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Gas hydrate reservoir and active methane-venting province in sediments on <20 Ma young oceanic crust in the Fram Strait, offshore NW-Svalbard

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ABSTRACT

Seafloor pockmarks are common indicators for vertical fluid flow and frequently associated with methane discharge through the gas-hydrate stability zone (GHSZ). The present-day flux through these degassing systems is presumably at a low level on most rifted continental margins. A pockmark-field on the NW-Svalbard passive margin is located on young ocean crust (<20 Ma) and shows evidence of ongoing, episodic degassing.

New geophysical data from the Vestnesa Ridge (~79°N), a mounded and elongated sediment drift in the eastern Fram Strait, reveal a gas-hydrate, free-gas and venting system that is exceptionally more dynamic than documented elsewhere along the northeastern North Atlantic margin. The prominent bottom-simulating reflection (BSR), about 200 mbsf, separates anomalously high P-wave velocities in the GHSZ from a remarkable underlying low-velocity zone, indicating the presence of gas hydrate and gas in the pore space. Inversion of P-wave velocity data using the differential effective medium theory yields a two-dimensional concentration model of methane hydrate and free gas. The model predicts saturations of up to 11% in the hydrate reservoir, which due to the seafloor topography forms a large anticlinal permeability-barrier. Below, in the low-velocity zone (i.e., 1350–1500 m/s), up to 3% of free gas is predicted across the apex of the Vestnesa Ridge and in the immediate vicinity of extensional faults. A conservative estimate indicates that 225 kg/m^2 of pure methane is stored in hydrate and gas in the upper 230 m of the sedimentary column.

An elongated pockmark-field, consisting of >100 individual pockmarks up to 600 m wide, systematically aligns the apex of the Vestnesa Ridge. Active, vigorous degassing from the topography-controlled pressure-valve system was evident from a 750-m-high and ~150-m-wide gas flare observed in the water column during a cruise with R/V Jan Mayen in October 2008. The gas flare documents dynamic degassing through the corresponding chimney, which penetrates the entire GHSZ and into the underlying free gas zone. Cruises in 2006 and 2007 did not detect active gas venting above the pockmark-field. Accordingly, vigorous degassing may operate in an episodic mode, where hydrothermal circulation systems through young ocean crust may play a significant role.

1. Introduction

The dynamic behavior of methane hydrate in subsurface marine environments has been a major focus of studies related to rapid climate change (e.g., Kennett et al., 2003; Dickens, 2004) and geohazards (e.g., Vogt and Yung, 2002; Mienert et al., 2005). Methane escape from the seafloor through the overlying water column may contribute to anomalies of methane in the atmosphere (Shakhova et al., 2008). Since many regions of continental margins document gas/fluid-escape chimneys that may terminate in pockmarks at the seafloor (Judd and Hovland, 2007), this geological fluid flow is becoming an important area of multidisciplinary research in Earth science.

The recent discovery of hundreds of gas flares on the NW-Svalbard shelf and the east Siberian shelf provides evidence for ongoing methane discharge from the seafloor to the hydrosphere (Nature News, 2008). Here, we document active gas venting from a confined deep-water gas hydrate and free gas reservoir at the Vestnesa Ridge in the eastern Fram Strait (~79°N), the only deep-water gateway between the Arctic and the northern Atlantic Ocean. The area is adjacent to a mid-ocean spreading centre situated on <20 Ma young ocean crust (Engen et al., 2008), and is atypical to most hydrate provinces found along continental margins in terms of its oceanographic and tectonic setting (Fig. 1).

The ice-like substrate of gas hydrate consists of light hydrocarbons (mostly methane) entrapped by a rigid cage of water molecules. Gas hydrates occur naturally in the pore space of sediments when

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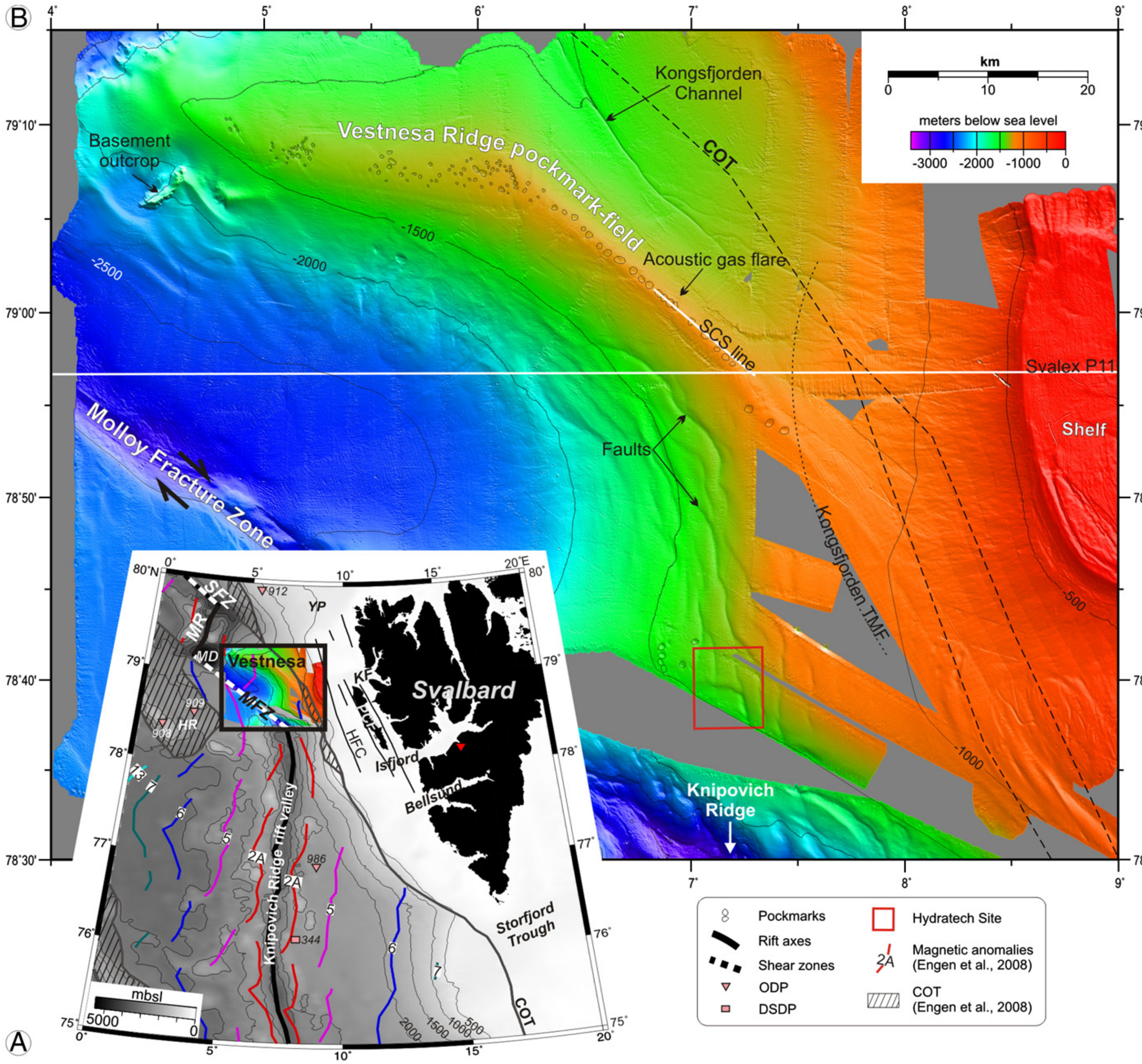

Fig. 1. A) Bathymetric map (IBCAO; Jakobsson et al., 2000) of the eastern Fram Strait and the W-Svalbard margin. The slow-spreading Molloy Ridge (MR), the Molloy Fracture Zone (MFZ), and the continent–ocean transition (COT) defines the up to 5 km thick sedimentary succession in the Vestnesa Ridge region. Magnetic anomalies C6 (19.6 Ma), C5 (9.8 Ma), and C2A (2.8 Ma) illustrate the young sub-sedimentary oceanic crust offshore NW-Svalbard (from Engen et al., 2008). B) Swath bathymetry shows the morphology of the Vestnesa Ridge sediment drift in detail. The discovery of a gas flare in the water column above one pockmark (location is annotated; October 27 2008) proves that the topographically controlled pockmark-field at the ridge crest (Vogt et al., 1994, 1999) is periodically active. Northward propagation of the Knipovich Ridge (Crane et al., 2001) and/or thermal subsidence of the oceanic basin are responsible for recent or ongoing extensional faulting of the sedimentary cover. The dashed and dotted lines mark the COT and the seaward limit of the glacigenic sediments of the Kongsfjorden trough-mouth-fan (TMF), respectively. Solid white lines show the location of seismic data. Abbreviations; SFZ, Spitsbergen Fracture Zone; MD, Molloy Deep; HFC, Hornsund Fracture Complex; YP, Yermak Plateau; HR, Hovgård Ridge; KF, Kongsfjorden, PCF; Prins Carls Foreland.

appropriate high pressure and low temperature conditions exist (Sloan, 1998). These requirements confine gas hydrates to the upper few hundred meters of sediments, the gas hydrate stability zone (GHSZ). Its base typically mimics the seafloor and is recognized as bottom simulating reflector (BSR) on seismic data. Pure gas hydrate has high P-wave velocity (>3000 m/s), and thus partially hydrate-saturated sediments are characterized by higher velocities than brine-saturated sediments (Ecker et al., 1998). The presence of hydrate in the pore space reduces porosity and permeability of the sediment, and typically, their occurrence form a hydrological seal for upward migrating fluid and gas (Nimblett and Ruppel, 2003). Hence, if only a small percentage of free gas is trapped below the GHSZ the P-wave velocity may sharply decrease to below the acoustic velocity of water (i.e., 1475 m/s; Ecker et al., 1998).

The high, negative acoustic impedance contrast across the phase-boundary between gas hydrate above and free gas below typically produces a distinct BSR (Shipley et al., 1979). Given that BSRs arise by the seismic response from the top of the free gas zone (FGZ), the absence of a BSR does not exclude the presence of gas hydrate (Holbrook et al., 1996; Bünz and Mienert, 2004). The P-wave velocity anomalies produced by the presence of gas hydrate and free gas relative to the velocity–depth trend of brine saturated porous media,