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Investigation on the geochemical dynamics of a hydrate-bearing pockmark in the Niger Delta

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ABSTRACT

A joint industrial project with IFREMER and Total provides insights into the tectonic setting and the geochemistry of a large active pockmark offshore W-Africa in the Niger Delta. The study combines both geophysical (seismic) and geochemical data to infer the dynamics of a 300 m wide pockmark located at 667 m water depth. Two Calypso cores, one at the centre and one outside the pockmark, along with three box-cores, two inside the pockmark and one outside, were collected to study the geochemistry of gas hydrates, carbonates and pore waters. Two seismic lines, a 3D high resolution random line and a 2D high resolution seismic line, provide a good description of the plumbing of the system. The integrated results depict a very active pockmark characterized by several gas charged-bodies, a well identified BSR marking a hydrate accumulation zone, charged from deeper sources via a network of faults. Hydrates and carbonate concretions have been detected inside the pockmark while only the latter has been found outside. The hydrate analyses show that the hydrate-forming gases are of thermogenic origin, albeit overwhelmingly composed of methane. Pore-water analyses reveal the occurrence of anaerobic oxidation of methane coupled with sulphate reduction at shallow depth (~200 cm). The chloride concentration profile exhibits both values lower than that of seawater which is inherent to hydrate dissociation after core recovery and positive anomalies (values 7% higher than that of seawater background) at the lowermost part of the core. The latter evidence suggests current or recent hydrate formation at this area. The carbonate dating provides additional temporal information and indicates that this pockmark has been active since ~21 kyr.

1. Introduction

Pockmarks are generally defined as nearly circular depressions resulting from the near-surface sediment deformation on the seafloor (Cathles et al., 2009; Hovland, 1989; Hovland, 2003; Hovland et al., 1997; Hovland et al., 2002; Hovland and Judd, 1988; Hovland et al., 1984). These are dynamic structures generated by fluid migration throughout the sediment. The fluids can be rich in methane, which has either a microbial (biogenic) or a thermogenic origin. For biogenic gas generation, the migration pathway of the gases is short; accordingly the gases can be trapped near their production area as free gas if a geologic cap rock lies at the top. In the case of a thermogenic origin, the gases may contain heavier hydrocarbons. They come from leaking deep subsurface reservoirs and seismic investigations can help in providing a better understanding of the migration pathways to the seabed. Frequently, such a study can even lead to the identification of the reservoirs. Depending on temperature and pressure conditions, pore-water chemical compositions and heat flow pattern of the shallow sediment, methane can either escape upwards to the seafloor then released to the seawater or be trapped as gas hydrates within the Gas Hydrate Stability Zone (GHSZ) (Hustoft et al., 2009, 2007; Plaza-Faverola et al., 2012; Rajan et al., 2012). The latter also releases methane to the seawater when it undergoes a destabilisation processes, *e.g.* dissolution or dissociation (Sultan et al., 2004, 2010). The discharged methane influences several biogeochemical processes. Pockmarks are often characterized by

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methane seeps which provide the energy for the development of different chemosynthetic communities (Hovland and Judd, 1988; Menot et al., 2010; Olu et al., 2009). The methane released from seeps could be oxidized by bacterial consortia or archea through a biogeochemical reaction called anaerobic oxidation of methane (AOM) (Boetius et al., 2000; Joye et al., 2004; Orcutt et al., 2004; Treude et al., 2003), which in turn, supply the chemical components for authigenic carbonate precipitations (Feng et al., 2009; Greinert et al., 2002, 2001; Naehr et al., 2007; Peckmann et al., 2001). Thus, methane seeps, gas hydrate deposits, carbonate precipitations and the presence of chemosynthetic communities are features which could be found on pockmarks and which could influence their morphology, sediment lithology and evolution (Hovland and Judd, 1988; Sultan et al., 2010). Accordingly, investigations of such features by considering both spatial and temporal aspects are key to qualitatively and quantitatively understand their behaviour.

The focus of this paper is placed on the description of an area characterized by a large active pockmark. It is located in the Niger Delta, off Nigeria (Fig. 1). This study is mainly concerned with the gas and fluid migration pathways as well as the geochemical processes occurring at the studied area. It is based on the geochemistry of pore waters, carbonates and gas hydrates, with emphasis on their inter-relationships. The resulting data are integrated with sediment core analysis and both 3D high resolution and 2D high resolution seismic lines.

2. Geological setting

The studied area is located offshore of the modern Niger Delta, on the west coast of central Africa, in the Gulf of Guinea (Fig. 1). The Niger Delta margin is undergoing deformation by gravity-driven tectonics as the sediment fill is laid on a mobile substratum (Bilotti and Shaw, 2005; Briggs et al., 2006; Corredor et al., 2005; Damuth, 1994; Garziglia et al., 2010; Riboulot et al., 2012). This substratum is formed by Early Tertiary overpressurised shale. The mobile shale has been deformed since the Oligocene, forming the major structures of the delta (Hooper et al., 2002; Wiener et al., 2006). The studied area is located on the continental slope, at water depth ranging from 600 to 800 m. It has been defined as a mud-diapir province (Corredor et al., 2005), and is characterized by a variety of seafloor features, especially by numerous circular and sub-circular features (Fig. 2A).

3. Materials and methods

3.1. Geophysics

The bathymetric map presented in Figure 2 comes from a derivate bathymetry obtained from seafloor-reflector picking on 3D industrial seismic data. 3D high resolution (HR) seismic data with a vertical resolution of 7 m and a bin size of 6.25 × 12.5 m, and

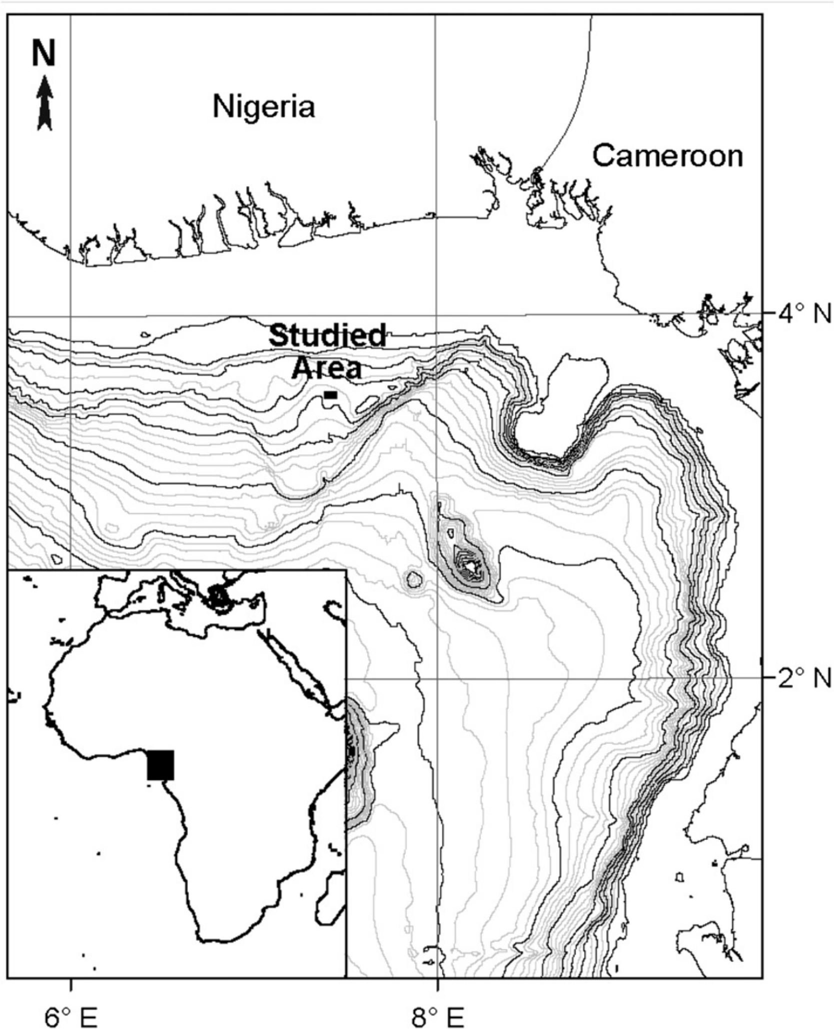

Figure 1. Geographical location map of the studied area.