SURFACE-WATER CONDITIONS IN THE NORTHERN BENGUELA REGION (SE ATLANTIC) DURING THE LAST 460 000 YEARS

Contributors: S. (Bas) West and J. H. Fred Jansen

The Benguela region near the coast of Africa in the SE Atlantic Ocean is one of the world's largest coastal upwelling areas. It plays a vital role in the transfer of heat and salt from the Indian Ocean into the Atlantic Ocean, which is a critical factor in driving the global conveyor belt. Thus, the variations in the Benguela Current system, can affect our climate on a global scale. Other important features are the leakage of warm Angola Current (AC) water from the north, and the influence of variations in the southern Benguela upwelling region introduced by the Benguela Current (Fig. 1 left). South of Walvis Ridge, the Benguela Current (BC) splits in a coastal (Benguela Coastal Current, BCC) and an oceanic branch (Benguela Oceanic Current, BOC). We applied planktonic foraminifera, a group of zooplankton producing calcitic tests, to investigate the variations of the surface water masses in the region and their driving forces. The foraminifera tests were sampled from the core ODP 1083 collected during Leg 175 of the Ocean Drilling Program in (1997).

The different foraminifera species in the surface sediments appear to reflect the major water-masses in the area (Fig. 1). *Neogloboquadrina pachyderma* (left + right coiled) mirrors the nutrient-rich coastal upwelling, the left-coiled species mirroring the coldest conditions of the two. *Globorotalia inflata* indicates the cold BOC, a group of tropical species the more oligotrophic central South Atlantic, and Globigerina bulloides the transitional environment between the upwelling cells and the BC.

During the last 460 000 years, archived in the upper 44 m of the core, the strongest variations are in the upwelling intensity as shown by the abundance record of *N. pachyderma* (l+r) (Fig. 2). The upwelling is orbitally controlled by Milankovic insolation cycles, with the strongest upwelling and highest productivity during glacial and precessional maxima (cycle period 100 and 21 thousand years (ky) respectively). The upwelling signal correlates well with the strength

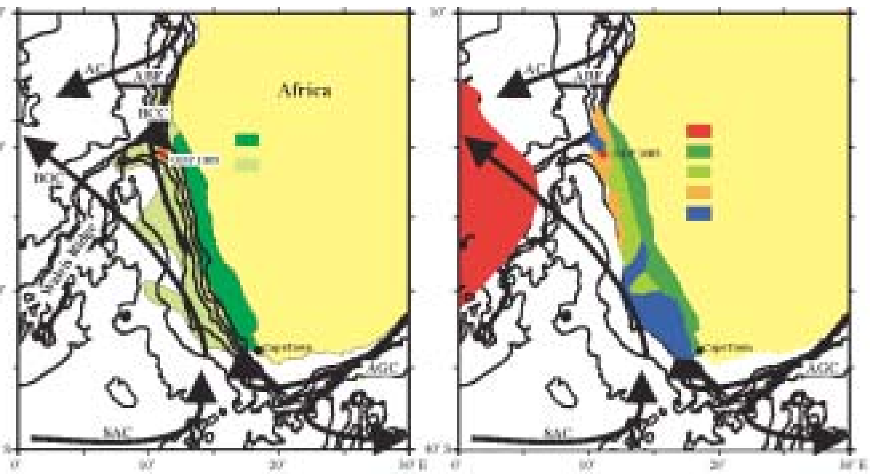

Fig. 1. Hydrographic features in the surface waters (left) compared with the actual distribution of planktonic foraminifera in the surface sediments (right) in the Benguela region, and location of core ODP 1083.

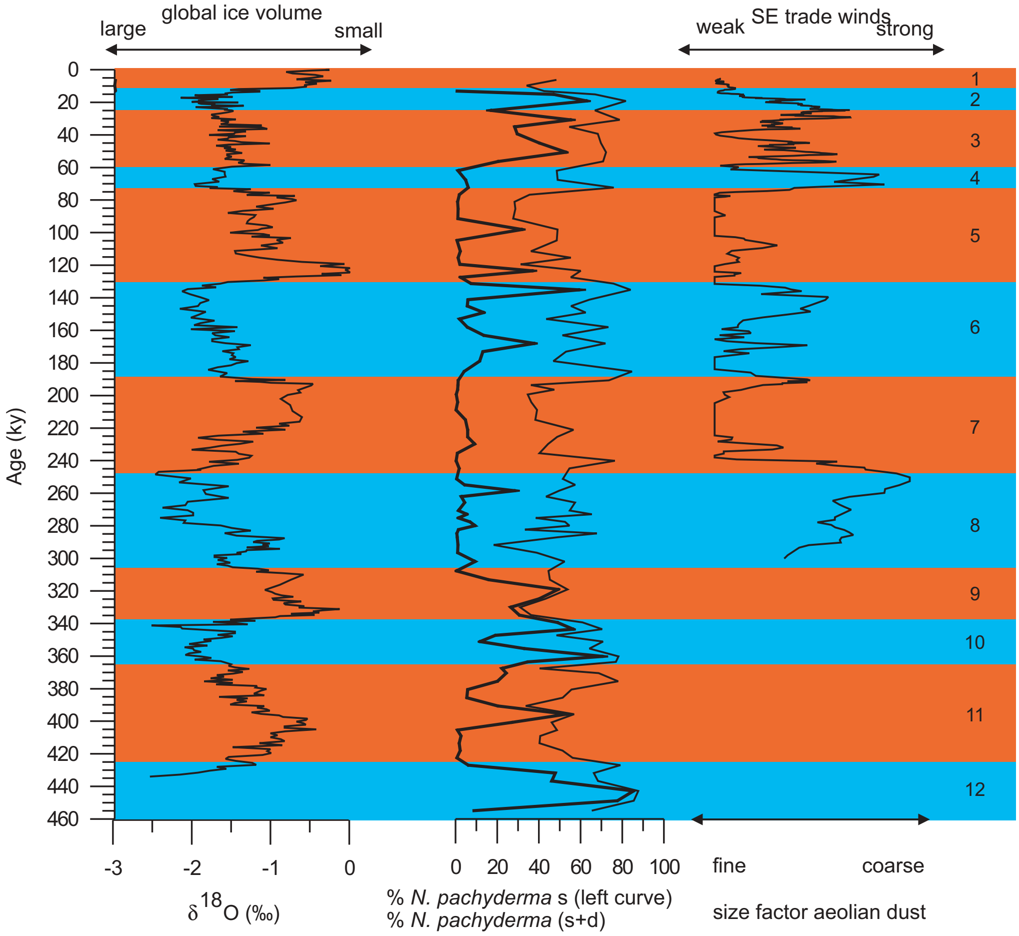

Fig. 2. Abundance of the upwelling species N. pachyderma (left coiled) and N. pachyderma (left + right coiled) compared with the grain size of the aeolian dust. The grain size reflects the strength of the SE trade winds. The global climate history is indicated by the δ18O of *G. inflata* in a nearby core. Red and blue time intervals represent interglacial and glacial stages respectively.

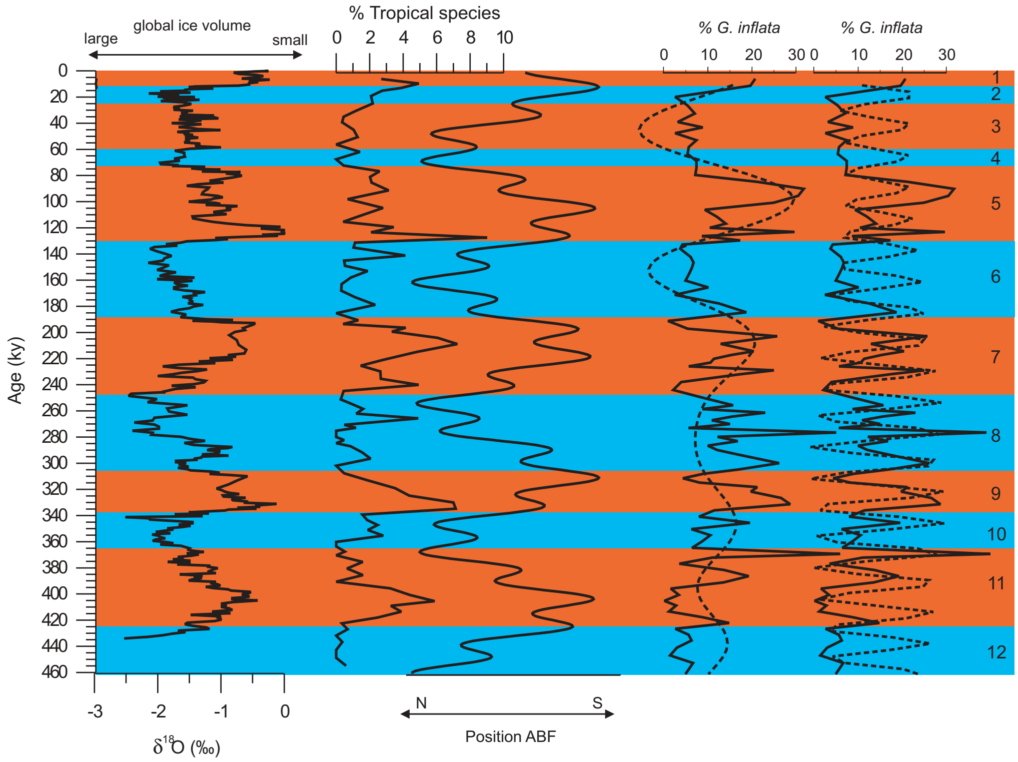

Fig. 3. Middle: Abundance of the tropical species compared with the predicted N-S movements of the Angola Benguela Front (ABF).
Right: Abundance of *G. inflata* and its 100-ky and 23-ky filtered components. The global climate history is indicated by the δ18O of *G. inflata* in a nearby core. Red and blue time intervals represent interglacial and glacial stages respectively.

of the SE trade winds, showing that stronger atmospheric gradients intensify the trade winds and upwelling during glacials. The *N. pachyderma* (right) record appears to deviate from the upwelling record. This suggests variations in the temperature of the waters rising from the deep that are caused by variations in the stratification of the water column in the central South Atlantic, the source of this water.

The increase and decrease of the upwelling intensity explains partly the downcore pattern of the tropical species (Fig. 3). During strong upwelling, the cold and nutrient-rich waters suppress the influence of the warm, low-nutrient water masses from the South Atlantic current (SAC). There is, however, a phase difference being most obvious in glacial maxima, where the minima of the tropical species precede the maxima of the global ice volume and upwelling by 15 to 20 ky. This phase difference indicates warm AC-water intrusions from the north following the N-S movements of the Angola Benguela Front (ABF) which explains why the minimum sea-surface temperatures occurred 45-50 ky BP, 30 ky before the last glacial maximum, when the ABF was at its northernmost position. The signal of the ABF movements deviates from the global ice-volume record because there is no orbital 41-ky obliquity component, a typical high-latitude Milankovic periodicity. To test the AC origin of the tropical foraminifera species, we extrapolated the ABF movements back to 460 ky BP. The extrapolation shows a good agreement with the tropical record, and appears to predict the lead of its 15-20-ky lows over the maxima in global ice volume.

The influence of the Benguela Oceanic Current (BOC), indicated by *G. inflata* (Fig. 3), depends for a large part on the local wind strength and direction, and the associated upwelling system. When the upwelling intensifies, the influence of the BOC reduces. Moreover, more zonal trade winds cause a more zonal BOC. Consequently, the contribution of the BC increases during interglacials when the upwelling was weaker and the BOC more N-S. This is particularly true for the last 200 ky, when maxima of *G. inflata* occur during warm and interglacial periods. *G. inflata* also shows a long-term change at 250-200 ky BP, from a high-frequency variation related to the earth's precession and obliquity cycles to a lower one dominated by the eccentricity cycle (Fig. 3). This change is observed neither in the upwelling indicators nor in the tropical species. A similar transition, observed in the Southern Cape Basin, suggests a long-term southward shift of the Antarctic circumpolar fronts around that time. We hypothesise that a shift of these fronts has changed the dominant frequencies. When the fronts were situated relatively north, the smaller high frequency movements of these fronts could be transferred to the BC. When, however, the fronts were situated further away to the south, the movements were less readily recorded in the BC. In this way, the position of circumpolar fronts may regulate the inflow of Indian Ocean water, subpolar water, and water from the transitional zone between the subtropical and sub-Antarctic water masses into the BC.