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Submarine pingoes: Indicators of shallow gas hydrates in a pockmark at Nyegga, Norwegian Sea

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Abstract

Complex pockmarks up to 300 m wide and 12 m deep are located in the Nyegga area in the Norwegian Sea. Bathymetric data and direct visual documentation and sampling with ROVs (remotely operated vehicles) have shown that these pockmarks contain abundant methane-derived authigenic carbonate rocks. Furthermore, geochemical results and the finding of seep-associated organisms, including tubeworms and bacteria shows that the pockmarks are still active fluid flow locations [Hovland, M., Svensen, H., Forsberg, C.F., Johansen, H., Fichler, C., Fosså, J.H., Jonsson, R., Rueslåtten, H., 2005. Complex pockmarks with carbonate-ridges off mid-Norway: Products of sediment degassing. Marine Geology, 218, 191–206.]. Here we report the discovery of localized pingo-like sediment mounds up to 1 m high and 4 m wide. They occur inside one of the Nyegga complex pockmarks, 'G11.' All of the seven structures we investigated have four characteristics in common. (1) They have a positive topography (rounded mounds and cones). (2) They are partly covered in bacterial mats (indicating ongoing fluid flow). (3) They are partly covered in a carpet of small, living tubeworms (polychaetes, which utilize methane). (4) They have distinct corrosion pits on their surfaces, indicating fluidization and point-source corrosion of the covering sediments (probably caused by localized sub-surface hydrate dissociation). We interpret the features as true submarine pingoes, formed by the local accumulation of hydrate (ice) below the sediment surface. It is inferred that the pingoes are formed as documented hydrocarbon gases, methane, ethane, propane, and butane migrate upwards through distinctive sub-surface channels or conduits inside the pockmark. We suggest that these submarine hydrate-pingoes manifest the exact locations where fluid flow through the seafloor is currently active, and that they can therefore be used as small-scale indicators of active seepage.

Keywords: hydrate pingo; complex pockmark; Nyegga; gas hydrates; fluid flow; sediment stability; shallow gas; methane flow; porewater flow

1. Introduction

It has long been known that gas hydrates hosted in oceanic low-permeable sediments have the ability to deform the sediment surface (Soloviev and Ginsburg, 1994; Ginsburg and Soloviev, 1998; Clennell et al., 1999; Hovland et al., 2001). Submarine structures suspected to have originated from the formation and dissociation of sediment-hosted gas hydrates have previously been described as 'hydrate mounds' (Aharon et al., 1992; MacDonald et al., 1994; Ginsburg and Soloviev, 1994; Sager et al., 2003; Chapman et al., 2004), 'giant gas mounds' (Kvenvolden, 1988; McConnell and Kendall, 2002), disruption craters (Prior et al., 1989; Lammers et al., 1995), sediment slides (Schmuck

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and Paull, 1993; Sultan et al., 2003) and large collapse features (Dillon et al., 1998).

Normal water-ice related pingoes have been described from offshore permafrost regions (Shearer, 1971; Bondarev et al., 2002). However, to our knowledge, submarine hydrate 'pingo-like structures' have only been found in Barklay Canyon, on the northern Cascadia Margin, Pacific Ocean (Chapman et al., 2004). But whereas the features we describe herein are totally covered and hidden by sediments (like the ice in terrestrial pingoes), the Barklay Canyon features represent large bodies of partly exposed massive gas hydrates covered by a very thin sediment dusting. The objectives of this paper are to characterise a new discovery of submarine hydrate pingoes from the mid-Norwegian margin, suggest a viable formation mode, and briefly discuss the implications for seep detection.

We discovered small (up to 1 m high) suspected submarine hydrate pingoes during a detailed visual ROV survey into complex pockmark "G11" at Nyegga (64°40′00″ N, 05°17′30″ E) an area also called 'the NE flank' of the Storegga slide offshore mid-Norway (Hovland et al., 2005).

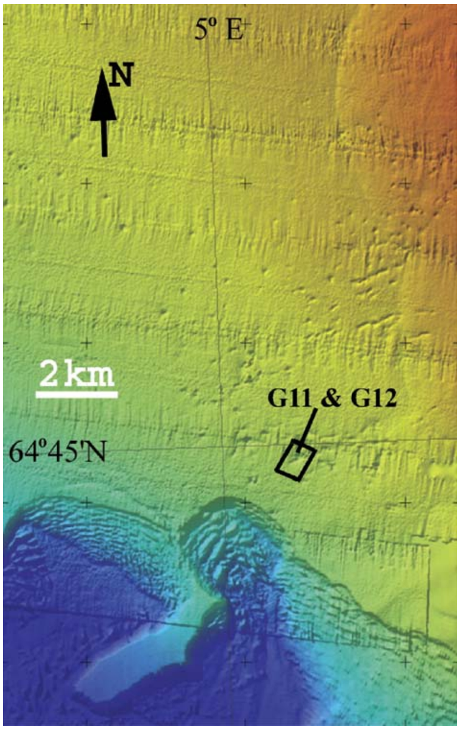

Fig. 1. General location of study area G11 (within small rectangle, see Fig. 2) is shown on this digital terrain model over the Nyegga area. Note that parts of the north-eastern failure front of the Storegga Slide occurs only 2 km south of the study area.

2. Geological setting

The seabed of the Nyegga region has a general slope angle of only 1° and represents the 'shoulder' of the continental slope leading down to abyssal depths of about 3000 m in the Norwegian Sea Basin, to the west. The region we studied (Fig. 1) lies at the border between two large sedimentary basins: the Møre Basin to the south, and the Vøring Basin to the north (Bünz et al., 2003; Hovland et al., 2005). A prominent BSR occurs in the Nyegga region and spreads to the north, west, and south of our study area (Mienert et al., 1998; Gravdal et al., 2003; Bouriak et al., 2000; Hovland et al., 2005). However, the presence of gas hydrates in this area has never been verified by sampling. More details of the general geological setting relative to the complex pockmarks of Nyegga can be found in Hovland et al. (2005). Our study area (Fig. 2) lies only 2 km north of the northern failure front (slide scar) of the Storegga Slide (Bugge, 1983; Bryn et al., 2003).

The pockmarks of the Nyegga area are morphologically more complex than 'normal' seabed pockmarks (Hovland and Judd, 1988), and occur as near-circular, up to 12 m deep and 300 m wide depressions. Their most distinctive feature is the occurrence of chaotic heaps of large carbonate rocks and slabs, which protrude from the central part of the depressions up to the mean surrounding seafloor level or, even slightly higher. A total of four complex pockmarks, named: A, C, G8, and G11 were investigated in 2003 (Hovland et al., 2005). The pockmarks are located at water depths between 600 and 750 m, and contain a variety of carbonate morphologies dominated by low $\delta^{13}C$ aragonite. Shallow push-cores from G11 showed the presence of occluded and adsorbed light hydrocarbon gases (Hovland et al., 2005).

On 2D-seismic records, the pockmarks are seen to occur immediately above vertical 'chimneys' or pipes (also called 'wipeout' zones, and 'blow-out pipes'), which extend down to and in some cases beyond the BSR, about 200 m sub seafloor (Mienert et al., 1998; Bünz et al., 2005). They are inferred to represent an endmember of a megapolygonal fault system.

3. Methods

We discovered small (up to 1 m high) mounds during a detailed visual ROV survey into complex pockmark 'G11' at Nyegga (64°40′00″ N, 05°17′30″ E) offshore mid-Norway (Hovland et al., 2005).