Quaternary Science Reviews 55 (2012) 23–33

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Invited paper

A re-examination of evidence for the North Atlantic "1500-year cycle" at Site 609

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ARTICLE INFO

Article history:
Received 27 March 2012
Received in revised form
7 August 2012
Accepted 13 August 2012
Available online 25 September 2012

Keywords:
North Atlantic
Paleoceanography
Ice-rafted debris (IRD)
Stratigraphy
Millennial climate variability
Solar variability

ABSTRACT

Ice-rafting evidence for a "1500-year cycle" sparked considerable debate on millennial-scale climate change and the role of solar variability. Here, we reinterpret the last 70,000 years of the subpolar North Atlantic record, focusing on classic DSDP Site 609, in the context of newly available raw data, the latest radiocarbon calibration (Marine09) and ice core chronology (GICC05), and a wider range of statistical methodologies. A ~1500-year oscillation is primarily limited to the short glacial Stage 4, the age of which is derived solely from an ice flow model (ss09sea), subject to uncertainty, and offset most from the original chronology. Results from the most well-dated, younger interval suggest that the original 1500 ± 500 year cycle may actually be an admixture of the ~1000 and ~2000 cycles that are observed within the Holocene at multiple locations. In Holocene sections these variations are coherent with ^{14}C and ^{10}Be estimates of solar variability. Our new results suggest that the "1500-year cycle" may be a transient phenomenon whose origin could be due, for example, to ice sheet boundary conditions for the interval in which it is observed. We therefore question whether it is necessary to invoke such exotic explanations as heterodyne frequencies or combination tones to explain a phenomenon of such fleeting occurrence that is potentially an artifact of arithmetic averaging.

1. Introduction

The late Gerard Bond and colleagues reported from multiple locations across the North Atlantic a "1500-year cycle" in ice-rafted, hematite-stained grains (HSG) that appeared to pace the Dansgaard–Oeschger (D–O) Events prominent in the last-glacial interval of the GISP2 Greenland ice core (Bond and Lotti, 1995; Bond et al., 1997, 1999). The subsequent interpretation of solar forcing of HSG variability during the Holocene (Bond et al., 2001) stimulated substantial debate on the mechanisms of millennial variability, due in part to the lack of a corresponding 1500-year solar cycle. This body of work remains widely discussed, with the above-mentioned four manuscripts being cumulatively cited in excess of 3000 times.

Classic DSDP Site 609 (49° 52.7′ N, 24° 14.3′ W; 3884 mbsl), located on the upper–middle eastern flank of the Mid Atlantic Ridge within the "IRD Belt" of Ruddiman (1977), produced one of the more well-known HSG records (Fig. 1). In addition, this site was instrumental in linking Greenland air temperature with North Atlantic sea surface temperature (SST) fluctuations, as well as in demonstrating that D–O Events are bundled into progressively cooler interstadials that culminate in a large ice discharge (Heinrich Event) (Bond et al., 1992, 1993).

During IODP Exp. 303, Site 609 was reoccupied, and a continuous 355 m sequence was recovered from Site U1308 (Exp. 303 Scientists, 2006). Hodell et al. (2008) used grayscale variations to correlate the two sites, allowing for the transfer of the Site 609 age model to Site U1308. However, the utility of the Site 609 age model is currently limited due to its basis in older chronologies that have since undergone significant revision.

Therefore, in this manuscript we reinterpret the HSG record of DSDP Site 609 (Bond et al., 1999) in light of an improved chronology for the last glaciation, Marine Isotope Stages (MISs) 2–4. We 1) reassess the chronostratigraphic correlation between Site 609 and the Greenland ice core record, 2) improve the early-glacial chronology with the virtually complete North GRIP (NGRIP) ice core (NGRIP Project Members, 2004), and 3) temporally extend the late-glacial radiocarbon chronology with the most recent marine radiocarbon calibration curve (Reimer et al., 2009). We then 4) apply an age uncertainty model to this thoroughly updated chronology to evaluate the effects of age perturbations on cyclicity.

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http://dx.doi.org/10.1016/j.quascirev.2012.08.008

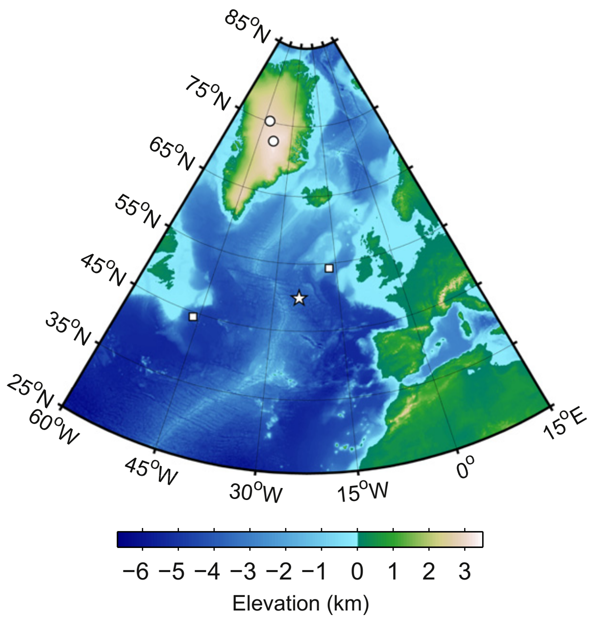

Fig. 1. Star depicts the location of Site 609 (49°52.7′N, 24°14.3′W; 3884 mbsl). Squares represent locations of western and eastern cores, MC21 and GGC22 (44°18′N, 46°16′W; 3958 mbsl), MC52 (55°28′N, 14°43′W, 2172 mbsl), V29-191 (54°16′N, 16°47′W, 2370 mbsl), and V23-81 (54°15′N, 16°50′W, 2393 mbsl). Circles denote Greenland ice cores GISP2 (72°36′N, 38°30′W; 3200 m) and NGRIP (75°6′N, 42°20′W; 2917 m).

Finally, we 5) make available the entire Site 609 dataset (see Supplemental Online Material) with the goal of enabling better global correlation to this important location.

2. Background

2.1. Sources and significance of hematite stained grains

Over forty years ago, Paleozoic red beds in the area of the Gulf of St. Lawrence, which contain abundant hematite-cemented quartz sandstones (e.g., Belt, 1965), were proposed as a primary source for ferruginous sediments transported to the North Atlantic basin during Pleistocene glaciations (Heezen et al., 1966). Ericson et al. (1961) first described these sediments in western North Atlantic sediment cores during the early days of the Lamont-Doherty Earth Observatory's "core a day" program. Subsequently, similar sediments were discovered at the mouth of the Gulf of St. Lawrence (Heezen and Drake, 1964) and in Baffin Bay (Marlowe, 1968). The latter, however, does not appear to significantly export ferruginous sediment because of the lack of such deposits in the Labrador Sea (Hollister, 1967). Pollen (Needham et al., 1969) and clay mineral (Conolly et al., 1967; Zimmerman, 1972) assemblages also strongly suggest a Gulf of St. Lawrence source.

Sediment cores taken along major iceberg trajectories later corroborated the interpretation that ice-rafted HSG were primarily derived from the Gulf of St. Lawrence during the last glaciation (Bond and Lotti, 1995). During the Holocene, however, core top analyses indicate other sources for HSG. Red beds from East Greenland and Svalbard, and likely the Arctic Ocean, contributed significant amounts of HSG, and changes in ocean circulation (as opposed to increased calving) are interpreted to be responsible for variations in the amount of HSG deposited in the modern subpolar North Atlantic (Bond et al., 1997). Thus, Bond et al. (1997) concluded that HSG deposition from melting ice is controlled by differing mechanisms during the Holocene and long interstadials (ocean circulation changes) and during glacial times (increased iceberg discharge).

2.2. HSG methodology

Bond and Lotti (1995), as well as Bond et al. (1997, 1999, 2001), performed counts of HSG, detrital carbonate (DC), and Icelandic glass (IG) on the 63–150 μm size fraction using grain-mount slides and a petrographic microscope. This size fraction was chosen to provide "greater accuracy in petrologic identification" (Bond and Lotti, 1995). Using a narrow range of relatively small-sized grains also reduces variability resulting from any relationship between grain size and composition (Bond et al., 1999) without introducing a compositional bias (Bond and Lotti, 1995). Grain-mount slides allow multiple grain faces to be viewed at once, increasing identification efficiency. In addition, the relative abundance of the 63–150 μm fraction remains high during interglacials, allowing standardized measurements from both interglacial and glacial times (Bond et al., 1999). Counts of bulk lithic grains and *Neogloboquadrina pachyderma* (s) were performed on the >150 μm fraction using standard techniques (Bond and Lotti, 1995; Bond et al., 1997).

2.3. Principal HSG results

Early discussion of HSG focused on its potential for integrating much of the observed last-glacial millennial variability. Grootes and Stuvier (1997) identified a sharp, highly significant 1470-year spectral peak in the Greenland GISP2 ice core $\delta^{18}O$ record. Coincidentally, Bond et al. (1997) reported a mean pacing of 1470 ± 523 years in HSG deposition. Peaks in HSG deposition occurred simultaneously with increases in IG and preceded each of the large "Hudson Strait" Heinrich Events (H1, H2, H4, H5), which are recognizable by abrupt increases in DC (Bond and Lotti, 1995; Bond et al., 1999). Therefore, the 1500-year cycle in HSG potentially explained not only the pacing of the D–O Events evident in Greenland ice cores (e.g., Schulz, 2002; Rahmstorf, 2003) but also offered an explanation for surging of the Laurentide Ice Sheet (LIS): climate acting on unstable ice in multiple locations that simultaneously surges and in turn destabilizes the LIS, perhaps due to the effects of sea level rise on grounded ice margins, producing a Heinrich Event.

However, neither the last glacial nor Holocene HSG records exhibit statistically significant 1500-year periodicity. Therefore these records were referred to as either "quasi-periodic" (Bond et al., 1997) or "cyclic" (in a geologic sense, implying repetition, not periodicity) (Bond et al., 2001). The mean pacing of 1470 ± 523 years was derived by interval counting (the elapsed time between cycle midpoints) and was the combined result of a composite record covering the last glaciation with V23-81 (1536 ± 563 years) and the Holocene with V29-191 (1374 ± 502 years) (Bond et al., 1997). Bond et al. (1999) later revised the V23-81 result to 1469 ± 514 years and presented results for the last glacial interval of DSDP Site 609 (1476 ± 585 years).

The most well-known HSG record is the eastern (MC21-GGC22) and western (MC52-V29-191) North Atlantic Holocene stack that was shown to be highly coherent with cosmogenic nuclide production. While this was used to suggest that "at least the Holocene segment of the North Atlantic's '1500-year' cycle appears to have been linked to variations in solar irradiance" (Bond et al., 2001), the coherency was, in fact, not at 1500 years at all but at primarily 500, 1000, and perhaps 2000 years. (Variability at the latter period was filtered out of the records prior to cross-spectral analysis.) The absence of coherency at a ~1500-year period reflects the lack of power at this band in the HSG and solar proxy records. Variations in this stacked record coincided with well-known climatic events, including the 8.2 ka Event, Medieval Warm Climate Anomaly, and Little Ice Age, (Bond et al., 1997, 2001),