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Geochemical distribution patterns as indicators for productivity and terrigenous input off NW Africa

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ABSTRACT

One hundred and twenty-eight surface-sediment samples collected off North-West Africa were studied geochemically to detect the expressions of different meridional climate regimes and zonal productivity gradients in the surface sediments. This geochemical multi-tracer approach, coupled with additional information on the bulk carbonate and TOC contents makes it possible to characterise the sedimentological regime in detail. Typical terrigenous elements like Al, K and Fe mirror the importance of the humid (fluvial) influence in the north of the study area and the dominance of aeolian input in the south. Furthermore, the distributions of Ti and Fe in the surface sediments serve as tracers for the supply of eolian volcanic material from the Canary Islands. The spatial variability of the TOC contents in the surface sediments closely follows the ocean surface productivity patterns, whereas the $CaCO_3$ contents are mainly controlled by dilution with terrigenous matter. The potential productivity proxy Ba is not a reliable tracer for productivity in this region, since it is mainly supplied by terrigenous input (coupled with aluminosilicates).

1. Introduction

The investigation area along the NW African continental margin extends from the Moroccan coast at about 33°N to the Mauritanian coast at about 18°N (Fig. 1, indicating the ocean surface current direction and the dominant wind systems). It covers the oligotrophic ocean waters of the North Atlantic subtropical gyre as well as the upwelling-influenced coastal waters off NW Africa. The sea floor morphology is characterised by a shallow continental shelf (< 150 m) with greatest extension offshore to approximately 140 km north of Cape Blanc and lower extension to roughly 25 km at Cape Ghir and 75 km north of Cape Yubi (Summerhayes et al., 1976).

The southward directed Canary Current (CC, Fig. 1) is part of the Eastern Boundary Current System of the subtropical North Atlantic gyre (Mittelstaedt, 1991; Knoll et al., 2002). The CC flows southward over the continental shelf and slope along the coast (Stramma and Siedler, 1988; Mittelstaedt, 1991). Off Cape Blanc the CC starts to deflect to the west and at approximately 15°N the current diverges (Sarnthein et al., 1982; Fütterer, 1983). The dominant fraction of this surface water veers, driven by the Trade Winds, from the continental shelf to the open ocean. A minor portion of the waters from the CC continues south and south-east-wards along the African coast. The pattern of the Eastern Boundary Current (EBC) is locally influenced by the presence of the islands, by the morphology of the shelf, the location of the shelf break and by variations in intensity and direction of local winds (Sarnthein et al., 1982). Mittelstaedt et al. (1975) described that occasionally enhanced southern monsoonal and other local winds can reverse the general direction of the surface water flow. This can cause the transport of warm tropical waters northward along the African coast as far as Cape Blanc.

The strong coastal upwelling regime in this region is driven by the interaction of the Northeast Trade Winds (NE Trades, Fig. 1) and the Canary Current (Mittelstaedt, 1991). The intensity of the upwelling along the Northwest African coast is linked to the seasonal variations of the Trade Winds which are generally correlated with the location of the Azores high-pressure system (Mittelstaedt, 1991). During summer the Azores High is situated at its northernmost position, and trade winds blow mainly between 32°N and 20°N. In winter the Azores High is in its southernmost position with the trade wind belt located between 25°N and 10°N. Thus, upwelling is constant throughout the year between 20°N and 25°N, while north of 25°N upwelling occurs only in summer (e.g., Mittelstaedt, 1991). South of 20°N upwelling occurs primarily during winter. The described seasonality is most pronounced in this southern part of the region where Trade Winds are dominant in winter and spring and are replaced by the southwest monsoon winds during summer and autumn.

A characteristic feature of the upwelling zone is the formation of filaments, which transport the cooler upwelled water offshore (Van

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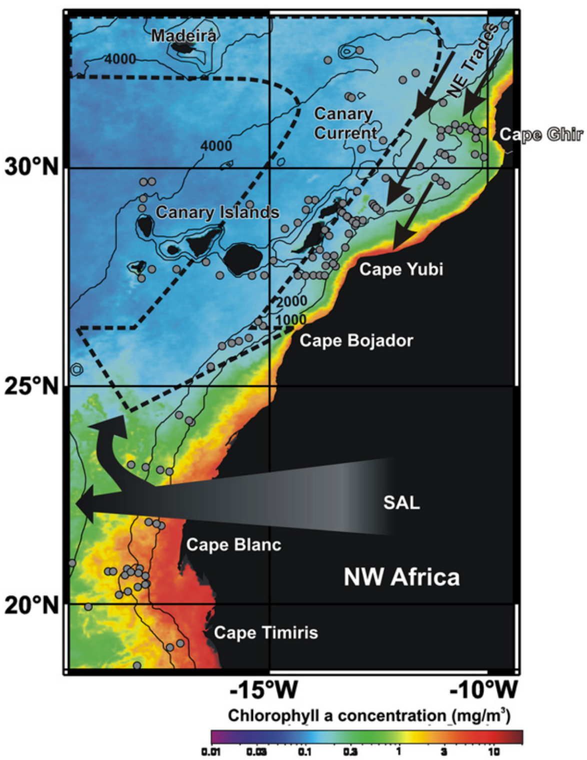

Fig. 1. Bathymetric map of northwest Africa with 1000 m, 2000 m and 4000 m depth contour lines. The grey circles show the locations of the surface samples used in this study. Dark arrows indicate the average positions of the present day dominant wind systems Northeast Trade winds (NE Trades) and Saharan Air Layer (SAL). The large black dashed arrow represents the average geostrophic current transport of the Canary Current (after Stramma and Siedler, 1988; Klein and Siedler, 1989). Included is the annual (2010) composite Chlorophyll concentration in the Canary Islands region as observed by MODIS Aqua (Feldman et al., 2012).

Camp et al., 1991; Nykjær and Van Camp, 1994). The development and growth of the larger, permanent filaments seems to be related to changes in topography such as headlands (Strub et al., 1991). Large filaments such as those found at Cape Ghir, Cape Yubi, Cape Bojador, Cape Blanc and Mauritania (20.8°N) are observable as colder jets and meanders extending several hundreds of kilometres offshore (Van Camp et al., 1991; Nykjær and Van Camp, 1994; Barton et al., 1998; Davenport et al., 1999, 2002; Barton and Arístegui, 2004). Although upwelling occurs mostly on the shelf, these filaments play an important role in carbon cross-shelf transport and export to the deep ocean as has been described by Strub et al. (1991), Gabric et al. (1993) and Barton et al. (1998). However, the zone between 1000 m and 2000 m water depth represents the locus of maximum concentrations of biogenic particulate matter in the surface sediments (Fütterer, 1983).

Another important role for sedimentation in this area plays the input of dust, which is mainly controlled by the Northeast Trade Wind, the Saharan Air Layer (SAL) and the Harmattan (Sarnthein and Koopmann, 1980; Van Camp et al., 1991). Torres-Padrón et al. (2002) observed a seasonal pattern of Saharan dust events with maximum fluxes in winter and summer related to two dominant meteorological scenarios.

In boreal winter, dust events occur favoured by the southward displacement of the Intertropical Convergence Zone (ITCZ) and the weakening of the Azores High. Bergametti et al. (1989) detected dust transport from the Sahelian regions during this time. Trade winds are then well developed between latitudes 10°N and 25°N (Martinez et al., 1999). Additionally, very dry and warm winds (Harmattan) blow occasionally offshore from the Sahara at latitudes between 15°N and 28°N. These winds can carry desert dust into and over the ocean, although most of the time the boundary between the Harmattan and the maritime Trades is located over the continent parallel to the coast (Van Camp et al., 1991). In contrast, dust outbreaks which appear in boreal summer, favours dust transport from a northern source (Torres-Padrón et al., 2002). Due to the northward migration of the ITCZ to ~19°N (Nicholson, 2000), trade winds blow further north between 20°N and 32°N (Martinez et al., 1999). The dust carried by the SAL originates from the southern Sahara and the adjacent Sahel zone (Koopmann, 1981; Sarnthein et al., 1982). This dust is then transported in a westerly direction. The SAL is divided into two branches, a northern one dispensing aeolian sediment over the northeast Atlantic Ocean and the Canary Islands, and a western branch transporting the aerosols far offshore (Fig. 1).

A further important source of terrigenous matter is the fluvial discharge of detrital material by northwest African rivers which is estimated to amount to a total of 110 million tons year^{-1} (Milliman and Meade, 1983; Hillier, 1995). In the northern part of the area, a number of seasonal rivers (e.g., the Souss at 30°N) transport sediment derived from the Atlas and Anti-Atlas Mountain hinterland to the continental shelf and slope (Sarnthein et al., 1982; Wynn et al., 2000). Today, the major proportion of this fluvial material is deposited on the continental shelf. However, numerous canyons, dissecting the shelf break, provide conduits for shelf material that bypasses the continental slope and is deposited on the Seine Abyssal Plain, the Agadir Basin and Madeira Abyssal Plain (Weaver et al., 2000; Wynn et al., 2000). The canyon systems in the northern part of the NW African continent are still influenced by fluvial drainage (Ercilla et al., 1998; Wynn et al., 2000). Further to the south, on the western Saharan margin between 17°N and 28°N, fluvial supply is significantly reduced compared to the area north of 29°N (Wynn et al., 2000). Here rivers and additional wadis reach the Atlantic Ocean only seasonally and, along the majority of the margin, there exists no significant fluvial input at all (Wynn et al., 2000).

The area along the NW African continental margin was chosen for investigation, because it comprises different climatic regimes, zonal productivity gradients and different geology of various source areas (Canary Islands, NW African continent) in a high spatial resolution. Our investigations cover an area reaching from Cape Ghir to Cape Timiris and comprise surface sediment samples from nearshore to offshore locations (spanning waterdepths of 355 m–4292 m). Previous studies on geochemical and micro paleontological sedimentary parameters as well as on grain size distributions within the surface sediments have been conducted in this region (e.g., Meggers et al., 2002; Holz et al., 2004). In addition to previous studies, this study provides a high-resolution overview and combination of parameters representing surface water productivity as well as input of terrigenous matter and related transport processes.

The study presented here is focussed on the clarification of two major problems: (1) Which geochemical parameter is the most reliable tracer for surface water productivity in the study area? (2) Which processes control the transport and distribution of terrigenous material originating from the adjacent NW African continent? To resolve the first problem (the most suitable surface productivity proxy), the spatial distribution of total organic carbon (TOC), calcium carbonate ($CaCO_3$), barium (Ba) and the carbon/nitrogen ratio (C/N) in surface-sediments was analysed. The second problem (dominant terrigenous sediment provenance and transport processes) was approached by determining the distributions of aluminium (Al), iron (Fe), potassium (K) and titanium (Ti) in the study area.