

## Geology

### Query paper:

**Title:** Massive iceberg discharges as triggers for global climate change

**Abstract:** Observations of large and abrupt climate changes recorded in Greenland ice cores have spurred a search for clues to their cause. This search has revealed that at six times during the last glaciation, huge armadas of icebergs launched from Canada spread across the northern Atlantic Ocean, each triggering a climate response of global extent.

### Candidate papers:

1. **Title:** Origin and consequences of cyclic ice rafting in the northeast Atlantic Ocean during the past 130,000 years

**Abstract:** Deep-sea sediment cores recovered from the Northeast Atlantic Ocean were examined in order to elucidate the influence of the Earth's orbital parameters on major ice rafting. Analyses of coarse-grained ice-rafted debris and planktonic foraminifers revealed a strong reaction to the precession signal. Since 130,000 yr B.P., dropstone layers have been deposited each half period of a precessional cycle ( $11,000 \pm 1000$  yr). Ice rafting occurs during times of winter minimum/summer maximum insolation and summer minimum/winter maximum insolation. In the first case, high summer insolation forces meltwater discharge from the ice sheets into the polar seas which subsequently enhances formation of sea ice during the winter. In the second case, growth of continental ice enhances iceberg production which also leads to a salinity reduction of surface seawater. Both situations result in a southward penetration of polar water. Thus, the marine record of dropstones documents ice rafting not only during Weichselian stades but also during cold events within interstades. The regularity of ice rafting yields a useful framework to calibrate and elucidate climatic changes, not only in the region of the North Atlantic Ocean but also in remote areas such as the Pacific Ocean and the Antarctic.

2. **Title:** Origin of the northern Atlantic's Heinrich events

**Abstract:** As first noted by Heinrich, 1988, glacial age sediments in the eastern part of the northern Atlantic contain layers with unusually high ratios of ice-rafted lithic fragments to foraminifera shells. He estimated that these layers are spaced at intervals of roughly 10 000 years. In this paper we present detailed information documenting the existence of the upper five of these layers in ODP core 609 from 50° N and 24° W. Their ages are respectively 15 000 radiocarbon years, 20 000 radiocarbon years, 27 000 radiocarbon years, about 40 000 years, and about 50 000 years. We also note that the high lithic fragment to foram ratio is the result of a near absence of shells in these layers. Although we are not of one mind regarding the origin of these layers, we lean toward an explanation that the Heinrich layers are debris released during the melting of massive influxes of icebergs into the northern Atlantic. These sudden inputs may be the result of surges along the eastern margin of the Laurentide ice sheet.

3. **Title:** Irregular glacial interstadials recorded in a new Greenland ice core

**Abstract:** THE Greenland ice sheet offers the most favourable conditions in the Northern Hemisphere for obtaining high-resolution continuous time series of climate-related parameters. Profiles of  $18O/16O$  ratio along three previous deep Greenland ice cores 1–3 seemed to reveal

irregular but well-defined episodes of relatively mild climate conditions (interstadials) during the mid and late parts of the last glaciation, but there has been some doubt as to whether the shifts in oxygen isotope ratio were genuine representations of changes in climate, rather than artefacts due to disturbed stratification. Here we present results from a new deep ice core drilled at the summit of the Greenland ice sheet, where the depositional environment and the flow pattern of the ice are close to ideal for core recovery and analysis. The results reproduce the previous findings to such a degree that the existence of the interstadial episodes can no longer be in doubt. According to a preliminary timescale based on stratigraphic studies, the interstadials lasted from 500 to 2,000 years, and their irregular occurrence suggests complexity in the behaviour of the North Atlantic ocean circulation.

4. **Title:** Younger Dryas age advance of Franz Josef glacier in the southern Alps of New Zealand

**Abstract:** A corrected radiocarbon age of  $11,050 \pm 14$  years before present for an advance of the Franz Josef Glacier to the Waiho Loop terminal moraine on the western flank of New Zealand's Southern Alps shows that glacier advance on a South Pacific island was synchronous with initiation of the Younger Dryas in the North Atlantic region. Hence, cooling at the beginning of the Younger Dryas probably reflects global rather than regional forcing. The source for Younger Dryas climatic cooling may thus lie in the atmosphere rather than in a North Atlantic thermohaline switch.

5. **Title:** Heinrich Events: Triggers of Ocean Circulation Change?

**Abstract:** Six layers rich in ice-rafted debris and poor in foraminifera shells have been identified in sediments of last glacial age in the northern Atlantic (Heinrich, 1988; Broecker et al., 1990). Based on their geographic pattern and composition, these layers appear to be debris released during the melting of armadas of icebergs (Bond et al., 1992). Abundant limestone fragments in the ice-rafted debris and the exceptionally high  $^{40}\text{K} - ^{40}\text{Ar}$  ages for the clay minerals point to Hudson Straits as the launching site. This interpretation is strengthened by the finding by Andrews and Tedesco (1992) of exceptionally thick Heinrich layers in cores from the Labrador Sea.

6. **Title:** A 50,000-Year Record of Climate Oscillations from Florida and Its Temporal Correlation with the Heinrich Events

**Abstract:** Oscillations of *Pinus* (pine) pollen in a 50,000-year sequence from Lake Tulane, Florida, indicate that there were major vegetation shifts during the last glacial cycle. Episodes of abundant *Pinus* populations indicate a climate that was more wet than intervening phases dominated by *Quercus* (oak) and *Ambrosia*-type (ragweed and marsh-elder). The *Pinus* episodes seem to be temporally correlated with the North Atlantic Heinrich events, which were massive, periodic advances of ice streams from the eastern margin of the Laurentide Ice Sheet. Possible links between the Tulane *Pinus* and Heinrich events include hemispheric cooling, the influences of Mississippi meltwater on sea-surface temperatures in the Gulf of Mexico, and the effects of North Atlantic thermohaline circulation on currents in the Gulf.

### Exemplary analysis:

1. **Relevance:** The detailed analysis of ice-rafted debris and its correlation with Earth's orbital parameters offers a foundational understanding of the natural cycles and mechanisms that could

be related to the events discussed in the query paper.

**Reason for Citation:** This paper is likely cited because it provides evidence of cyclic ice rafting events in the Northeast Atlantic Ocean and their potential climatic impacts, which aligns with the query paper's focus on iceberg discharges and climate change.

2. **Relevance:** The Heinrich events, characterized by layers of ice-rafted debris in the North Atlantic, are directly relevant to the query paper's topic.

**Reason for Citation:** This citation provides historical evidence and a timeline for massive iceberg discharges, supporting the query paper's argument that such events have occurred in the past and have had significant climatic implications. The detailed documentation of these events in core samples offers concrete examples that bolster the query paper's thesis.

3. **Relevance:** The relevance lies in the potential connection between these milder periods and the massive iceberg discharges discussed in the query paper. The irregular occurrence of interstadials might be influenced by or have an influence on the iceberg discharge events, suggesting a complex interaction between ocean circulation and climate.

**Reason for Citation:** This paper is cited for its insights into the climate variability during the last glaciation, particularly the identification of interstadial periods of milder climate conditions.

4. **Relevance:** The synchronous global effects of the Younger Dryas event, as evidenced by glacier advance in New Zealand, underscore the global reach of climate triggers, possibly including iceberg discharges.

**Reason for Citation:** This citation supports the query paper's assertion that massive iceberg releases can have worldwide climatic consequences, not just regional ones. It highlights the interconnectedness of Earth's climate systems and the potential for events in one region to affect conditions globally.

5. **Relevance:** The detailed analysis of ice-rafted debris and its sources complements the query paper's discussion on the mechanisms through which iceberg discharges influence climate.

**Reason for Citation:** This paper likely provides a direct link to the query paper's hypothesis by discussing the potential of Heinrich events to trigger changes in ocean circulation, a key mechanism by which climate can be affected globally.

6. **Relevance:** The correlation between climate oscillations in Florida and Heinrich events offers evidence of the far-reaching impacts of iceberg discharges on climate.

**Reason for Citation:** This citation supports the query paper's argument by showing how events in the North Atlantic can correlate with significant climatic shifts in distant regions, reinforcing the idea of global climate interconnectedness.

**Exemplary ranking:** Ranked order: paper 2, paper 5, paper 1, paper 6, paper 3, paper 4

1. **Explanation:** This paper provides essential context on the cyclic nature of ice rafting events and their climatic impacts, offering a broader understanding of the natural cycles that could relate to the massive iceberg discharges discussed in the query paper.

2. **Explanation:** This paper is foundational, providing historical evidence and a timeline for massive iceberg discharges, which is central to understanding the phenomena discussed in the query paper. It offers direct evidence of the events that are hypothesized to trigger global climate changes.

3. **Explanation:** This paper's insights into climate variability and the identification of interstadial periods provide a nuanced understanding of the climate conditions that could be influenced by or influence iceberg discharge events, relevant to the query paper's discussion on climate interactions.
4. **Explanation:** While offering evidence of the global reach of climate triggers, this paper is ranked last as its focus on the Younger Dryas event and a specific glacier's advance provides a more indirect connection to the query paper's broader theme of iceberg discharges and global climate change.
5. **Explanation:** Given its focus on the potential of Heinrich events to trigger changes in ocean circulation, this paper is crucial for understanding the mechanisms through which iceberg discharges could influence global climate, aligning closely with the query paper's hypothesis.
6. **Explanation:** The correlation between climate oscillations in Florida and Heinrich events underscores the global impact of iceberg discharges, supporting the query paper's assertion of widespread climatic effects.