Past climate clues from anoxic basin sediments : Cariaco Basin (Venezuela) as a tropical climate type sections

Bull. angew. Geol. Vol. 13/1, 2008 S. 35-39

Past Climate Clues from Anoxic Basin Sediments: Cariaco Basin (Venezuela) as a Tropical Climate Type Section

Larry C. Peterson[1]

Anoxic conditions in the ocean are the result of a dynamic balance between oxygen supply and oxygen consumption. Anoxia in the ocean is today restricted to a limited number of locations but evidence of widespread anoxic conditions in the deep sea in the geological past has led to the concept of global-scale oceanic anoxic events. A significant consequence of these ancient anoxic episodes was that the accumulation and preservation of organic matter in marine sediments were greatly enhanced, allowing the generation of potential petroleum source rocks in many environments across the globe. Roughly three quarters of the source rocks that formed the basis for currently exploited oil and natural gas deposits were deposited during anoxic intervals of the warm Mesozoic.

Modern anoxic settings have been studied as analogs for understanding the conditions that contribute to the accumulation of organic-rich source rocks (e.g. Demaison & Moore 1980). However, anoxic environments can also be valuable for the study of past climates since oxygen-free conditions on the sea floor can lead to virtually undisturbed sediment sequences that preserve high-frequency climate information. One such location, the Cariaco Basin off northern Venezuela, has yielded one of our most important records of tropical climate history and abrupt climate change in the late Pleistocene.

[1] Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL 33149

Our understanding of the nature of late Pleistocene climate variability has changed dramatically during the last two decades. We now know that the climate system can undergo large amplitude fluctuations on much shorter timescales than previously thought, an observation that has important implications for potential future climate change. Ice core records from Greenland were among the first to show that dramatic changes in regional temperature during the last glacial period and deglaciation occurred over timescales of a few decades at most (Fig. 1). The events during the last glacial have come to be known as Dansgaard-Oeschger, or D-O events, and show up as abrupt warmings (interstadials) over Greenland of as much as 10°-12°C, followed by a somewhat more gradual return to cold glacial (stadial) conditions (Dansgaard et al. 1993; NGRIP Project Members 2004). Evidence of rapid, correlative excursions in high latitude North Atlantic sea surface temperatures (SST) were soon thereafter identified in geochemical and microfossil proxies preserved in rapidly accumulated drift sediments, suggesting a dynamic linkage between oceanic and cryospheric processes in this region.

The discovery of abrupt climate change of the magnitude revealed in the ice cores has led to a sweeping reevaluation of the processes that drive major changes in the climate system, since no obvious external forcing exists that can cause change on these timescales. At present, the favoured paradigm for explaining these abrupt climate events centers on freshwater input to the subpolar North Atlantic and its effect on heat transport into the region via disruption of the density-driven meridional overturning of the Atlantic (e.g. Broecker et al. 1985; Rahmstorf 1995). Today, warm salty surface waters from the tropical Atlantic are transported via surface currents into the high latitudes where they cool and release their heat and become dense enough to sink, forming North Atlantic Deep Water that flows to the south and fills much of the deep ocean. It is argued that periodic discharges of large quantities of freshwater into the North Atlantic Ocean from the surrounding land masses abruptly disrupt the delivery of heat from the tropics to the high latitude region by stratifying the near-surface water column and weakening or shutting down the sinking. According to this model, the delivery of heat to the region resumes when the freshwater supply is eliminated and/or salinity levels increase again through other processes. The most obvious source of this freshwater would be from periodic releases of meltwater derived from the surrounding ice sheets, though what might cause these releases is presently unknown.

While the early ice core discoveries generated considerable excitement, it was initially unclear if this climate behavior was limited to the North Atlantic, with the peculiarities of ocean overturning in this region, or if the climate changes extended to other oceans and other parts of the globe. Throughout much of the ocean, slow rates of pelagic sedimentation preclude the preservation of high frequency climate signals such as those seen in the ice cores. However, a number of marine locations have now been identified far removed from Greenland where unusual depositional conditions have yielded records comparable to the ice cores in terms of their resolution and fidelity. Cariaco Basin in the southern Caribbean was one of the first to be exploited.

Cariaco Basin is a small, deep pull-apart basin on the northern continental margin of Venezuela and, after the Black Sea, is the second largest anoxic marine basin on Earth today. Here, high sedimentation rates (0.3 to >1.0 mm/year), a strong seasonal depositional signal, and the lack of biological mixing because of the anoxic water column has produced an annually laminated (varved)

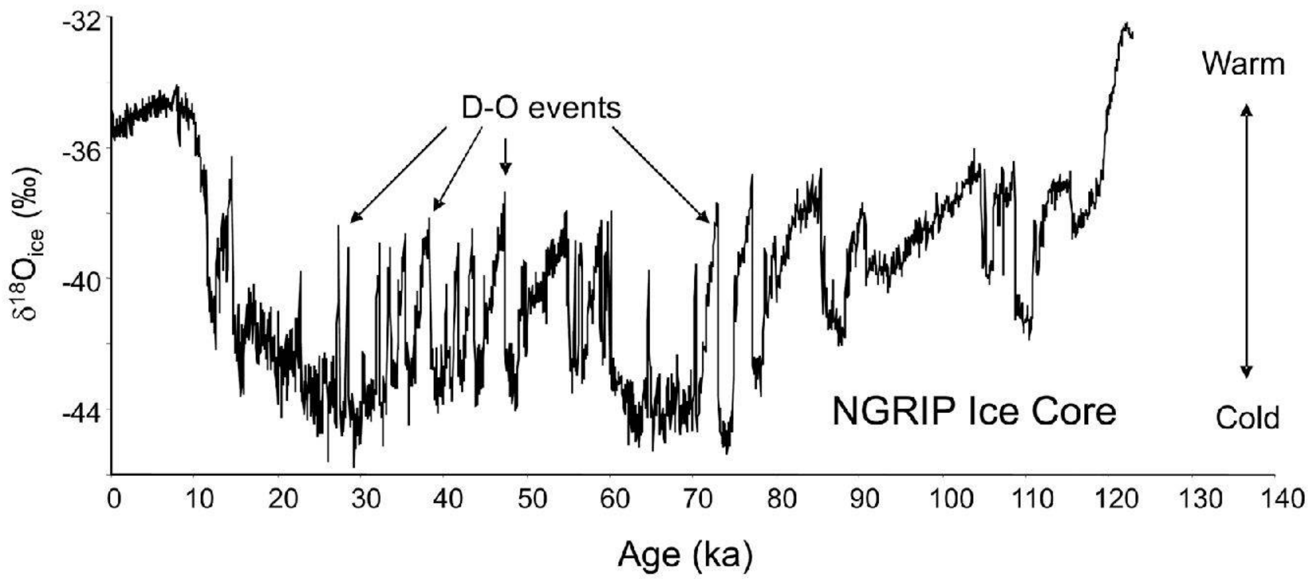

Fig. 1: Oxygen isotope record from the Greenland NGRIP ice core (NGRIP Project Members 2004), a proxy for air temperature changes. The high-resolution NGRIP record spans the last 123,000 years and reveals pervasive century- to millennial-scale variability. Rapid warming during the Dansgaard-Oeschger (D-O) events of the last glacial appears to have occurred over a few decades at most. Greenland ice core records helped introduce the term «abrupt climate change» to the lexicon of climate scientists.

and virtually undisturbed sediment sequence. The strong seasonality that influences sedimentation in Cariaco Basin is the direct product of the predictable migration of the Intertropical Convergence Zone (ITCZ) with respect to the basin's location. During the winter and spring, upwelling of cold nutrient-rich waters occurs along the Venezuelan coast in response to strong trade winds as the ITCZ sits far to the south. This stimulates high surface productivity which results in the preferential sinking of biogenic materials during this portion of the year. Northward movement of the ITCZ in the summer to a position near the Venezuelan coast triggers the regional rainy season and increases the fluvial discharge of silts and clays from rivers that drain into Cariaco Basin.

Studies of sediments recovered from the

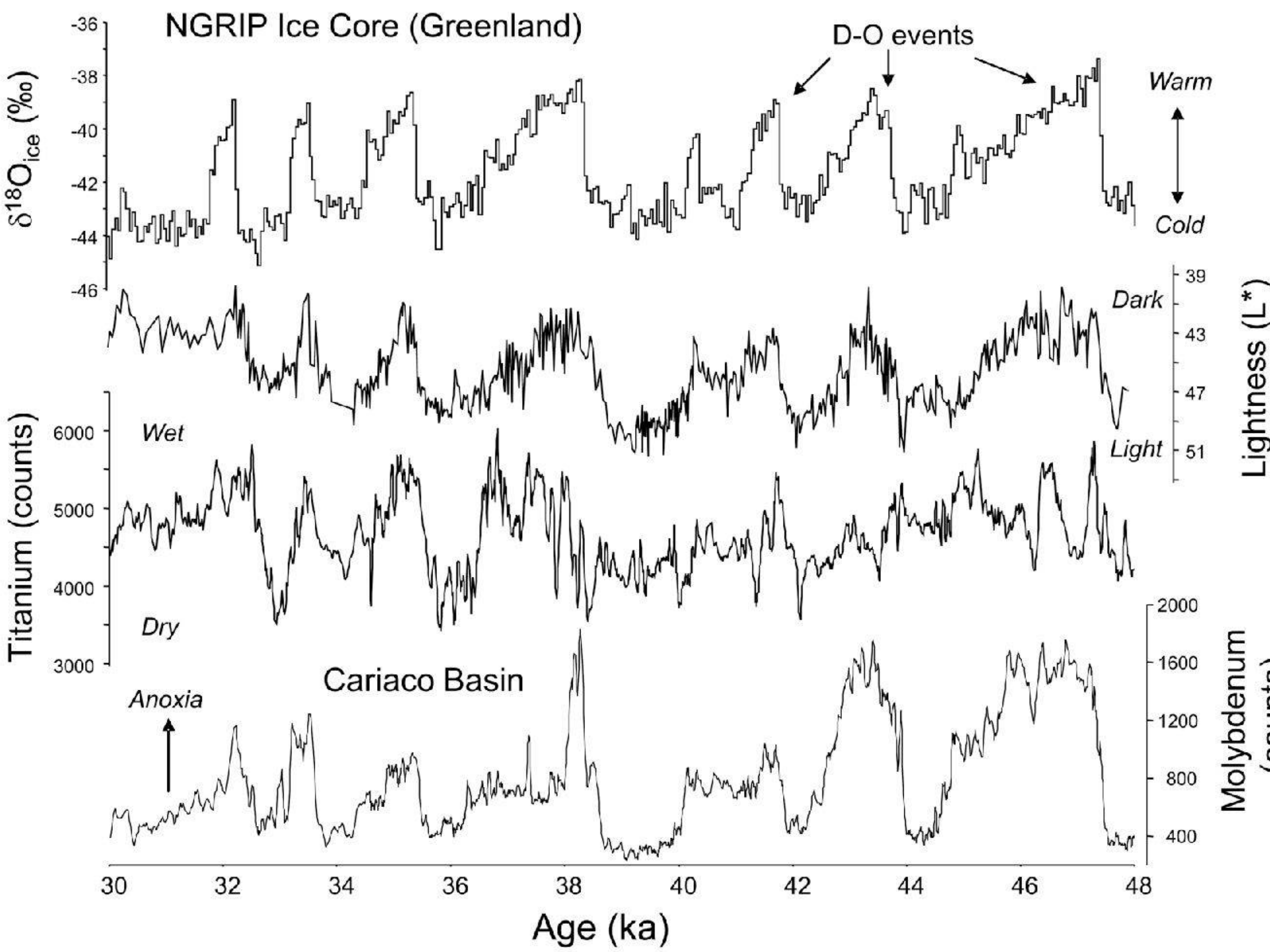

Fig. 2: Paleoclimate time-series showing examples of abrupt climate change during the last glacial period between 48,000 and 30,000 years ago. The top time-series shows oxygen isotope variations in the NGRIP ice core from Greenland (NGRIP Project Members 2004); oxygen isotope variations here serve as a proxy for air temperature variations. The lower three time-series show data from Cariaco Basin sediment core MD03-2620. Lightness is a standard measure of sediment reflectance and captures color variations that alternate between dark, organic-rich intervals, corresponding to warm Dansgaard-Oeschger (D-O) events, and light colored sequences that reflect deposition during cold intervals of the glacial. The titanium content of Cariaco Basin sediments, as measured by scanning x-ray fluorescence (XRF) techniques, is interpreted as an index of regional hydrologic variability and riverine runoff, with higher values indicating wetter conditions over northern South America when Greenland is relatively warm. Molybdenum contents, also measured by scanning XRF, indicate redox variations on the Cariaco Basin seafloor, with Mo accumulating at times when anoxic conditions are present. Though separated by some 65° of latitude, Cariaco Basin sediments reveal a tight linkage between the tropics and Greenland on the time scales of abrupt climate change.

basin by both conventional coring and through drilling by the Ocean Drilling Program have revealed a complete sequence of D-O events recorded in multiple climate proxies that mimic those first observed in Greenland. Furthermore, the remarkable behavior of these tropical climate events is so similar to those of the Greenland ice cores that some form of teleconnection via the atmosphere is strongly implicated. The D-O events in sediments of the Cariaco Basin are recorded by alternating dark and light intervals which reflect climatically-driven oscillations between anoxic and oxygenated deep basin conditions (Hughen et al. 1996; Peterson et al. 2000). These variations are expressed in Fig. 2 by measurements of sediment reflectance and by changes in the bulk molybdenum (Mo) content of the sediments, a redox-sensitive proxy measured by scanning x-ray fluorescence methods. Stratigraphic intervals corresponding to the cold stadials of the last glacial are represented by light colored sediments which accumulated under oxygenated conditions (low Mo) while the warm interstadials are characterized by deposition of dark, organic-rich, laminated sediments (high Mo). The D-O events in Greenland ice are also intimately tied to rapid oscillations in the riverine input of siliciclastic sediments (as measured by bulk Ti content; Fig. 2) to the Cariaco Basin.

These oscillations implicate past changes in the average position of the ITCZ and its associated belt of convective rainfall. Periods of high input of continental sediment are in phase with the warm interstadials and indicate higher regional precipitation and a more northerly position of the ITCZ; periods of low siliciclastic input are evidence of dry regional conditions and southerly displacement of the ITCZ during the colder stadials (Peterson & Haug 2006). This observation is in fact consistent with climate model experiments which predict a southward shift of the ITCZ and pronounced changes in the distribution of tropical precipitation upon a meltwater-induced collapse of the Atlantic's meridional overturning circulation (e.g. Vellinga & Wood 2002). Data from the Cariaco Basin provided the first direct evidence for rapid hydrologic changes in the tropics during the last glacial episode that could be unambiguously linked to D-O events.

Now that we know what to look for, evidence is emerging that the abrupt events of the last glacial were global. While it seems clear that the Atlantic's meridional overturning circulation is involved in abrupt climate change, it is not yet apparent that changes in the high-latitude North Atlantic alone can drive changes around the world. Records from Cariaco Basin and now elsewhere in the low latitudes confirm that a prominent signature of abrupt climate change in the tropics is in the hydrological cycle, which raises the possibility that water vapor and wetland-produced methane changes play a role in amplifying and transmitting the climate signal.

Anoxic basins like the modern Cariaco Basin offer great potential as archives for climate and ocean history because of the limited disturbance by burrowing organisms. Where recent deposited sediments are varved (i.e. annually-laminated), overlap and direct calibration to instrumental data can be achieved, making possible studies of natural climate variability on interannual and longer time scales. Sediments from ancient anoxic settings offer similar opportunities for high-resolution paleoclimate studies and represent an underexploited archive of climate and paleoceanographic information.

Literature

Broecker, W.S., Peteet, D.M. & Rind, D. 1985: Does the ocean-atmosphere system have more than one stable mode of operation? Nature, 315: 21-25.

Hughen, K.A., Overpeck, J.T., Peterson, L.C. & Trumbore, S.E. 1996: Rapid climate changes in the tropical Atlantic during the last deglaciation. Nature, 380: 51-54.

Dansgaard, W., Johnsen, S., Clausen, H.B., Dahl-Jensen, D., Gundestrup, N.S., Hammer, C.U., Hvidberg, C.S., Steffensen, J., Sveinbjörnsdottir, A.E., Jouzel, J. & Bond, G. 1993: Evidence for general instability of past climate from a 250-kyr ice core record. Nature, 364: 218-220.

Demaison, G.J. & Moore, G.T. 1980: Anoxic environments and oil source bed genesis. American Association of Petroleum Geologists Bulletin, 64. 1179-1209.

North Greenland Ice Core Project Members (NGRIP) 2004: High-resolution record of Northern Hemisphere climate extending back into the last interglacial period. Nature, 431: 147-151.

Peterson, L.C., Haug, G.H., Hughen, K.A. & Röhl, U. 2000: Rapid changes in the hydrologic cycle of the tropical Atlantic during the last glacial. Science, 290: 1947-1951.

Peterson, L.C. & Haug, G.H. 2006: Variability in the mean latitude of the Atlantic Intertropical Convergence Zone as recorded by riverine input of sediments to the Cariaco Basin (Venezuela). Palaeogeography, Palaeoclimatology, Palaeoecology. 234: 97-113.

Rahmstorf, S. 1995: Bifurcations of the Atlantic thermohaline circulation in response to changes in the hydrological cycle. Nature, 378: 145-149.

Vellinga, M., & Wood, R. A. 2002: Global climatic impacts of a collapse of the Atlantic thermohaline circulation. Climatic Change, 54: 251-267.