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Science 315, 1525 (2007);
DOI: 10.1126/science.315.5818.1525

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Race to Plumb the Frigid Depths

In the Arctic Ocean, research fueled by national claims could reveal past climates, unknown life forms—and vast natural resources

By all appearances, Trine Dahl-Jensen and Ruth Jackson have transcended national boundaries in the name of science. Working for the geological surveys of Denmark and Canada, respectively, the geophysicists are mapping the structure of undersea rocks hundreds of kilometers north of Greenland and Canada’s Ellesmere Island. In this forbidding region, habitual convergences of winds and currents force ice floes into solid jumbles 100 meters thick. Polar bears, whales, and even icebreakers are frozen out. Most knowledge of the depths comes from a few sounding tracks made by Cold War subs. To gather data, Dahl-Jensen and Jackson land by helicopter, set off explosives, collect echoes from the bottom, and then scramble back to the Canadian military base of Alert, humanity’s northernmost toehold on land.

Actually, national interests are their reason for being here. The five nations bordering the Arctic Ocean are in an underwater land rush to legally divvy up much of the sea bottom, based on its geology. In this particular region, Canada and Denmark have teamed up to cut costs. Other scientists are hunting for oil and minerals or seeking sea-floor records that might suggest how fast global warming could peel back Arctic ice. Denmark and Canada have budgeted $80 million for mapping over several years. Jackson compares it to the Americans’ 1867 purchase of Alaska from Russia. “It might not have seemed too useful at the time,” she says, “but give it another 30 or 100 years.”

Similar nationally funded projects have already sparked some nasty disputes, but the money is sloshing over into the International Polar Year (IPY), where it might foster cooperation. Researchers say that once the politics are sorted out, the same might be tapped soon, but other resources could become available, says James Hein, a senior researcher at the U.S. Geological Survey (USGS), who tracks Arctic minerals. These might include placer deposits of diamonds or gold washed by rivers onto shallow continental shelves from Canada or Siberia. Dramatic summer melting in the last decade has opened shipping channels, and companies have begun prospecting. “No one is going to know what they’ve found until they’re ready to move,” says Hein.

The big prize, almost certainly, is hydrocarbons. In 2000, USGS estimated that maybe a quarter of the world’s undiscovered hydrocarbons—an estimated 3.1 trillion to 11 trillion barrels of oil—lies in the Arctic. USGS research geologist Donald Gautier is co-heading a new circumpolar hydrocarbon survey. When it comes out in 2008, “it is logical to think” the estimate will go up, he says. Along with known oil and gas reserves already mapped in near-shore zones, such as Alaska’s Prudhoe Bay, deposits may be locked up in gas hydrates farther out. One speculative map from the Geological Survey of Canada forecasts hydrate fields extending to the pole. Although all wells currently hug the shore, many companies are developing hardware to expand deep into ice-covered waters, says Graham Thomas, chief of cold-regions technology for the oil company BP.

Geologic information is central to the territorial claims themselves. Under the U.N. Convention on the Law of the Sea, the United States, Russia, Norway, Canada, and Denmark (which administers Greenland) may claim underwater rights beyond their 200-nautical-mile economic zones via any submerged “natural prolongation” of their landmasses. The U.N. rules are based on formulas that take into account the contour line where water depth reaches 2500 meters, along with details of seabed geology, including measurements of sediments that may have eroded off continental shelves. Most of the Arctic Ocean is ringed with expansive shallow continental shelves and possibly related topographic features, so nearly the whole ocean may someday be claimed, except for a couple of small doughnut holes way out in the middle. The United States, which has yet to ratify the convention, has been mapping the seabed since 2003; it could
Some experts don’t buy this argument. Lawrence Lawver, a marine geophysicist at the University of Texas, Austin, says such claims “are based more on desire than geology.” It’s hard to argue that the Lomonosov is not actually connected to either, the midline above Greenland and Ellesmere, or what it’s attached to now.” Under a 2005 agreement, their findings are secret, but the scientists hope to gain some 600,000 square kilometers of Alaskan shelf, worth $650 billion if present oil estimates hold up.

The really dicey part is mapping the deep, central Arctic, which is crisscrossed by a half-dozen huge underwater mountain ranges that may or may not be connected to certain landmasses, depending on whose scientists you listen to. One major feature is the 1800-kilometer-long Lomonosov Ridge, which runs from above the central Siberian continental shelf through the North Pole, to above Greenland and Ellesmere. Most scientists agree that it peeled off from the shelf of what is now Russia and Scandinavia some 60 million years ago. One end stuck near Siberia while the rest pivoted outward, like a splinter being pried off a log. Based on this history and proximity, the Russians say it is theirs, up to the pole. On the other side of the pole, Jackson and Dahl-Jensen are building the case for Canada and Greenland. If they succeed, Denmark stands to gain up to 180,000 square kilometers—four times the size of Denmark itself.

By measuring seismic waves passing through the sea floor, the scientists hope to establish that the rocks under the Lomonosov are deep-seated and of low density, and thus probably of continental origin. They are also mapping sediments and bathymetry in an effort to show that their lands and the Lomonosov may be linked. Never mind where the ridge came from, says Jackson. “The question is what it’s attached to now.” Under a 2005 agreement, their findings are secret, but the scientists make no bones about their governments’ aim: With the ridge neatly straddling a midline above Greenland and Ellesmere, although not actually connecting to either, the nations aim to divide it up.

Some experts don’t buy this argument. Arthur Grantz, a retired USGS polar expert, calls the idea that buoyant crust could somehow sink into the abyss “kind of nutty.” He and others contend it is a notion peculiar to Russia—and old-fashioned even there—and long discredited by plate tectonics. “I understand where they’re coming from, though,” Grantz says. “They’re under great pressure. Their government gave them a lot of money, and it expects them to come up with a certain result.” Lawver, Dahl-Jensen, and others agree. Geologist Ron MacNab, a member of the Canadian Polar Commission, labels Russia’s conclusions “embarrassing” and “Stalinist.”

Russian scientists have shot back. An official summary of a 2003 conference organized by their Ministry of Natural Resources calls the criticisms “presumptuous” and “strange.”

Because there is so little credible data, the Arctic sea floor’s history is largely a mystery, admits MacNab—and scientists are unlikely to figure it out if they don’t stop bickering. “We’re developing a train wreck in the Arctic unless we get together on this,” he says.

Curious cores

If the sea ice keeps melting at its current rate, the confrontation over Arctic territory will intensify; yet most scientists are loath to predict what the climate will do, because it is difficult to disentangle the effects of humanmade greenhouse gases from natural cycles of warmth and cold. For this, bottom cores recording past sea-ice cover, water temperatures, and movements of glacial sediments may provide the most telling evidence.

The first deep-sea Arctic sediment cores of great age—still the only such samples—were brought up by the Integrated Ocean Drilling Program (IODP) in 2004, 320 kilometers from the North Pole. Detailed analyses published in Nature and Geophysical Research Letters last year portray the Arctic of 45 million to 55 million years ago as a landlocked, scummy pond. Sea temperatures were warm enough to support thick layers of ferns and algae. Younger layers show long-term cooling, with more cold-water plankton and superthick glaciations or sea ice scouring the bottom. Subsequent warm
Thriving Arctic Bottom Dwellers Could Get Strangled by Warming

Ten years ago, biologists skirting Canada’s mainland Arctic coast on an icebreaker lowered a video camera to the bottom and got a surprise. Instead of the desolation they expected below ice-covered waters, there was a crowd. Slender brittle stars elbowed each other; fish glided by; anemones writhed under the camera’s bright light. This wonderland could be jeopardized by climate change. “We don’t know until it happens, but if you have no ice, you probably have no typical Arctic fauna,” says Julian Gutt, a marine ecologist at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany.

The Arctic bottom fauna, or benthos, is surprisingly rich in species, abundance, and ecological significance. Of the northern ocean’s 5000 known marine invertebrates, 90% live on the bottom. In shallow waters, they form the basic diet of many topside creatures including seabirds, walruses, bearded seals, and bowhead whales. Although many of the tiny creatures are migrants from North Atlantic waters, up to 20% are Arctic endemics.

The bounty exists because of the cold, not in spite of it. During the brief summer warmth, ice algae and cold-water plankton explode into life. In warmer waters, such simple organisms are devoured by zooplankton, which are devoured by predators, and so on up the food chain; thus nutrients stay in the water column. But in icy Arctic water, zooplankton do not grow fast enough to consume the sudden rushes of plant life. As a result, much of the plant life sinks to the bottom, where creatures there get it. For this reason, the benthos “can have production that is actually greater than in the tropics,” says Bodil Bluhm, a benthic ecologist at the University of Alaska, Fairbanks (UAF).

Efforts are under way to beef up the records. Last year, the Healy and the Swedish icebreaker Oden teamed up in the central Arctic Ocean to pull sea-floor cores that researchers hope will cover the last million years. Leonid Polyak, a marine geologist at Ohio State University in Columbus who participated, says some cores exhibit up to 80 cycles of apparent glacial melting, indicated by alternating bands of different-colored grains. Polyak says it appears that the bands come at intervals of 20,000 years, suggesting that they represent fluctuations in Earth’s orbit; however, he is unsure, because the cores have not yet been well dated.

Many biologists hypothesize that climate change could hurt the Arctic benthos and the large creatures that live off it by wiping out ice (and hence ice algae), lengthening growing seasons for zooplankton, and giving warm-water species a foothold. “The way the system works now is very much in favor of the benthos,” says UAF polar ecologist Rolf Gradinger. “If the system changes, things could go downhill fast.”

A preview might come from the Bering Sea, between Russia and Alaska. There, higher water temperatures and pullbacks in seasonal ice have progressed fast in recent decades. Oxygen uptake in sediments (an indicator of carbon supply to living things) has dropped by two-thirds, and populations of benthic creatures such as mussels have declined by half. Diving ducks, walruses, and gray whales are moving away, while pollock and other southern pelagic fish are streaming in (Science, 10 March 2006, p. 1461).

Preliminary evidence suggests that higher temperatures may be starting to have similar effects in the more northerly Barents and Laptev seas, off Scandinavia and Siberia, says Dieter Piepenburg, a marine biologist at the University of Kiel in Germany. Piepenburg, who wrote a 2005 review on Arctic benthos in Polar Biology, says it remains to be seen whether this would spell the end. He says that Arctic benthic organisms have probably already weathered not only warm cycles but also cold ones so extreme that deep ice sheets repeatedly scour bottoms clean of life far out to sea. Piepenburg thinks the organisms may have migrated to deep waters and then recolonized when the coast was clear.

Those deep waters may also contain more life than previously believed. In 2001, U.S. researchers over the remote Gakkel spreading ridge detected chemical plumes indicating hydrothermal vents—which feed biological hot spots in other parts of the world—but were unable to locate a source. Indeed, no vents have yet been found anywhere in the Arctic, but as part of the International Polar Year (IPY), U.S. researchers in July will return to the Gakkel and deploy new under-ice autonomous vehicles to hunt down and sample the chemical plumes. If they find vents and vent creatures, the organisms may well be unique, because the narrow straits connecting the Arctic to other oceans are too shallow to allow movement of deep-sea creatures and thus mingling of genes.

Researchers are bound to discover many polar organisms, especially in deep places like this, says Gradinger, who is leading the Arctic Ocean inventory for the worldwide Census of Marine Life. The deep basins are mostly unexplored, he says, and many small creatures that live buried in sediments even in shallow areas have yet to be glimpsed. IPY may help change this; within its framework, Gradinger counts 20 biological collecting projects slated so far.

--K.K.
Alaska shows a separate 240-year freeze-thaw cycle, written in sediments scraped from continental shelves by sea ice. Darby believes this periodicity must be connected to some ocean-circulatory pattern that presumably still exists but has not yet been noted in modern times. He, Polyak, and others presented preliminary findings at the American Geophysical Union (AGU) meeting in San Francisco, California, last December.

Next August, during IPY, a European consortium hopes to recover cores from the Fram Strait, which runs between Greenland and Norway, connecting the Arctic Ocean to the North Atlantic. Here they hope to find records tracing sea ice and currents decade by decade during historical time. This would fill an important gap. Although researchers have good decadal climate records from glacial ice cores, they lack comparable data from the sea because sediment accumulates too slowly in most of the Arctic.

Researchers identified the Fram site last October as a place where currents concentrate sediments faster. They hope to cover the Medieval Warm Period, when melting may have rivalied today’s. “The extent of short-term ocean variability during the past, especially in warm periods, is practically unknown,” says paleoceanographer Robert Spielhagen of the Leibniz Institute of Marine Sciences in Kiel, Germany, who is involved in the coring. “If scientists or policymakers want to understand our present situation, we have to have those records.”

Another open question is the extent to which long-term tectonic rearrangement of the landmasses around the heavily landlocked Arctic Ocean has influenced climate. Before the drift of landmasses opened the Fram Strait, the region was more closed in. Slower circulation, or no circulation, could be one reason it was once so warm, says geologist Martin Jakobsson of Stockholm University. Estimates of when the strait formed vary; recent research says 15 million years ago. In any case, the circulation may have helped vent heat to the Atlantic, pushing the Arctic into the deep freeze we see today, Jakobsson says. Understanding the Fram’s history would help us predict what will happen if the circulation begins to change again, he says.

Other events, including sea-level fluctuations and periodic blockages or openings of the shallow Bering Strait between the Arctic and the Pacific, may also have influenced climate. And entirely unexpected events may have been critical. At the December AGU meeting, a group of top Arctic researchers including Bernard Coakley, a geophysicist at the University of Alaska, Fairbanks, proposed that a previously undetected 200- by 600-kilometer meteorite crater lies at the bottom of the central Arctic Ocean. Such a massive event, which they say may have taken place more than 800,000 years ago, surely would have disrupted climate signals. But so far the group has only a hypothesis, based on overturned bottom sediments found in cores and unusual nickel spherules found on some of Canada’s northernmost islands. “Climate change is a very alarming issue, but anyone who says we really understand it—what are they basing this on?” says Jakobsson.

Transcending borders
It’s hoped that IPY will soften rhetoric and get nations working together. At least a half-dozen Arctic cruises are planned for the Polar Year, all of which will include scientists from several nations. Russia has submitted three proposals to resurvey major ridges and basins using seismic reflection, bottom sampling, gravity measurements, and other methods. In an abstract, Poselov acknowledges that existing data on areas Russia is claiming are “subject to controversial interpretations” and proposes that Russia, Sweden, Germany, and the United States pool their icebreakers, possibly in 2008, to study the Alpha-Mendeleyev ridges and other remote areas. “It’s quite possible something will work out,” says Coakley, who is helping pull together various efforts.

Germany already plans to send its icebreaker, the Polarstern, to the Alpha in 2008. Studies would include identifying sites for future deep drilling—not attempted in the Arctic since the initial IODP foray in 2004. Scientists at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven are already talking about the drilling itself—again, via a multiship expedition—although this would come after IPY.

Large-scale cooperation is needed both for science and safety. Pressure from constantly shifting pack ice makes it nearly impossible for an icebreaker to remain stationary long enough to drill; the 2004 deep cores came up only with triple teamwork: One vessel drilled while two others broke up approaching floes. And an icebreaker has never penetrated the region north of Greenland and Ellesmere, where Jackson and Dahl-Jensen are working. This summer, as part of IPY, a European group chaired by Jakobsson hopes to get there in the Oden to do geophysical, geological, and paleoclimatic work; the Swedish government is negotiating to rent a nuclear Russian breaker to make sure the diesel-powered Oden does not get trapped. Even so, says Jakobsson, there is no guarantee they will make it in.

The treachery of the ice became clear last August, when the Healy stopped 800 kilometers northwest of Barrow and two U.S. Coast Guard officers descended through a crack in the ice on a practice dive. After they failed to surface, comrades hauled them up on a line from an estimated depth of 60 meters. They were dead. The Coast Guard is investigating what went wrong—still a mystery. Pending reviews of safety protocols, the Healy’s remaining 2006 cruises were canceled.

Some say simpler is better. Since 2003, groups from Columbia University, the University of Hawaii, and other institutions have been developing seismic-sounding buoys to be set adrift in the ice, where they can take advantage of vigorous, predictable currents to sweep large areas without a need for icebreakers. Plans to deploy a large number for IPY have slipped, but a few should be put in next year, and perhaps 100 by 2009, says Yngve Kristoffersen, a marine geoscientist at the University of Bergen in Norway. For setting them out, he is pushing for a new mode of transport: hovercraft.

The cause has been taken up by John K. Hall, an American marine geophysicist who recently retired from the Geological Survey of Israel. Hall became a convert after a 2005 trip through the central Arctic on the Healy, during which, he says, ice-topography measurements showed that 85% of the voyage could have been made by hovercraft, at a tiny fraction of the cost. He has committed money inherited from his grandparents—the makers of Chiclets gum—to buy a small, well-heated transport: hovercraft.

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—Martin Jakobsson, Stockholm University