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Shallow gas off the Rhône prodelta, Gulf of Lions

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Abstract

Sediment cores acquired in 2004 off the Rhône prodelta show consistent anomalous methane concentrations of up to 87,440 ppm. Methane compositional and isotopic data support a biogenic origin, although there are a few sites that show strongly depleted $\delta^{13}C$ values (−53‰ PDB) suggesting a mixed source for the gas (biogenic and thermogenic). Anomalous methane concentrations (samples with more than 90 ppm) are discussed and integrated with organic carbon data, sedimentary rates and ADCP profiles. Highest gas concentrations were found directly off the river mouth (20–40 m water depth) and where the IFREMER models point to the thickest accumulation (>2 m) in response to the Rhône flood event.

In areas unaffected by the high flux of organic matter and rapid/thick flood deposition, or in between flood events, the conditions for methanogenesis and gas accumulation have not been met; in these areas, the physical and biological reworking of the surficial sediment may effectively oxidize and mineralize organic matter and limit bacterial methanogenesis in the sub-surface. We propose that in the Rhône prodelta flood deposits deliver significant amounts of terrigenous organic matter that can be rapidly buried, effectively removing this organic matter from aerobic oxidation and biological uptake and leading to the potential for methanogenesis with burial.

Keywords: shallow gas; biogenic methane; flood deposits; Rhône prodelta; Gulf of Lions

1. Introduction

Deltaic environments are characterized by very high rates of sediment accumulation and are the gateway by which much of the world's terrigenous organic matter is delivered to the marine environment. Anaerobic bacterial methanogenesis of this buried organic matter can lead to the generation of shallow gas in sediments, where sulfate reduction and methane production dominate decomposition (Berner, 1980; Martens and Klump, 1984). If present in sufficient concentrations to exceed solubility, shallow gas can impact impedance contrasts in

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the sub-surface, the bathymetry and backscatter of the seafloor, and the backscatter within the water column (Hovland and Judd, 1988). As part of the EuroSTRATA-FORM program, we have been evaluating the causes of anomalous sub-surface and seafloor features, and specifically quantifying shallow gas and identifying its impact on geophysical properties in Northern Gulf of Lions (GoL), West Mediterranean Sea.

A considerable set of high-resolution data of the GoL has been published so far, such as detailed morpho-bathymetric charts (Berné et al., 2001, 2004) or studies based on high-resolution reflection-seismic datasets, to aid understanding of the Quaternary stratigraphic setting (Tesson et al., 1990; Gensous and Tesson, 1996; Chiocci et al., 1997; Rabineau et al., 1998; Tesson et al., 2000; Migeon et al., 2001; Lobo et al., 2004).

Extensive studies about recent processes, sedimentation and circulation in the GoL, in particular related to the Grand Rhône River delta sediments, have also been published in the last years (Estournel et al., 1997; Radakovitch et al., 1999; Marty et al., 2001; Estournel et al., 2001; Thill et al., 2001; Beaudouin et al., 2004; Petrenko et al., 2005). In the present paper we discuss the occurrence of shallow gas evidences in the recent sediments off the Grand Rhône prodelta.

One of the goals of our sampling program was to understand the relationship between flood deposition, primary productivity and gas (methane) formation. The two main mechanisms for methane formation are: low-temperature bacterial methanogenesis and high-temperature kerogen thermal cracking (Friedman et al., 1992). In geological literature, the gas generated by the decomposition of organic matter by anaerobic microbes at low temperatures is commonly referred to as 'biogenic' gas, which is distinguished from 'thermogenic' gas by its composition and isotopic signature (Kotelnikova, 2002). Biogenic gas has a high concentration of methane relative to other hydrocarbons (more than 99%; Clayppol and Kaplan, 1974; Vogel et al., 1982) and a very depleted (light) stable carbon isotope (^{13}C) content ($\delta^{13}C$ PDB <-25‰ Schoell, 1983; Whiticar et al., 1986).

2. Background

The continental margin in the GoL is characterized by relatively low annual sediment inputs, which are irregularly discharged over the years (Courp and Monaco, 1990). The Grand Rhône River is the dominant (80%) source of sediment for the continental shelf. The mean long-term suspended particulate discharge of the Grand Rhône is 7.4×10^6 tons/y, with an important variability (1 to 10×10^6) related to the hydrological regime of the river (Pont et al., 2002). The GoL is a modern wave-dominated shelf, where the tidal range is only a few cm and waves have moderate energy (Rabineau et al., 1998). The largest swell is from the South–East, with maximum wave heights of 5 m and periods of about 8 s, occurring 0.1% of the time (Rabineau et al., 1998).

A geostrophic current, known as the Liguro Provençal Current (LPC), flows south-westward along the continental slope. Its average velocity near the seafloor on the outer shelf is 5 cm/s, but its orientation and magnitude may be modified by seasonal stratification and wind effects, by up to 30 cm/s (Millot, 1981; Millot and Crépon, 1981). The LPC has an impact on sediment transport and deposition in the GoL; this current moves westward along the slope at 0.25–0.31 m/s in the 0–100 m layer, with flow rates from 0.94–2.7 Sv (Bethoux et al., 1998). A Northern branch of this current is permanently flooding the shelf area, with a strong impact on the suspended particles from the Grand Rhône plume and on the remobilized sediments (Aloïsi et al., 1979).

On the continental shelf, the associated currents to the LPC are often a few cm/s and almost negligible at the surface, when compared to the circulation induced by two strong regional winds (Pinazo et al., 1996); in addition to the Western Mediterranean mesoscale circulation and the fresh water input of the Grand Rhône River, the other main hydrodynamic forces on this continental shelf are the strong Northwestern (tramontane) and Northern (mistral) winds (Millot, 1999). The North-west sector winds, induced by a ridge of high pressure over the nearby Atlantic, blow intensively every other day throughout the year, encouraging the formation of coastal upwellings along the north coast (Estournel et al., 1997). The most intense cold water upwelling occurs specifically in front of the area where the Grand Rhône River plume is most likely to flow.

Fresh water inputs in the gulf vary throughout the year, with peaks in rainy seasons, generally spring and fall (Moutin et al., 1998), but the main input is the Grand Rhône River plume (Petrenko et al., 2005), whose direction and extent are greatly affected by the wind (Demarq and Wald, 1984; Marsaleix et al., 1998; Estournel et al., 2001; Naudin et al., 2001). The plume sometimes extends all the way to the Spanish coast (Castellon et al., 1985). In the last 2003 flood event, the peak of the flow of the Grand Rhône was 13,000 m^3/s (Kettner et al., 2004).

The Grand Rhône drainage basin is 98,000 km^2, its length is 1100 km, and its water discharge is 1700 m^3/s