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Research paper

Controlling mechanisms of giant deep water pockmarks in the Lower Congo Basin

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ABSTRACT

Effective seal breaching is a major contributor to methane seepage from deep sea sediments as it ensures the migration of gas and liquid hydrocarbons from buried reservoirs to the seafloor. This study shows two giant pockmarks on the lower slope of the Lower Congo Basin associated with salt-tectonic faulting and the buried Pliocene Congo deep sea fan. The progressive burial of Pliocene fan deposits results in mobilization of methane from gas hydrates at the Base of the Gas Hydrate Stability Zone which migrates through the hemipelagic seal towards the seafloor along salt-induced faults. Seal-breaching in this part of the Lower Congo Basin relies solely on salt-tectonic faulting contrasting with upslope seafloor seepage settings where polygonal faulting within the hemipelagic seal occurs. Dedicated 2D and 3D seismic and acoustic surveying allows the detailed reconstruction of the evolution of pockmarks which appear to have been active for the last 640 kyr. We also show indications that the modern seafloor depression formed due to reduced sedimentation in the vicinity of active seepage. The presented seafloor seepage features illustrate the mode of gas release from the Pliocene fan in the Lower Congo Basin, which contrasts with previously investigated seepage environments further upslope.

1. Introduction

Seafloor methane or oil seepage depends on a supply of gas and/or liquid hydrocarbons from depth or intermediate reservoirs to support sustained seepage activity, which leads to the formation of a wide variety of seafloor topographic features such as mud volcanoes, pockmarks or diatremes (Judd and Hovland, 2007). Examples of such seepage sites have been found in many parts of the world's oceans in various geological settings starting during the 1980s, e.g., the North Sea (Hovland, 1981), the Gulf of Mexico (Paull et al., 1984) and the Northeast Pacific Margin (Davis et al., 1990; Suess et al., 1999). Seafloor seepage is widespread at passive continental margins, potentially prolific hydrocarbon areas, which are affected by salt tectonic activity (e.g. Gulf of Mexico, Lower Congo Basin). This is mostly because salt-tectonic deformation promotes pathways for fluid/gas migration that facilitate seafloor seepage (Rowan et al., 1999; Whelan et al., 2005). Pockmarks were first described on the Scotian Shelf (King and MacLean, 1970) and have since been widely discovered, mostly because of the increasingly detailed mapping of the seafloor (Judd and Hovland, 2007). Seepage phenomena in general and pockmarks in particular have been under investigation for the last decades in order to understand their functioning (Hovland, 1981; Heggland, 1997; Ondréas et al., 2005; Gay et al., 2006b; Cathles et al., 2010; Andresen, 2012; Ho et al., 2012; Serié et al., 2016), their impact on deep sea ecosystems (Sibuet and Olu, 1998; MacDonald et al., 2003), seafloor stability (Evans et al., 1996), and global climate (Judd et al., 2002; Riboulot et al., 2013). Recently, fluid system research has focused on potential migration pathways for ascending fluids, e.g. faults and their formation mechanisms, as these features dominate the leakage from hydrocarbon reservoirs as well as the formation of seafloor seepage features (Cartwright et al., 2007; Løseth et al., 2009, 2011; Andresen, 2012; Chand et al., 2012; Moss et al., 2012; Plaza-Faverola et al., 2015; Roy et al., 2015, 2016). Furthermore, the formation process of seafloor pockmarks is still only poorly understood and appears to include different stages and processes depending on what kind of fluid is seeping, its geological availability, the background lithology and oceanographic setting (Hovland et al., 2005; Sultan et al., 2010, 2014; Ho et al., 2012; O'Regan et al., 2015; Mazzini et al., 2016; Riboulot et al., 2016).

In this study, we investigate the geological setting and evolution of seepage features on the lower slope of the Lower Congo Basin

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(LCB). The area shows lithological and structural constraints for fluid migration and seepage that are distinct from upslope areas of the LCB. Especially the transition between the Miocene fan and the adjacent Pliocene fan to the West represents a major change in post-Miocene sedimentation. The presence of shallow Pliocene fan deposits and the absence of polygonal faulting on the lower slope led to the development of seafloor seepage that differs from morphologically similar sites of seepage activity in upslope areas of the LCB.

2. Geological setting

The study area is located in the northern part of the LCB (Fig. 1) in ~3000 m water depth ~35 km east of the seaward termination of the Cretaceous salt province (Fig. 2). The LCB was formed during the opening of the Atlantic Ocean and is generally dominated by large evaporite sequences as well as the input of large quantities of terrigenous sediment via the Congo River (Marton et al., 2000). Evaporites were deposited in the Aptian during the opening of the Atlantic Ocean and are the dominating factor in the structural evolution of the margin (Cramez and Jackson, 2000; Marton et al., 2000; Brun and Fort, 2004; Fort et al., 2004). In the study area, Aptian salt forms an imbricated toe thrust at several kilometers depth with associated diapiric structures further upslope (Fig. 1B) (Dupré et al., 2007). The salt is overlain by Cretaceous marine sediments including organic-rich clays that form hydrocarbon source rocks in the LCB (Burwood, 1999; Anka et al., 2009; Figueiredo et al., 2010). Approximately the upper km of the sedimentary column comprises Oligocene and Miocene fan deposits which accumulated prior to the formation of the Congo Canyon (Ferry et al., 2004; Anka et al., 2009). Channel-related sand bodies within these sequences may act as hydrocarbon reservoir rocks (Gay et al., 2003, 2006b; Fraser et al., 2005). Gases from such reservoirs have been found to be of mixed thermogenic and microbial origin (Gay et al., 2006a). Since the late Miocene, material from the Congo River mouth has effectively been transported through the Congo Canyon to the deep sea, thereby bypassing most of the slope (Babonneau et al., 2002; Anka et al., 2009). The deep sea fan (Fig. 1) that is fed by the Congo Canyon shows a thickness of up to 1 km and forms large parts of the sedimentary column in the LCB, covering older Tertiary fan deposits towards the deep basin (Anka et al., 2009). The study area (Fig. 1) was also subjected to sedimentation

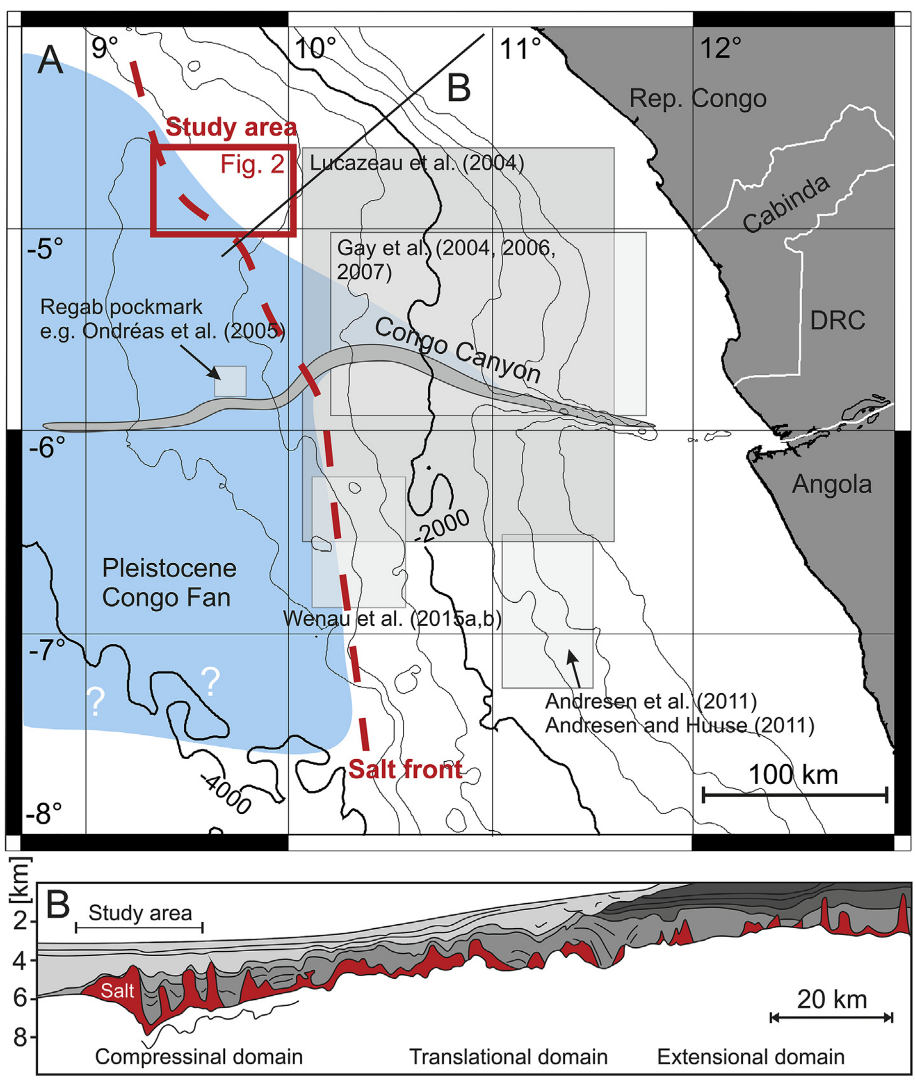

Fig. 1. A: Map of the Lower Congo Basin (LCB) showing the Congo Canyon and the extent of the Pleistocene Congo Fan in relation to the western boundary of the salt province. The study area is located in the NW part of the LCB seaward of the extensively investigated upper and middle slope. B: Regional seismic line from the northern LCB (redrawn from Dupré et al., 2007) showing the salt-tectonic regimes of the region. The study area is located at the salt front and influenced by diapiric structures.