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Catastrophic fluid escape venting-tunnels and related features associated with large submarine slides on the continental rise off Vesterålen–Troms, North Norway

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ABSTRACT

Video inspection of the seabed on the continental rise (ca. 2200 m water depth) off Vesterålen–Troms, North Norway has revealed several remarkable features, including large tunnels, small tunnels, chimney tunnels, carbonate crusts and bacterial mats. The structures occur in landslide areas with slide blocks up to 2 km long, 1 km wide and 100 m high. We hypothesize that the large seabed tunnels, in and between slide blocks and with opening diameters up to 1 m and apparent inner diameters of 10–20 cm, are formed by dewatering of fine-grained sediments buried by the slide masses and possibly venting of underground gas reservoirs related to sliding and loading. This process probably occurred instantaneously after sliding. Numerous small tunnels with diameters up to a few centimetres, in slide blocks of compacted sediments, may have formed by dewatering following sudden pressure release or by decomposition of gas hydrates following off-loading of sediments due to sliding. Bacterial mats and carbonate crusts indicate active leakage of subsurface fluids and methane through the seabed and the gas hydrate stability zone, either from thermogenic sources or from shallow reservoirs. Cemented chimney tunnels up to 15 cm tall, and with inner diameters up to a few centimetres occur both on slide blocks and on flat and even seabed. The presence of apparently both inactive and active chimney tunnels indicates that gas and fluid release is a process that has been periodically active, possibly from before sliding up to the present.

1. Introduction

Seabed seeps occur in many geological settings, including subduction zones (Ashi et al., 2002; Collier and Lilley, 2005; Jin et al., 2011), translational margins (Orange et al., 1999), hydrothermal vents (Rona and Clague, 1989; Giambalvo et al., 2000) and mud volcanoes (Damm and Budeus, 2003; Milkov and Etiope, 2005; Perez-Garcia et al., 2009). Numerous seabed pockmarks are also indicative of seeps from deeper layers, e.g. Bøe et al. (1998), Rise et al. (1999) and Chand et al. (2009, 2012). Seeps are important because they may give an indication of which geological processes are active, although recognition and correct interpretation of seep related features may be challenging.

This paper is based on data collected by the MAREANO programme (Marine AREAl database for NOrwegian waters), that conducts detailed mapping of topography, geology, biology and pollutants along the Lofoten–Vesterålen passive margin and in the southwestern Barents Sea (www.mareano.no) (Fig. 1). One driver for this mapping program is the ongoing consideration by the government of Norway to open the Lofoten–Vesterålen margin for hydrocarbon exploration. MAREANO aims to map physical setting, fauna and environmental status prior to any such activities.

Seabed video inspection used to map megafauna (>5 cm) and document habitats (Mortensen et al., 2009), has uncovered large and small tunnels, chimney tunnels, carbonate crusts and bacterial mats on the seabed (Bellec et al., 2010a, 2010b). The aim of this paper is to describe these features and suggest possible processes behind their formation.

The study area is situated on the continental rise off Vesterålen–Troms, North Norway (Fig. 1) which has been affected by major canyon formation and slide activity (Laberg et al., 2000; Rise et al., submitted for publication). The structures described occur in very rugged terrain (Buhl-Mortensen et al., 2010a, 2012a; www.mareano.no) interpreted to be formed by enormous landslides.

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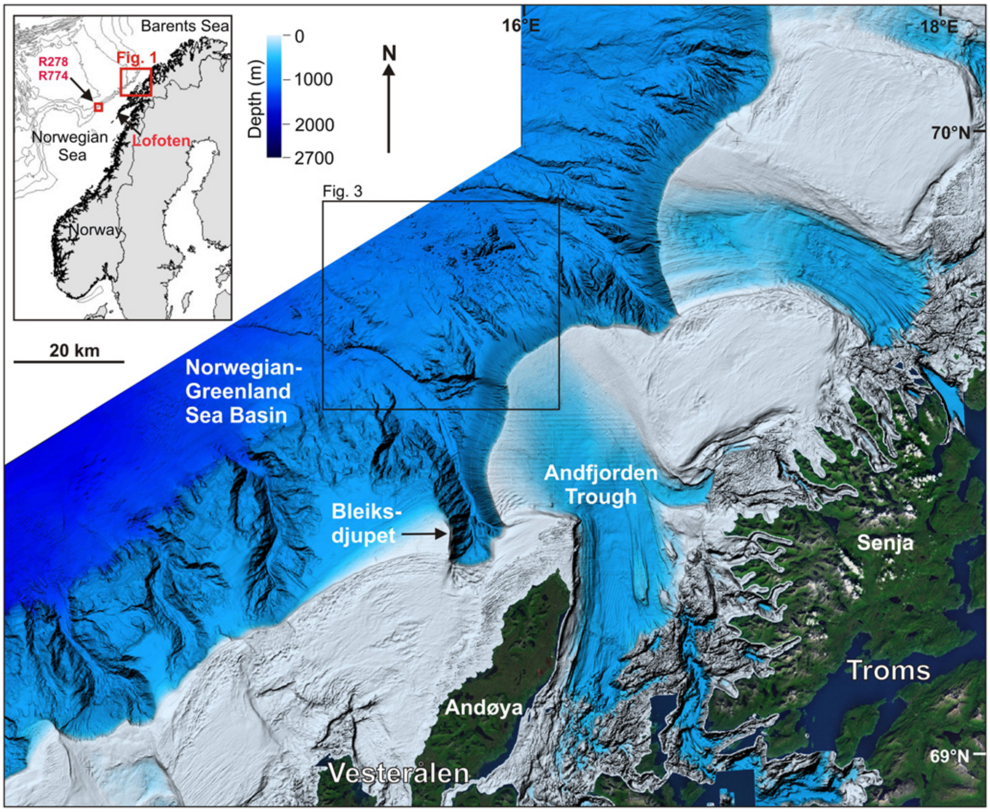

Figure 1. Overview map with location of study area. Shaded relief illuminated from the northwest.

2. Physical setting

2.1. Geological setting

During the Quaternary, glacial ice streams repeatedly advanced through fjords, onto the continental shelf following glacial troughs, and to the shelf edge. The Andfjorden Trough (Fig. 1) was the major pathway for transport of sediments to the continental shelf and slope in this region while the high mountains of Lofoten–Vesterålen partly protected the shelf outside Andøya from glacial advances (Rise et al., 2012). The last, late Weichselian ice sheet reached a maximum around 18 000 ^{14}C BP, while deglaciation along this margin took place from ca. 15 000 ^{14}C BP on the outer shelf, according to the dated onset of glaciomarine and then open-marine sedimentation (Vorren and Plassen, 2002). At ca. 13 600 ^{14}C BP the ice margin was located along the present coast of Vesterålen, while Andfjorden was deglaciated later (Vorren and Plassen, 2002; Ottesen et al., 2005; Knies et al., 2007).

Below the outer continental shelf and the continental slope the Quaternary sediment thickness is several hundred metres (Zwaan et al., 1998). Underlying the Quaternary is a thick succession of Tertiary and Cretaceous sedimentary rocks (Zwaan et al., 1998) that thins to the northwest. The sediment thickness in our study area is largely unknown although new data suggest that the Plio-Pleistocene succession is around 1 km (Rise et al., submitted for publication). Sea-floor spreading has operated since early Eocene times in the Norwegian–Greenland Sea Basin, and the steep continental slope may be explained by rapid thinning of the continental crust at the Lofoten–Vesterålen margin (Rise et al., submitted for publication). The continent–ocean boundary is located farther west (Olesen et al., 2007), where the area was influenced by volcanic processes (Tsikalas et al., 2008).

The continental slope has been affected by major canyon formation and slide activity (Laberg et al., 2000; Rise et al., 2009) (Fig. 2). Rise et al. (submitted for publication) suggest that canyons have been periodically active since mid Tertiary times. It is thus possible that slide deposits, with mega-slide-blocks, could be as old as Tertiary. This part of the Norwegian margin is seismically active (Byrkjeland et al., 2000), which could be a factor explaining the numerous slides. Present sedimentation rates on the continental rise are generally low (Rise et al., submitted for publication) and the seabed is locally undergoing erosion.

2.2. Bathymetry

The study area is located off Andøya and Andfjorden, where the Norwegian continental shelf is at its narrowest (40–60 km wide) (Figs. 1 and 2). The distance from land to canyon head (Andøya to the entrance of Bleiksdjupet, Andøya Canyon cf. Laberg et al., 2007) is only 10 km, and this is the deepest submarine canyon on the Norwegian margin (1 km from its shoulders to the thalweg). The shelf comprises glaciated banks, 50–200 m deep, cut by glacial shelf-crossing troughs 150–500 m deep (Buhl-Mortensen et al., 2012). Water depth on the continental slope increases to more than 2000 m over a distance of only 20 km, at which depth there is transition to a wide continental rise.

2.3. Oceanographic setting

Three well defined water masses occur offshore Vesterålen–Troms (Mosby, 1968; Ersdal, 2001; Ingvaldsen et al., 2004;