Recent sedimentation of organic matter along the SE Atlantic Margin : A key for understanding deep offshore petroleum source rocks.

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RECENT SEDIMENTATION OF ORGANIC MATTER ALONG THE S-E ATLANTIC MARGIN: A KEY FOR UNDERSTANDING DEEP OFFSHORE PETROLEUM SOURCE ROCKS

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ABSTRACT

1. Introduction

Classical views for the deposition of organic-rich sediments in deep-sea environments invoke two principal types of oceanographic and sedimentologic settings. The first is confined basins in which stratified oxygen depleted waters lead to anoxic preservation of organic matter in the water column and in underlying sediments (Demaison and Moore, 1980). The second is an open ocean setting where the episodic mass transfers due to slope sediment instability lead to the rapid burial of outer-shelf and upper slope-derived organic matter and its consequent preservation due to limited oxic or anoxic degradation (Stow, 1987). Other studies have shown, however, that organic matter in modern deep-sea sediments may occur in high amounts where oxygen is not significantly depleted (Pedersen and Calvert, 1990). Recent studies have demonstrated that highly biological productive areas, such as the upwelling zones associated to the Benguela Current in S-E Atlantic, may deliver sufficient quantity of organic material to (1) outbalance the degradative capacity of the water column and (2) sustain the formation of organic-rich sediments even in deep and oxygenated conditions (Bertrand et al., 2003). It appears that the S-E Atlantic margins provide a good example for revisiting the sedimentology of organic matter in deep water environments in the frame of the *GDR Marges Continentales*. This may have important implications for a better understanding of the distribution of ancient source rocks in deep offshore petroleum systems (Huc et al., 2001; Bertrand et al., 2003).

2. Material and methods

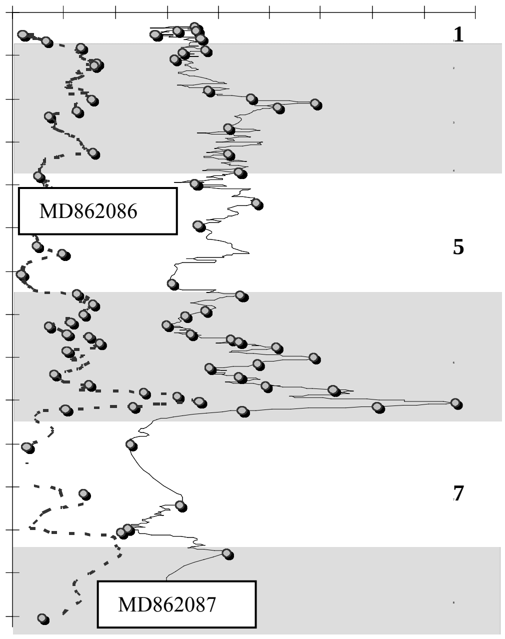
Thirteen giant piston cores, recovered during the NAUSICAA-IMAGES II cruise onboard the *R/V Marion-Dufresne* in 1996, allow to study several bathymetric transects perpendicular to the margin, within a depth range from ~1000 to ~4000 m (Bertrand et al., 1997). The latitude of two transects correspond to those of the most active and permanent upwelling cells of the Benguela System, namely the Lüderitz and Walvis Bay cells. Two transects are located offshore South Africa in an area of non permanent upwelling cells, whereas the last transect is located along the Angolan margin, away from the upwelling system. The Lüderitz transect was investigated in order to obtain a better understanding of the organic matter sedimentation through time. Two entire giant piston cores were studied for the last 300 kyr. The spatial distribution of organic matter takes into account all the cores, but the temporal investigation is limited to the last 20 kyr. Age models were established using $\delta^{18}O$ and ^{14}C radiocarbon dates.

Sedimentological (smear slides, microgranulometry, major and selected trace elements), geochemical (Rock-Eval pyrolysis, molecular characterisation), isotopic ($\delta^{13}C$, $\delta^{15}N$) and palynological analyses were performed on several hundred of samples. Finally, we try to translate our understanding of the organic sedimentation for the Benguela System into laws to be introduced in the stratigraphic model Dionisos (IFP).

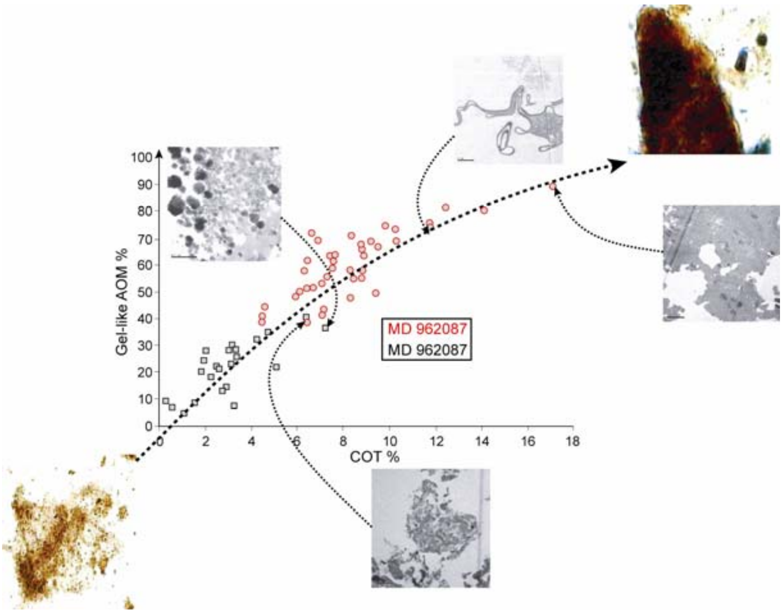
3. Main results

3.1 Characterisation of organic matter enrichment through time

Within any given core, the organic content is mainly related to climate changes. Based on the age models of the cores, we observe that carbonate depletion and related organic enrichment correspond statistically to warm to cold transitions and vice versa (Fig. 1). As expected, the average organic matter content decreases with increasing depth, but in the deepest site C_{org} contents are never lower than 1.7% and reach concentration as high as 7% (Fig. 1). In the middle slope, the C_{org} contents are never lower than 5% (Bertrand et al., 2002, 2003). Such concentrations are amongst the highest observed in the world in modern marine sediments. This provides clear evidence for the possibility of accumulation of organic rich pelagic/hemipelagic sediments in deep oxygenated oceanic setting. Optical examination of palynofacies reveals that the volume proportion of marine organic particles ranges between 80 and 95% of the total organic fraction. The degree of preservation of the organic matter seems constant as shown by constant HI values (350 to 450 mg HC g^{-1} TOC) whatever the concentration. TEM observations reveal three main types of marine amorphous organic matter corresponding to three modes of preservation (Fig. 2): selective preservation (ultralaminae), organo-mineral aggregates (clottered AOM) and recondensation (gel-like AOM). Their proportion changes with TOC contents, i.e. with depth and probably primary productivity level.



🡐 Fig. 1 – Vertical variation of the TOC content in pelagic/hemipelagic sediments from MD 962087 (1029 m-depth) and MD 962086 (3606 m-depth) cores for the last 280 kyr. Organic matter concentration is higher during cold periods (grey bands).



➔ Fig. 2 – Aspect (photonic and transmitted electronic microscopy) and proportion of the amorphous organic matter with TOC increase.

3.2 Mapping of the petroleum potential along the margin

The same temporal variability of organic carbon shown along the Lüderitz transect is observed along the entire margin from the north of Walvis ridge to south Africa. An enrichment in total organic carbon characterised the Last Glacial Maximum with respect to Holocene Climatic Optimum. Biogenic silica, mainly related to diatoms input, follows the same climatic logic, whereas carbonate contents are negatively correlated with TOC and biogenic silica.

Different zones may be characterised by their accumulation rates in organic matter, as well as by the different type of amorphous organic matter and the related petroleum potential. Several maps of the distribution of organic matter and its petroleum potential are drawn from the present-day to the Last Glacial Maximum (Fig. 3).

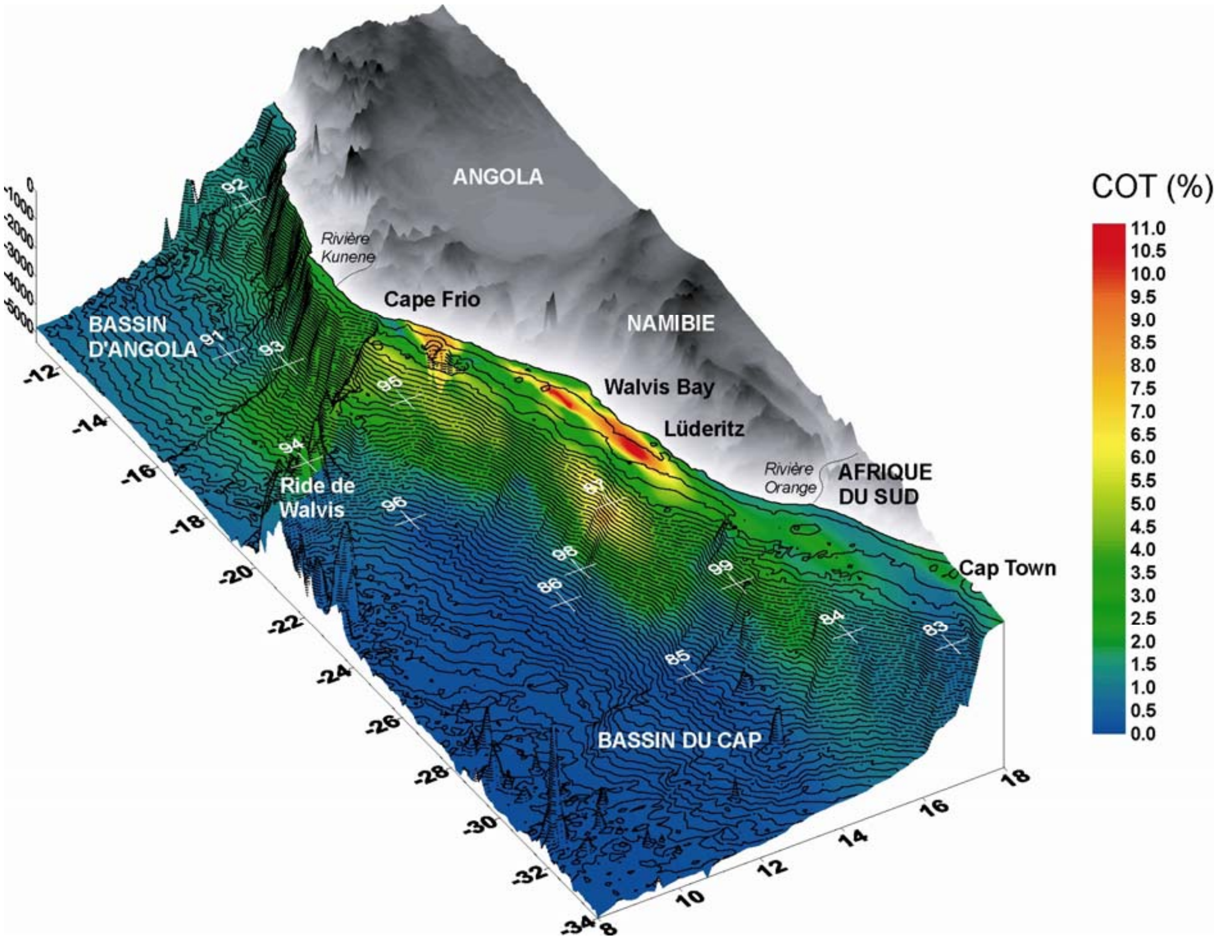


Fig. 3 – Map of the present-day organic content (in TOC %) of the superficial sediments along the S-E Atlantic margin.

3.3 First steps in modelling deep offshore organic matter sedimentation

The first step in modelling the deep organic matter sedimentation is to decipher between the main controlling factors the key parameters to be introduce in the Dionisos model. This imply to define simple laws for productivity, degradation, advection of sediment, etc.

A first run will try to simulate the organic sedimentation for the Lüderitz transect at a stationary state (high sea-level), close to the present-day situation.

4. Preliminary conclusions

The recent sedimentation along the S-E Atlantic margin provide clear evidence for the possibility of accumulation of organic-rich pelagic/hemipelagic deposits in deep to very deep oxygenated settings. This implies that anoxia is not a prerequisite for the accumulation of a sediment with an organic content sufficient to become a potential petroleum source rock. The occurrence of this substantial amount of organic matter reaching very deep settings can be explained firstly by the high biological surface productivity. This promote repacking of organic particles by physico-chemical (i.e. flocculation) and biological processes (faecal pellets, marine snow) producing large aggregates having rapid sinking rate through the water column. The final enrichment of the sediment is controlled by a combined effect of organic and biogenic silica input, as well as carbonate dissolution. We suggest that, mainly because of climate-related sea level changes, the sedimentary fluxes that reach deep slope sites off southwest Africa derive from more or less eutrophic conditions. The upwelling regimes that produce eutrophic conditions are located closer to such deep-slope sites during sea level low stands in glacial periods than during highstands in warm intervals. Thus, organic matter delivery to the deep slope is strengthened by the more eutrophic conditions that prevail in overlying surface waters during cold episodes. At such times, metabolizable organic matter is more efficiently transferred to the deep seafloor due to a larger ratio between total primary productivity and export productivity, and a shorter residence time in the oxic water column. An important consequence of this is that particulate carbonates on the bottom may be partly or entirely dissolved by the oxic degradation of the metabolisable organic matter arriving at the seafloor. This leads to the relative concentration of resistant organic matter, as well as the other conservative detrital fractions.

Such sedimentation has occurred for more than 2 million years and is geographically distributed over hundreds of kilometers along the margin, so that the sediments of this region contain a huge concentrated stock of organic carbon. The topography of the margin is the last factor which monitor the organic matter enrichment. Stratigraphic modelling are in progress in order to propose a hierarchy of these different factors.

We believe that the probability that such organic-rich facies occurred in the past in equivalent oceanographic settings at the edge of large oceanic basins should be carefully considered in deep offshore exploration.

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