Available online at www.sciencedirect.com
ScienceDirect
Marine Micropaleontology 64 (2007) 91 – 119
MARINE MICROPALEONTOLOGY
www.elsevier.com/locate/marmicro

Distribution of organic-walled dinoflagellate cysts in shelf surface sediments of the Benguela upwelling system in relationship to environmental conditions

Ulrike Holzwarth [a,*], Oliver Esper [b], Karin Zonneveld [a]

[a] *Research Center Ocean Margins, University of Bremen, P.O. Box 330440, D-28334, Germany*
[b] *Alfred-Wegener-Institute for Polar and Marine Research, Columbusstrasse, D-27568, Germany*

Received 28 November 2006; received in revised form 28 March 2007; accepted 2 April 2007

Abstract

To obtain insight in the relationship between the spatial distribution of organic-walled dinoflagellate cysts (dinocysts) and local environmental conditions, fifty-eight surface sediment samples from the coastal shelf off SW Africa were investigated on their dinocyst content with special focus on the two main river systems and the active upwelling that characterise this region. To avoid possible overprint by species-selective preservation, samples have been selected mainly from shelf sites where high sedimentation rates and/or low bottom water oxygen concentrations prevail.

Multivariate ordination analyses have been carried out to investigate the relationship between the distribution patterns of individual species to environmental parameters of the upper water column and sediment transport processes.

The main oceanographical variables at the surface (temperature, salinity, nutrients chlorophyll-*a*) in the region show onshore–offshore gradients. This pattern is reflected in the dinocyst associations with high relative abundances of heterotrophic dinocyst species in neritic regions characterised by high chlorophyll-*a*and low salinity conditions in surface waters. Phototrophic dinocyst species, notably *Operculodinium centrocarpum*, dominate in the more oceanic area. Differences in the distribution of phototrophic dinocyst species can be related to sea surface salinity and sea surface temperature gradients and to a lesser extent to chlorophyll-*a* concentrations.

Apart from longitudinal gradients the dinocyst distribution clearly reflects regional environmental features. Six groups of species can be distinguished, characteristic for (1) coastal regions (cysts of *Polykrikos kofoidii* and *Selenopemphix quanta*), (2) the vicinity of active upwelling (*Brigantedinium* spp., *Echinidinium aculeatum*, *Echinidinium* spp. and *Echinidinium transparantum*), (3) river mouths (*Lejeunecysta oliva*, cysts of *Protoperidinium americanum*, *Selenopemphix nephroides* and *Votadinium calvum*), (4) slope and open ocean sediments (*Dalella chathamense*, *Impagidinium patulum* and *Operculodinium centrocarpum*, (5) the southern Benguela region (south of 24°S) (*Spiniferites ramosus*) and (6) the northern Benguela region (north of 24°S) (*Nematosphaeropsis labyrinthus* and *Pyxidinopsis reticulata*).

No indication of overprint of the palaeo-ecological signal by lateral transport of allochthonous species could be observed.

Keywords: Organic-walled dinoflagellate cysts; Upwelling; Benguela System; Productivity; Chlorophyll-*a*; River mouths

* Corresponding author.
E-mail address: holzwarth@rcom-bremen.de (U. Holzwarth).

0377-8398/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.marmicro.2007.04.001

1. Introduction

The Benguela upwelling system (BS) along the west coast of Southern Africa is one of the most productive areas of the world ocean (e.g. Shannon, 1985). This is not only important for the fishing industry but also for the accumulation of organic carbon which is a factor of major importance in relation to the global carbon cycle and consequently to global climate change. The high productivity in the region is induced by high input of marine and terrestrial nutrients and trace metals into the photic zone. This supply results from the presence of permanent upwelling as well as aeolian and riverine sources. The temporal dynamics of the carbon production, transport and storage in the BS are not sufficiently understood. To learn more about the reasons of its variability, it is essential to perform detailed reconstructions of the conditions in the past.

Together with diatoms and coccolithophores, dinoflagellates represent a major part of the eukaryotic primary production in marine environments (e.g. Parsons et al., 1984). During their life cycle dinoflagellates produce hypnozygotes during sexual reproduction for a resting phase of variable duration. Hypnozygotes of several species are protected by an organic-walled cyst (e.g. Dale, 1976; Head, 1996) which can be fossilized in the sediment. More than 80 species of marine dinoflagellates are now known to produce these cysts (Matsuoka and Fukuyo, 2000).

The quantitative analysis of organic-walled dinoflagellate cysts (dinocysts) has become a valuable tool for palaeoclimatic and palaeoceanographic reconstructions, especially in coastal high productive environments where proxies based on calcareous plankton are often problematic (Dale, 1996; Versteegh, 1997; Zonneveld et al., 1997; Rochon et al., 1998; Santarelli et al., 1998; de Vernal et al., 2001; Esper et al., 2004). In regions with high marine productivity the microbial degradation of organic matter in the sediments causes carbonate dissolution (Berger et al., 1982).

The relationship between modern assemblages in the sediment and the environmental conditions in the upper water column is the basis for the use of dinocysts as a proxy for oceanographic conditions.

Studies from quaternary open oceanic environments (e.g. Harland, 1983; Turon, 1984; Mudie and Short, 1985; de Vernal and Giroux, 1991; Edwards and Andrle, 1992; Matthiessen, 1995; Marret and de Vernal, 1997; Rochon et al., 1998; Marret and Zonneveld, 2003) suggest that it is basically nutrient concentration, turbulence, sea surface temperature and sea surface salinity which are related to the composition of the dinocyst assemblage. Though the general knowledge about modern dinocyst distribution in coastal areas increased considerably (Davey and Rogers, 1975; Lewis et al., 1990; Powell et al., 1990; Dale and Fjellså, 1994; Biebow, 1996; Thorsen and Dale, 1997; Rochon et al., 1999; Zonneveld and Brummer, 2000; Radi et al., 2001; Dale et al., 2002; Matsuoka et al., 2003; Pospelova et al., 2002, 2004, 2005; Kawamura, 2004; Radi and de Vernal, 2004), the understanding of dinocyst assemblages in upwelling systems is still limited. Especially the recognition of the differential effects of upwelling and river discharge on the composition and distribution of the dinocyst association in bottom sediments has not yet been studied in detail. Another complicating factor is the recent discovery that species-selective aerobic degradation can severely alter the dinocyst association in bottom sediments where high oxygen concentrations in bottom/pore waters and low sedimentation rates prevail (Zonneveld et al., 1997, 2001b, 2007). Consequently, previous concepts concerning the ecological relationship of several species have to be revised. Detailed studies in regions where aerobic diagenesis does not overprint the ecological signal are required.

In the present study, we therefore relate the spatial distribution of dinocyst species to the environmental parameters in the upper water column at the sample sites. To avoid possible overprint of the ecological signal by species-selective aerobic degradation, we focussed on shelf samples of sites that are characterised by high sedimentation rates and/or low bottom water oxygen concentrations. Our study complements the work of Zonneveld et al. (2001a) and Bockelmann et al. (submitted for publication), where mostly offshore locations and locations along bottom water oxygen gradients were examined. It extends the work of Davey and Rogers (1975) by examining the continental shelf of the Benguela System (BS) in detail.

2. Regional setting

The oceanography of the BS has been reviewed by several authors (e.g. Nelson and Hutchings, 1983; Lutjeharms and Meeuwis, 1987; Peterson and Stramma, 1991; Shannon and Nelson, 1996; Shillington, 1998). Fig. 1 shows the main oceanographic features.

The highly productive BS is situated along the southwest coast of Africa and characterised by wind-driven coastal upwelling. The oceanic circulation of this region is controlled by the semi-permanent high pressure system over the subtropical South Atlantic Ocean and a low pressure system that develops over Southern Africa during the austral summer. These atmospheric conditions