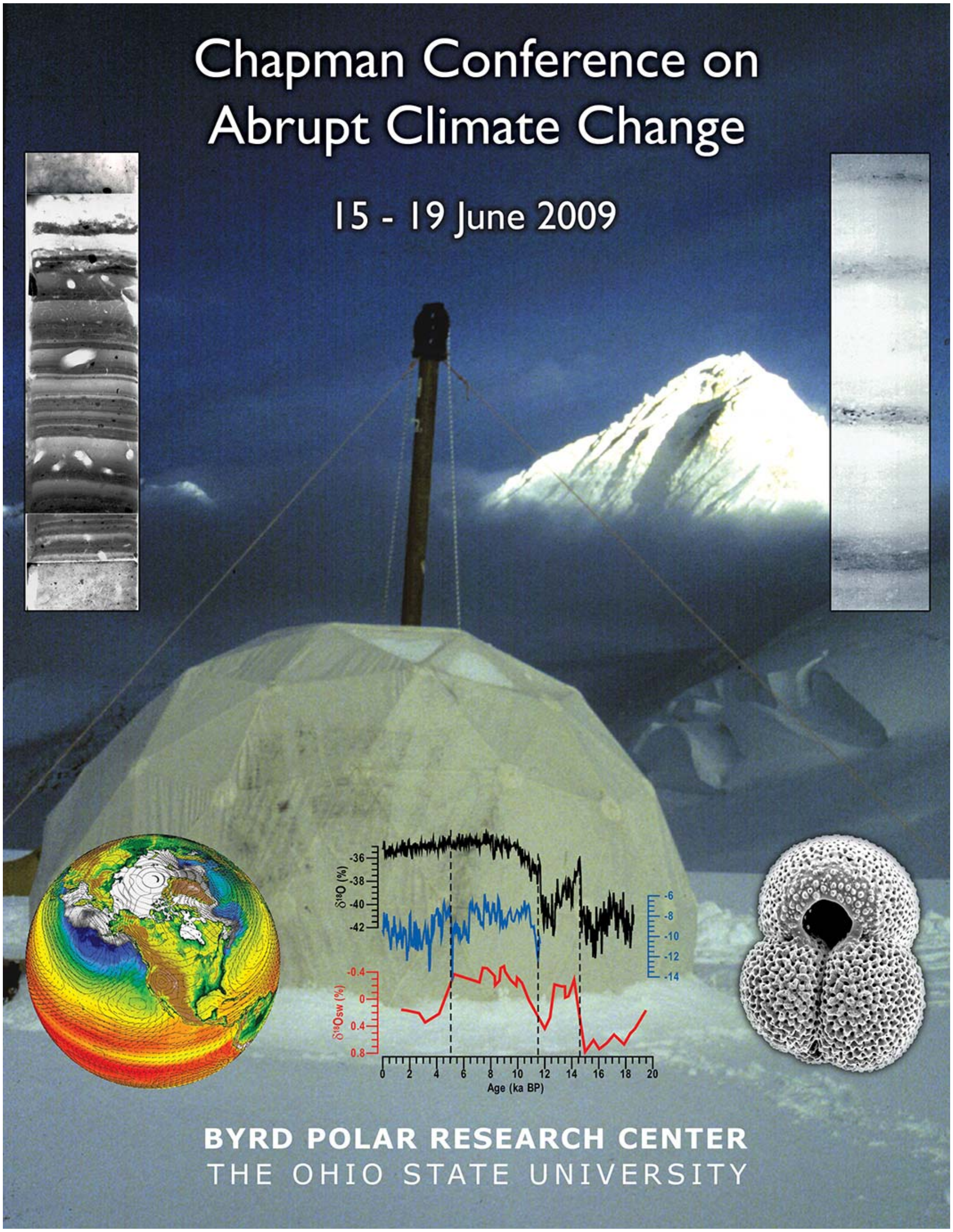
Chapman Conference on
Abrupt Climate Change
15 - 19 June 2009
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BYRD POLAR RESEARCH CENTER
THE OHIO STATE UNIVERSITY

Harunur Rashid

Lonnie Thompson

Leonid Polyak

Byrd Polar Research Center

The Ohio State University

1090 Carmack Road

Columbus, OHIO

Executive Summary

Nearly 100 scientists working in disciplines ranging from atmospheric and marine chemistry, paleoclimatology, paleoceanography, paleoclimate model-data comparison to archaeology attended a weeklong American Geophysical Union Chapman Conference on Abrupt Climate Change. The conference was held at the Byrd Polar Research Center of the Ohio State University, Columbus, Ohio, from 15-19 June, 2009. The basic purpose of the conference was to understand the spatiotemporal extent of abrupt climate change and the forcings behind it. Most of the presenters demonstrated that, regardless of whether the paleo-records were from lakes, speleothems (cave formations), ice-cores, or marine sediments, abrupt climate change was a recurrent phenomenon at least during the last glacial-interglacial climate cycle (14.6-116 ka). Whether such recurrent events occurred during previous glacial cycles is not well documented due to the scarcity of very long paleo-records with the requisite spatial and temporal resolution. Participants noted that the number of paleo-records from the Southern Hemisphere (SH) irrespective of glacial cycles was very low and stressed the need to increase efforts to acquire more paleo-records from the SH.

Many important discoveries and well dated paleo-records were presented at the conference and will be published in an upcoming Geophysical Monograph. Several new areas of inquiry were discussed, including (1) the role of Southern Hemisphere local insolation in developing an independent chronostratigraphy circumventing the traditional method of deriving an age using orbital tuning and using the chronostratigraphy to correlate the Northern Hemisphere insolation with the glacial terminations, (2) phasing between the deep ocean and surface water warming (derived from benthic and planktonic foraminifers oxygen isotope ($\delta^{18}O$) across the terminations, (3) indication of monsoon failure from atmospheric oxygen isotope ($\delta^{18}O_{atm}$) and deep ocean temperature change from inert gases, (4) timing of the opal flux and deep ocean carbon dioxide (CO_2) release in the atmosphere and phasing with the position of the westerlies, (5) dynamic proxies and models' response to freshwater forcing in assessing meridional overturning circulation strength, and (6) the role of the Antarctic intermediate water in distributing heat and transporting old carbon around the ocean.

Conference Objectives

The main objective of the Chapman conference on Abrupt Climate Change was to bring together a diverse group of researchers who deal with paleo-proxy records such as ice cores, corals, marine sediments, terrestrial archives (lakes and speleothems), and coupled ocean-atmosphere climate models to discuss recent advances in understanding the mechanisms of abrupt climate changes. Since the discovery of the Dansgaard-Oeschger (D/O) events in Greenland ice cores and their subsequent cousins in the marine sediments of the North Atlantic, search for these abrupt, millennial-scale events across the globe has been intensified. A good compilation of these abrupt climate events are given by Voelker et al. (2002) and Clement and Peterson (2008). Since then, the number of paleoclimatic records has increased with most Northern Hemisphere records showing teleconnections with the D/O cycles in Greenland. However, the evidence for the abrupt climate change from the Southern Hemisphere is not clear although there appears to be a one-to-one correlation of the new Eastern Droning Maud Land (EDML) records of Antarctica, recovered from a location facing the South Atlantic, with Greenland (EPICA, 2006).

Marine and terrestrial paleoclimate records from the Southern Hemisphere are sparse and do not have enough temporal resolution to characterize the relevant timescales of climate variability. The paleo-records from the northern tropics and subtropics mainly show concordant climate changes with those in the North Atlantic, while asynchronous and even anti-correlated phenomena are exhibited in records from the southern tropics and from the high latitudes of Southern Hemisphere. For example, the Indian and East Asian monsoon systems seem to correlate with the North Atlantic climate, whereas the South American monsoon records show anti-correlation to the Greenland records (Wang et al., 2006). Moreover, paleo-proxy records from the equatorial Pacific are characterized by a complex pattern of abrupt climate change that borrows elements from both the Northern and Southern Hemispheres end members, suggesting that the tropical Pacific may have played a significant role in mediating abrupt climate change between the hemispheres.

Three mechanisms have often been invoked to explain these abrupt climate changes: (a) freshwater forcing in which meltwater was injected from the circum-North Atlantic ice-sheets through icebergs-rafting which may have disrupted the meridional overturning circulation (MOC) by preventing the formation of North Atlantic Deep Water (NADW) in the Nordic seas; (b) Expansion of sea-ice extent in which the albedo effect through altering the local and global energy and thus insulating the ocean from the atmosphere by cutting off the heat and moisture supply; and (c) the tropical forcing which calls for a combinations of the orbital configuration, El Niño-Southern Oscillation (La Niña) and sea-surface temperature (SST) conditions.

A number of outstanding scientific questions regarding Abrupt Climate Change were discussed in the meeting which includes:

- Given the amount of attention focused on meltwater forcing in modulating the MOC from the circum-North Atlantic, the extent to what degree and with what level of confidence do paleo-proxies suggest a one-to-one relationship between the freshwater fluxes and the strength of the MOC, as well as the sources of meltwater pulses?
- Are kinematic and nutrient proxies for the strength of the MOC congruent across the Abrupt Climate Changes? How do these proxies differ between the climate mean state and transient periods?
- Do current general circulation models (GCMs) simulate abrupt strengthening and gradual weakening of thermohaline circulation (THC), consistent with the rapid warming and gradual cooling of D/O events? If not, what other factors need to be considered other than the THC?
- Is there robust evidence for sea-ice in the Atlantic Ocean during the last glacial cycle? How much has sea-ice extent fluctuated on millennial-time scales? How has the fluctuations influenced the surface salinity and thus the density and water-mass stratification?
- With the exception of the tropical Atlantic marine record, most tropical paleo-records show a clear lack of D/O cooling. Does this indicate that the parts of the tropics respond differently due to ensuing changes in the hydrological cycle and temperature nested in the THC?
- Given the dramatic changes in Arctic sea-ice and hydrography, how did the Arctic freshwater budget affect the overturning circulation of the North Atlantic?

- Why does the Antarctic temperature show a more gradual and less pronounced warming and cooling compared to the D/O events in Greenland? Does this indicate a direct role for deep ocean circulation in ushering the abrupt climate changes?
- In light of the current concern about the instabilities of the West Antarctic and Greenland Ice Sheets how can the paleoceanographic records be used to decipher past ice-sheet dynamics?
- What is the link between sea-ice extent and ice-sheet dynamics? How does the ocean heat transport influence the dynamics of the ice-sheet margin? Is the coastal ice-shelf a slave to the ocean currents?
- Was there any relationship between the demise of past civilizations and climatic deterioration? What are the climate tipping points that have driven past civilizations to collapse or dismantle?

The meeting spent five days with the ice-breaker on Sunday, the June 14th, 2009. Each meeting day consisted of a morning and afternoon session, beginning with a keynote lecture, and then continuing with two sessions on each of the main focus areas (see below). In the Wednesday afternoon, most of the participants took part in the field trip (see below for details) which investigated the margin of the Laurentide Ice Sheet. The sessions were scheduled in a way where the both the paleo-data and data-model comparison modeling results were presented. The conference topics were divided into seven themes which are as follows (see http://bprc.osu.edu/~rashid/Chapman.ACC/program.html for full program).

1. Polar climate variability;
2. High latitude atmosphere-ocean dynamics and the meridional overturning circulation;
3. Low to mid-latitude ocean-atmosphere dynamics (and coupled systems);
4. Abrupt climate forcing from CO_2;
5. Abrupt changes during the Holocene and their impact on civilizations;
6. Abrupt climate Change during glacial Terminations, and
7. Abrupt climate Change and the meridional overturning circulation.

Discussions

Late Holocene tropical climate variability:

It is clear that during the past 5 thousand years Earth experienced at least 2 global-scale abrupt climatic excursions, each of which was associated with devastating consequence to human life. At 5.2 and again at 4.2 ka, the climate experienced a profound change that persisted for at least three centuries. Each abrupt event dramatically changed human cultures and changed the course of human history. However, due to the lack of spatial coverage, it was not clear the mechanisms of such abrupt changes during warm periods (such as the Holocene – the last ~10,000 years). It was emphasized that these climate events occurred within the past 5 ka when the climatic boundary conditions were similar to today's (prior to the rise in anthropogenic greenhouse gases). These two events were spaced approximately 1000 years apart. The abrupt onset of these events was followed by changes to the hydrologic cycle which was nearly (excluding the Polar Regions) and sustained for multiple centuries. Dramatic examples were presented at the meeting.

The event at 5.2 ka is preserved in diverse paleoclimate records that include the oxygen isotope records from Kilimanjaro, methane records from Antarctica and Greenland, the Soreq Cave isotopic records and marine records of the onset of arid and hyperarid conditions in the Andaman Sea and Bay of Bengal and Saharan desert. Other evidence includes preserved trees standing hundreds of feet below the surface of Lake Tahoe, 5.2 ka plants emerging from the retreating margins of an Andes glacier, the recent emergence of Özti (the 5.2 ka old ice man) in the Eastern Alps. All these data point to a near global low to mid low latitude abrupt climate event that impacted civilizations on three different continents. There were likely several hundred million people on the planet that time. For example, the 4.2 ka climate event that lasted at least 300 years is revealed in numerous paleoclimate histories. It is associated with the only major dust event in the last 17 ka of the Huascarán ice core from northern Peru. Archeologically recorded droughts in the Euphrates and Tigris drainage basins are recorded in the Kilimanjaro ice cores and cores drilled in the Gulf of Oman, Andaman Sea and Bay of Bengal and lake records from the

Gharwal Himalayas. The impact of such a rapid and sustained drought event today with 7 billion people would be devastating.

It is clear that the paleoclimate community has uncovered information about Earth's natural climate behavior that is unprecedented in the instrumental record and is unappreciated by the broader climate science community. This information is highly relevant to the USCCSP. Given the growing concern that Earth may be experiencing another abrupt climate change today, these past episodes of abrupt climate change provide us an opportunity to study how the climate system enters an abrupt change by developing the necessary data that can be coupled with model experiments designed to answer why Earth has experienced such dramatic changes in the recent past.

Paleoceanography of the Indian Ocean

The under investigated ocean in the paleoceanographic studies is the Indian Ocean. Many meeting participants pointed out that the ocean drilling program has not been active in the Indian Ocean since 1989. Four drilling proposals **514**-Droxler et al.; **552**-France-Lanord et al.; **596**-Clift et al., and **549**-Lückge et al. are under review by the SSP panel of the IODP for a future Leg in the Northern Indian Ocean. For example, Clift et al. proposed to drill the Bay of Bengal deep-sea Fan to elucidate the erosion and uplift history of the Himalayas. However, none of the proposals deals with reconstruction of the outflow from the Ganges-Brahmaputra-Meghna-Irrawaddy rivers. Recent studies have shown that the Indian summer monsoon can be modulated by the millennial-scale climate variability, where both short-and longer-term paleoclimatic records are critical for understanding the history of hydrological cycle, which is important for nearly one-billion population of this region. In addition, the proposed sites are too far offshore to record freshwater outflow from rivers. Therefore it is recommended to double the effort: not only to extend the site survey for future drilling closer to the mouths of these rivers, but also to integrate the effort from many research groups such as the University of Bremen, LSCE (France), and the Ohio State University. It is worthy of note that India became a member of the IODP, and hence the IODP's efforts in the northern Indian Ocean would be highly appreciated.

The other important point discussed was to drill a few selected land-ocean transacts along the eastern African continental margin. This would enhance our understanding of the long-term changes in the east African climate and, thus evolution and dispersal of hominids. It was pointed out that Lake Challa may provide a longer time-scale terrestrial climate yet an equivalent climate records from the Indian Ocean is yet to be obtained.

Past climate of the Southern Ocean

It was agreed that paleo-records from the Southern Ocean are very sparse, especially from the southern sectors of the Pacific and Indian Oceans. The recent recovery of the centennial- to millennial-scale nearly a million years long climate records from the European Ice Core Activity in Antarctica (EPICA) should pave the way to search for equivalent climate records from the southern Oceans. Participants recognized that there are no coordinated activities to achieve such goals, and that focused efforts are needed.

Several participants stated their concerns about the post-cruise funding environments after the drilling activities. For example, the NSF has a program termed the Expedition Objectives Research to fund work on the collected drilling samples. However, as many participants stated, after repeated submissions of proposal to work on the collected samples, they were unsuccessful to secure funding. This situation worsened since 2005. Therefore, even though the scientific community should focus on drilling new, scientifically rewarding sites, the data gap might not improve unless the NSF takes a hard look at how to improve the funding of post-cruise activities.

Paleoclimate simulation and data/model comparison

Well respected and active members of the paleoclimate modeling community of abrupt climate change attended and presented at the meeting. Most of the modelers stressed the need to improve the data resolution as well as tighter age-constraint on the paleo-records. In addition, it was suggested to further explore “the meaning of proxies”, resolve the leads and lags in important paleo-records and provide a bench-mark test for climate sensitivity analysis. For example, the oxygen isotopes in speleothems could represent the precipitation amount, changes in seasonality, or changes in source region of moisture. A clear understanding of the oxygen isotopes and the variables mentioned above need a better corroboration. Furthermore, modelers also asked questions to resolve the sources for carbon dioxide increase during the Antarctic warming events, and what factors attribute to the deep ocean warming during Heinrich events.

Recommendations

Many meeting participants agreed that more high quality paleo-records with improved temporal resolution, as well as "zero" uncertainty dating, are required for state-of-the-art model-data comparison studies. The presenters further stressed the urgent need to formulate strategic plans to expand on the excellent data sets already available from the last glacial-interglacial cycle and take on new challenges to contribute to efforts predicting climate changes in a warmer world, as undertaken by the Intergovernmental Panel on Climate Change.

To contribute to climate change prediction efforts, it is important to understand the mechanisms of the Holocene (0 to 11.6 ka) transient climate events such as those 5.2 and 4.2 ka ago. These events are found mainly in low latitude climate archives related to hydrological history and are contemporaneous with the disruption of civilizations on three different continents. Most of the participants also agreed that given that more than half of humanity lives in the tropical belt, any changes in regional hydrological cycles cannot be overemphasized. Therefore, focused research needs to be conducted to understand the tipping points of the tropical hydrological cycle.

Participants recommended several main areas to improve the approaches for understanding abrupt climate change, including:

(**1**) Collecting more high quality data and improving coordination of paleoclimate and modeling approaches;

(**2**) Concentrating on a few key time horizons but using many proxies;

(**3**) Studying sea-ice proxy biomarker IP25, a fast and powerful feedback in subpolar regions such as the North Atlantic and sub-Antarctic; and

(**4**) Investigating new proxies such as clumped isotopes, a promising tool to provide an independent temperature proxy.

Drilling recommendations

Drilling sites in the Indian Ocean, both in the southern Indian Ocean facing the EPICA drill site and northern and western Indian Ocean are deemed necessary. Most of the scientists agreed that funding should be focused to search for high sedimentation rate sites especially the sediment drifts which may provide the centennial-millennial-scale resolution paleo-climate records. Sites closer to the mouths of the Ganges-Brahmaputra-Meghna-Irrawaddy rivers are necessary for the reconstruction of the past Indian summer monsoon. Suitable sites in the western margin of the Indian Ocean especially a shallow to deep water transact along the Kenya-Tanzania margin are needed to be explored.

New drilling sites in the southern sectors of the Pacific and Indian Oceans need to be explored. Drilling and subsequent paleo-records from the Chattam Rise and Chilean margin were very valuable but the vast Southern Ocean remains an open area for research.

Field Trip - Laurentide Ice Sheet Margin at LGM, Central Ohio

During the Last Glacial Maximum (LGM) (18-24? ka) Columbus, Ohio was covered by the Scioto Lobe of the Laurentide Ice-Sheet (LIS), which reached the Appalachian Plateau to the east. There it disrupted drainage, formed ice-marginal lakes, end moraines, and ice-contact topography (kames) and outwash terraces (see the Appendix for a graphical identification of these glacial land features, maps of the field trip route with stops, color maps provided by the Ohio Geological Survey --Glacial, Bedrock Geology and Physiographic Regions-- and other related materials). The objective of the half-day field trip was to understand the development of these terrestrial features which were dominated by till plain, end moraines and outwash and ice-contact deposits. We made several stops to examine till and outwash deposits. These gave us opportunity to enhance our understanding of the Quaternary history of the region and helped us to visualize changes beneath the ice and at the ice margin.

Across the glaciated portions of Ohio there are landforms and sediment that record the advance of several ice sheets during the last ice age. Deposits range from ancient river terraces as found in southern Ohio, to end moraine, kames, and kettles scattered across the landscape in northeastern to southwestern Ohio. These ancient deposits record three major advances with one other advance inferred from elevated river terraces and exotic boulders.

In older literature four glacial advances are recognized during the Pleistocene time. However, it is now assumed that many smaller advances and retreats occurred over the same time span. Since relatively little recent work has been done on the terrestrial glacial history covering the four glacial advances defined in the older literature, we used terms often cited in the literature which, in order from oldest to youngest: Nebraskan, Kansan, Illinoian, and Wisconsin.

The Nebraskan glaciation was the first glaciation, and it is unclear when it was first initiated as there are no definite sediments that record this glacial advance (Hansen, 1974). All that is left may suggest an early glaciation as evidenced from the river terraces found at high elevations, as well as exotic boulders.

The next advance, the Kansan, made it all the way to Cincinnati as revealed from glacial sediments. These are the oldest known sediments left by glaciers in Ohio. Again, due to small amount of these sediments that are left, as well as their poor quality not much can be said about this early glaciation other than there was an ice sheet in Ohio during this glacial stage.

The next glacial advance, the Illinoian, occurred ~70 ka ago, and sediments of this glaciation are more prominent in Ohio. Morainic drift spans from southwestern Ohio into the northeastern Ohio at the very limit marking this glacial advance.

During the Wisconsin period, the first major advance of the Erie lobe, the LIS made its way to Columbus (Goldthwait, 1965). The next major advance was associated with the spreading of the LIS possibly as far south as Dayton (Goldthwait, 1965). Two of these glacial advancements were followed by the smaller retreat during the interstadials. The third and the most extensive glaciation occurred ~20 ka ago and ended between 10 and 12 ka ago (Goldthwait, 1959, 1965). The third advancement was very extensive and assumed that the LIS extended as far south as the Cincinnati/Richmond area and buried Columbus and Dayton under approximately 3,000 feet of ice (Goldthwait, 1959)!

The advance of these lobes took place between ~24 and 16 ka ago. The Miami lobe was still active 19.5 ka (± 400 yrs), while the Scioto lobe remained active up until 18 ka (±400 yrs.). The retreat of the glaciers then began between ~18 ka ago (±400 yrs) and 16.6 ka (±230 yrs), at a rate of about 300ft per year until the ice front had probably reached Toronto (Goldthwait, 1959, 1965). Approximately 14.5 ka there was yet another surge which brought ice into northern Ohio but only into the present day Cleveland area (Goldthwait, 1959). Once this ice left, it never returned to Ohio again!

The glacial ice from Canada probably originated as a sheet of grounded ice approximately 600 ft thick (Goldthwait, 1959), in the region of the present day Lake Erie. This ice sheet behaved like alpine glaciers, or warm based glaciers, as they moved. This means that instead of moving by internal deformation of ice crystals above a frozen base like polar ice, this ice sheet moved as a result of basal shearing along a slushy base. This promoted extensive erosion and is the reason why there are extensive deposits recording this glaciation. At the time spruce forests, similar to those found in northern Canada, probably characterized the periglacial environment in Ohio. The typical creatures such as Mammoths and Mastodons roamed the landscape as well as other Pleistocene mammals.

As a result of this glaciation many new landforms were generated and others destroyed. As glaciers advanced they destroyed deposits of past glaciations and filled in valleys with their tills. As they retreated they deposited landforms of their own. These landforms allow for the reconstruction of the ice advance into Ohio.

Glaciers also modified drainage. In one instance it destroyed an ancient river and gave birth to a river we know well today, the Ohio River. Over two million years ago a river formed that stretched from North Carolina, northward through West Virginia through what is now called the New River Gorge (Hansen, 1995), and Kentucky up into Ohio and westward to Illinois where it emptied into an embayment that occupied the present-day Mississippi river. This river is known as the Teays river.

As the earliest glaciation came down, whether it be the Nebraskan, or Kansan cannot be determined, but early glacial ice dammed the waters of the Teays river to the north forming a huge lake in south-eastern Ohio, north-eastern Kentucky, and western West Virginia. The waters continued to rise to a depth of at least 900ft encompassing an area of approximately 7,000 square miles, slightly smaller than the present day Lake Erie (Hansen, 1995).

The ice lead to the formation of a variety of other lakes such as the Great Lakes. It is believed that the great lakes formed when ice-dammed water was draining during the glacial retreat, but was eventually trapped due to isostatic uplift of the crust as the weight of the ice was removed by melting.
Professor Garry McKenzie of the School of Earth Sciences and Harunur Rashid, Byrd Polar Research Institute, The Ohio State University, lead the field trip.

Conference support

Support for the conference was augmented by the contribution from the National Science Foundation, Climate, Water and Carbon Program and Office of the Research of the Ohio State University in addition to the support from the Ocean Leadership. As a result, we were able to provide travel support to all the participating graduate students, postdoctoral

researchers and a few young investigators. We were also able provide travel support to most of the invited speakers.

Conveners:

Harunur Rashid, Byrd Polar Research Center, Ohio State University, OH.
Lonnie Thompson, Byrd Polar Research Center, Ohio State University, OH.
Leonid Polyak, Byrd Polar Research Center, Ohio State University, OH.

List of invited speakers who spoke in the conference:

Richard Alley, Penn State University
Robert F. Anderson, LDEO/Columbia University
Henning Bauch, Oregon State University
Ed Boyle, Massachusetts Institute of Technology
Tom Delworth, GFDL/Princeton University
Roger Francois, University of British Columbia
Benjamin Flower, University of South Florida
Konrad Hughen, Woods Hole Oceanographic Institution
Kenji Kawamura, National Institute of Polar Research, JAPAN
Peter deMenocal, LDEO/Columbia University
Shawn Marshall, University of Calgary, CANADA
Bette Otto-Bliesner, National Center for Atmospheric Research (NCAR), Boulder
Jonathon Overpeck, The University of Arizona
Katharina Pahnke, University of Hawaii
Thomas Marchitto, University of Colorado, Boulder
Aradhna Tripati, Cambridge University
Jeff Severinghaus, Scripps Institute of Oceanography, San Diego
Jean-Lynch Stieglitz, Georgia Institute of Technology, Atlanta
Lowell Stott, University of Southern California, Los Angeles
Harvey Weiss, Yale University
Antje Voelker, INETI, PORTUGAL

Program Committee

- Henning Bauch, IFM-GEOMAR, Bremen, GERMANY
- Claire Waelbroeck, LSCE-CNRS, Paris, FRANCE
- Valerie Masson-Delmotte, IPSL/CEA-CNRS, Paris, FRANCE
- Larry Edwards, University of Minnesota, Minneapolis
- Ian Hall, School of Earth Sciences, Cardiff University, UK
- Ian Howat, School of Earth Sciences/Byrd Polar Research Center, Columbus
- Konrad Hughen, Marine Chemistry and Geochemistry, WHOI
- Tom Marchitto, Department of Geological Sciences/INSTAAR, U. Colorado, USA
- Antje Voelker, INETI, PORTUGAL

Media coverage:

A good numbers of local as well as national both print and on-line media covered the conference. The AGU brought their entire media crew for a pilot project as a result a good number eminent scientist were able to be interviewed on the conference venue. These video clips will be available on the YOUTUBE and the copyright for the video belongs to the AGU media and publications department. We have also written an EOS meeting a report which can also be consulted from the AGU website.

List of attendees and their full contact address

The list of participants who attended the Chapman conference on Abrupt Climate Change is given below. This list provides the attendant who registered before the start of the conference. Twenty three (23) participants registered onsite but apparently the AGU is unable to provide the list of those attendees for this report.

AGU Chapman Conference on Abrupt Climate Change
15-19 June 2009 ♦ The Ohio State University
Columbus, Ohio, USA

Registration List

Paul Aharon
University of Alabama
Dept Geological Sciences
Box 870338
Tuscaloosa, AL 35487-0338
paharon@geo.ua.edu

Jinho Ahn
Oregon State University
Dept of Geosciences
104 Wilkerson Hall
Corvallis, OR 97331-5506
jinhoahn@gmail.com

Richard Alley
Pennsylvania State University
Dept Geosci & Earth Env. Syst.
517 Deike Bldg
University Park, PA 16802-0000
rba6@psu.edu

Robert Anderson
Lamont-Doherty Earth Obs.
POB 1000
Palisades, NY 10964-0000
boba@ldeo.columbia.edu

Patrick Applegate
Penn State
Geosciences
532 Deike Bldg.
University Park, PA 16802-0000
papplegate@psu.edu

Eleanor Bash
University of Calgary
Department of Geography
2500 University Dr NW
Calgary, AB T2N1N4
Canada
eleanor.bash@gmail.com

Henning Bauch
Mainz Academy/IFM-GEOMAR
Wischhofstrasse 1-3
Kiel, 24148
Germany
hbauch@ifm-geomar.de

Mark Besonen
University of Massachusetts
611 North Pleasant Street
233 Morrill Science Center
Amherst, MA 01003-5820
besonen@geo.umass.edu

Ronny Boch
Univ. of Innsbruck, Austria
Institut f|r Geologie
Innrain 52 Bruno-Sander-Haus
Innsbruck 6020
Austria
Ronny.Boch@uibk.ac.at

M B E Boslough
Sandia Labs
998 Lynx Loop NE
Albuquerque, NM 87122-1314
mbboslo@sandia.gov

Raymond Bradley
University of Massachusetts
Dept Geosci Morrill Sci Ctr
611 N Pleasant St
Amherst, MA 01003-9297
rbradley@geo.umass.edu

Chad Briggs
Lehigh University
Environmental Initiative
31 Williams Drive
Bethlehem, PA 18015-0000
chad.briggs@lehigh.edu

Sean Bryan
University of Colorado
University of Colorado Boulder
Campus Box 450
Boulder, CO 80309-0450
sean.bryan@colorado.edu

Min-Te Chen
National Taiwan Ocean Univ
Inst Applied Geosciences
2 Pei-Ning Road
Keelung 20224
Taiwan
mtchen@mail.ntou.edu.tw

James Crampton
GNS Science
PO Box 30368
Lower Hutt 5040
New Zealand
j.crampton@gns.cri.nz

Kevin Crawford
The Ohio State University
1220 Chambers Road
Apt 414c
Columbus, OH 43212-0000
crawford.357@osu.edu

Ricardo De Pol-Holz
Woods Hole Oceanographic Inst.
Earth System Sciences
B321 Croul Hall
Irvine, CA 92697-0000
rdepolho@uci.edu

Thomas Delworth
GFDL/NOAA
Princeton Univ
POB 308 Geophysics Dynamics
Princeton, NJ 08542-0000
tom.delworth@noaa.gov

Simon Engelhart
University of Pennsylvania
Hayden Hall
240 South 33rd Street
Philadelphia, PA 19104-6316
simoneng@sas.upenn.edu

Alexey Fedorov
Yale University
Geology & Geophysics
210 Whitney Ave
New Haven, CT 06511-0000
alexey.fedorov@yale.edu

Joan Feynman
JPL, California Inst of Tech
MS 169-506
4800 Oak Grove Dr
Pasadena, CA 91109-8099
Joan.Feynman@jpl.nasa.gov

Roberto Filippi
Byrd Polar Research Center
1800 Lafayette Apt 12
Columbus, OH 43212-0000
robertofilippi82@gmail.com

Benjamin Flower
University of South Florida
College Marine Science
140 7th Ave South
Saint Petersburg, FL 33701-0000
bflower@marine.usf.edu

Roger Francois
UBC, Vancouver
Earth & Ocean Sciences
6270 University Blvd
Vancouver, BC V6T 1Z4
Canada
rfrancois@eos.ubc.ca

- 1 -

Paolo Gabrielli
The Ohio State University
Byrd Polar Research Center
1090 Carmack road
Columbus, OH 43210-0000
gabrielli.1@osu.edu

Konrad Gajewski
University of Ottawa
Dept Geography
60 University
Ottawa, ON K1N 6N5
Canada
gajewski@uottawa.ca

Eric Galbraith
Princeton University
Atmospheric & Oceanic Sciences
Sayre Hall, Forrestal Campus
Princeton, NJ 08540-0000
egalbrai@princeton.edu

Sarah Gray
University of San Diego
Marine Science
5998 Alcala Park
San Diego, CA 92110-0000
sgray@sandiego.edu

Eddie Haam
Harvard University
24 Oxford Street #402
Cambridge, MA 02138-0000
keh@eecs.harvard.edu

Darrell Hanson
237 Country Club Road
Shalimar, FL 32579-0000
oaktreedgh@aol.com

Feng He
UW-Madison
401 Eagle Heights Apt K
Madison, WI 53705-0000
fenghe@wisc.edu

Sharon Hoffmann
University of Michigan
2534 C.C. Little Building
1100 North University Ave.
Ann Arbor, MI 48109-0000
sshoffma@umich.edu

Yongsong Huang
Brown University
Dept Geological Sciences
POB 1846
Providence, RI 02912-1846
yongsong_huang@brown.edu

Konrad Hughen
Woods Hole Oceanographic Inst
MS 25
360 Woods Hole Rd
Woods Hole, MA 02543-0000
khughen@whoi.edu

Kenji Kawamura
Natl. Inst. of Polar Res., JPN
10-3 Midorichou
Tachikawa
Tokyo 190-8518
Japan
kawamura@nipr.ac.jp

Andrew Kemp
University of Pennsylvania
Earth and Environmental Sci
240 South 33rd Street
Philadelphia, PA 19104-0000
kempac@sas.upenn.edu

Robert Kopp
Princeton University
STEP, Woodrow Wilson School
405A Robertson Hall
Princeton, NJ 08544-0000
rkopp@princeton.edu

Elisabeth Levac
Bishop's University
Environmental Study Geography
2600 College Street
Sherbrooke, QC J1M 1Z7
Canada
elevac@ubishops.ca

David Lund
Univ of MI-Geological Sciences
2534 C.C. Little Bldg.
1100 N. University Ave.
Ann Arbor, MI 48109-1005
dclund@umich.edu

Jean Lynch-Stieglitz
Georgia Tech
School Earth & Atmospheric Sci
311 Ferst Drive
Atlanta, GA 30332-0340
jean@eas.gatech.edu

Bjoern Machalett
Humboldt-University, Germany
Department of Geography
Bjoern Machalett
Siedlung 16
Schmiedefeld/Rennste 98711
Germany
b.machalett@nakula.de

Candace Major
National Science Foundation
GEO-OCE, Rm 725
4201 Wilson Blvd
Arlington, VA 22230-0000
cmajor@nsf.gov

Thomas Marchitto
University of Colorado
INSTAAR & Dept Geological Sci
Campus Box 450
Boulder, CO 80309-0000
tom.marchitto@colorado.edu

Shawn Marshall
University of Calgary
ES 356
2500 University Dr NW
Calgary, AB T2N 1N4
Canada
shawn.marshall@ucalgary.ca

Katrin Meissner
University of Victoria
SEOS
PO Box 3055 Stn CSC
Victoria, BC V8W 3P6
Canada
katrin@ocean.seos.uvic.ca

Joe Melton
University of Victoria
School of Earth and Ocean Sci.
SEOS Building 414
PO Box 3055 STN CSC
Victoria, BC V8W 3P6
Canada
jrmelton@uvic.ca

Gifford Miller
Univ. Colorado, Boulder
INSTAAR
Boulder, CO 80309-0450
gmiller@colorado.edu

Ann Miller
Marine G. E. O. S.
PO Box 2253
Wolfville, NS B4P 2N5
Canada
marine.geos@ns.sympatico.ca

Mahyar Mohtadi
MARUM Uni-Bremen
Postfach 330440
Bremen 28334
Germany
mohtadi@uni-bremen.de

Martin Montes-Hugo
Inst of Marine & Coastal Sci
Rutger University
71 Dudley Rd
New Brunswick, NJ 08901-8521
montes@marine.rutgers.edu

Carrie Morrill
University of Colorado & NOAA
325 Broadway
Code E/CC23
Boulder, CO 80305-3328
carrie.morrill@noaa.gov

Ellen Mosley-Thompson
Ohio State University
Byrd Polar Research Center
108 Scott Hall
1090 Carmack Rd
Columbus, OH 43210-1090
thompson.4@osu.edu

Ian Orland
Univ. of Wisconsin - Madison
Geology and Geophysics
1215 W Dayton St
Madison, WI 53705-0000
orland@geology.wisc.edu

Anais Orsi
Scripps Inst. of Oceanography
SIO Graduate Department-0208
9500 Gilman Drive
La Jolla, CA 92093-0208
aorsi@ucsd.edu

Bette Otto-Bliesner
NCAR, Boulder
CCR/CGD
POB 3000
Boulder, CO 80307-3000
ottobli@ucar.edu

Katharina Pahnke
University of Hawaii
Geology and Geophysics
1680 East-West Rd., POST 719B
Honolulu, HI 96822-0000
kpahnke@hawaii.edu

Julie Palais
OPP/NSF
Natl Sciences Fdn
4201 Wilson Blvd Rm 755
Arlington, VA 22230-0000
jpalais@nsf.gov

Bhawani Paliwal
Jai Narain Vyas University, New Campus
Department of Geology
Jodhpur, Rajasthan 342005
India
paliwalbhawani@yahoo.co.in

Alexander Pastukhov
Inst of Biology Komi SC UB RAS
R 28 Kommunisticheskaya Str
Komi Republic
Syktyvkar 167982
Russia
alpast@mail.ru

Genevieve Patton
University of Chicago
Geophysical Sciences
5734 S. Ellis Ave.
Chicago, IL 60637-0000
gpatton@uchicago.edu

Henry Pollack
University of Michigan
Dept Geological Science
2534 C C Little Bldg
Ann Arbor, MI 48109-1005
hpollack@umich.edu

Leonid Polyak
Byrd Polar Research Center
108 Scott Hall
1090 Carmack Rd
Columbus, OH 43210-1002
polyak.1@osu.edu

Terrence Quinn
Jackson School of Geosciences
University of Texas
Institute for Geophysics
10100 Burnet Rd.
Bldg 196-ROC
Austin, TX 78759-8500
quinn@ig.utexas.edu

Harunur Rashid
The Ohio State University
108 Scott Hall
1090 Carmack Road
Columbus, OH 43210-1002
rashid.29@osu.edu

Bob Raynolds
Denver Museum of Nature & Sci.
12384 Oxford Road
Longmont, CO 80504-0000
bobraynolds@yahoo.com

Jose Rial
Univ North Carolina
Dept Geology
CB #3315 Mitchell Hall
Chapel Hill, NC 27599-0000
jose_rial@unc.edu

Angela Robertson
IUPUI
Earth Sciences
723 W. Michigan St #SL118
Indianapolis, IN 46202-0000
akrobert@iupui.edu

James Russell
Brown University
324 Brook St
Box 1846
Providence, RI 02912-0000
James_Russell@Brown.edu

Alexander Ruzmaikin
JPL, California Institute of Tech
MS 169-506
Pasadena, CA 91109-0000
Alexander.Ruzmaikin@jpl.nasa.gov

Jeffrey Severinghaus
Scripps Oceanography
260 East Cliff St
Solana Beach, CA 92075
jseveringhaus@ucsd.edu

Liang-Jian Shiau
Institute of Applied Geosciences
2, Pei-Ning Rd.
Keelung 202
Taiwan
paleoshiau@gmail.com

Mary Smith
Ohio State University
6048 Trafalgar Lane
Dublin, OH 43016-0000
smith.5268@buckeyemail.osu.edu

Robert Spielhagen
Acad.Sci.Mainz/IFM-GEOMAR
Wischhofstr 1-3 Geb 4
Kiel 24148
Germany
rspielhagen@ifm-geomar.de

Lev Tarasoff
Memorial U. of Newfoundland
37 Forbes Ave
Guelph, ON N1G1G2
Canada
lev@mun.ca

Thomas Tesche
Climate & Atmospheric Research
3479 Reeves Dr
Ft Wright, KY 41017-0000
twt@carallc.net

Lonnie Thompson
Ohio State University
Byrd Polar Research Center
108 Scott Hall
1090 Carmack Rd
Columbus, OH 43210-1001
thompson.3@osu.edu

David Thornalley
Cardiff University
Earth and Ocean Sciences
Main Building
Park Place
Cardiff, CF10 3YE
United Kingdom
d.thornalley@cantab.net

Oliver Timm
IPRC University of Hawaii
Intl Pacific Research Ctr
1680 East West Rd.
Honolulu, HI 96822-0000
timm@hawaii.edu

Adi Torfstein
LDEO, Columbia University
Lamont-Doherty Earth Obsv
61 Rt 9W
Comer 221
Palisades, NY 10964-1000
adi.torf@ldeo.columbia.edu

Aradhna Tripati
University of Cambridge
Dept Earth Science
Downing St
Cambridge, CB2 3EQ
Great Britain
atri02@esc.cam.ac.uk

Antje Voelker
Dept. Geologia Marinha - LNEG
Dept Geologia Marinha
Estrada da Portela, Zambujal
Alfragide 2721-866
Portugal
avoelker@softhome.net

Amy Wagner
CIRES, Univ. of Colorado
325 Broadway
Code E/CC23
Boulder, CO 80305-3337
amy.wagner@noaa.gov

Xianfeng Wang
University of Minnesota
108 Pillsbury Hall
310 Pillsbury Dr SE
Minneapolis, MN 55455-0000
wang0452@umn.edu

Peter Ward
Teton Tectonics
P.O. Box 4875 (Mail)
1150 Park View Lane (UPS)
Jackson, WY 83001-0000
peward@wyoming.com

Stephen Wathen
University of California Davis
18001 Old Cutler Rd Suite 419
Suite 419
Palmetto Bay, FL 33157-0000
sfwathen@gmail.edu

Harvey Weiss
Yale University
300 Ogden
New Haven, CT 06511-0000
harvey.weiss@yale.edu

Jianjun Xu
JCSDA
WWB, Room 207
5200 Auth Road
Camp Springs, MD 20746-0000
jianjun.xu@noaa.gov

→ Bob

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