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Research paper

Gas venting that bypasses the feather edge of marine hydrate, offshore Mauritania

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ABSTRACT

Methane can be released from the vast marine hydrate reservoirs that surround continents into oceans and perhaps the atmosphere. But how these pathways work within the global carbon cycle now and during a warmer world is only partially understood. Here we use 3-D seismic data to identify what we interpret to be a gas venting system that bypasses the hydrate stability zone (HSZ) offshore of Mauritania. This venting is manifested by the presence of the acoustic wipe-out (AWO) across a densely faulted succession above a salt diapir and a set of morphological features including a substantial, ~260 m wide and ~32 m deep, pockmark at the seabed. The base of the HSZ is marked by a bottom simulating reflector (BSR) which deflects upwards above the diapir, rather than mimicking the seabed. We use a numerical modelling to show that this deflection is caused by the underlying salt diapir. It creates a trapping geometry for gas sealed by hydrate-clogged sediment. After entering the HSZ, some methane accumulated as hydrate in the levees of a buried canyon. Venting in this locality probably reduces the flux of gas to the landward limit of feather edge of hydrate, reducing the volume of gas that would be susceptible for release during a warmer world.

1. Introduction

Methane is a potent greenhouse gas and vast quantities of it are stored in marine hydrate, a crystalline lattice of water and methane-dominated gas (Sloan and Koh, 2008). Its susceptibility to ambient conditions (pressure, temperature and salinity) makes it an unstable large carbon capacitor (Dickens, 2003; Ruppel, 2011). Long-term atmospheric temperatures could change if a small proportion of released gas entered the atmosphere (Archer et al., 2009). Therefore, understanding under what circumstances methane can bypass hydrated sediment and enter the atmosphere is important for assessing the impact of deep-buried methane on climatic change. Vigorous gas plumes in which gas bubbles rise within clusters and reach sea surface before not all of these gases are dissolved and oxidised in water body (McGinnis et al., 2006). This mechanism could take place where effective venting systems operate.

The feeder system for the gas vents can be detected by seismic imaging and can take the form of gas chimneys, which are vertically aligned reflections that probably represent clusters of hydraulic fractures (Hovland and Judd, 1988; Cartwright et al., 2007). Gas-rich pore fluid can be vented at different flux rates (Roberts, 2001). As a result, the morphological feature at the seabed can be pockmarks (Moss and Cartwright, 2010), pingoes that host hydrate in the near-seabed sediment (Serié et al., 2012), and mud volcanoes produced by the outflowing mud and water (Milkov, 2000). Gas venting from these point sources constitutes an important part of the known output of gas escaping from marine sediments (Judd, 2003).

Here we use 3-D seismic dataset to image what we interpret to be a gas venting system in which gas bypasses the feather edge of marine hydrates. What is unique here is the spatial relationship between the feather edge and the gas vent. It increases gas emission and hence prevents free gas from migrating landward, thus

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reducing the volume of gas located in the feather edge of hydrate, that is susceptible to melting during short-term ocean warming.

2. Gas hydrate and feather edge

In deep-water settings gas hydrates can be revealed by a bottom simulating reflector (BSR) in seismic reflection data. It marks the base of the hydrate stability zone (HSZ) and is produced by an acoustic impedance contrast between sediments containing gas and hydrate (Shipley et al., 1979; MacKay et al., 1994). This base shallows landwards until it intersects the seabed and this zone is termed the feather edge, a critical site for understanding the dynamics of marine hydrate (Ruppel, 2011; Berndt et al., 2014). Here ~3.5% of the global gas hydrate inventory is trapped (Ruppel, 2011) and warming of bottom water can destabilise the near-seafloor gas hydrate, which is evidenced by the presence of gas plumes (Westbrook et al., 2009; Skarke et al., 2014) and predicted by numerical modelling (Phrampus and Hornbach, 2012; Marín-Moreno et al., 2013). The released methane can lead to ocean acidification and deoxygenation and perhaps climatic warming (Kvenvolden, 1993; Archer et al., 2009; Biastoch et al., 2011).

3. Geological setting

The sedimentary features along the Mauritanian continental slope include canyon channel systems, submarine slides and contourite moats (Krastel et al., 2006). The sedimentation rates in different locations vary considerably (Krastel et al., 2006). Core samples of up to 10 m long were recovered from GeoB 8509-2, GeoB 8520, GeoB 9624-1, GeoB 9623-2 and GeoB 9626-1 and show that the near-seabed deposit is predominately turbidite and hemipalegic sediments (Zühlsdorff et al., 2007; Henrich et al., 2008, 2010). Halokinesis is evidenced by the diapiric structures in a narrow elongate zone between 16 °N and 19 °N offshore the West Africa Continent and the age of the salt is probably Early Jurassic (Rad et al., 1982). A salt diapir (located in 18°30′N, 16°50′W) has been revealed by the negative Bouguer Anomaly. The study area is to the south of the Tioulit Canyon (Fig. 1). To the north seismic features of complete feather edge have been recorded before (marked by blue box of solid line in Fig. 1a, Davies et al., 2015).

Two wells, Chinguetti-6-1 and V-1, have been drilled within the 3-D seismic survey and ~30 km north of the study area, confirming that the coastal basin of Mauritania is a potential petroleum province and the Cenomanian-Turonian mudstones are able to generate hydrocarbons (Vear, 2005). Seismic features linked to vertical gas migration include seismic chimneys (Davies and Clarke, 2010) and large-scale gravity-driven faults (Yang and Davies, 2013). The BSRs, either relict or modern ones, can be observed, which makes this site ideal to research methane recycling in marine hydrate system (Davies and Clarke, 2010; Davies et al., 2012a,b).

4. Seismic dataset and methodology

The 3-D seismic data cover an area of ~4000 km^2. They have been processed by multiple suppression and post-stack time migration. The final bin spacing is 25 m × 25 m. These data are

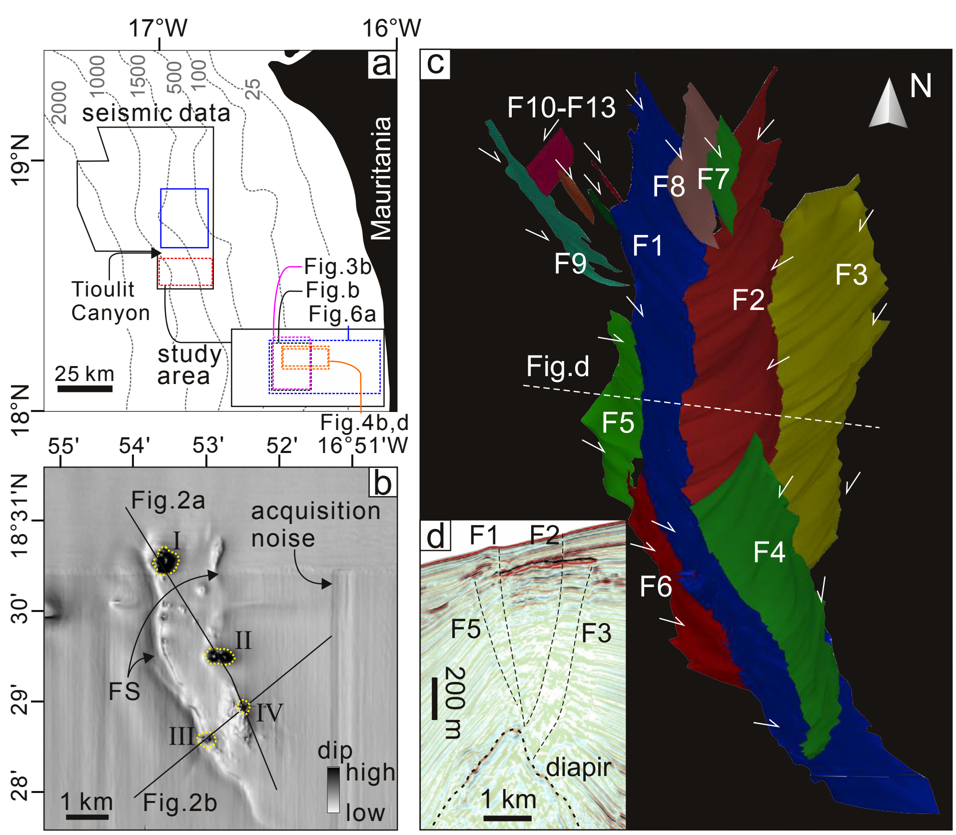

Fig. 1. (a) Extent of the area covered by the 3-D seismic survey and the location of the study area. The blue box of solid lines marks where the relatively complete feather edge was described by Davies et al. (2015). (b) Dip-magnitude map of the seabed in the study area showing the fault scarp and some reliefs (named as I, II, III and IV). FS – fault scarp. There are some linear features caused by acquisition noise and they are parallel to the inline direction. (c) 3-D imaging of the faults (named as F1–13) from top view. The white arrows mark the displacement direction of the hanging wall. Please note not all the faults terminate at the seabed. (d) A representative seismic cross section showing the pattern of the faults and their spatial relationship between the underlying salt diapir. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)