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Pockmarks on the South Aquitaine Margin continental slope: The seabed expression of past fluid circulation and former bottom currents

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ABSTRACT

Inactive and mostly elongated pockmarks of 100–200 m in dimension were recently discovered on the South Aquitaine Margin continental slope. They are distributed at water depths greater than 350 m in both interfluve and sediment-wave areas, and are strongly controlled by the sedimentary morphology and architecture. Water column and seafloor backscatter and sub-bottom profiler data do not exhibit present-day or past gas evidence, e.g., massive and continuous gas releases at the seabed and fossil methane-derived authigenic carbonates. It is thus proposed that the pockmarks originated from a shallow source and result from relatively recent and short-duration gas or water expulsion events. Former near-bottom currents may have contributed to the elongation of these WNW–ESE-oriented pockmarks, whereas present-day weaker near-bottom currents may induce upwelling, contributing to the maintenance of the elongated shapes of the pockmarks.

1. Introduction

Pockmarks were first described by King and MacLean (1970) as seafloor morphological depressions, formed by fluid escapes. Pockmarks are commonly encountered and, are worldwide, related to fluid migrating upward (Judd and Hovland, 2007) and triggering-sediment resuspension during leakage and sediment collapse. These depressions are observed from shallow environments (Rise et al., 2015) to deep bathyal environments (Gay et al., 2006). Pockmark morphologies can be associated with various types of fluids and processes, e.g., small-scale pockmarks can be related to a unique local gas source (Gay et al., 2007), to dewatering of the sediments upon compaction (Harrington, 1985) and to freshwater seeps (Whiticar, 2002) while pluri-kilometre-scale pockmarks may indicate hydrate dissolution (Sultan et al., 2010). Pockmarks may occur as clusters (Hovland et al., 2010) or as strings of pockmarks (Pilcher and Argent, 2007). Strings of pockmarks are commonly related to geological features focusing fluid

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flows, e.g., fractures and faults (Gay et al., 2007) and buried valleys (Baltzer et al., 2014).

The modification of the original pockmark morphologies will depend on internal factors such as successive fluid expulsion events (Judd and Hovland, 2007), the presence of methane-derived authigenic carbonates (Gay et al., 2006), and external factors such as bottom currents (Bøe et al., 1998; Josenhans et al., 1978; Schattner et al., 2016), slumping and sedimentary destabilization along the slope direction (Brothers et al., 2014), presence of benthic fauna and debris accumulation (Webb et al., 2009), e.g., coarser sediments (Pau and Hammer, 2013). Bottom currents may contribute to elongate pockmarks along the direction of the currents by eroding sediments and preventing sedimentation over the pockmarks (Andresen et al., 2008; Dandapath et al., 2010). Bottom currents may induce upwelling within the pockmarks that would limit the sedimentation of fine-grained sediments, therefore maintaining pockmark morphology (Brothers et al., 2011; Hammer et al., 2009; Pau et al., 2014). Moreover, coalescent pockmarks (merging depressions) (Gay et al., 2006) may be a result of successive fluid escapes or external processes as cited above, eventually forming elongated pockmarks. Pockmark morphological characteristics, accessible through their acoustic signature, may be used to determine potential activity (Dupré et al., 2010; Hovland et al., 2010), and the nature of fluids involved (Gay et al., 2006; Judd and Hovland, 2007) and also to address the relative timing of pockmark formation with regards to surrounding sedimentation (Bayon et al., 2009).

The present study mainly focuses on the geophysical characterization of a wide pockmark field discovered on the continental slope of the Aquitaine Margin (offshore France) in 2013 during the GAZCOGNE1 oceanographic expedition. Pockmark activity and the nature of fluids involved in pockmark formation are discussed. Particular attention is paid to the pockmark reshaping related to external factors such as bottom currents.

2. The setting

Related to the opening of the North Atlantic Ocean, the Bay of Biscay initially corresponded to a V-shaped rift, initiated during the Late Jurassic and aborted in the mid-Upper Cretaceous (Roca et al., 2011). Its extensional phase was stopped during the Santonian age by the opening of the South Atlantic Ocean. The subsequent northward drift of the Iberian plate and the related compression phase led to the Pyrenean orogeny (Roca et al., 2011). The Bay of Biscay is surrounded by different shelves, the large Armorican Shelf, the Aquitaine Shelf, the Basque Shelf, and the Iberian Shelf (Fig. 1) with a major morphological high, the Landes Plateau. The hydrocarbon Parentis Basin, created during the Pyrenean Orogeny, extends from the onshore to the offshore domain, in the southern part of the Aquitaine Shelf (Biteau et al., 2006) (Fig. 1).

The study area is located in the French EEZ (Exclusive Economic Zone) on the continental slope of the Aquitaine Shelf, from 200 m to 1600 m water depths, with a mean smooth slope of ~3° (Figs. 1 and 2). This area is 60–80 km westward of the coastline, between the Cap Ferret Canyon

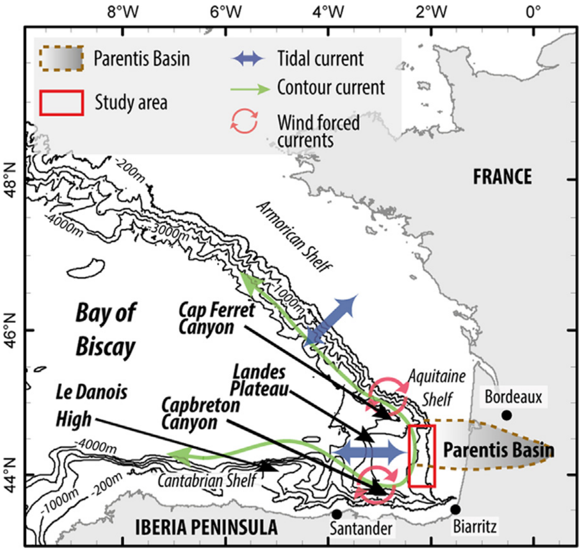

Fig. 1. Synthetic map of the Bay of Biscay with indication of the main current regimes (see references therein) and main isobaths (Sibuet et al., 2004). The study area (red rectangle) covers the western extension of the Parentis Basin (Biteau et al., 2006) and the eastern Landes Plateau.

(44°40′N) and the Cap breton Canyon (43°30'N). The study area can be divided into two main morphological domains. The northern part, from 44°35′50″N to 44°11′44″N of latitude, is deeply incised by east–west-oriented canyons with heads rooted at the shelf-break edge. There, the inter-canyon areas are kilometer-wide along the north–south axis (Fig. 2a) and are affected by slope instabilities within a context of silt dominated sedimentation (Schmidt et al., 2014). The southern part, from 44°11′44″N to 43°52′37″N of latitude, does not show any canyons, only some landslide scarps located at 230 m in water depth and a wide sediment-wave field located between 250 and 1000 m in water depth (Fig. 2), with a surficial sandy silt sedimentation, extending from the shelf break to the foot slope (Faugères et al., 2002; Gonthier et al., 2006). Sediment wave morphologies, with wavelengths between 800 m and 1600 m and heights from 20 m to 70 m show crests slightly oriented at an oblique angle of the main slope, between 010°N and 035°N. The influence of bottom currents in the formation processes of sedimentary waves along the Aquitaine slope has been indicated (Faugères et al., 2002; Gonthier et al., 2006). The sedimentary waves are covered by a thin homogenous layer corresponding to the U4 unit described by Faugères et al. (2002), which is 12–15 m in thickness (Gonthier et al., 2006) and pinches out on the upper slope between 400 and 300 m water depth. The surficial sedimentary cover of the Aquitaine Shelf is mainly composed of sand and silty sand (Cirac et al., 2000). Inactive pockforms and pockmarks have been described on the Landes Plateau (Baudon et al., 2013; Iglesias et al., 2010) and on the Basque Shelf (Gillet et al., 2008), respectively. Recently, Dupré et al. (2014a) described an active cold seep system at the edge of the Aquitaine Shelf without any pockmarks.

The hydrography regime of the study area appears to be complex, due to the semi-enclosed morphology of the