Geologie en Mijnbouw **74:** 241–243, 1995.

The Younger Dryas in the marine record (extended abstract)

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Received 1 March 1994; accepted in revised form 30 June 1995

Paleoceanographic research in the seventies and early eighties resulted in the reconstruction of the history of the Quaternary ice ages by analysing deep-sea sediments. Oxygen isotope records of foraminiferal shells from all oceans reveal the glacial cycles of the Quaternary. The past 750 000 years are characterized by long intervals of progressive cooling and build-up of ice-caps, terminated by relatively abrupt warmings and ice-cap decay, bringing the system to full interglacial conditions. Spectral analysis of these records resulted in the acceptance of Milankovitch's theory that the glacial cycles are driven by variations in the earth's orbit (Hays et al. 1976; Imbrie et al. 1984).

These oxygen isotopic records derive from sediments which accumulated relatively slowly (2–3cm/ka). Time resolution is low and bioturbation of the sediment by benthic organisms smoothes possible short-term climatic fluctuations beyond detection.

More recent isotope studies sustained by radiocarbon measurements on rapidly accumulated sediments covering the last deglaciation have shown that two major steps of rapid deglaciation took place between 14–12ka BP and 10–9ka BP. Between 11 000 and 10 000 radiocarbon years ago a brief episode of return to nearly fully glacial conditions occurred, recognized as the Younger Dryas event (Bard et al. 1987; Berger et al. 1985; Duplessy et al. 1981)

Further evidence that the Younger Dryas is recorded in marine sediments comes from the planktonic foraminiferal record in the North Atlantic Ocean. The southernmost occurrence of the polar species *Neogloboquadrina pachyderma* (sinistral coiling) has been used as indicator for the position of the polar front (Ruddiman & McIntyre 1981). The retreat of this front during the last deglaciation was interrupted by a major readvance between 11 and 10ka BP.

While the Younger Dryas in first instance was considered to be limited to the North Atlantic region, records from the Pacific (Kallel et al. 1988) and Indian Oceans (Duplessy et al. 1981) and from marginal seas (Red Sea (Almogi-Labin et al. 1991), Indonesian Sea (Ganssen et al. 1989), Sulu Sea (Kudrass et al. 1991; Linsley & Thunell 1990), Mediterranean Sea (Troelstra et al. 1991), Gulf of Mexico (Flower & Kennett 1990)) prove it to be recognizable over the entire Northern Hemisphere. It is perhaps even a global phenomenon.

The chronology of the Younger Dryas from marine records based on radiocarbon datings was found not to match the time-span calculated from annual layers in Greenland ice-cores, which delivered a considerably higher age. Parallel radiocarbon and radiothorium measurements from Barbados corals resulted in the conversion of radiocarbon to calendar years (Bard et al. 1990). Applying this conversion, the Younger Dryas period lasted from 12 800 to 11 600 calendar years BP which is in perfect agreement with the latest GISP II ice-core chronology (12 860–11 690 years, Alley et al. 1993).

By now, a satisfactory explanation for the cause of the Younger Dryas catastrophic event is still lacking. The search for possible causes concentrated on external processes such as volcanism, cosmic dust, orbital forcing and on various components, processes and feedback mechanisms within the complexly operating climatic system (for a thorough discussion see Berger 1990). The abruptness of the glacial–interglacial transitions at the beginning (about 100 years) and the ending (3 years) of the Younger Dryas period as documented by the GISP II ice-core chronology (Alley et al. 1993) restricts the search for the cause of this cold spell to very rapidly acting processes.

It is quite generally accepted that at the beginning of the Younger Dryas period atmospheric and oceanic heat transport into the North Atlantic region must have been reduced. However, whether this is cause or effect of the cold spell is not clear. The most plausible mechanism to reduce northward heat transport is a shutdown of North Atlantic Deep Water (NADW) production as explained hereafter.

At present, the North Atlantic Ocean operates as a heat pump; warm, relatively high-saline surface waters move north into high latitudes and become very dense upon cooling while releasing heat into the atmosphere. They sink and flow as NADW as far south as the deep Pacific in exchange for (warm) thermocline waters from south of the equator. A shutdown of NADW production would consequently result in a cooling of the North Atlantic region.

There is evidence that during the retreat of North American glaciers at about 11 000 radiocarbon years BP meltwaters changed from flowing down the Missisipi River into the Gulf of Mexico to flowing via the Great Lakes and the St. Lawrence River directly into the North Atlantic Ocean (Teller 1990). As a result, salinities and densities of surface waters decreased, preventing them from sinking at high latitudes and forming NADW.

Climate models suggest that this shutdown hypothesis (Broecker et al. 1988) for the origin of the Younger Dryas is completely feasible (Maier-Reimer & Mikolajewicz 1989).

In support of this hypothesis geological evidence can be found in the geochemical composition ($\partial^{13}C$, Cd/Ca ratio) of benthic foraminifera. While the $\partial^{13}C$ pattern is too complicated to give conclusive results, relatively high Cd/Ca ratios in cores from the Bermuda Rise indicate that NADW production rapidly decreased during four phases between 15 and 10ka BP, i.e. at about 14.5, 13.5, 12.0 and 10.5ka BP (Keigwin et al. 1991). However, the fact that NADW reduction at the time of the Younger Dryas was the weakest of these four and took at least 2000 years, puts serious doubts on the validity of the data as a proof for the shutdown hypothesis. In addition, time-slice reconstructions of East Atlantic deep-water circulation for the past 30 000 years based on the $\partial^{13}C$ of benthic foraminifera (Sarnthein et al. 1994) do not document shutdown of NADW for more than 1500 years prior to and during the early Younger Dryas cooling episode.

The question whether the Younger Dryas is a unique phenomenon or whether similar cold spells also occurred during earlier deglaciations, cannot be definitely answered. In a high-resolution isotope record of the past 650 000 years off northwest Africa, Sarnthein & Tiedemann (1990) provide evidence for Younger Dryas-type climatic rebounds during earlier glacial–interglacial transitions (Terminations VI to II), which they interpret as brief shutdowns in the production of NADW.

Future research in paleoceanography will have to focus on high-resolution marine records to answer the questions around the Younger Dryas.

This is contribution 950610 of the Netherlands Research School of Sedimentary Geology.

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