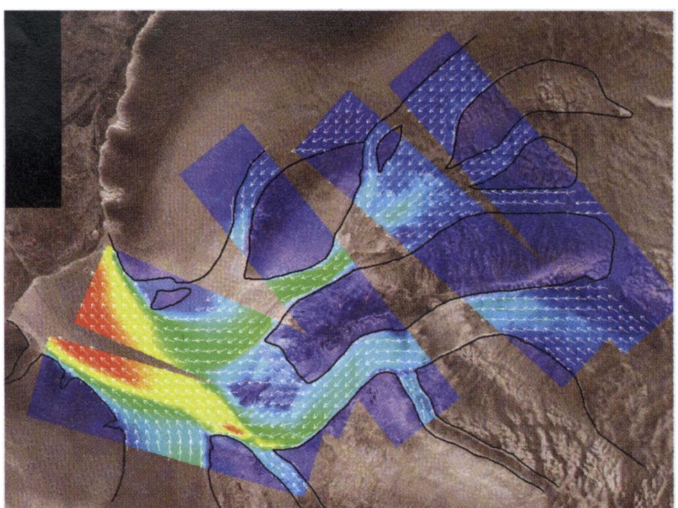
FITS AND STARTS

What regulates the flow of huge ice streams?

BY SID PERKINS

Imagine the consternation that your high school physics teacher would have shown if, during a lab demonstration, the little wheeled block placed on an inclined plane had violated the law of gravity. Imagine the block sometimes speeding up, sometimes slowing down, and sometimes stopping dead on the slope. Scientists have faced a similar situation as they've studied some of Antarctica's most massive glaciers. The researchers are eager to understand the behavior of these ice streams because they have considerable influence on sea levels worldwide.



DOWN THE RIVER — The material in ice streams flows much faster than does the ice on nearby highlands. Blue tint denotes speeds of less than 10 meters per year; red denotes speeds of 1 kilometer per year or more.

BYRD POLAR RESEARCH CENTER, NASA, CANADIAN SPACE AGENCY

Scientists estimate that ice streams contribute about 90 percent of the ice flowing directly off Antarctica into the surrounding sea. However, "we can't now predict how much ice will flow into the sea in the future," says Ted A. Scambos, a glaciologist at the National Snow and Ice Data Center in Boulder, Colo.

Some factors that influence ice streams are well known, but others are just being revealed. New findings show complex aspects of ice streams that have yet to be incorporated into models of how such ice behaves, Scambos notes.

New studies bolster the notion that bodies of water beneath glaciers accelerate the streams by warming the ice and lubricating its flow. Other recent research hints that immense volumes of sediment that the streams scrape off the continent pile up where the ice meets the sea. This sediment may act as a buttress to slow ice flow.

Furthermore, Antarctic field studies suggest that the Kamb Ice Stream stopped in its tracks 150 years ago. The neighboring Whillans Ice Stream is slowing significantly and, at the current rate of deceleration, may shut down a little more than a century from now. So far, scientists can't fully explain these unusual slowdowns.

Factors that affect the flow rates of ice streams operate at many time scales. Ocean tides produce daily and weekly variations in flow speed at some locations, while the draining and filling of subglacial lakes and the climate cycles, such as ice ages, appear to cause variations over decades, centuries, or millennia. The deceleration that eventually immobilized the Kamb Ice Stream may have been triggered by cooling that occurred during the Little Ice Age several centuries ago.

GOING DOWNHILL All the ice in Antarctica eventually flows to the sea. Just as the water flowing off warm landmasses reaches the sea via rivers, most of the ice spilling off Antarctica and Greenland is carried by ice streams. These massive glaciers typically flow much faster than nearby ice does. Many ice streams are unexplored, and others haven't been visited by scientists in decades. Some of these flows didn't even have names until about 5 years ago.

Many ice streams nourish broad regions of floating ice that remain attached to the land at their upstream boundaries, or grounding lines. These floating masses, called ice shelves, connect to about 44 percent of the continent's coast.

Some regions of ice flow much faster than others. For example, one section of an ice stream can flow hundreds of times faster than a higher area nearby does.

Several factors affect the flow rate of an ice stream, says Richard Hindmarsh, a glaciologist with the British Antarctic Survey in Cambridge, England. The temperature of the ice plays a big role. Ice flows more rapidly at 0°C than does ice at –10°C, he notes, because viscosity at the higher temperature is only 10 percent of that at the lower temperature.

The roughness and grade of the terrain underlying the ice are other major influences on flow rate. They affect the friction at the base of the ice stream.

In most locations, friction at the base of an ice stream changes slowly, if at all. However, that's not the case where these megaglaciers meet the sea and are supported by the water rather than by underlying terrain. Near the grounding line, the effects of ocean tides become readily apparent, says Sridhar Anandakrishnan, a glaciologist at Pennsylvania State University in University Park.

For example, the tide influences how forcefully an ice stream presses against the shoreline terrain, Anandakrishnan notes. Some ice streams come to a halt twice a day, typically near low tide, when they weigh most heavily against the streambed. Later, when rising tides lift some of the ice shelf's weight, the ice stream surges forward, thereby decreasing the friction on the ground just inland.

Because of this surge-and-stall behavior, scientists must carefully synchronize their measurements with tidal cycles to accurately estimate an ice stream's overall velocity, says Anandakrishnan.

New data suggest that ocean tides can cause the velocity of an ice stream to vary not only over the course of a day but also over the course of a month. Glaciologist G. Hilmar Gudmundsson of the British Antarctic Survey in Cambridge, England, examined the Rutford Ice Stream in western Antarctica. That stream is 150 kilometers long, 25 km wide, and as much as 3 km thick.

Gudmundsson used global positioning system (GPS) equipment to measure the rate of ice flow at several points on the Rutford Ice Stream every 5 minutes between late December 2003 and mid-February 2004. On average, the ice in that stream slides seaward about 1 meter each day, he found.

However, ice-stream velocity varied significantly during the 7-week period. At neap tides—the exceptionally small tides that occur when the moon is in one of its quarter phases—the ice stream's peak velocity measured about 0.90 m/day at the grounding line. During the highest tides of the month—the so-called spring tides that occur when the moon is full or new—the ice stream clocked in at a velocity of 1.15 m/day.

Gudmundsson's report, the first to describe fortnightly, tidally induced variations in ice-stream velocity, appeared in the Dec. 28, 2006 *Nature*.

Similar biweekly variations in ice-stream velocity were observed at all sites where Gudmundsson had installed the GPS equipment, even at a spot 40 km inland of the ice stream's grounding line. Seeing a tidal effect at such a distance "was a total surprise," says Gudmundsson. "For such a large mass of ice to respond to ocean tides like this illustrates how sensitively the Antarctic ice sheet reacts to environmental changes."

SLIPPIN' SLIDE Scientists have long presumed that an ice stream can move more rapidly when water lubricates its base. Field studies and data gathered by satellites now directly demonstrate the link between ice streams and subglacial water.

The Recovery Ice Stream, which drains a 1-million-square-kilometer area of eastern Antarctica, penetrates farther into the continent's interior than any other ice stream, says Michael Studinger, a glaciologist at Columbia University's Lamont-Doherty Earth Observatory in Palisades, N.Y. By combining new satellite observations and field data gathered decades ago, Studinger and his colleagues have identified four immense subglacial lakes beneath the ice stream.

Together, the lakes stretch across the upper reaches of the Recovery Ice Stream's catchment area, a distance of more than 350 km. They cover an area of about 13,300 km^2, about half the size of North America's Lake Erie. Ice over the lakes is flat, featureless, and more than 3 km thick, the researchers report in the Feb. 22 *Nature*.

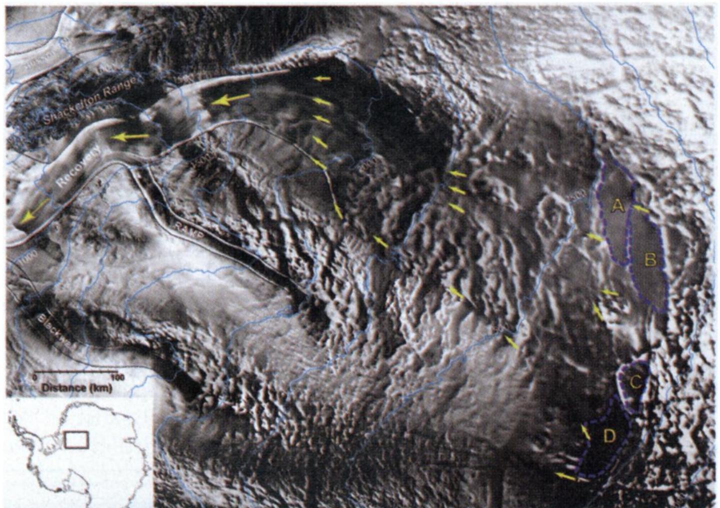
Upstream of the newly discovered lakes, ice velocities clock in at only about 2 m/yr, says Studinger. Then, where the ice stream flows onto a lake, it suddenly speeds up.

Over a lake, the flowing ice floats on water and experiences almost no friction, the researchers note. The acceleration stretches and thins the ice slightly at the upstream lakeshore, creating a distinctive, broad trough a few meters deep. Similarly, when the ice reaches the downstream shore of the lake, it decelerates in response to the friction there. That slowdown generates a small ridge in the ice stream's surface.

Immediately downstream of the lakes, the ice stream flows at rates between 20 and 30 m/yr. That's faster than upstream of the lakes because the stream's bottom surface soaked up heat during its several-millennium-long trip across the lakes, says Studinger. Also, water flowing from the lakes, either in trickles or in occasional floods, probably lubricates the base of the ice stream.

Even farther downstream of the lakes, the ice zips along at an impressive 100 m/yr.

Coincidentally, Anandakrishnan and another team of scientists report that they've discovered a shallow body of water beneath the head of an ice stream in western Antarctica. During the 2002–2003 field season, the researchers collected seismic data along a 16.7-km stretch of a tributary of the Bindschadler Ice Stream. Taking advantage of the well-known vibration-transmitting characteristics of ice, the researchers inferred the characteristics of the rock and sediments that underlie the region.



GREASING THE SKIDS? — A recently discovered series of subglacial lakes (outlined in blue) underlie the region where the Recovery Ice Stream accelerates to speeds of up to 30 meters per year. Arrows denote direction of ice flow.

C.A. SHUMAN AND V. SUCHDEO/NASA

Under most of the sites that they studied, a layer of sediment 5 to 20 m thick was sandwiched between the base of the ice stream and the bedrock, says Anandakrishnan. Some segments of the streambed were lined with well-packed sediment, where seismic waves of the type that transmits shear forces through the ground traveled about 1 km per second. In other sections, the ice rested on loosely packed sediment, where shear waves traveled less than 200 m/s.

Along one kilometer-long portion of the streambed, the scientists received no reflections of shear waves at all—a sign that a pocket of water sat beneath the ice stream. The time lag in the echoes of other seismic waves indicated that the water was between 5 and 10 m deep, Anandakrishnan and his team report in the March *Geology*.

There's evidence of recent water movement beneath the ice stream. In 2005, researchers reported that a kilometers-wide region of ice upstream of the seismic survey sank about 30 centimeters during a 24-day period in 1997. In the same interval, a broad region about 10 km downstream of the survey site rose about 50 cm. That change reflects a surge of about 10 million cubic meters of water, the team calculated.

Occasional floods and the long dry spells in between may contribute to the irregular behavior of ice streams, says Scambos.

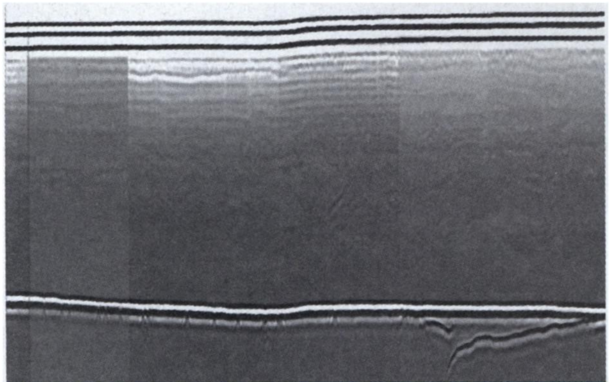
WEDGE ISSUE As ice streams wend their way to the sea, they scour the landscape, shattering the underlying bedrock into particles ranging from boulders to fine grounds called rock flour. Some of this material becomes embedded in the lowermost layers of ice.

When the stream reaches the sea, some of the particles stay in the icebergs that break off and float away. The particles eventually melt and scatter the detritus across distant seafloors. Other material remains onshore and lines the streambed. Much of the rest is bulldozed off the continent by the advancing ice and ends up just offshore.

Observations of the continental shelf beneath the open water off Antarctica have revealed many such deposits. Each is typically between 5 and 15 km long, tens of meters high, and wedge-shaped, with the narrow portion of the wedge pointing toward shore.

The wedges were laid down by ice streams during the last ice age, which ended around 10,000 years ago. Then, sea levels were more than 100 m lower than they are today, and the streams had to flow much farther to reach the ocean, says Anandakrishnan.

The sediment deposits were left behind as sea levels rose and the ice streams retreated. Up and down each ancient channel, they're spaced about 50 km apart. Similar deposits probably lie beneath the floating ice shelves that rim much of Antarctica, but scientists can't yet conduct surveys of those areas to confirm the features' presence.



I SEE ECHOES — The broad, horizontal lines across the bottom of the image depict the lower surface of Antarctica's Whillans Ice Stream. The faint, slanted line at lower right traces the lower edge of the underlying sediment wedge, which slows ice flow from the continent.

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However, a seismic survey of the Whillans Ice Stream at its grounding line shows that a wedge of sediment is accumulating there. "It's being replenished as we speak," says Anandakrishnan.

The seismic reflections from the terrain beneath the ice stream suggest that the wedge is no more than 30 m or so thick. It stretches at least 8 km along the ice stream's channel. Anandakrishnan says that the wedge may extend another 10 km or so offshore of the grounding line, but the water beneath the ice shelf interferes with the echoes of seismic-shear waves and so masks any underlying material. Anandakrishnan and his colleagues describe their findings in the March 30 *Science*.

Data also show that ice is piling up atop the sediment wedge at the grounding line, so the wedge appears to act as a speed bump for the ice stream, says Anandakrishnan. The extra weight stabilizes the location of the grounding line because modest rises in sea level—increases of 5 m or less, the team's models suggest—wouldn't cause the ice stream to float free.

The wedge's buttressing effect slows down the ice flow from the continent—an important role, to be sure. Because Antarctica holds about 90 percent of the world's land-based ice, scientists have long been concerned about a surge in the rate of Antarctic ice reaching the ocean. There's enough ice there to boost worldwide sea level by 60 m.

Global warming, which increases ice temperature and makes glaciers flow faster, may be only part of the problem. Computer models suggest another factor: Ice streams often accelerate when the ice shelf into which they flow disappears (*SN: 2/3/01, p. 70*), potentially boosting sea level. Indeed, five of the six large glaciers flowing into the Larsen A Ice Shelf accelerated soon after that mass of ice disintegrated early in 1995 (*SN: 3/8/03, p. 149*).

With the host of new findings—including the subglacial lakes that tend to accelerate ice streams and the sediment wedges that hold them in check—researchers expect to improve their predictions of ice-stream behavior.

"These are incredible discoveries," says Scambos. "They're a big plus for modeling of the Antarctic ice sheet."

Slowly but surely, scientists are discovering the factors that underlie previously puzzling megaglacier behavior. The ice streams aren't defying gravity, after all. As Scambos says, "It's all about the balance between friction and freezing." ■

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males are still flirting with females and accepting contributions to the egg pile. Tests showed that females looked more favorably on a male with young eggs in the pile. Once the flirting period was over, however, the males tended to snack on the younger eggs.

Besides egg age, certainty of paternity can influence a father's choice of edible offspring. Earlier tests had suggested that when another male tries to fertilize the eggs during spawning, the brood-guarding male is more likely to turn cannibal.

New work shows that an intruding male has this effect even on a fish that doesn't take care of his eggs. The colorful males of *Telmatherina sarasinorum* compete fiercely to spawn with the drab females of Indonesia's Lake Matano. Even after a couple has paired up, another male may dash over to it and release sperm that might reach at least some of the eggs. The original male then might understandably make the best of a bad job and get lunch.

For three breeding seasons, Suzanne M. Gray of Simon Fraser University in Burnaby, British Columbia, watched several hundred encounters of courting *T. sarasinorum*. If a second male showed up, the chances tripled that the original male would turn around right after spawning and gobble some of the brood off the lake bottom. If a third male showed up, the chances of egg cannibalism rose almost sixfold, Gray and her colleagues report in the February *American Naturalist*.

This is the first time that anyone has shown cannibalism increasing as evidence of cuckoldry increases, says Gray.

In calculating the difference between the effects of one bounder and of two, scientists may be making a fine distinction in working out the nuances of filial cannibalism. But that research demonstrates how dramatically ideas have changed since the days when eating the kids was considered just a crazy, stupid mistake. ■