NEWSLETTER OF THE NATIONAL ICE CORE LABORATORY — SCIENCE MANAGEMENT OFFICE

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Ice Core Paleoclimate Records from Combatant Col, British Columbia

By Peter Neff, University of Washington

Setting up the drill tower with Mt. Waddington in the background. Photo: Doug Clark, Western Washington University.

IN JULY OF 2010, a team led by Peter Neff and Eric Steig from the University of Washington and Doug Clark from Western Washington University spent 26 days retrieving ice cores at Combatant Col, near Mt. Waddington, British Columbia, Canada (51.39°N, 125.22°W). Mt. Waddington, at 4019 meters (13,186 feet), is the highest massif entirely within British Columbia and is one of very few sites in North America which has demonstrated potential for obtaining an ice core paleoclimate record so far south of 60° North latitude. The goal of this project is to develop a record of annual snow accumulation for the last 200-500 years. Such a record may provide insight into how climate in the North Pacific region has varied in the past, extending understanding beyond that gained from short instrumental records in the region.

Beth Bergeron (Ice Drilling Design and Operations) led the operation of 4-inch electromechanical and 3-inch thermal drills, reaching a maximum depth of approximately 140 meters at the initial borehole before difficulties, resulting from glacial meltwater filling the borehole, halted drilling. A second borehole reached 90 meters depth. GPS surveys conducted in previous years and a high-resolution ground penetrating radar grid surveyed in late May 2010 indicate an ice depth of 250 to 300 meters. In addition to these new cores, work completed in 2006 yielded 65 meters of ice and demonstrated preservation of annual stratigraphy regardless of summer melt at Combatant Col (elevation 3000 meters, ~10,000 feet).

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In-Depth

In-Depth is published semi-annually by the **National Ice Core Laboratory - Science Management Office (NICL-SMO)**.

We are interested in project stories and news from the ice coring community. Please contact us if you are interested in submitting a story or news item to *In-Depth*.

***In-Depth* Newsletter**
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Masthead photos courtesy of Lonnie Thompson and Michael Morrison.

Message from the Director

As of November 1, 2010, NSF is providing 100% of the funds for the operation and maintenance of the National Ice Core Laboratory. The inter-agency agreement between NSF and the USGS, originally established in 1996, is still active although the USGS fiscal responsibilities have ceased. The USGS staff continues their responsibilities related to the operation and maintenance of NICL and plan to continue until the establishment of a new entity for NICL's future management. In the near future, we expect NSF will release a call for proposals to establish a new management entity for this facility. NICL-SMO will keep the community informed about NSF's path forward on the new management entity for the NICL. As always, NSF and the USGS are committed to the mission of NICL and plan to work towards a smooth and seamless transition.

-MST ■

Ice Core Paleoclimate Records from Combatant Col

— *continued from cover*

> *"The goal of the project is to develop a record of annual snow accumulation for the last 200-500 years. Such a record may provide insight into how climate in the North Pacific region has varied in the past..."*

Despite drilling little more than halfway to bedrock, the field season was very successful. The ice core collected is sufficiently long enough to examine the relationship of snow accumulation at Combatant Col to instrumental records of climate. The core field crew of five spent nearly one month on the ice, waiting out day-long windstorms, shaking off the loss of three larger communal tents, dodging at least one significant avalanche, and enjoying the company of up to five other researchers at any one time during the season. Constant radio contact was maintained with the King family of White Saddle Air, whose helicopter support and able assistance proved essential in the safe and efficient execution of the major field component of this project.

Work developing this new ice core record is ongoing, as detailed visual and chemical records must be produced to develop a reliable annual chronology for the core. Lab technicians at the Desert Research Institute will develop the geochemical record from the core, the National Ice Core Laboratory supports digital imaging work to identify summertime melt layers, and water isotopes will be analyzed throughout the length of the core by students and technicians at the University of Washington. Under the guidance of Erin Pettit, undergraduate students at the University of Alaska, Fairbanks are examining meteorological, geophysical, and snowpit data with support from an NSF Research Experience for Undergraduates grant.

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A 2 meter section of ice from Combatant Col is removed from the 3-inch Thermal Drill. Photo: Doug Clark, Western Washington University.

Collaborative Research: Ice Core Paleoclimate Records from Combatant Col, British Columbia, Canada

NSF Award Number 0902240
Principal Investigator: Eric Steig, University of Washington

NSF Award Number 0902734
Principal Investigator: Joe McConnell, Desert Research Institute

NSF Award Number 0902392
Principal Investigator: Doug Clark, Western Washington University

NSF Award Number 0903124
Principal Investigator: Erin Pettit, University of Alaska-Fairbanks

Subglacial Antarctic Environments: The *Other* Deep Biosphere

By Brent Christner, Department of Biological Sciences, Louisiana State University

EXPLORATIONS FOR LIFE in Earth's deep terrestrial and oceanic subsurface have revealed an astonishing reality: most of the microbes on Earth exist deep within the planet's crust. Based on the data available, it has been estimated that 3.8-6.0 x 10^{30} microbial cells exist in the oceanic and terrestrial subsurface combined, and the subsurface could harbor a pool of carbon biomass that is 60-100% of that estimated for all plants. To provide some context, the total pool of microbes in the subsurface is approximately 20- and 50-times larger than the global inventory for the planet's soil and aquatic habitats, respectively. A number of outstanding questions remain regarding the nature of life in the subsurface, its connection to photosynthetic activity on the surface, the major redox processes fueling biochemical activity, and the contribution of these systems to global carbon budgets (to name just a few). Several reports have provided evidence for the presence of chemosynthetic microorganisms (i.e., microbes which derive their reducing agents and carbon from inorganic sources) in samples from the deep hot terrestrial subsurface, raising the possibility of ecosystems that operate independently of the photosynthetic world. The ramifications of this new vision for life on Earth cannot be overstated and have provided the proper perspective to determine the extent of our biosphere and extrapolate the distribution of life in the Solar System and beyond.

Research on microbial life in the subsurface is still in its infancy, and to date, most efforts have focused on the study of thermophilic (heat loving) microorganisms that have been described and characterized in samples retrieved from a variety of high temperature subsurface biomes (e.g., oceanic crust, aquifers, and gold mines). In contrast, virtually nothing is known about the diversity of microorganisms and range of habitable environments that exist beneath the planet's expansive ice sheets (>1.5 x 10^7 km^2). In the 1960's, seismic data collected in the vicinity of Vostok Station and drilling at Byrd Station (Fig. 1) provided evidence that water is widespread at the ice sheet bed. In addition, basal water was encountered during drilling at NGRIP in

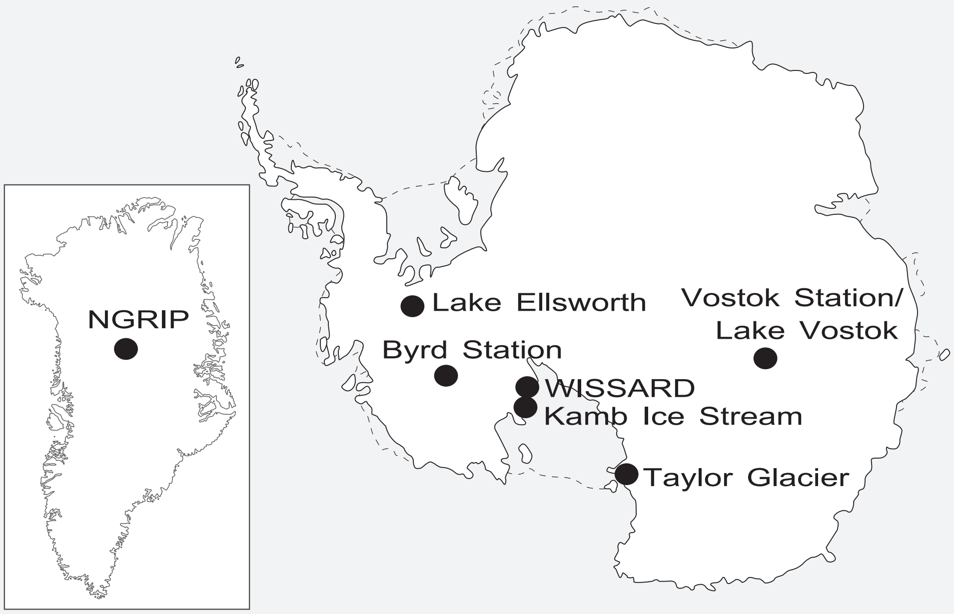

Figure 1. Map of Greenland (inset at left) and Antarctica showing locations mentioned in the text. Figure: NICL-SMO.

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Upcoming Meetings

13-17 December 2010
AGU Fall Science Meeting, San Francisco, CA
www.agu.org/meetings/

3-4 March 2011
2011 Ice Core Working Group Meeting, Denver, CO
www.nicl-smo.unh.edu

21-25 March 2011
AGU Chapman Conference on Climates, Past Landscapes, and Civilizations, Santa Fe, New Mexico
www.agu.org/meetings/chapman/2010/ecall

3-8 April 2011
European Geosciences Union, Vienna, Austria
http://meetings.copernicus.org/egu2011/

5-10 June 2011
International Symposium on Interactions of Ice Sheets and Glaciers with the Oceans, La Jolla, CA
www.igsoc.org/symposia/2011/California/

June 28 - July 7 2011
Session C02: Ice Cores and Climate - International Union of Geodesy and Geophysics (IUGG) General Assembly, Melbourne, Australia
www.iugg2011.com/program-iacs.asp

10-16 July 2011
11th International Symposium on Antarctic Earth Sciences, Edinburgh, Scotland
www.isaes2011.org.uk/

22-27 April 2012
IPY 2012 Conference "From Knowledge to Action", Montreal, Quebec
www.ipy2012montreal.ca/index.html

Ice Core Working Group

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Mark Skidmore
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Biogeochemistry

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University of Washington
Isotopes

Stefan Vogel
Northern Illinois University
Sub-glacial Environments

Kendrick Taylor
Desert Research Institute
At Large

In 1986, the National Academy of Sciences recommended developing an Ice Core Working Group of representatives from institutions prominent in ice coring activities. Administered by the NICL-SMO, ICWG is organized around scientific disciplines, rather than institutions. Members are elected to a three year term, with the committee chair typically serving three years.

Subglacial Antarctic Environments

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Northern Greenland (Fig. 1), indicating that liquid water also exists at certain locations at the bed of the Greenland ice sheet and wet-based conditions may be more prevalent than previously thought. Despite extremely cold air temperatures above the ice, liquid water is stable in the basal zone of ice sheets owing to the combined effect of background geothermal heating, the insulating properties of the overlying ice sheet, and pressure induced lowering of the freezing point.

Microbiological investigations on deep portions of the Vostok Ice Core (i.e., the accretion ice) and sediments recovered from the base of the Kamb Ice Stream represent the only available data sets to provide context on the nature and distribution of life beneath the Antarctic ice sheets. Heterotrophic bacteria and fungi (i.e., microbes which use organic carbon as a reducing agent and carbon source) have been directly isolated from these samples and molecular analysis of DNA sequences extracted from the samples indicates that subglacial Antarctic environments are inhabited by at least 4 different bacterial phyla. Comparing the evolutionary relatedness of an environmental DNA sequence with closely related microbial species with known properties provides a basis to form hypotheses about the physiology of the source organism. In Subglacial Lake Vostok (Fig. 1), the recovery of DNA sequences most closely related to those of a hydrogen-utilizing thermophile has been used to argue that geothermal energy input from high-temperture mantle processes or tectonic activity may fuel a chemosynthetic community within the lake (Fig. 2). One commonality between some of the DNA sequences reported in Kamb Ice Stream

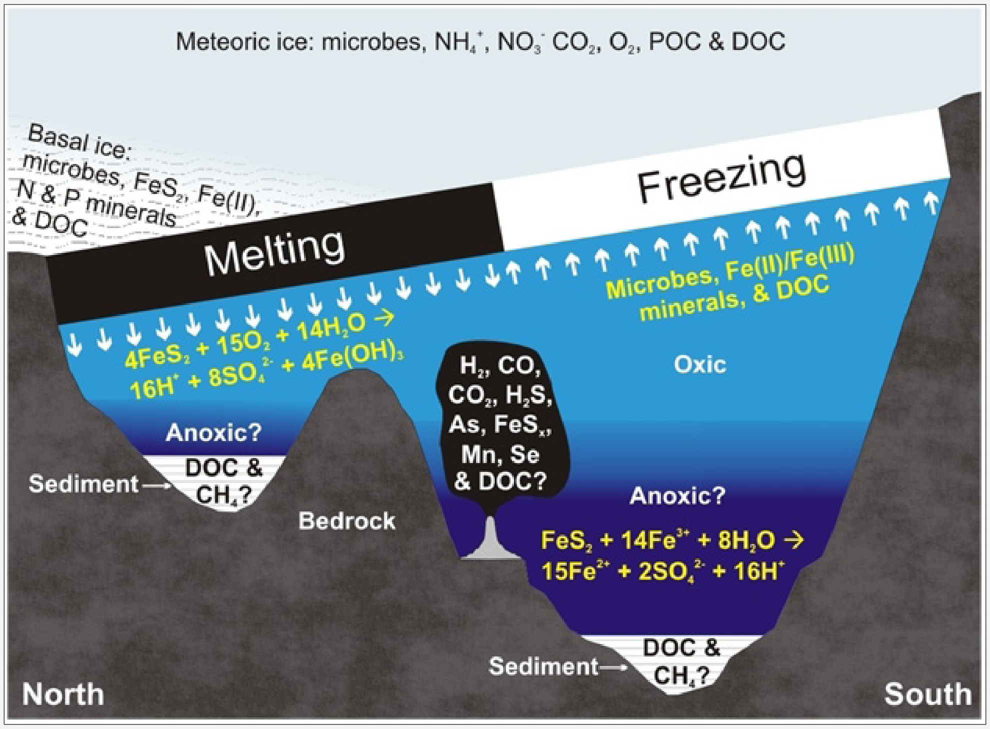

Figure 2. Hypothetical scenario for a chemosynthetic ecosystem in Subglacial Lake Vostok. Inputs to the system (northern portion of the lake; see text) are through the melting of basal ice, which contains crushed sulfide and iron minerals and organic material from the bedrock, and glacial ice, which provides a constant supply of oxidants (O_2 and NO_3-), nutrients, and organic material (POC and DOC and particulate and dissolved organic carbon, respectively. Microbes, minerals, and organic carbon are removed from the lake via the accretion ice (southern portion of the lake). Fault vents may be present in the shallow embayment of the lake, which could introduce significant amounts of thermal energy, geochemical energy, and organic carbon to the lake. If biotic and/or abiotic oxygen sinks exist in the lake, then the deep waters and sediments would be expected to be anaerobic. Adapted from Christner et al. (2008)

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sediments, Subglacial Lake Vostok accretion ice, and subglacial outflow from the Taylor Glacier (Fig. 1) are a close relation to species with metabolic lifestyles that revolve around iron and/or sulfur respiration or oxidation. The erosion of bedrock via glacial processes liberates crushed sulfide and iron minerals from the bedrock, where they are subject to chemical and/or biological weathering reactions (Fig. 2). A key point about the latter mechanism is that the physical action of ice and bedrock is all that is necessary to supply the energy for a chemosynthetically-based ecosystem.

Liquid water is abundant beneath the West and East Antarctic ice sheets, with subglacial lakes containing ~10,000 km^3 of liquid water (for comparison, Lake Superior contains 12,000 km^3 of water). Assuming a subglacial aquifer extent of at least 1 km, the total volume of groundwater beneath the Antarctic ice sheets is estimated at ~10^7 km^3. Based on available data from the ice and sediments (see above), the subglacial environment of Antarctica may harbor ~10^{29} prokaryotic cells, which equates to ~4.4 gigatons of cell carbon and is about 20% of that reported for the surface soils on Earth. In terms of dissolved organic carbon (DOC), the Antarctic ice sheets and subglacial aquifer are estimated to contain 10 gigatons of DOC, which is nearly 20-fold higher than values in all the planet's surface freshwater ecosystems. Clearly these estimates are tentative and should be revised when new data are available. However, they do indicate that Antarctic ice and its associated subglacial aquifer system contains a globally relevant yet virtually ignored pool of microbes and carbon, which should be considered when addressing issues concerning global carbon dynamics.

The technological and logistical issues, together with concerns for environmental protection, make subglacial lake environments challenging systems for scientific study. Despite these challenges, 3 pioneering projects are currently underway to drill into and sample subglacial aquatic environments beneath the ice sheet in East and West Antarctica.

Funded by the Antarctic Integrated System Science Program of NSF's Office of Polar Programs, Antarctic Division, the objective of the Whillans Ice Stream Subglacial Access Research Drilling project (WISSARD; http://wissard.org/) is to assess the role of water beneath a West Antarctic ice stream (Fig. 1) and associated ice shelf in interlinked glaciological, geological, microbiological, geochemical, hydrological and oceanographic systems. WISSARD is a 6-year project (2009-2015) and represents an unprecedented opportunity to make direct observations and analyze basal ice, subglacial water, and sediments to address fundamental scientific questions pertaining to: (1) past and future marine ice sheet (in)stability, (2) subglacial hydrologic and sedimentary dynamics; (3) subglacial metabolic and phylogenetic biodiversity; and (4) the biogeochemical transformation of major nutrients within a selected subglacial environment.

At Vostok Station, a project funded by the Russian Federal Service for Hydrometeorology and Environmental Monitoring reinstated drilling in the 5G borehole during 2006, and currently, are ~150 m from entering Subglacial Lake Vostok. The current plan is to replace the kerosene-based fluid in the bottom of the borehole with silicone oil prior to penetrating the lake with a thermal drill, which is scheduled to occur during the 2011/12 season. Lake water entering the borehole will eventually freeze and this material will be drilled and recovered for analysis during a subsequent field season. More information on the water sampling plan is available at the Russian Antarctic Expedition web site (http://www.aari.aq/).

A collaboration of scientists in the United Kingdom is also preparing to drill into a subglacial lake in West Antarctica, named Subglacial Lake Ellsworth (Fig. 1; see http://www.geos.ed.ac.uk/research/ellsworth/). As in the WISSARD project, the team will enter the lake by hot water drilling through the overlying 3400 m of ice, lower an instrument probe to measure the biological, chemical and physical characteristics of the lake water and sediments, and then return water and sediment samples to the surface for analysis. Direct access, measurement and sampling of Subglacial Lake Ellsworth is planned for the 2012-13 Antarctic field season.

Subglacial environments remain one of the last unexplored frontiers on our planet and efforts to explore these systems will be at the forefront of cryospheric research in the future. The presence of viable microbial life in deep regions of the cryosphere and realization that large quantities of liquid water and biomass exist beneath the World's ice sheets has changed the way biologists think about life in the polar regions. In the not too recent past, the ice-covered regions of Antarctica and Greenland were viewed as environments with conditions too extreme to support life. That view has changed in the last decade as evidence has accumulated which supports the view of the subglacial environment as an oasis for life in the polar regions. The efforts to enter, sample, and explore the subglacial aquatic environments of Antarctica are sure to contribute to our understanding of the physical, chemical and biological processes operating beneath the ice sheet. The years to follow should prove to be an interesting and unique time of discovery in Antarctic research.

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Further reading:

Christner, B.C., M.L. Skidmore, J.C. Priscu, M. Tranter, and C.M. Foreman (2008) Bacteria in subglacial environments. *In* R. Margesin, F. Schinner, J.-C. Marx, and C. Gerday (eds), Psychrophiles: From Biodiversity to Biotechology. Springer, New York.

On the Line

Researchers spend summer in deep-freeze to slice and dice WAIS Divide ice core

By Peter Rejcek, Antarctic Sun Editor
Courtesy: *The Antarctic Sun,* U.S. Antarctic Program

Science technician Tommy Cox measures a section of the WAIS Divide ice core as it begins its journey down the core processing line at the National Ice Core Laboratory near Denver. The technicians will cut the ice so it can be sent to labs around the country for anlaysis. Photo Credit: Peter Rejcek

IT'S MIDSUMMER IN DENVER, and the city has been baking under a heat wave for a couple of months. But in one small corner of the sprawling Denver Federal Center campus in the nearby suburb of Lakewood, about a dozen people are bundled up in thickly insulated Carhartt jumpsuits, wool caps, scarves and gloves.

The constant whine of saws in the room echoes loudly, like some busy school woodshop class. But there's no smell of woodchips in the air. In fact, it's hard to smell anything with a runny nose that begins almost immediately upon stepping into the freezing cold lab where scientists are slicing and dicing ice.

And not just any ice. This is ice from Antarctica, extracted from the middle of the West Antarctic Ice Sheet (WAIS) by the world's most advanced ice-coring drill. Researchers from across the United States will eventually analyze various properties of the ice to reconstruct the last 100,000 years of climatic and atmospheric conditions.

The results will lead to one of the most detailed histories of the last glacial period, when ice sheets once blanketed parts of North America. The information about the past will also help scientists better understand the links between climate change and greenhouse gases, as the world continues to warm in the 21st century.

But first those hundreds of meters of ice cores — which have traveled thousands of kilometers from Antarctica by ship, plane and truck — must be processed.

That's where the National Ice Core Laboratory (NICL), a facility managed by the U.S. Geological Survey at the Denver Federal Center and mostly funded by the National Science Foundation (NSF), comes in.

Getting in line

Researchers from around the country, including young scientists working on their doctorates, spent part of their summer at NICL helping to measure, catalog, cut and ship pieces of the ice core to their respective universities and laboratories.

The operation is called the core processing line, or CPL.

"This is the most challenging CPL we've had at the National Ice Core Lab in terms of the amount of ice, the number of projects that are involved in it, the complexity of the sampling, and the coordination of all the groups," said Kendrick Taylor, the chief scientist for WAIS Divide Ice Core, a $30 million project funded by the NSF.

"We've got a really good group of people. Everyone is in super good spirits, which is amazing considering the working environment," added Taylor, a thickly bearded research professor at the Desert Research Institute in Nevada.

The CPL team has less than three months to work its way through 1,400 meters of ice. Most people will spend up to eight hours a day in the CPL lab, which stays at a constant minus 23 degrees Celsius, with plenty of breaks to warm up. It's even colder in NICL's main storage warehouse, at minus 34 centigrade, where some 17,000 meters of ice cores from around the world are stored.

Sean Michael, an undergraduate from the University of Washington, prepares a section of ice core so that its electrical conductivity can be measured. Photo Credit: Peter Rejcek

"It's kind of brutal with the temperature changes," said T.J. Fudge, a PhD student from the University of Washington who recently arrived at NICL.

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On the Line

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Ken Taylor, chief scientist of the WAIS Divide Ice Core project from the Desert Research Institute, monitors an instrument that measures electrical conductivity in the ice, a key piece of information for defining and dating the layers of the ice core. Photo Credit: Peter Rejcek

Fudge will help run a machine that measures the electrical conductivity of the ice by running electrodes along the length of an ice core section that's been split and planed smooth.

Electrical conductivity varies seasonally, offering a way to define and date the layers of the ice core in conjunction with other methods, such as visual stratigraphy, which involves putting a trained eye on each one-meter-long core section.

That job falls to Matt Spencer, an assistant professor in the department of geology and physics at Lake Superior State University. Spencer learned how to read the nuances of ice cores — the bleeding of one summer storm into another, a dark layer that could indicate a change in chemistry — while working on the Siple Dome ice core project in Antarctica more than 10 years ago.

It's a rare skill, one that Spencer has volunteered to the CPL team for the summer. He spends his time in a small enclosure shrouded by a black curtain. The core slides along a conveyer belt of rollers into the darkroom, illuminated only by a light table. Spencer bobs his head and shifts his body to peer at the chunk of ice from every possible angle.

"It's really the luck of the draw what you find here in terms of good annual [layers] and bad annual [layers]," he explained.

For instance, at a depth of about 1,362 meters, each layer is roughly 15 centimeters wide. But one section seems about double that breadth. There's probably a divide in there somewhere — but where?

"Where the divide is between those two years is sometimes arbitrary," he said. Other analyses will help sort out the ambiguity.

Slicing and dicing

At the front of the CPL, where the core handlers are using lasers to measure the length of each section of core before the cutting and examinations begin, precision is of utmost importance.

"This is probably the most critical part for us right now — making sure we get a good length. This is what's going to give us the true depth of the ice we're hauling up out of the hole," explained Geoffrey Hargreaves, NICL curator since 1993.

Together with the electrical conductivity measurements, the length measurements provide an age-to-depth relationship, which is important for the subsequent analyses involving chemistry, isotopes and gases, according to Hargreaves.

"Without good age, without good depth control, you've got nothing," he said.

Then the ice is ready for various dissections. Top sections are cut into different slabs that are ripped and chopped into smaller pieces depending on what they'll be used to measure. For example, 3-centimeter-square sticks of ice will be used for different chemical measurements covering 70 percent of the elements in the periodic table.

The chemistry can reveal information about past conditions such as sea ice extent, the amount of dust in the atmosphere and even seasonal changes, which reveals clues to the environmental conditions of the time.

Bagged sections of the ice core await to be returned to the freezer warehouse archive. Photo Credit: Peter Rejcek

The other half of the core then undergoes the electrical conductivity measurement before a camera creates a high-resolution scan. Spencer then makes his visual inspection before pushing the core farther down the line where some of the best sections are removed for later gas analysis, particularly carbon dioxide, methane and nitrous oxide.

"The gas guys get the best ice," Hargreaves noted.

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On the Line

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Bess Koffman prepares a snowpit speciment for a density measurement at WAIS Divide during the 2009-10 field season. Photo Credit: Tommy Cox/WAIS Divide

Currently, the CPL chews through about 35 meters of ice in a day. The best day so far was 39 meters. "That's when everything is working," Spencer said.

At each step along the way the team members log the core sections before they disappear into plastic casings and insulated boxes destined for individual labs across the country. About a third or more of each core section will remain untouched, returned to its tube and the deep-freeze warehouse. The CPL database will eventually be merged into the NICL database to ensure the inventory in the freezer is up to date.

"I know exactly what's in the tube sitting on the shelf. It makes it a lot easier to come back when somebody is looking for ice," Hargreaves said.

The archive at NICL includes ice that was retrieved in 1958 at the Little America V station during the International Geophysical Year, when the modern era in polar science began. The oldest ice dates from the Vostok core, some 400,000 years.

As technologies change and improve, scientists still request samples from ice that's been in the collection for decades.

"We resample cores from 15 to 20 years ago all the time," Taylor said.

From beginning to end

The WAIS Divide project is the first ice-coring venture in which NICL staff has been involved from when the ice first emerges from the borehole in Antarctica to when it enters the CPL sawmill.

"It makes sense that we who handle the ice in the end should be there in the beginning to make sure it starts in the right way," Hargreaves said.

Spruce Schoenenmann has experienced both the cold of the freezer room at WAIS Divide and at NICL as a science technician responsible for handling the core. And he'll see some of the same ice a third time when he finally melts it for analysis in the lab at the University of Washington, where he is a PhD student under WAIS Divide principal investigator (PI) Eric Steig.

"I will see it all the way through from start to finish," Schoenenmann said.

Taylor noted that many of the graduate students at NICL will handle the ice multiple times before it is melted and the water sucked into a spectrometer or other instrument for analysis. Many have their PhDs riding on the results.

"That's great because they have a very vested interest in making sure [the CPL is] done right," Taylor said.

Most of the technicians who head south to Antarctica are hired for the project because they are involved directly in the research or plan to continue their education in a related field, according to Mark Twickler, manager of the WAIS Divide Science Coordination Office (SCO). The WAIS Divide SCO, based at the University of New Hampshire, manages the day-to-day operations of the project.

"It's interesting; a lot of the PIs now that are working on the ice core were graduate students during the GISP-2 days," said Twickler, referring to an ice core project in Greenland during the 1990s.

"It was a great training experience for the students. The same thing is true today with the students coming to NICL and the science techs going down. We're still trying to get people field experience and ice-processing experience," he added.

The Greenland ice core project is partly responsible for Bess Koffman becoming a polar scientist.

During her junior year at college, she heard a lecture by the well-known glaciologist Richard Alley of Penn State University about the discoveries from the GISP-2 core. She read his book on the subject, *The Two-Mile Time Machine*, and two years later she was on the Ice working as a field technician at the U.S. Antarctic Program's Palmer Station.

Now a PhD student at the University of Maine, Koffman sees the experience of doing the grunt work involved in ice-core drilling and handling, in both Antarctica and at NICL,

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as an important lesson on the path of her academic career.

"The ability to participate in every step of the process has allowed me to see my PhD research in the context of the whole. I really feel part of the overall WAIS Divide community," said Koffman, who is busy back at her lab melting water from the upper meters of the core for analysis. She worked at the WAIS Divide field camp in 2008-09 and 2009-10.

Her research focuses on the role of atmospheric dust in the climate system that can be found in the ice. She is particularly interested in understanding how dust controls iron geochemistry in the ocean. Iron is an important but limited nutrient for phytoplankton growth in the Southern Ocean.

"Aerosol iron fertilization of photosynthetic algae can lead to decreased atmospheric CO2 concentrations," Koffman explained. "Dust indirectly modulates this greenhouse gas."

Nicolai Mortensen and Patrick Casssidy work on the sonde electronics of the DISC Drill during the 2009-10 WAIS Divide ice-coring field season in West Antarctica. The drill is the most advanced of its kind on the planet. Photo Credit: Tommy Cox/WAIS Divide

New methodologies

Schoenenmann, a tall, lean man with a fondness for rock climbing, is interested in developing a new methodology for measuring the stable isotope oxygen-17. The work will provide new information on the sea surface humidity during the Last Glacial Maximum (LGM), when the last glacial period peaked about 20,000 years ago.

Previous research indicated conditions were dry, but other data suggest the humidity may have been higher, accompanied by more precipitation, according to Schoenenmann. He hopes the O17 record will shed more light on the issue.

"It's really an exciting new measurement," he said. "The WAIS Divide record will be the first one to have an O17 record."

Thomas Bauska is another PhD student who has worked in the Middle of Nowhere, West Antarctica, on the ice-coring project. He was at WAIS Divide during the most recent field season, when the drill reached a bottom depth of 2,560 meters.

Like Schoenenmann, he has developed a new methodology to analyze stable isotopes in the gases trapped in the ice — in this case, carbon-12 and carbon-13 — working in the laboratory with WAIS Divide PI Ed Brook at Oregon State University.

The gas measurements are perhaps some of the most exciting because they will address a central question regarding the relationship between carbon dioxide and temperature.

Current ice core records show that in the past temperature increased, followed several centuries later by an increase in carbon dioxide — but there is still a large uncertainty in the timing of this sequence.

Most scientists believe past climate warming was caused by variations in the Earth's orbit, called Milankovitch cycles, which changed how sunlight was distributed on the surface of the planet. But the orbital changes alone are probably not enough to end an ice age, just to initiate environmental changes that allow more carbon dioxide into the atmosphere to create the greenhouse effect.

"Humans are now increasing the level of CO2 in the atmosphere to levels higher than at any time in the last 800,000 years," Taylor explained. "The effect will be similar to what happened when changes in the Earth's orbit caused the oceans to release CO2: No change for awhile, then lots of warming and changes in rainfall on a scale that humans have never experienced."

By studying ice cores, which record how this process worked in the past, scientists will be able to predict more accurately how human releases of CO2 will affect climate. Specifically, the analysis of the ancient ice by Bauska and others will identify the sources of CO2 and help figure out why it varies naturally.

"You need the large amount of samples that WAIS Divide can give us to make these measurements," Bauska noted.

Ice core storage room at WAIS Divide. Photo Credit: Chad Naughton/ NSF

Ice time

Results from the work by young scientists like Schoenenmann, Koffman, Fudge, Bauska and the many PIs are still well down the road, according to Taylor. Only about 600 meters of ice has been processed previously, containing the most recent 2,000 years of climate history.

"That's the annoying thing with these

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On the Line

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The core-handling room at WAIS Divide, which is kept at minus 25 centigrade. Photo Credit: Chad Naughton/ NSF

ice cores. You drill them, and it can be like two years before the ice gets to the lab. It's another year or two of measurements. And then another couple of years to figure out what it [means]," Taylor mused.

The brittle ice being processed this summer was originally cored from the ice sheet during the brief 2008-09 field season. It had to spend a year on site before it could be moved to allow the ice to "relax" so it would not become brittle and get damaged during transport to the United States.

The delay is partly due to the need for conducting the CPL and the different analyses back in the United States. That's in contrast to projects like GISP-2, Greenland Ice Sheet Project 2, or the recently completed North Greenland Eemian Ice Drilling project, which hit bedrock last month.

In Greenland, the scientists make many measurements in a snow trench carved out for that purpose. However, it's too expensive to bring all of the equipment and people needed for such an operation to West Antarctica, where the field camp is reached by a ski-equipped military aircraft when the weather is good enough to fly.

"Going to Greenland is like a vacation compared to a place like WAIS Divide, where it takes at least three weeks just to come and join us for lunch," Taylor said.

By the time the CPL crew reaches about 2,000 meters in mid-August, the climate record will reach back about 8,000 years. The first 40,000 years are expected to be thick enough for the annual layers to be counted before the ice flow makes the layers too thin to resolve.

Taylor said he is hopeful that the drilling team will reach its final target depth of 3,330 meters during the 2010-11 season, bringing back another 1,400 meters of ice for next summer's CPL.

"We're really looking forward to pushing that last piece of ice through the drill," Taylor said.

NSF-funded research in this story: Kendrick Taylor, Desert Research Institute, Award Nos. 0944191, 0440817, 0440819, 0944348, 0739780 and 0230396. For a complete list of all funded projects related to the project, see the WAIS Divide webpage of funded projects at http://waisdivide.unh.edu .

WAIS Divide Ice Core Update

2010 Core Processing Line Review

THE 2010 CORE PROCESSING LINE (CPL) was extremely successful. It was the most complex cut plan and the most ice (~1,365 meters) that the U.S. ice core community has ever pushed through a CPL in a summer. The CPL was organized by NICL and it went off without any significant problems (see Peter Rejcek's *On the Line* story on page 6 for more information).

2010-2011 Field Season

The 2010-2011 field season is underway. A seven person put-in crew arrived to WAIS Divide via Basler aircraft on November 8 after a 16 day weather delay. There is a normal amount of drifting at camp and the skiway has been prepared and is accepting LC-130 flights.

The arch is open and has full power. RPSC has been working hard to repair the floor and drill slot that shifted, as expected, due to the weak structural nature of the firn. The Ice Drilling Design and Operations group, SCO and NICL crews were at WAIS Divide as of December 2. Kristina Dahnert (Lead Driller), Don Voigt (SCO Representative), and Geoff Hargreaves (NICL), along with their crews, are now preparing all the equipment and training for normal and emergency procedures. Everything is going well, but we are running about a week behind what we were hoping for due to the early season weather delays.

First view of the arch facility by the camp put-in crew. To get a feel for the amount of drifting, this photo is taken looking at the end of the drilling arch, which is 27 feet tall. Photo Credit: Raytheon Polar Services

For the latest field season news, be sure and read the weekly field updates located at:
http://waisdivide.unh.edu/ProjectUpdates/ViewProject.shtml

National Science Foundation Projects Related to

Ice Cores or Ice Core Data

The table below shows projects related to ice core research that have been funded by the National Science Foundation (NSF) since the last issue of *In-Depth* was published. To learn more about any of the projects listed below, go to the NSF Award Search page (http://www.nsf.gov/awardsearch/) and type in the NSF Award Number. If you have a newly-funded NSF project that was omitted from this listing, please let us know and we will add it to the next issue of *In-Depth*.

Title of the Funded Project	Investigator	Award Number
Collaborative Proposal: Aerosol Concentrations, Sources and Transport Pathways within the Arctic Polar Dome during Recent Millennia	Flanner, Mark McConnell, Joseph	1023387 1023672
Collaborative Research: A pan-Arctic, storm-by-storm isotopic investigation of the influence of Arctic sea ice on precipitation - a crucial link in the coupled climate system	Burkhart, John Feng, Xiahong	1023651 1022032
Collaborative research: acoustic logging of the WAIS Divide borehole	Anandakrishnan, Sridhar Matsuoka, Kenichi	0944285 0944199
Collaborative Research: Analysis of McCall Glacier ice core and related modern process studies	Cassano, John McConnell, Joseph Nolan, Matt Reese, Carl	1023214 1023318 1023509 1023449
Collaborative Research: Annual satellite era accumulation patterns over WAIS Divide: A study using shallow ice cores, near-surface radars and satellites	Forster, Richard Rupper, Summer	0944653 0944730
Collaborative Research: Climate, Ice Dynamics and Biology using a Deep Ice Core from the West Antarctic Ice Sheet Ice Divide	Taylor, Kendrick Twickler, Mark	0944348 0944266
Collaborative Research: Deglaciation of the Ross Sea Embayment - constraints from Roosevelt Island	Brook, Edward Conway, Howard Hawley, Robert	0944021 0944307 0943466
Detangling Flow Regimes and Paleoclimate in the Deepest Section of the EDML Ice Core using U-series Ages	Aciego, Sarah	1043367
EAGER: 1500 Years of Indian Summer Monsoon Variability Reconstructed from High-Resolution Tibetan Lake Sediments	Thompson, Lonnie	1023547
Observations, Reanalyses and Ice Cores: A Synthesis of West Antarctic Climate	Reusch, David	1066348
PIRE: International Collaboration and Education in Ice Core Science (ICE-ICS)	Brook, Edward	0968391
The Relationship between Climate and Ice Rheology at Dome C, East Antarctica	Pettit, Erin	0948247
Workshop Proposal: West Antarctic Ice Sheet (WAIS)	Anandakrishnan, Sridhar	1048878

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