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Research paper

Methane hydrate recycling offshore of Mauritania probably after the last glacial maximum

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A B S T R A C T

To what extent methane liberated from marine hydrate will enter the ocean during a warmer world is unknown. Although methane release due to hydrate dissociation has been modelled, it is unclear whether or not methane will reach the seafloor during a warmer world and therefore contribute to oceanic and atmospheric budgets. Here we show, using a new three-dimensional (3-D) seismic dataset, that some hydrate deposits surround the gas chimneys passing through the HSZ. Bottom water warming since the last glacial maximum (LGM) is interpreted to cause hydrate dissociation but critically some of the released methane was not vented to the ocean. The released gas caused seal failure and free gas entered the hydrate stability zone (HSZ) through vertical gas chimneys to where new hydrate accumulations formed. This process is a new evidence for methane recycling and could account in part for the lack of methane in ice core records that cover warming events during the late Quaternary. This research provides new insight into how methane could be recycled rather than vented during a warmer world.

1. Introduction

Methane is a potent greenhouse gas and vast quantities of it are locked-up in marine hydrate along the continental margins (Kvenvolden, 1993). Methane released from hydrate could have a role in accelerated climatic warming, ocean acidification and de-oxygenation (Biastoch et al., 2011; Dickens, 2003). There is already potential evidence, such as plumes of gas bubbles, for methane liberated from hydrates venting into the ocean due to oceanic warming in the Arctic (Westbrook et al., 2009) and along the US Atlantic margin (Phrampus and Hornbach, 2012; Skarke et al., 2014). But isotopic records that cover rapid Quaternary climate change events from ice cores of polar region indicate that methane from hydrate is not released during periods of rapid warming (Sowers, 2006). Methane stored in hydrate is probably a contributor rather than the main source of atmospheric methane budget after the last glacial maximum (LGM, Chappellaz et al., 1993). The fundamental question of whether large amount of methane from hydrate escapes into oceans and the atmosphere remains unanswered. If it did not reach the seabed, how is methane retained in the subsurface?

Hydrates are usually identified in marine settings through the identification of bottom simulating reflectors (BSRs) in seismic reflection datasets. BSRs mark the base of the hydrate stability zone (BHSZ) below which free gas is often trapped and this configuration yields a medium to high acoustic impedance contrast (Shipley et al., 1979). As the water depth shallows at continental margins, the BSR also shoals and seismic imaging sometimes shows examples of it intersecting the seabed at a water depth between ~350 and ~600 m (Boswell and Collett, 2011). In general the ascent of methane into the hydrate stability zone (HSZ) should be impeded, as hydrates clogs interconnected pores and fractures (Nimblett and Ruppel, 2003). But methane can sometimes pass through the HSZ and arrive at the seabed (Liu and Flemings, 2006). Seismic evidence for this methane venting is often gas chimneys with pockmark at the seabed and they are thought to represent the occurrence of vertical migration of pore fluid (Hovland and Judd, 1988; Cartwright and Santamarina, 2015).

Venting into the atmosphere is not necessarily the fate of gas that has been liberated from methane hydrate. Methane could be recycled to the BHSZ (Davies and Clarke, 2010; Paull et al., 1994), dissolved into the ocean and replaced by other gases such as oxygen during its ascent (McGinnis et al., 2006) and oxidised aerobically in the shallow ocean (Ward et al., 1987) or anaerobically in the sub-

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seabed sediment (Hoehler et al., 2000). Using a new 3-D seismic survey offshore of Mauritania, we consider the fate of methane liberated due to oceanic warming since the LGM as a potential scenario for how marine hydrates will behave due to a future warmer world.

2. Geological setting

The area covered by the 3-D seismic survey is offshore of Mauritania (Fig. 1) where the water depth ranges from 50 to 1800 m (Fig. 1b). The shelf-slope break occurs at ~120 m water depth and the continental slope dips at ~3°. In the southeast of the survey there are a number of canyons that are part of the Cap Timiris Canyon system. The study area is located between two of these canyons and covers an area of ~23 km^2 and the uppermost ~100 m of the sedimentary succession. It is most likely dominated by the fine-grained hemi-pelagic sediment interbedded with turbidite mud and sand, deposited during alternating climatic periods of aridity and humidity in the Pleistocene and Holocene (Henrich et al., 2008; Zühlsdorff et al., 2007). The gravity cores of GeoB 8507-3 (Fig. 1a) record the uppermost 10 m-thick sediments in the Timiris Canyon and show that the sedimentation rate averages at 190 m/my (metres per million years) in the Holocene (Zühlsdorff et al., 2007), but this rate may not be typical in the study area. This rate can be up to 685 m/my in the records of GeoB 8509-2 (Zühlsdorff et al., 2007). The commercial wells, Ras Al Baida-1 and Al Kinz-1, show that there are traces of hydrocarbons throughout late Cretaceous and Paleogene sediments (Vear, 2005). Gas migration in the marine hydrate system has been documented in the area covered by another 3-D seismic survey offshore of Mauritania, which is ~130 km to the south of the study area (Davies et al., 2012; Yang and Davies, 2013; Yang et al., 2013; Davies et al., 2014).

3. Seismic data and methodology

The 3-D seismic data cover an area of ~3800 km^2. The bin spacing is 12.5 m × 25 m. The recording is cut by a frequency filter of 3–200 Hz. The dominant frequency in the upper 100 m-thick sediment is 55 Hz. These data have a sampling rate of 2 ms and are zero-phased. They are displayed in the depth domain after being Kirchoff depth migrated. The velocity model for this migration is not provided in this research. A positive polarity is defined by a peak on the seismic trace and displayed by a black-red-black seismic loop on the cross section, which represents an increase in the acoustic impedance. The extracted seismic attributes include RMS (root mean square) amplitude and dip-magnitude. The maps of these attributes are utilised to pinpoint the hydrate/gas and visualise the migration-related features (e.g. pockmarks) in an area of interest.

The BSR is picked along the troughs of the seismic traces that together produce a reflection usually cross-cutting the stratal reflections. At the places where this cross-cutting cannot be identified the BSR depth is inferred by linear interpolation or consistent with the high-amplitude, horizon-parallel reflection. A numerical model for 2-D heat conduction is used to simulate the location of the present BHSZ (appendix) and validate the interpretation of the BSR.

4. Observations

4.1. Seabed and BSR

The seabed dips to the southwest and only one pockmark (~200 m in diameter) is found to the northeast of the landward terminus of the BSR (Fig. 1b). No seabed amplitude anomaly can be

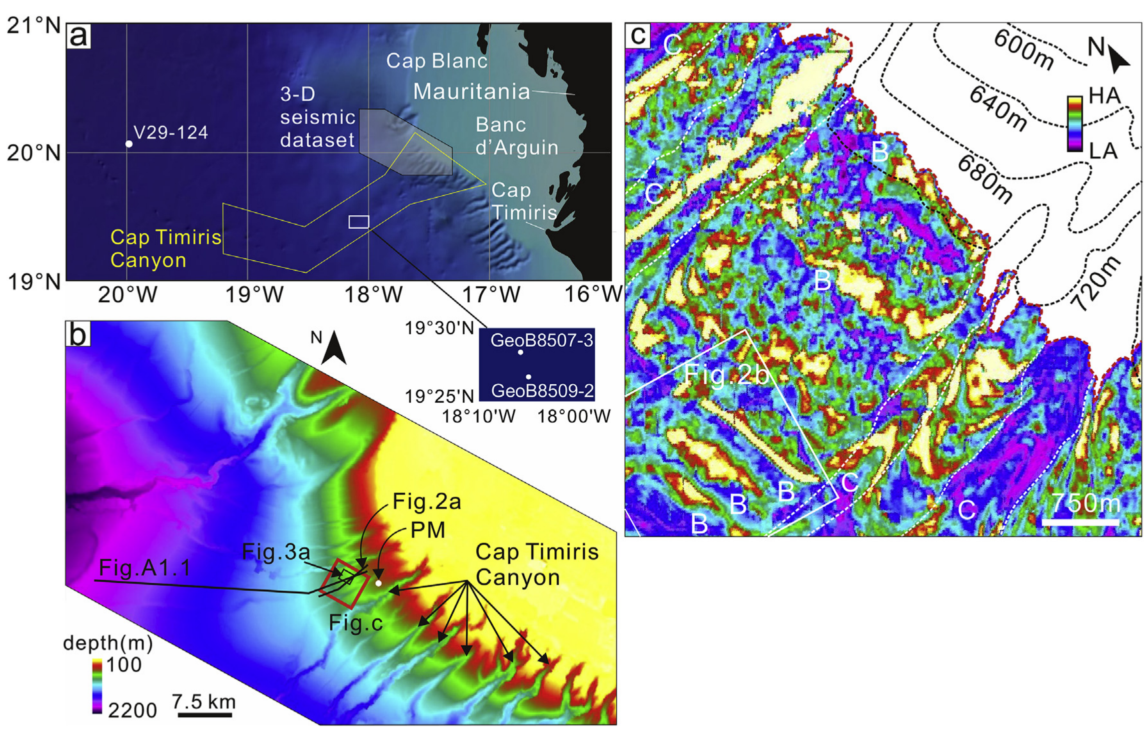

Fig. 1. (a) Location of the 3-D seismic survey. The base map is from the online data provided by National Geophysical Data Centre (https://www.ngdc.noaa.gov/). Data of geothermal gradient and heat flow was measured at site V29-124 in 1977. (b) Bathymetric map showing the morphology of the seabed. Red box – study area. PM – pockmark. (c) The RMS amplitude map of the BSR in the study area. Red dashed line marks the landward extent of BSR and black dashed lines represent isobaths. The seismic features of bands (B) are interpreted in section 5.1. C – canyon, HA – high amplitude, LA – low amplitude in this and subsequent figures. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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