Reports

A Mid-Brunhes Climatic Event: Long-Term Changes in Global Atmosphere and Ocean Circulation

J. H. F. Jansen, A. Kuijpers, S. R. Troelstra

A long-term climatic change 4.0 × 10^5 to 3.0 × 10^5 years ago is recorded in deep-sea sediments of the Angola and Canary basins in the eastern Atlantic Ocean. In the Angola Basin (Southern Hemisphere) the climatic signal shows a transition to more humid ("interglacial") conditions in equatorial Africa, and in the Canary Basin (Northern Hemisphere) to more "glacial" oceanic conditions. This trend is confirmed by comparison with all well-documented marine and continental records from various latitudes available; in the Northern Hemisphere, in the Atlantic north of 20°N, climate merged into more "glacial" conditions and in equatorial regions and in the Southern Hemisphere to more "interglacial" conditions. The data point to a more northern position of early Brunhes oceanic fronts and to an intensified atmosphere and ocean surface circulation in the Southern Hemisphere during that time, probably accompanied by a more zonal circulation in the Northern Hemisphere. The mid-Brunhes climatic change may have been forced by the orbital eccentricity cycle of 4.13 × 10^5 years.

On a time scale of 1 × 10^6 years, climatic development in the Late Cenozoic is primarily related to plate movements affecting the geometry of the continents and the ocean basins. On a much shorter term, 1 × 10^4 to 1 × 10^5 years, many climatic records indicate a dominance of glacial and interglacial fluctuations that are relatable to orbital cycles. In this report we present evidence of a global climatic change 4.0 × 10^5 to 3.0 × 10^5 years ago on a time scale of 1 × 10^5 to 1 × 10^6 years which is superimposed on the glacial and interglacial cycles. Unlike other Late Cenozoic climatic variations reported so far, the change shows opposite trends in the Northern and Southern hemispheres.

Results from multidisciplinary studies of piston cores from the Zaire (Congo) deep-sea fan of the eastern Angola Basin (location 1 in Fig. 1) and the Canary Basin (location 2) show long-term environmental changes occurring in the mid-Brunhes (*1, 2*).

Angola Basin. In the Zaire deep-sea fan this change is reflected by a distinct break in sediment accumulation rates and mineralogical composition. During glacial periods, terrigenous accumulation rates were high (*1, 3*) and the Zaire River transported mainly high-crystalline smectites toward the ocean floor (*4*). These are signals of aridification in tropical Africa and desertification of the Congo and Angola coastal zone (*1, 3, 4*). During interglacials, the tropical rain forest expanded and the Zaire River supplied less sediment (*1, 3*). In these periods the clay-mineral associations were dominated by kaolinite and low-crystalline smectites, which are weathering products from igneous rocks in the tropical rain forest (*4*).

From 4.0 × 10^5 to 3.5 × 10^5 years ago there was a decrease in the rates of terrigenious accumulation (*1*) and in the supply of high-crystalline smectites (*4*) (Fig. 2). The decreasing accumulation was recorded in all six piston cores that contain sediments of this age. This fan-wide event is recognizable either by the decrease in accumulation rates and the disappearance of silt and mica from the sediments (Fig. 2) or by the extinction of a large-scale turbidite sequence (*1*). Decreases in the accumulation rate of terrigenous matter and of high-crystalline smectite reflect a long-term change from arid to more humid conditions in equatorial Africa.

Canary Basin. In all cores from the Canary Basin reaching back to over 3 × 10^5 years ago, a change in planktonic foraminiferal composition is observed. Between 3.7 × 10^5 and 3.1 × 10^5 years ago, faunal assemblages changed and tropical and subtropical forms such as *Pulleniatina* spp. and *Globorotalia menardii/tumida* became absent in the sediments in the central part of the basin (30° to 33°N, 24° to 25°W) (Fig. 3) (*5*). At present these species have their northern limit at about 28°N (*6*). More to the west, however, near 30°W, tropical and subtropical foraminifera do persist after 3.0 × 10^5 years ago (*7*). Apparently, in the central and eastern part of the basin a southward migration of the interglacial subtropical front took place over a distance of at least 4° of latitude (*2*). The change reflects enhanced advection of cool eastern boundary current water masses in the central part of the basin. It is inferred that these oceanic processes have occurred in relation to increased meridional atmospheric circulation. Stronger southward transport of cool northern surface water along northwest Africa is characteristic of the circulation pattern during glacial stages (*8*).

The abyssal carbonate preservation pattern shows distinct fluctuations during the past 1.4 × 10^6 years (Fig. 3) (*2*). Intergla-

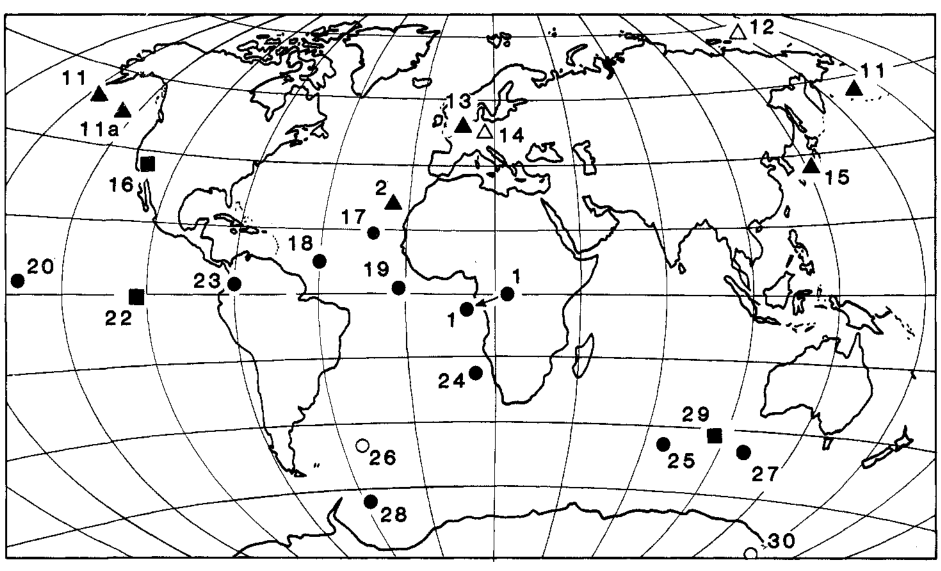

Fig. 1. Locations of climatic records showing a long-term change at 4.0 × 10^5 to 3.0 × 10^5 years ago. Symbols: (▲, △) changes toward more glacial conditions; (●, ○) changes toward more interglacial conditions; (△, ○) less well dated changes; (■) changes not defined in terms of glacial or interglacial conditions. Numerals correspond to the references and notes.

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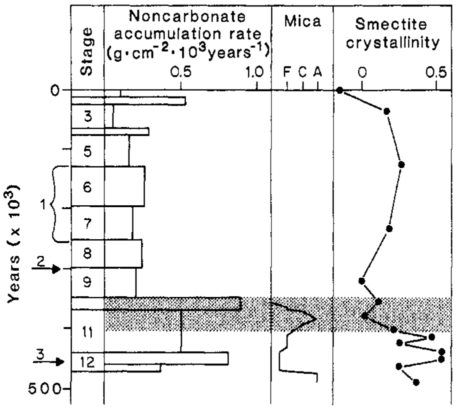


Fig. 2. Noncarbonate accumulation rates (*1*), mica abundance (*1*), and smectite crystallinity (*4*) of the pelagic core T78-38 from the Zaire deep-sea fan. F, C, and A indicate few, common, and abundant, respectively; 1, *Dictyocha perlaevis perlaevis* acme zone (*1, 41*); 2, ^{230}Th-excess dating of 3×10^5 years ago (*1*); and 3, LAD *Stylatractus universus* (*1, 42*). Time interval of climatic change is shaded. For location, see location 1 in Fig. 1. The stages are calcium carbonate preservation stages; 37 radiocarbon datings of 14 cores from the fan prove that the stage boundaries fit in well with oxygen isotope boundaries (*1*).

cial high values of 80 to 95 percent $CaCO_3$ are characteristic of the geological record before 4.0×10^5 to 3.0×10^5 years ago, while they do not exceed 70 percent after that time. This shift to lower interglacial values is a widespread phenomenon in the sediments of the basin (*9*). In the Atlantic, poor carbonate preservation is generally a signal of glacial oceanic conditions (*1, 3, 10*), although it may have other causes too (*2*). The shift, therefore, indicates a long-term environmental change in the Canary Basin with a similar trend as displayed by the surface water circulation.

The mid-Brunhes changes in the Angola and Canary basins are not merely regional phenomena, as is demonstrated by all other well-documented marine and terrestrial records available.

Northern Hemisphere. Diatom evidence from the subarctic Pacific shows that *Rhizosolenia curvirostris* is replaced by the cold-water form *Rhizosolenia hebetata* in the isotope stages 10 to 8, 3.5×10^5 to 2.7×10^5 years ago (Fig. 4A), indicating a transition to more extreme glacial conditions (*11*). It suggests a southward migration of the polar front. This time interval precedes a prolonged period of ice-rafting during stages 9 and 8 in the easternmost North Pacific (*11*). Foraminifera associations in the eastern Arctic Ocean point to a general cooling in the mid-Brunhes (*12*). Pollen studies (*13*) and lithological data (*14*) from northwest Europe indicate that the lowest average temperatures and most severe glaciations occurred after 3×10^5 years ago. A general cooling can also be inferred from the climatic curve on the basis of pollen studies of Lake Biwa, southwestern Japan (Fig. 4B) (*15*). This curve shows an increase in periods with cool-temperate to subpolar floras 3.0×10^5 to 2.7×10^5 years ago. A lacustrine record from Searles Lake, California, which is dominated by long-term ($>1 \times 10^5$ years) phenomena, demonstrates a transition from relatively saline and arid to more humid conditions around 3×10^5 years ago (Fig. 4C) (*16*).

Equatorial regions. Oceanic and continental records from equatorial regions point to a change toward warmer conditions. The *G. menardii* curve of core V26-41 (19°N) mirrors such a change at 4.5×10^5 to 4.0×10^5 years ago (*17*). An increase in mean sea-surface temperature (SST) occurred in the equatorial Atlantic 4.2×10^5 to 3.7×10^5 years ago (Fig. 5, A and B) (*18, 19*). The total carbonate curve of core RC11-209 indicates a transition to more interglacial conditions in the equatorial Pacific 4.3×10^5 to 4.0×10^5 years ago (Fig. 5C) (*20*). Although basically representing a bottom-water signal, the curve is well-correlated with SST data (*21*). The Radiolaria content of core RC10-65 from the eastern equatorial Pacific shows a generally increasing upwelling assemblage and a decreasing western tropical assemblage 4.0×10^5 to 3.0×10^5 years ago (*22*). Furthermore, palynological evidence from a long core near Bogotá, Colombia, reflects a change to higher forest lines after 3.9×10^5 to 3.7×10^5 years ago (*23*).

Southern Hemisphere. Radiolarian studies from the eastern South Atlantic Ocean (*24*) and southern Indian Ocean (*25*) indicate a trend toward higher SST values after the mid-Brunhes change 4.1×10^5 to 3.4×10^5 years ago (Fig. 6, A and B). This is also evident from the data on Pleistocene migrations of the polar front in the western South Atlantic (*26*). These data demonstrate that, in the early Brunhes, the polar front was situated on average about 4° farther to the north. In two cores from the southeast Indian Ocean, radiolarian abundances of glacial intervals decreased approximately 3.0×10^5 years ago (*27*). This was accompanied by a generally improving carbonate preservation 4.5×10^6 to 3.0×10^6 years ago (*27*) and indicates also a southward displacement of the polar front. In the Weddell Sea a severe cold period of long duration ended around 3.0×10^5 years ago (*28*). Bottom-water conditions also changed. Fluctuations in benthonic foraminifera associations show evidence of a decrease in the extension of Antarctic Bottom Water into the southeastern Indian Ocean 3.2×10^5 to 2.8×10^5 years ago (Fig. 6C) (*29*). It coincided with a climatic change in Taylor Valley, East Antarctica, where signals of global interglacials of Brunhes age are recognized only in sediments less than 3.5×10^5 years old (*30*).

Several other long oceanic and continental records have been found, and all of them reflect a long-term change 4.0×10^5 to 3.0×10^5 years ago (*31, 32*). A satisfactory paleoceanographical or paleoclimatological interpretation of these records has not yet been given.

In summary, all ocean surface and terrestrial records available demonstrate a major climate change in the mid-Brunhes 4.0×10^5 to 3.0×10^5 years ago. This is evident in spite of the different quality of the records and the differences in time control. The changes are not necessarily synchronous, since the records reflect the responses of different paleoceanographical and paleoclimatological parameters. They fall into two distinct groups. Records from the Northern Hemisphere, in the Atlantic north of 20°N, show a trend toward more "glacial" conditions. The only exception is the Searles Lake

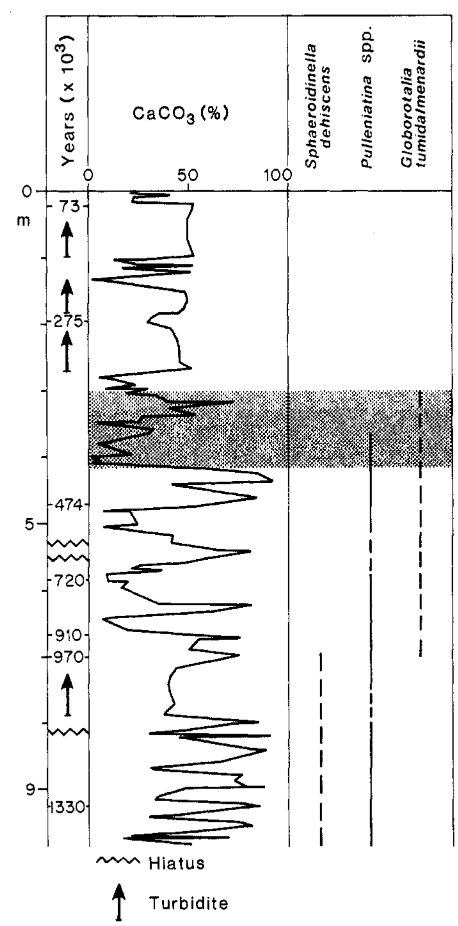
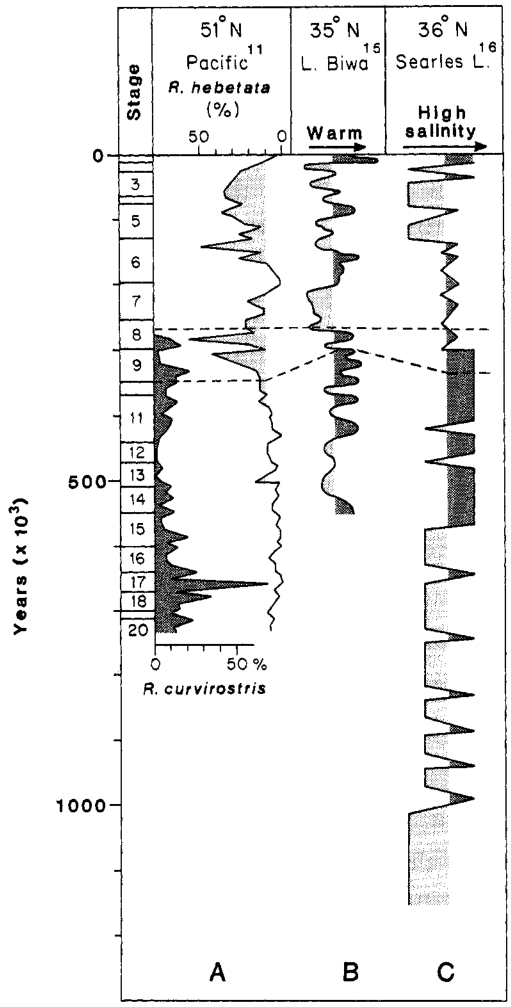
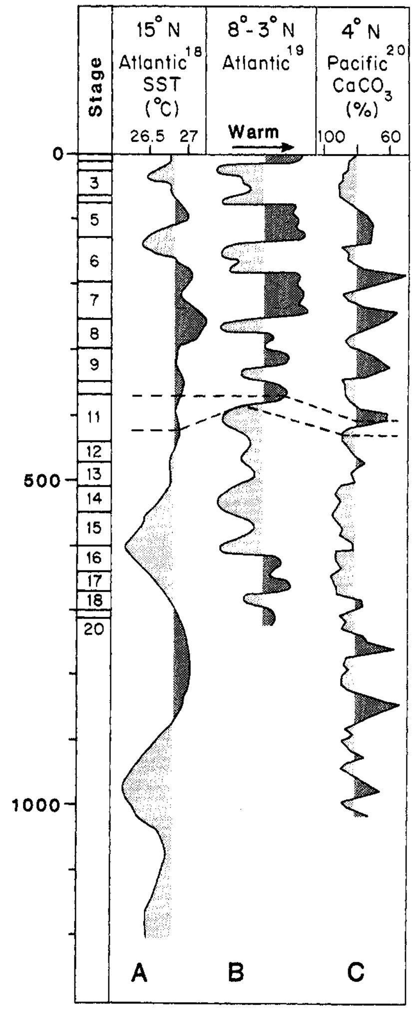


Fig. 3. Carbonate contents (*2*) and distribution of tropical and subtropical planktonic foraminifera (*5*) in core 82PCS18 from the Canary Basin. Time interval of climatic change is shaded. For location, see location 2 in Fig. 1.





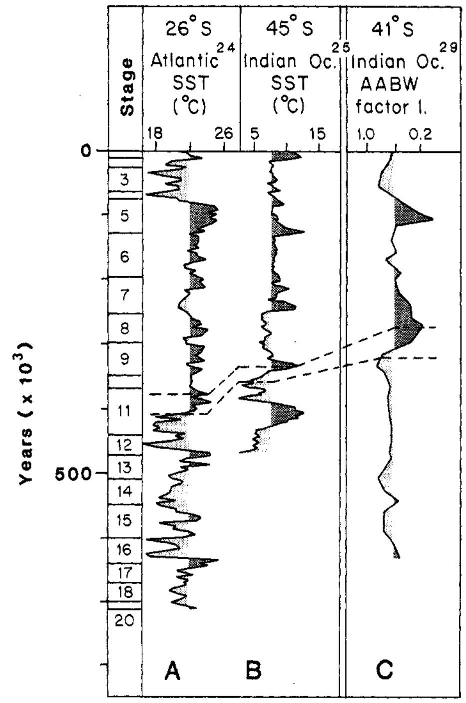


Fig. 4 (left). Long-term climatic records from the Northern Hemisphere. Indices correspond to the locations in Fig. 1 and to the references and notes. The *R. hebetata* curve A and curve C are mirror images of the originals. Fig. 5 (middle). Long-term climatic records from equatorial regions. Indices correspond to the locations in Fig. 1 and to the references and notes. Curve C is a mirror image of the original. Fig. 6 (right). Long-term climatic records for the Southern Hemisphere. Indices correspond to the locations in Fig. 1 and to the references and notes. Curve C is a mirror image of the original.

record, which cannot be described in terms of glacial and interglacial stages (*16, 33*). In contrast, an opposite trend is observed in the records from equatorial regions and from the Southern Hemisphere, with a transition toward higher SST's and more "interglacial" conditions in the equatorial regions of Africa and South America. During the early Brunhes the polar fronts in the North Pacific (*11*), South Atlantic (*26*), and southeast Indian (*27*) oceans and the interglacial subtropical fronts in the Canary Basin (*2*) were all generally situated more to the north. The magnitude of the displacements in the Canary Basin and South Atlantic suggests that climatic and oceanic zones migrated toward the south over a few degrees of latitude after that time. Thus the zone affected by equatorial upwelling in the east Pacific may have migrated toward the latitude of core RC10-65 (*22*).

Today the tracks of extratropical low-pressure centers in the Southern Hemisphere are tied to the position of the South Atlantic polar front (*34*), and a stronger atmospheric circulation there favors zonal circulation in the Northern Hemisphere (*35*). If these relations are applied to the displaced South Atlantic front in the early Brunhes, then it appears that the atmospheric depression paths in the Southern Hemisphere were generally located more to the north. This implies an intensified atmospheric circulation, while circulation was most likely more zonal in the Northern Hemisphere.

Origin of the change. Some records also show long-term climatic changes 7.0×10^5 to 6.0×10^5 years ago (*16, 18–20, 26, 31, 36*) and possibly 1.5×10^5 to 1.0×10^5 years ago (*18, 20, 22–24, 29, 31, 37*)—in directions, however, opposite those of the mid-Brunhes change (Figs. 4 to 6). Evidence of the change 1.5×10^5 to 1.0×10^5 years ago also comes from the Zaire deep-sea fan, where unusually high accumulation rates point to increased aridity in tropical Africa during stages 2 to 4 (*1, 3*). Spectral analyses of the three longest marine records referred to demonstrate significant wavelengths of approximately 4.0×10^5 years (*38*). This periodicity may explain the long-term fluctuations of these three records (Fig. 5, A and C) (*17*). A period of 4.0×10^5 years is near to the astronomical eccentricity period of 4.13×10^5 years (*39*) for which an asymmetric response was already predicted 120 years ago (*40*). Therefore, we hypothesize perturbation by the orbital eccentricity cycle as a possible cause of the mid-Brunhes event.

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Archaeopteryx Is Not a Forgery

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Archaeopteryx lithographica might be regarded as the most important zoological species known, fossil or recent. Its importance lies not in that its transitional nature is unique—there are many such transitional forms at all taxonomic levels—but in the fact that it is an obvious and comprehensible example of organic evolution. There have been recent allegations that the feather impressions on _Archaeopteryx_ are a forgery. In this report, proof of authenticity is provided by exactly matching hairline cracks and dendrites on the feathered areas of the opposing slabs, which show the absence of the artificial cement layer into which modern feathers could have been pressed by a forger.

The holotype of *Archaeopteryx lithographica* (*1–4*), the oldest species of fossil bird, was found in the lithographic Solnhofen Limestone near Pappenheim (Bavaria) in 1861. Five other fossil birds, generally attributed to the same species with varying degrees of certainty, have been found in the same geological formation. Two of those were found before the holotype: a partial skeleton in 1855 [described in 1857 (*5*) as a new species of pterosaur *Pterodactylus crassipes* and not recognized as another *Archaeopteryx* until 1970 (*6, 7*)], and an isolated but well-preserved feather found in 1861 (*1, 2, 8*) only a few months before the holotype was discovered. The other specimens were found in 1877 (*9*), 1951 (*10, 11*), and 1956 (*12*), respectively.

The skeleton of the species is essentially reptilian (more specifically dinosaurian) with teeth, a long bony tail, abdominal ribs, and three digits on each hand; but it also shows certain bird characters, notably a furcula (wishbone) representing the fused clavicles, a retroverted pubis, and an allegedly perching foot. These avian characters correlate very well with distinct impressions of feathers which, in their distribution around the forelimbs and tail and in their detailed structure, are exactly like those of modern birds. Some at least of these so-called impressions of feathers are now thought to be casts (*13, 14*); for the sake of simplicity, however, we shall refer to them below as impressions.

The authenticity of *Archaeopteryx* has recently become controversial. A group of investigators including N. C. Wickramasinghe and Sir Fred Hoyle, who are associated with University College, Cardiff), has concluded in published material (*15–18*), in the popular media (*19–21*), and at a formal meeting (*22*) that the feather impressions on the holotype of *Archaeopteryx* [now in the British Museum (Natural History)] are forgeries. This has led them to suspect the genuine nature of the other five Late Jurassic bird specimens presently known, all of which are accepted by most modern workers as belonging to the genus *Archaeopteryx* and usually to the species *lithographica*. More specifically, doubt has been cast on the original isolated feather impression of 1861 and on the impressions on the 1877 specimen (housed in Berlin), and they consider the feather impressions on the other three specimens to be so poor as to be unsatisfactory evidence of plumage. Science editors, photographers, and others have been making their own comments (*23*); some preliminary observations were noted by ourselves (*24*).

It has been speculated (*15*) that the motive for the alleged hoax, the subject of which was found only 2 years after the publication of Darwin's *Origin of Species* in 1859 (*25*), was to produce an impressive piece of "evidence" for the concept of evolution. A recent paper (*18*) seems to suggest that there may also have been a financial

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