Deep Earth Academy
CONSORTIUM FOR OCEAN LEADERSHIP

Inquiry into High-Resolution Ice Core and Marine Sediment Records

Archives of Suborbital (Millennial) Oscillations in Climate

Summary

High-resolution marine ice core and marine sediment records contain climate proxy data (e.g., sediment lithology, stable isotopes preserverd in foraminifera tests). Studying global climate involves collecting ice and sediment cores from key sites and comparing the response and timing of climate change among sensitive regions.

Learning Objectives

Students will be able to:

- Explain the scientific value of long, continuous ice core and marine sediment records from key regions.
- Discuss what makes a region climatically sensitive.
- Discuss millennial oscillations in global climate and what may cause them.

National Science Education Standards

Standard A: Science as Inquiry

Standard D: Earth and Space Sciences

Ocean Literacy Essential Principles

7. The ocean is largely unexplored.

Target Age: Grades 9-12, undergraduate

Time: One class period

Background

Understanding the mechanisms and causes of abrupt climate change is one of the major challenges in global climate change research today and constitutes a vital initiative of the *Initial Science Plan of IODP*. Ideally, the best approach to this problem would be to collect records of climate variability from a dense geographic network of sites, but this is impractical in paleoceanographic research. In the absence of dense coverage, the most viable approach is to obtain long, continuous time series from key regions and compare the response and timing of climate change among sensitive regions.

From: *Scientific and Operational Objectives of Expedition 303*, Climate Objectives, 2005; *http://iodp.tamu.edu/publications/PR/303PR/prel7.html#1007325*

What To Do

1. Speculate on what makes a region climatically sensitive.
2. What characteristics of a marine depositional environment are optimal in order for millennial oscillations in climate to be recorded in the sediments?
3. Where are these sites located?

   DSDP 609 (VM-23-081)

   ODP Site 893A

   ODP Site 1002C

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4. What type(s) of marine sediment data are presented for these sites?

   DSDP 609 (VM-23-081)

   ODP Site 893A

   ODP Site 1002C

5. How might these types of data be recorders (proxies) of climate change?
6. Are there persistent, repeated patterns in your record? Describe.
7. Do the millennial oscillations at your marine site correlate with the Greenland Ice Core (GISP2 or GRIP) oxygen isotope record?

8 Is the evidence of millennial oscillations in climate global, or tied to a particular region?

9. Speculate on what could cause such rapid oscillations in global climate.
10. What implications do these millennial oscillations in climate have for modern society?

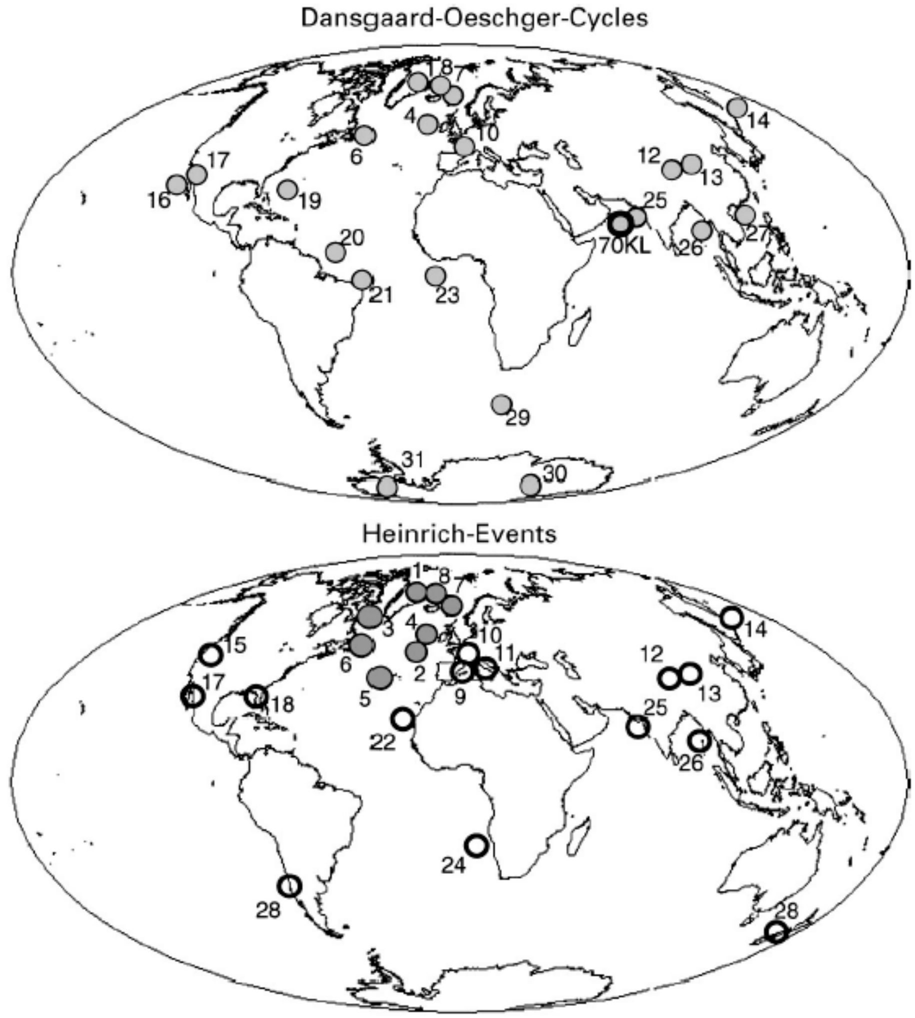


Fig. 1. The global distribution of selected (a) Dansgaard–Oeschger and (b) Heinrich Event records. Solid markers represent "sensu stricto" Dansgaard–Oeschger cycles and Heinrich Events. Open circles indicate features which have been interpreted as connected with Heinrich Events. (1) GRIP (Johnsen et al., 1992); GISP (Grootes et al., 1993). (2) NOAMP (Heinrich, 1988); DSDP 609 (Bond et al., 1993). (3) HU 75-55,56; HU 87-09 (Andrews et al., 1994). (4) VM23-81 (Bond and Lotti, 1995); V28-82 (Broecker, 1994). (5) CHN 82-20 (Keigwin and Lehman, 1994). (6) P-012, P-013, P-094 (Stoner et al., 1996; Stoner et al., 1998). (7) ENAM93-21 (Rasmussen et al., 1996; Rasmussen et al., 1997). (8) PS2644 (Voelker et al., 1998). (9) BC15 (Rohling et al., 1998). (10) Lac de Bouchet (Reille and de Beaulieu, 1990; Thouveny et al., 1994). (11) Lago Grande di Monticchio (Watts et al., 1996; Zolitschka and Negendank, 1996). (12) Luochuan loess (Porter and An, 1995). (13) Yuanbo loess (Chen et al., 1996). (14) ODP 882, 883 (Kotilainen and Shackleton, 1995). (15) Northwestern American Glaciers (Clark and Bartlein, 1995). (16) ODP 893 (Behl and Kennett, 1996); AHF 11343, AHF 28181 (Thunell and Mortyn, 1995). (17) Sierra Nevada (Benson et al., 1996). (18) Lake Tulane (Grimm et al., 1993; Watts, 1994). (19) GPC-9, GPC-5 (Keigwin and Jones, 1994). (20) EW9209-1JPC (Curry and Oppo, 1997). (21) GeoB 3104-1; GeoB 3912-1 (Arz et al., 1998). (22) ODP 658C, BOFS 31K (Zhao et al., 1995). (23) RC2402, RC2408, RC2417 (McIntyre and Molfino, 1996). (24) GeoB 1711; PG/PC 12 (Little et al., 1997). (25) 88KL; 93KL; 111KL; 136KL (Schulz et al., 1998); NIOP 453; 455; 458; 464; 478, 497 (Reichart et al., 1998). (26) MD77-169; MD77-180 (Colin et al., 1998). (27) 17940; 17954-2; 17961-2; 17927-2; V35-5 (Wang et al., 1999). (28) Piedmont Glacier Chile; Southern Alps New Zealand (Lowell et al., 1995). (29) RC11-83 (Charles et al., 1996). (30) Vostok (Bender et al., 1994; Blunier et al., 1998). (31) Byrd (Blunier et al., 1998).

From: Leuschner and Sirocko, 2000. The low-latitude monsoon climate during Dansgaard-Oeschger cycles and Heinrich Events, Quaternary Science Reviews *19, 243-254.*

Fig. 2. Lithic and foraminiferal concentrations, in numbers of grains >150 μm per gram of sediment, and the percentage of lithic grains measured relative to the sum of lithic grains and foraminifera >150 μm in sediment from DSDP 609 and VM23-81 (Fig. 1). The records from the two cores face in to emphasize the correlation. Radiocarbon ages given by a (ǀ) and the age models are from (*5*, *7*). Both cores reveal prominent cycles in lithic concentrations at the levels of Heinrich layers and in-between these levels as well. The concentrations of foraminifera and the percentages of ice-rafted debris were originally part of the definition of Heinrich events in (*4*, *5*, *30*). Low foram zones, which are so prominent in DSDP 609, are less dramatic in VM23-81 however, and are absent at the level of Heinrich event 4. The percentages of lithic grains delimits the Heinrich events as they were originally defined (*30*), through either a decrease in foraminiferal concentration, an increase in lithic concentration, or a combination of both. The record of lithic percentages does not, however, delimit all of the ice-rafting cycles. Hence, lithic concentrations are the best indicator of ice-rafting events.

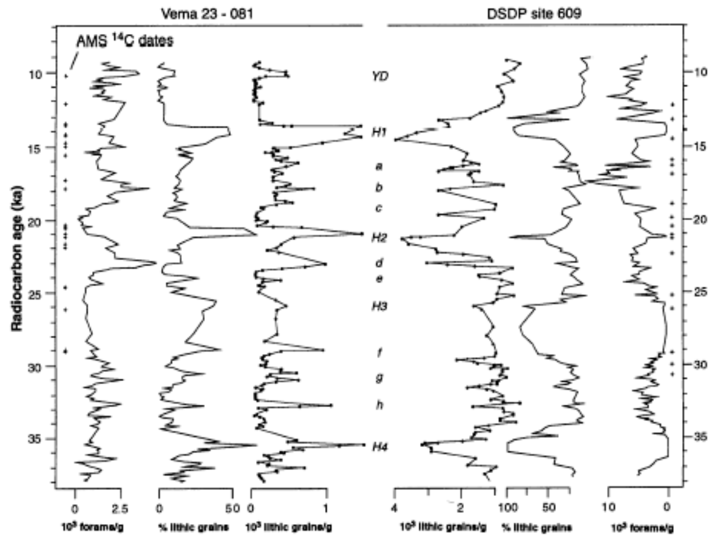
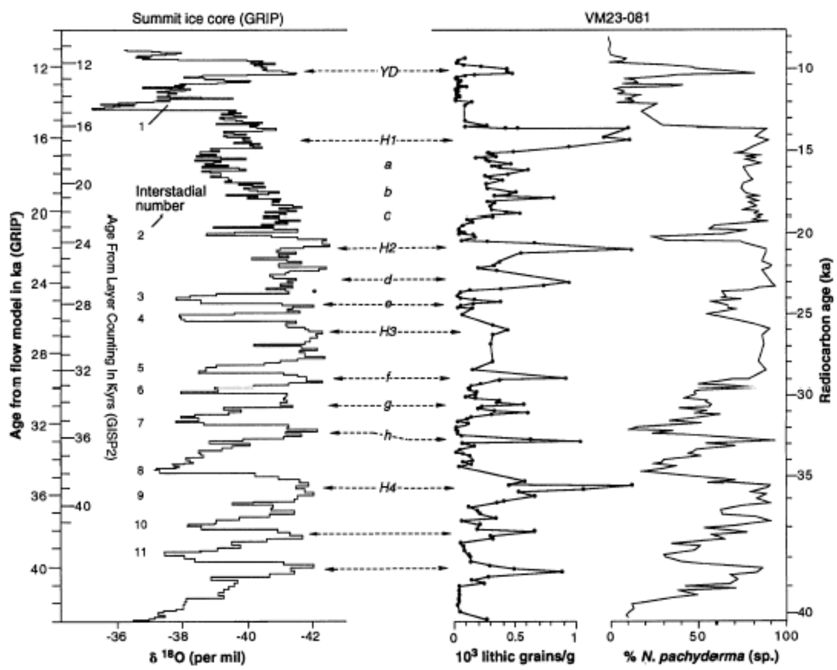


Fig. 3. Comparison of the oxygen isotope record and age model for the GRIP ice core, Summit, Greenland (*11*), with measurements of lithic concentrations (as in Fig. 2) and percentages of the planktic foraminifera *Neogloboquadrina pachyderma* (left coiling), a proxy for surface water temperatures, in VM23-81 (*7*). That foraminifera today lives in waters <10°C and comprises about 95% of the fauna at summer temperatures of <5°C. Age model for the marine record is the same as in Fig. 2. Coring sites are located in Fig. 1. Cycles between the Heinrich events are given letters to aid their description in the text. We find a striking match between the lithic concentration cycles and the temperature cycles in the ice core; the match of the lithic cycles to the ocean surface temperatures, however, is much poorer. We included the GISP2 time scale derived from layer counting to 41,000 years for comparison with the GRIP time scale and the ^{14}C time scale. The GISP2 time scale was transferred into the GRIP record at the sharp interstadial boundaries, which are precisely located in both ice core records (*11*, *12*), and then the ages were interpolated between those boundaries. The progressive difference in ages, reaching about 10% at 40,000 calendar years ago, is consistent with error estimated for the ice core dating (*31*).



From: Bond and Lotti, 1995. Iceberg Discharges into the North Atlantic on Millennial Time Scales During the Last Glaciation, Science*, 267, 1005-1010.*

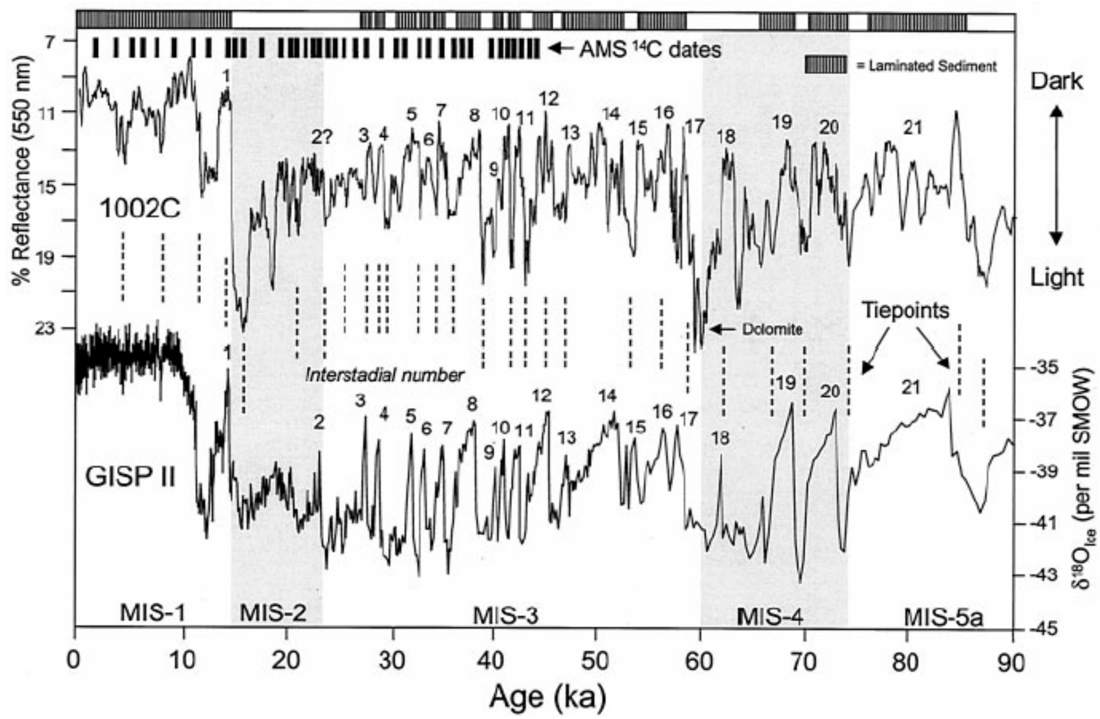
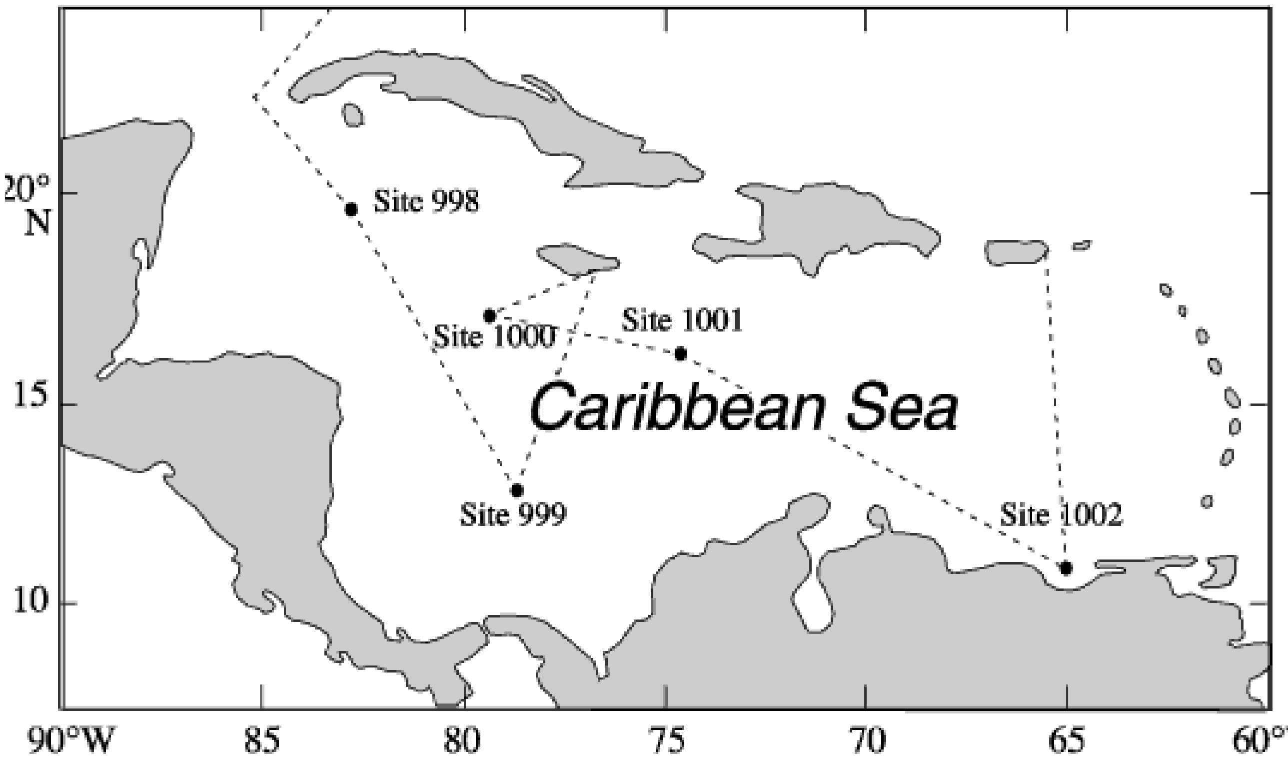
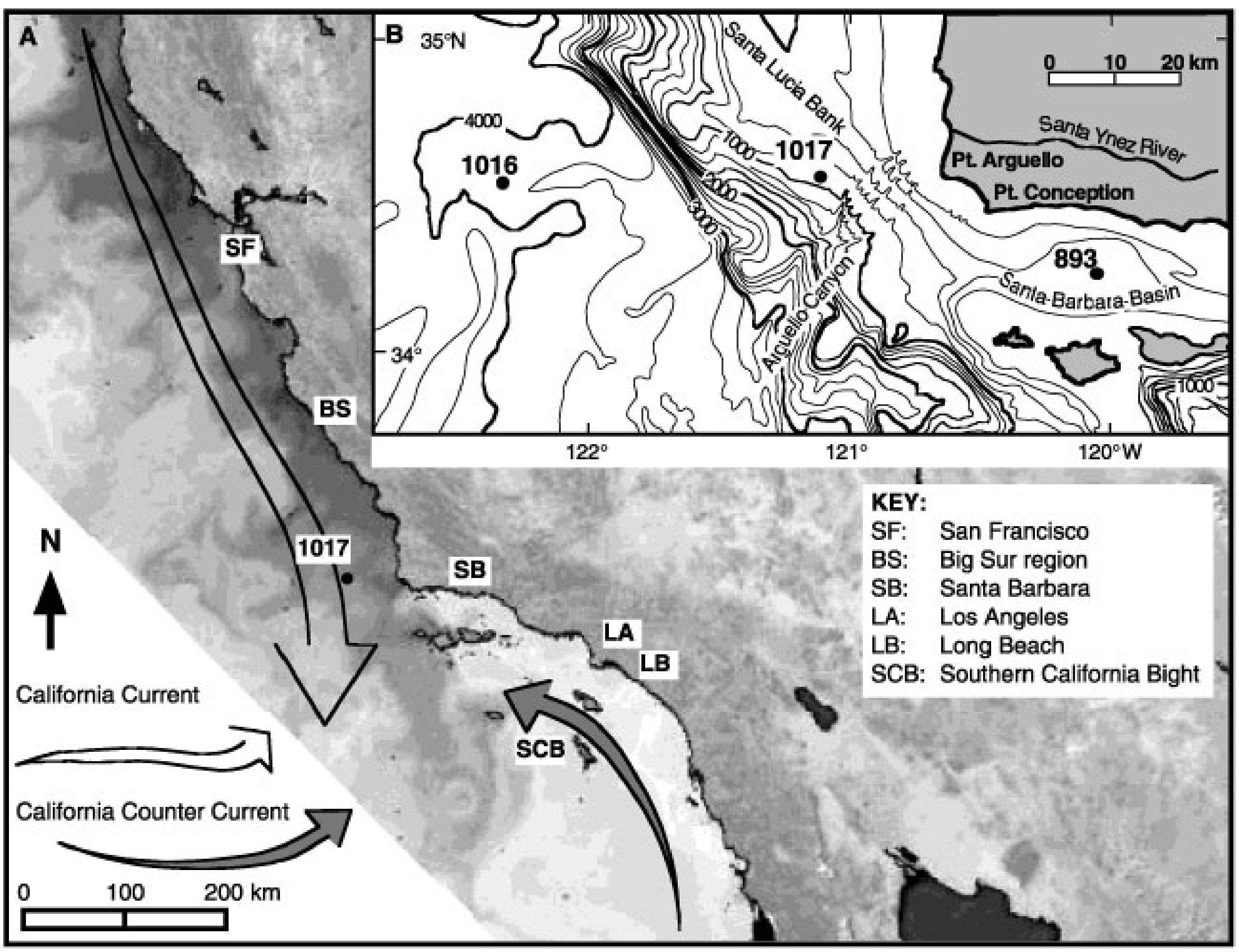


Fig. 1. Comparison of measured color reflectance (550 nm) (five-point moving average) of Cariaco Basin sediments from ODP Hole 1002C to $\delta^{18}O$ from the GISP II ice core (*9*). MIS boundaries in Hole 1002C are from (*7*), and detailed age control over the upper 22 m is based on AMS ^{14}C dating of the planktic foraminifer *G. bulloides* (*10*). Additional visual tie points between the color reflectance and GISP $\delta^{18}O$ records are shown. The distribution of laminated intervals is indicated across the top. The presence of a semi-indurated dolomite layer in Hole 1002C at 28.3 m below the sea floor resulted in minor core disturbance at this level. Deposition of dark, generally laminated sediments preferentially occurs during warm interglacial or interstadial times (numbered events), whereas deposition of light-colored bioturbated sediments was restricted to colder stadial intervals of the last glacial. Sediment color variations in the Cariaco Basin are driven by changing surface productivity, with increased organic rain leading to darker sediments and, through remineralization reactions, periods of anoxic or near-anoxic conditions in the deep basin. SMOW, standard mean ocean water.

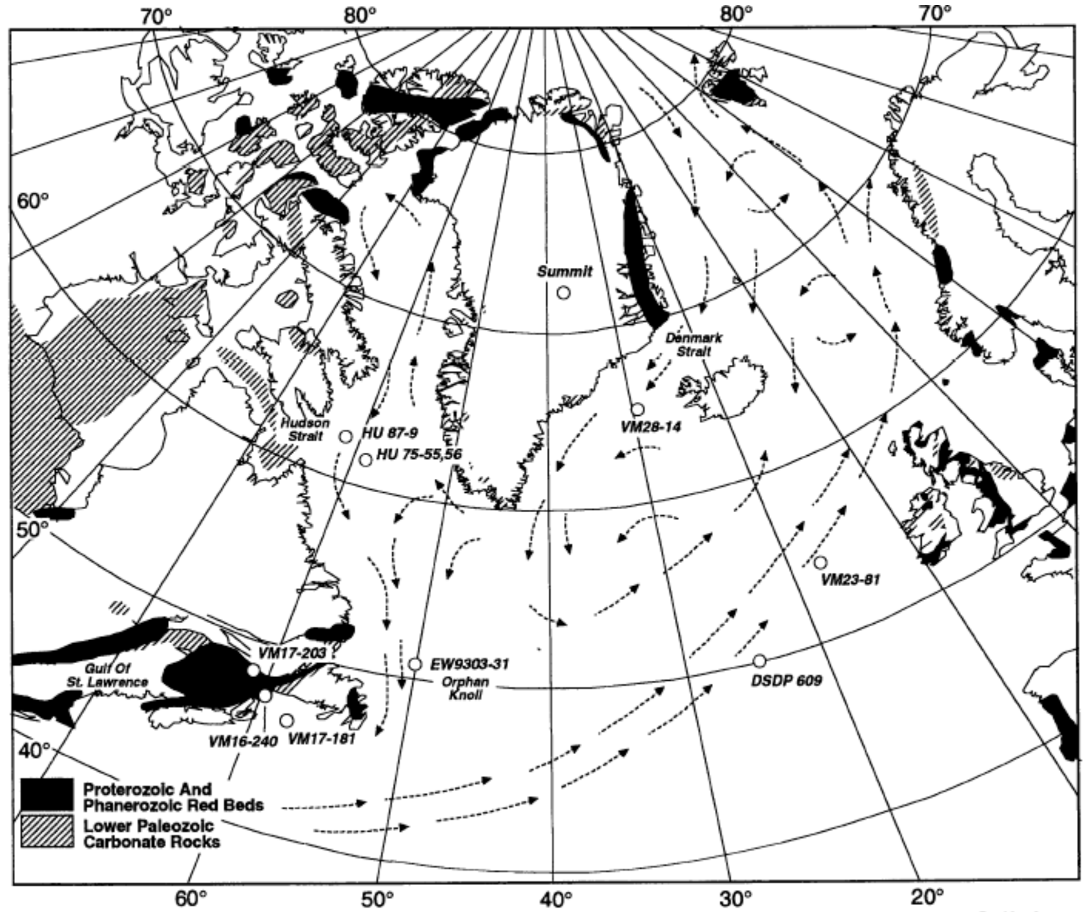
From: Peterson, Haug, Hughen, and Rohl, 2000. Rapid Changes in Hydrologic Cycle of the Tropical Atlantic During the Last Glacial. Science*, 290, 1947-1951.*



Location of ODP Leg 165 Site 1002, Cariaco Basin. From: www-odp.tamu.edu/publications/165_SR/chap_19/chap_19.htm



Location of ODP Leg 143B Site 893 (inset), Santa Barbara Basin. From: www-odp.tamu.edu/publications/167_SR/chap_22/c22_f1.htm



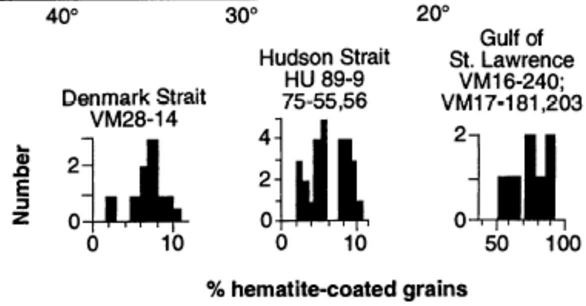


Fig. 1. Map showing the modern circulation in the North Atlantic Ocean and Nordic and Labrador Seas (dashed arrows), locations of cores discussed, and the distribution of rock types that are potential sources of detrital carbonate and hematite-coated grains (data from *28*) that we have identified in the lithic cycles in Fig. 4. The histograms show the number frequency of percentages of hematite-coated grains from 63 to 150 mm across in samples from the indicated cores. For VM28-14, grains were counted in samples containing each of the peaks in basaltic glass (Fig. 5). For the cores near Hudson Strait, grains were counted in samples every 10 cm beginning 60 cm above H1, then from between H1 and H2, and from between H2 and H4(?). In cores from the Gulf of St. Lawrence, grains were counted in samples from within and between the "brick red layers" (*29*); the uppermost of those layers has an AMS radiocarbon age of 13,300 years (*24*). The sampled interval probably extends to close to Termination 1. As explained in the text, we measured the abundances of hematite-coated grains in these places as an aid in identifying possible sources of those grains in ice-rafted sediment in the eastern North Atlantic.

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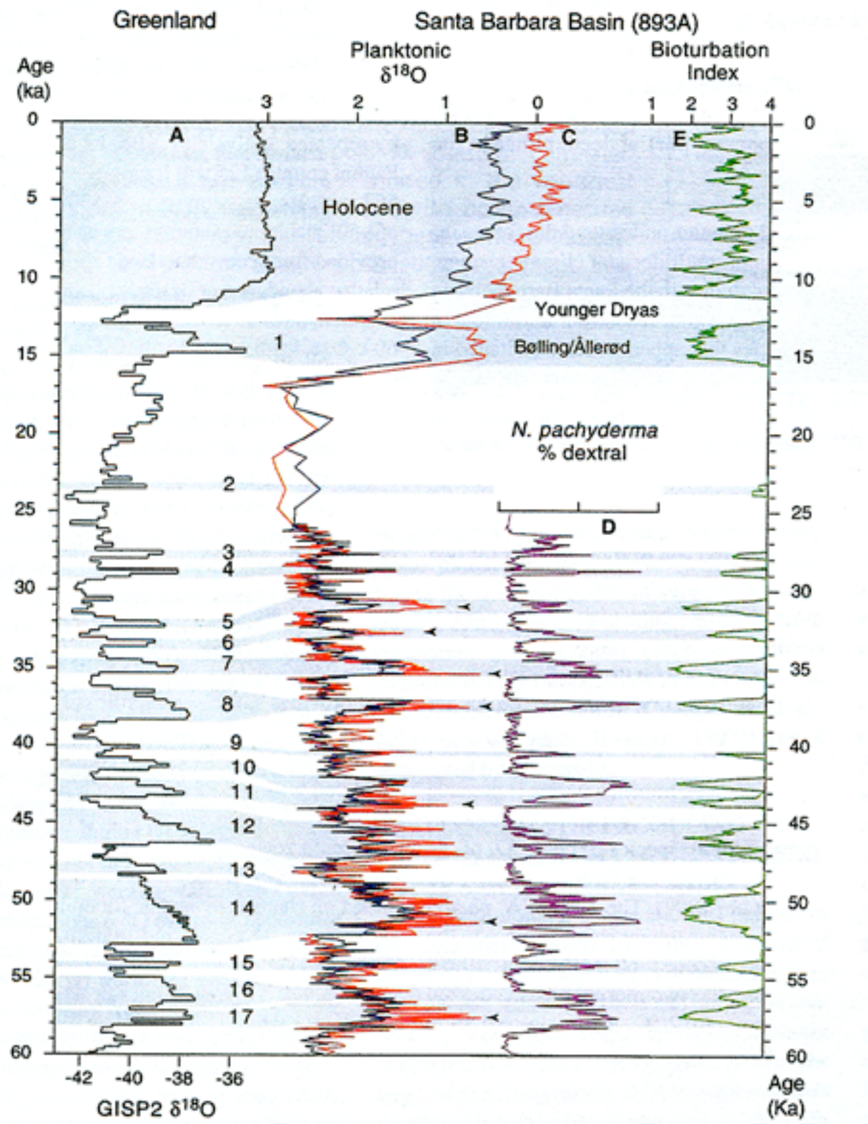
From: Bond and Lotti, 1995. Iceberg Discharges into the North Atlantic on Millennial Time Scales During the Last Glaciation, Science, 267*, 1005-1010.*



Correlation between ***(A)*** *GISP $\delta^{18}O$ (standard mean ocean water) isotope time series* **(Bender et al., 1994)** *and planktonic formainiferal and ventilation time series for Ocean drilling Program Hole 893A (Santa Barbara basin) for the past 60 ky. These include $\delta^{18}O$ (Peedee belemnite) records of* ***(B)*** *theromocline planktonic foraminifera* N. pachyderma *(blue), and* ***(C)*** *surface-water planktonic foraminifera* G. bulloides *(red), and from 25-60 ka* ***(D)*** *relative abundance of dextral to sinistral coiled* N. pachyderma *(as shown by percent dextral* N. pachyderma, *purple). On continuum of 893A bioturbation index (Behl and Kennett, 1996)* ***(E)****, 1 indicates laminated sediment facies and 4 indicates massive bioturbated sediment facies (green). Changes in all of these parameters clearly define Dandgaard-Oeschger (D-O) climate oscillations (numbers 17-3) during OIS 3 and Bolling-Allerod. Blue bands represent warm intervals (interstadials and Holocene). Interstadials (D-O events) are numbered according to GISP2 scheme. Arrows identify negative $\delta^{18}O$ overshoots in* G. bulloides *record. From: Hendy and Kennett, 1999. Late Quaternary North Pacific surface-water responses imply atmosphere-driven climate instability,* Geology *27, 291-294.*

Hemming: HEINRICH EVENTS

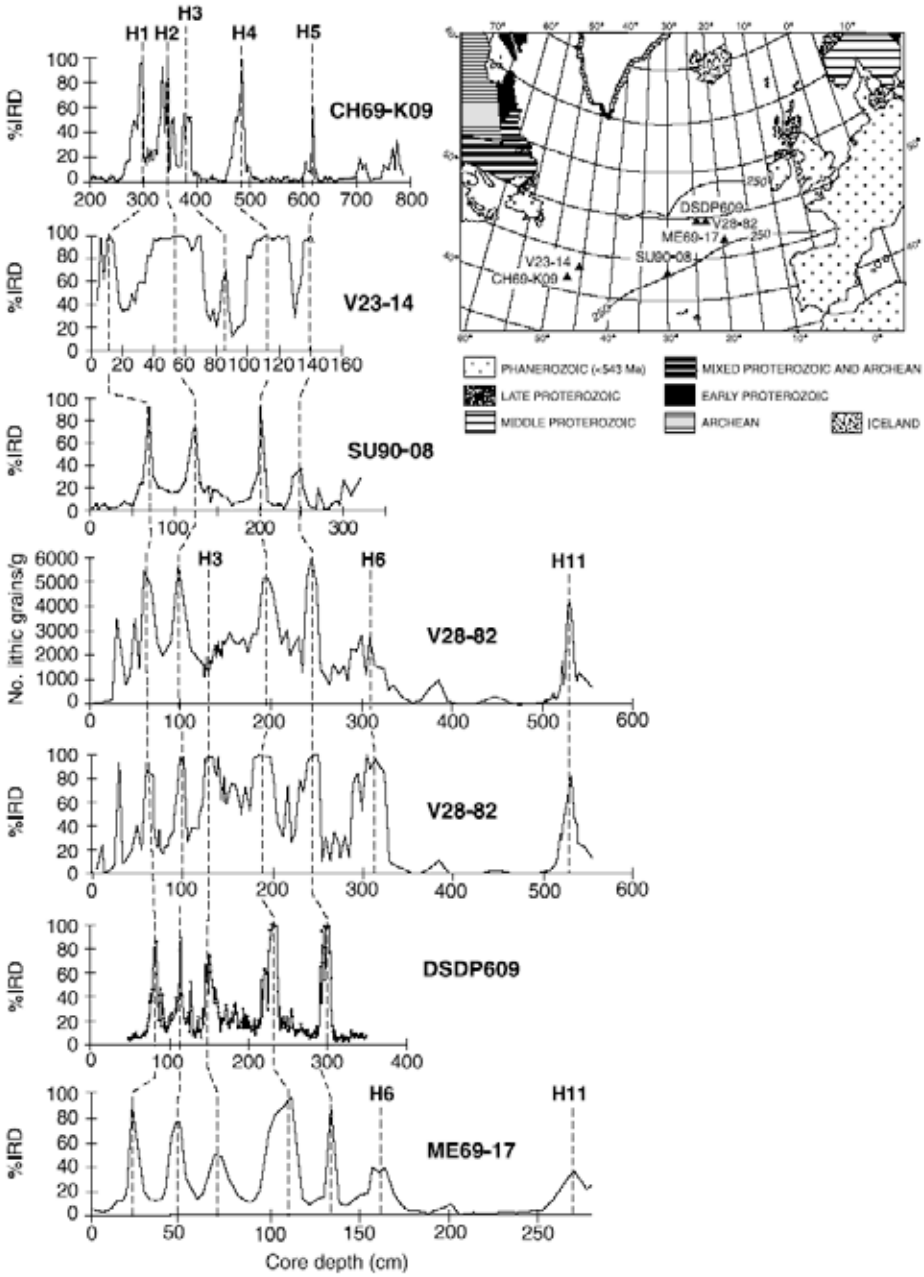
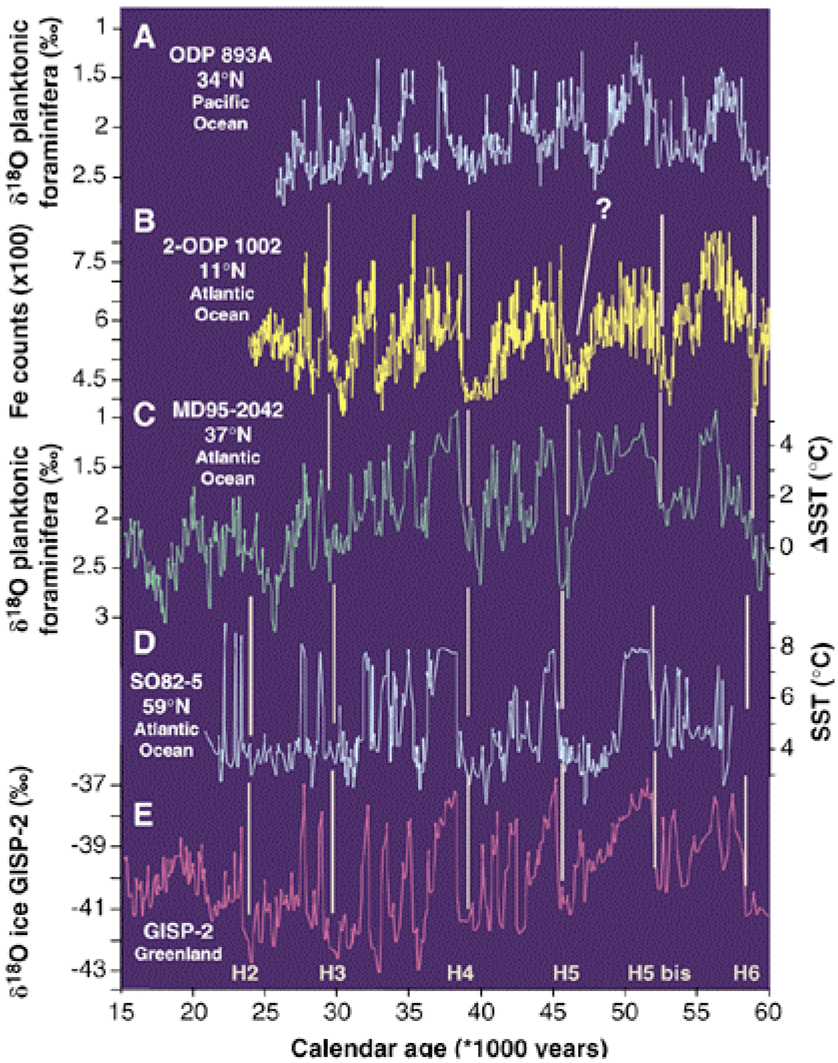


Figure 1. Ice-rafted detritus (IRD) data for North Atlantic sediment cores with Heinrich layers. Most of the data are the percentage of lithic grains in the >150 μm fraction; however, the data from ME69-17 [*Heinrich*, 1988] is the percentage of lithic grains in the 180–3000 μm fraction. Also shown is the record of number of lithic grains >150 μm per gram of dry sediment from core V28-82. The map shows the location of the cores. Data sources are CH69-K09 [*Labeyrie et al.*, 1999], V23-14 [*Hemming and Hajdas*, 2003], SU90-08 [*Grousset et al.*, 1993], V28-82 [*Gwiazda et al.*, 1996a; *McManus et al.*, 1998; *Hemming et al.*, 1998], DSDP609 [*Broecker et al.*, 1992; *Bond et al.*, 1992], and ME69-17 [*Heinrich*, 1988].

From: Hemming, 2004. Heinrich events: Massive late Pleistocene detritus layers of the North Atlantic and their global climate imprint, Rev. Geophys., 42*, RG1005, doi:10.1029/2003RG000128.*



Comparison of climatic change records for the last glacial period. *Foraminiferal $\delta^{18}O$ is a proxy for relative sea surface temperature (SST) changes. Fe content is a proxy for rain and detrital fluxes from the nearby continent. Time scales derived from AMS ^{14}C dating and correlation with the GISP-2 $\delta^{18}O$ record (10, 11).* ***(A)*** *$\delta^{18}O$ of planktonic foraminifera from ODP hole 893A, Santa Barbara basin (12).* ***(B)*** *Fe record from ODP hole 1002C, Cariaco Basin (2).* ***(C)*** *$\delta^{18}O$ of planktonic foraminifera from core MD95- 2042, Iberian margin (13).* ***(D)*** *SST record derived from foraminifera species distribution in core SO82-5, Irminger Sea.* ***(E)*** *Greenland GISP-2 $\delta^{18}O$ record (11). Timing of large meltwater Heinrich events (H2 to H6) from (3, 4, 14). The North Atlantic records (C and D) track the south-north oscillations of the polar front for all D-0 events. Each record has its own dynamic, but strong links are demonstrated by their detailed similarity.*

From: Science*, Vol 290, Issue 5498, 1905-1907, 8 December 2000; www.sciencemag.org/cgi/content/full/290/5498/1905*