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Ice Shelf Break-Up and Ecosystem Loss in the Canadian High Arctic

PAGES 548, 552

Over the last 3 years, extensive fractures have appeared in the ~3000-yr-old Ward Hunt Ice Shelf (83°N, 75°W). The largest fracture, a north-south-oriented serpentine feature (Figure 1), now forms an obvious dividing line between the west and east sides of the ice shelf. Secondary fractures extending westward from the central fracture have fragmented a large area of the ice shelf into free-floating ice blocks. The fractures have severely weakened the ice shelf, although for the moment it remains pinned in place by a number of islands and ice rises. An immediate consequence of the fracturing was the catastrophic drainage of a fresh water lake that was dammed behind the ice shelf. This "epishelf" lake represented a rare ecosystem type in the northern hemisphere, which was particularly vulnerable to climate change. In a recent paper in *Geophysical Research Letters* [*Mueller et al.*, 2003], a recent 30-year period of accelerated warming, part of a longer 20th-century warming trend, is implicated as a factor in the fracturing of the ice shelf and the drainage of the epishelf lake.

The Ward Hunt Ice Shelf, located close to the most northerly point in North America in Quttinirpaaq National Park, is the largest of five remnants of a much larger ice shelf discovered in 1906 by Admiral Peary. Massive ice islands, such as the famous T-3, calved from the former ice shelf and were observed in the Arctic Ocean in the late 1940s and early 1950s. Ice island calving has continued sporadically over the last century; important events occurred in the 1960s and 1980s. The precise triggering mechanism for the recent fractures is not known, but it might include tidal activity, wind stress, or freeze-thaw cycles acting on the climate-weakened ice shelf. A change in the course of fresh water drainage out of Disraeli Fiord below the ice shelf is also a possibility and might explain the sinuous nature of the main fracture.

Prior to the fracturing of 2000–2002, a fresh water epishelf lake with a depth believed to be equivalent to the draft of the ice shelf existed at the surface of Disraeli Fiord, south of the Ward Hunt Ice Shelf. Between 1967 and 1999, the depth of fresh water decreased from 43 m to 28 m. The freeboard of the recently created free-floating ice blocks in the ice shelf suggests an ice thickness in the vicinity of 25 m, 15–20 m less than the last reliable estimate of ice thickness made by airborne radio-echo sounding in 1980. The reduction in ice thickness can be accounted for by mass wasting at the surface and/or the underside. Alternatively, under-ice drainage of Disraeli Fiord may have changed, causing localized thinning and fracturing of the ice shelf. There is evidence that the sub-ice outflow from the epishelf lake previously contributed to the mass balance of

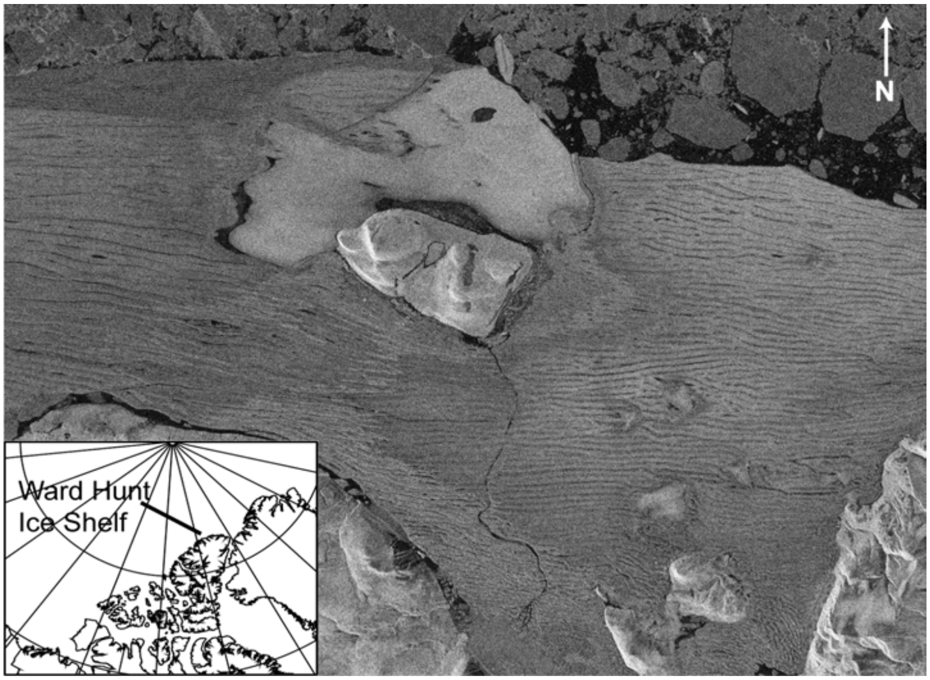

Fig. 1. This RADARSAT image (30 August 2002) of the Ward Hunt Ice Shelf shows the serpentine crack that now provides a conduit for fresh Disraeli Fiord water (at the bottom of the image) to drain northward to the Arctic Ocean. Ward Hunt Island and grounded ice to the north are at the top center of the image. The fracture is 15 km long. Image courtesy of the Alaska Satellite Facility, Geophysical Institute, University of Alaska-Fairbanks, © Canadian Space Agency. The inset map shows the location of the Ward Hunt Ice Shelf with respect to Ellesmere Island in the Canadian High Arctic.

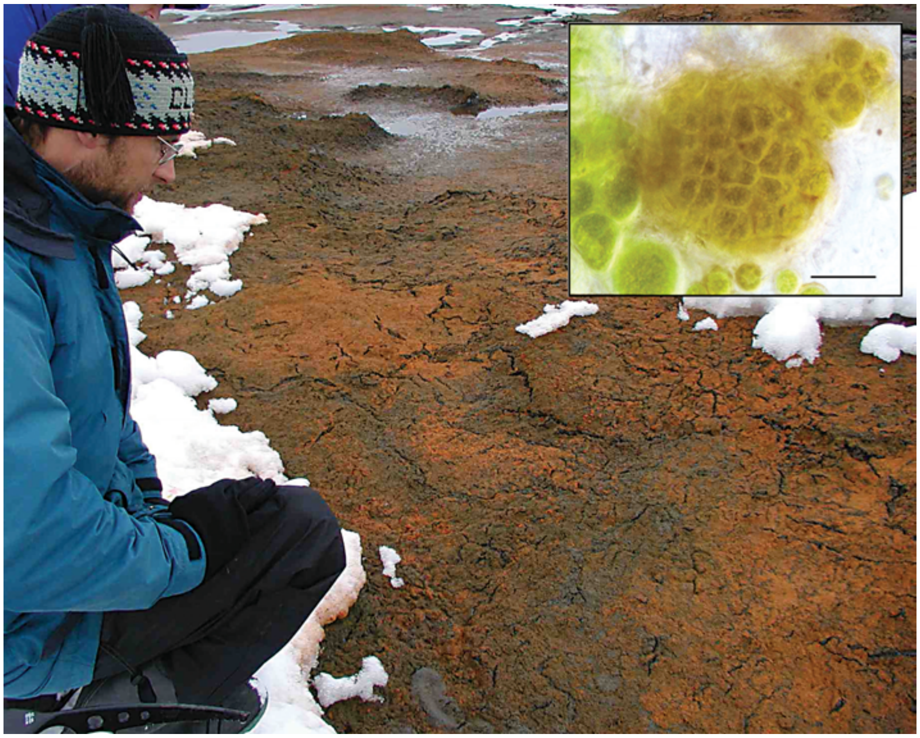

Fig. 2. This image shows microbial mats on the Markham Ice Shelf, one of the last remaining ice shelf ecosystems at the northern coast of Ellesmere Island. The orange color is due to carotenoids that protect the algal cells against bright solar radiation. (Photograph courtesy of W. F. Vincent.) The inset shows a micrograph of the mat algae; the scale bar represents 10 μm. (Image courtesy of S. Bonilla).

the ice shelf by basal accretion. This process can no longer continue now that the fresh water lake has drained. Determining exactly what occurred is difficult due to large gaps in surface mass balance records and uncertainties in basal ice processes.

The first detailed investigation of the physical oceanography of Disraeli Fiord was conducted in 1967. In 1999, biologists discovered fresh water copepods co-existing with marine copepods, a curious ecological situation that is possible in a fresh water lake with sea water at its bottom. The abrupt loss of the epishelf lake in Disraeli Fiord underscores the sensitivity of ice-dependent ecosystems to climate change. The Ward Hunt Ice Shelf itself also supports an ice-dependent ecosystem. Our studies of ice shelf surface ecology have revealed microbial communities composed of algae, micro-invertebrates, and bacteria that can tolerate harsh conditions (Figure 2). Frozen for 10 months of the year, the organisms grow slowly in summer in near-freezing water, enduring freeze-thaw cycles and using pigments to cope with damaging ultraviolet radiation. Should the Ellesmere ice shelves continue to shrink and ultimately disappear in response to the projected high-latitude warming this century, the ice shelf biota would also be lost.

Underlying the many unusual characteristics of the Ward Hunt Ice Shelf, one thing seems clear: it and the other Ellesmere ice shelves are sentinels of high Arctic environmental change. This sensitivity is amplified by the absence of glacial input to the Ward Hunt Ice Shelf; it is a relatively simple system, without the complexities of glacier dynamics and their delayed response to climate variability.

Climate data are sparse in this remote region, but proxy climate data from ice cores and lake sediments indicate that the Little Ice Age ended roughly 150 years ago and that the climate has been warming since. The disintegration of the original Ellesmere Ice Shelf may already have been underway when explorers traveled this coast in 1906. Now, only 10% of the original ice shelf remains. An instrumental temperature record from Alert, 175 km east of the Ward Hunt Ice Shelf, shows a statistically significant increase in mean annual air temperature during the last 30 years in parallel with the thinning and loss of the epishelf lake.

After 2 decades of stability, the inconspicuous Ward Hunt Ice Shelf was brought into the limelight as a result of these recent events. This highlights the widespread public interest in climate and polar environmental change. These observations also reveal that much remains unknown about the complex interactions among ice, ocean, atmosphere, and biosphere in this remote region.

Reference

Mueller, D. R., W. F. Vincent, and M. O. Jeffries, Break-up of the largest Arctic ice shelf and associated loss of an epishelf lake, *Geophys. Res. Lett., 30, 2031*, doi:10.1029/2003GL017931, 2003.

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MEETINGS

International Ice Core Community Meets to Discuss Best Practices for Ice Core Curation

PAGE 549

Several countries now have national ice core laboratories, or substantial ice core facilities, where these proxy archives of the Earth's past climate and atmosphere are safeguarded, processed, and analyzed. Australia, China, Denmark, Japan, Argentina, and the United States have formal, dedicated ice core repositories with laboratories. India's is under construction, in Goa. France, Germany, Russia, and the U.K. have long had substantial ice core holdings and facilities for analysis of ice cores. Brazil, Chile, Italy, and Switzerland have expanding field acquisition and analytical programs that require favorable storage conditions for ice cores.

Representatives of 12 countries gathered in Milan, Italy, in late August for a first meeting, InterICE, of "international ice core establishments," to compare and discuss ideas about best practices for acquisition, storage, curation, and distribution of the ice cores that have been drilled from the polar and temperate glaciers of the world, representing up to a half-million years of the Earth's most recent past.

The meeting began with overview presentations by the labs of Denmark, Australia, Japan, the United States, Italy, France, Russia, China, and Germany. These emphasized both the nature of the physical facilities (one of the two Japanese labs is the coldest, -50°C, to slow loss of gases from cores and dissociation of clathrate hydrates in cores; the U.S. lab has the largest cold room) and the practices favored by each to safeguard the collections (Denmark and the U.K. store cores in insulated chests inside the cold room, to maximize thermal protection; Australia, France, Germany, and U.K. enjoy added security from the value of commodities in the commercial freezer facilities they use; Russia keeps some of the famous Vostok core in the field, in the uniquely cold and stable conditions of the East Antarctic Plateau).

Lab presentations were followed by a panel discussion featuring six people nominated for their contributions to the field and their long experience working with ice cores in field, laboratory, and scientific investigative environments (J. P. Steffensen of Denmark, Takeo Hondoh of Japan, Jean Robert Petit of France, Geoffrey Hargreaves of the U.S., Vincent Morgan of Australia, and Josef Kipfstuhl of Germany), concentrating on the related topics of field procedures, accession of cores into collections, storage and curation methods, and de-accession strategies (eventually removing some cores from collections). For the subsequent whole-group discussion (about 20–25 total participants), additional topics were processing and storage conditions of the core collections, and transportation of cores and samples to and between labs.

It was agreed by the entire group that rigorous, detailed, and consistent logging and documentation of the core in the field is essential, partly due to the need for precise and reproducible reference to time-stratigraphic locations within cores, and the climatic and atmospheric records that they contain. With continual changes in drilling technology, field records of drilling conditions and history may take on importance equivalent to that of records about the cores themselves. "Touch screen" computers may increase the accuracy and detail possible for field records. Removal of drilling fluid from cores can be done most efficiently in the field, and this is necessary to prevent continuing penetration of these fluids (such as n-butyl acetate) into the axial portions of the cores. For deep drilling (bedrock is at 3 km where the ice is thickest in Greenland; deeper in Antarctica) a fluid with approximately the same density as glacial ice (∼0.92) must be used to prevent closure of the boreholes in the high-pressure, plastic flow conditions of the deeper portions of the ice sheets. Instead of evaporative removal, physical removal by vacuum sweepers or "air knife" tunnels may be adopted in the future. European programs have long used research scientists as drillers and core handlers and loggers in the field; U.S. drilling programs have used contract personnel in the field, but plan in the future to have greater involvement by permanent staff of the national laboratory. Field storage conditions and "relaxation times" must be carefully considered, especially for core from the "brittle zone" in which ice has not fully equilibrated to the transition in which bubbles of atmospheric gasses fully collapse, and the gasses go into clathrate form in the ice structure. Ice from this zone (commonly several hundred meters below surface) is subject to shattering, even with careful drilling and field handling.

Ice Core Preservation

A central goal of ice core repositories is to prevent sublimation loss of ice in collections, beginning at the time of first removal from the ice sheet, and continuing through several decades of storage. (Some cores still in curation date back to the IGY of the 1950s.) Different labs have distinct, successful strategies toward this goal, but all labs put cores inside closed plastic sleeves. Some labs then favor maximum thermal protection for the cores, placing them inside insulated boxes within cold rooms