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Millennial-scale atmospheric variability over the Mediterranean during the last climatic cycle revealed by clay-mineral association and pollen analyses

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The Alboran Sea is a semi-enclosed basin in a transitional area between the Atlantic Ocean and the Mediterranean Sea. Therefore the climate changes are recorded in sediments at very high resolution. Therefore some marine proxies reveal Dansgaard/Oeschger variability (Cacho *et al.*, 2000, Moreno *et al.*, 2002, 2004). In order to better understand the links between the cold climatic events recorded in Greenland ice-core and the climatic changes over the Mediterranean area, high-resolution multiproxy analyses of sediments from the ODP site 976 (36˚12N, 4˚18W) have been performed for the last 130,000 years.

Pollen assemblages have been compared to clay mineral analyses and oxygen isotope stratigraphy in order to reconstruct the western Mediterranean oceanic and continental paleoenvironments and climate changes during the last climatic cycle. Chronology of the core is based on 14C dating and oxygen isotopes record.

Paleoenvironmental interpretation of pollen assemblage is based on the assumption that the primary pollen contribution to the Alboran sea sediments comes from western Mediterranean borderlands. This study concentrate on the alternation between temperate association composed of European-Siberian trees associated with Ericaceae, reflecting the warmer and moist climate characteristics of interstadials and the steppe to semi-desert association which marks the dry and cold climatic conditions of stadials.

The results indicate an increased continental dryness at the time of the Heinrich events, which may be the consequence of prolonged stability of atmospheric high-pressure over the southwestern Mediterranean (Combourieu-Nebout *et al.*, 2002). These results are in agreement with the evidence of higher intensity of wind systems over the northern hemisphere during cold intervals (stadials and Heinrich events) revealed by the dust content in Greenland ice cores.

Fluvial and aeolian processes mainly control the present-day clay sedimentation in the Alboran Sea. Among the typical clay association, palygorskite and kaolinite are of particular interest because they characterise the detrital supplies from the African continent. They both form under warm climatic conditions, but kaolinite indicates an intense hydrolysis on the continent whereas palygorskite reflects arid continental climatic conditions. Moreover, palygorskite is more likely transported by winds because of its fibrous texture and is used to retrace the aeolian contributions from the Sahara. The presence of palygorskite within the classic clay association, determined by X-ray diffraction has been confirmed by MET observations of the palygorskite-rich samples. The Heinrich events are characterized by a rapid increase of the palygorskite content, whereas interstadials are associated with the increase of the total clay-size particles flux.

According to the general aeolian patterns and to the main clay sources: palygorskite, kaolinite and illite, originating from northern Africa, may be transported by winds over the Mediterranean Sea and Europe. The dominant source of palygorskite for the studied interval appears to be located in the northwestern part of Morocco while Tunisia can be considered as a potential source since the Holocene. Saharan dust trajectories are very complex: the Sirocco (blue and green outbreaks) provides Saharan dust to central Mediterranean area, to Sicily and Italy whereas Vendavel (red outbreaks) transports dust over the Alboran Sea and the Iberian Peninsula. The latter is assumed to be responsible for the enhanced supply of palygorskite during Heinrich events and Dansgaard/Oeschger stadials.

The Saharan dust flux over the Mediterranean Sea is not continuous. In fact main part of the Saharan dust is produced during the warm and hydrolysing period (interstadials) in Central Sahara. But transport of dust mainly occurs during dry intervals when vegetation becomes scarce, and when aeolian erosion is much more efficient. Several authors indicate that Saharan dust to Europe is sporadic in nature occurring during summer and originates from the westernmost and central parts of Sahara (Guerzoni *et al.*, 1997). Indirect measurements (Meteosat) show that maximum transport occurs during summer.

The transport of desert aerosols is linked to the position of both anticyclone and de-

pression over the Northeast Atlantic Ocean and over the Mediterranean. Saharan air masses reach the western part of the Mediterranean Sea (Rodriguez *et al.*, 2001) when the synoptic situation is controlled by depressions located to the west/southwest of Iberian Peninsula during winter or when the North African anticyclone shift westward during summer (Moulin *et al.*, 1997).

The first synoptic situation is illustrated by a dust-outbreak that reached the south-eastern France in February 2004. The Meteosat views show the dust trajectory and the atmospheric situation over North Africa and Europe during the dust-event. The X-Ray analysis performed on the dust recovered on the continent during the dust-outbreak reveals the presence of palygorskite. But the winds trajectory recorded during this wintertime-event prevents any dust supply over the westernmost part of the Mediterranean Sea (Alboran Sea). The increased supply of palygorskite characterizing the Heinrich events seems to be linked with the development of a stable anticyclonic situation over the Mediterranean. Such a synoptic situation corresponds to the positive phase of the North Atlantic Oscillation (NAO+).

To summarize, both pollen and clay-mineral records exhibit a millennial-scale variability linked to the Dansgaard/Oeschger oscillations seen in Greenland ice cores and North Atlantic Ocean sediments. Pollen and clay-mineral records both indicate dry and cold continental climatic conditions at the time of the Heinrich events and Dansgaard/Oeschger stadials over the Mediterranean area. According to mineralogical evidences, the enhanced supply of palygorskite probably originates from the north-western part of Morocco. Atmospheric situations allowing the transport of Saharan palygorskite-rich dust to the Alboran Sea correspond to the pressure-system characterized by the presence of the anticyclone over North Africa. These results indicate the presence and the stability of a high-pressure system over North Africa during the Heinrich events and Dansgaard/Oeschger stadials (cold intervals). The atmospheric situation during the Heinrich events should have been similar to the synoptic situation described for the positive phases of the NAO. The North Atlantic Oscillation is characterized by a decennial variability. Our results would indicate that the stadials might correspond to pluri-decennial/secular periods of dominant positive NAO phases.

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