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Migration pattern of methane related to glacio-tectonic deformation of marine deposits in the Kattegat-Skagerrak area

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Abstract. Numerous seeps of Pleistocene methane occur in the northern Kattegat. The seeps are found where glacigene marine deposits are found at shallow sub-bottom depths. Migration probably occurs where Eemian-Weichselian marine deposits have been deformed by glacial tectonic to depths of 100 m or more. No seepage of methane occurs from areas with Holocene methane, due consumption by sulphate reduction in the upper sub sea-floor layers.

1 Introduction

The contribution of methane from coastal areas to the atmosphere is presently being investigated as part of the METROL project sponsored by the EU. One area of interest is the northern Kattegat – Skagerrak area where numerous methane seeps are present. Some of them have been observed directly, others were inferred from methane derived carbonate cement on the sea-floor, Fig. 1. The relationship between methane and carbonate cement was documented using stable carbon isotopic analyses – the cement being very much depleted with respect to carbon-13, δ^{13}C: ÷45‰ to ÷55‰ (Jensen et al., 1992) compared to normal marine carbonates, δ^{13}C ∼0‰. Thus, the carbonates were formed as a result of methane oxidation at shallow depths below sea-floor.

A previous estimate of the methane contribution from the Kattegat seeps, equivalent to 1.9×10^3 g C km^{-2} y^{-1},was based on monitoring results from a beach site located 5 km south of Frederikshavn, Fig. 1 (Dando et al., 1994). Very little consideration was given to the geology of the area by Dando et al. (1994), so we do not know how well this site represents other seepage sites in the Kattegat. Therefore, the geological conditions responsible for gas seepage have been examined in more detail combining information from seismics and stratigraphy of on-shore wells. Layers exposed in a coastal cliff also helped understanding how gas may migrate in this glacio-techtonised region.

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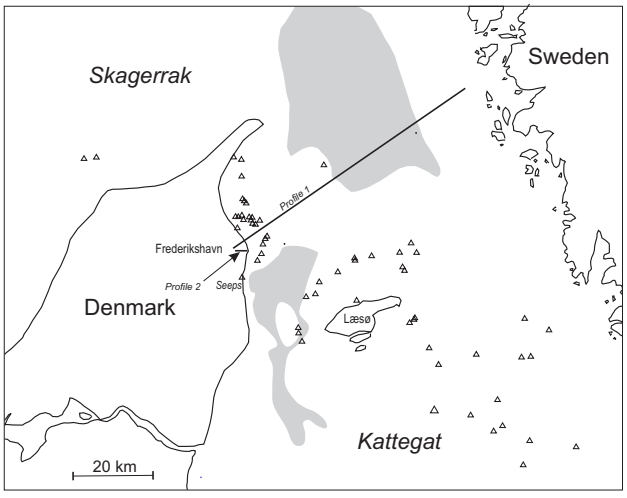

Fig. 1. Location of shallow gas (shaded area) and carbonate crust (triangles) indicative of methane seepage in the northern Kattegat.

2 Gas occurrences

Methane occurs widespread on-shore as well as offshore in northern Denmark and Kattegat (Jørgensen et al., 1990). The gas is biogenic, δ^{13}C: ÷65‰ to ÷80‰, most likely generated in the Quaternary deposits, where it is found (Laier et al., 1992). No thermogenic gas has been observed in the area, as the crystalline basement occurs at shallow depth in all of the area, Fig. 2.

Methane contribution to the atmosphere derive almost entirely from seepage sites indicated on Fig. 1, as methane is efficiently consumed in the upper layers of the large shallow gas area (Fig. 1) due to sulphate reduction (Iversen and Jørgensen, 1985). The seepage gas is much older, >40 000 y than the shallow gas, <3 000 y (Laier, et al., 1996), so it probably derives from the Eemian – Early Weichselian deposits (Laier et al., 1992). Methane from these deposits accumulated in minor local reservoirs 80–120 m below surface, and was exploited in the 1930s and 1940s in the towns near the

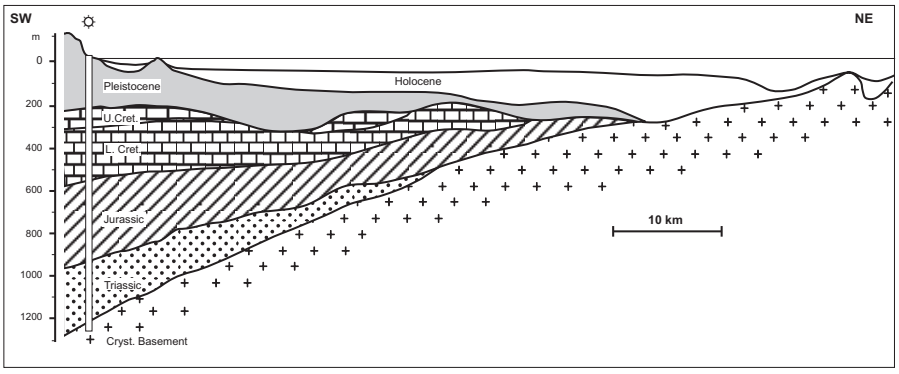

Fig. 2. Geological profile accros northern Kattegat, modified after Lykke-Andersen, 1992. Location of profile 1 is shown in Fig. 1.

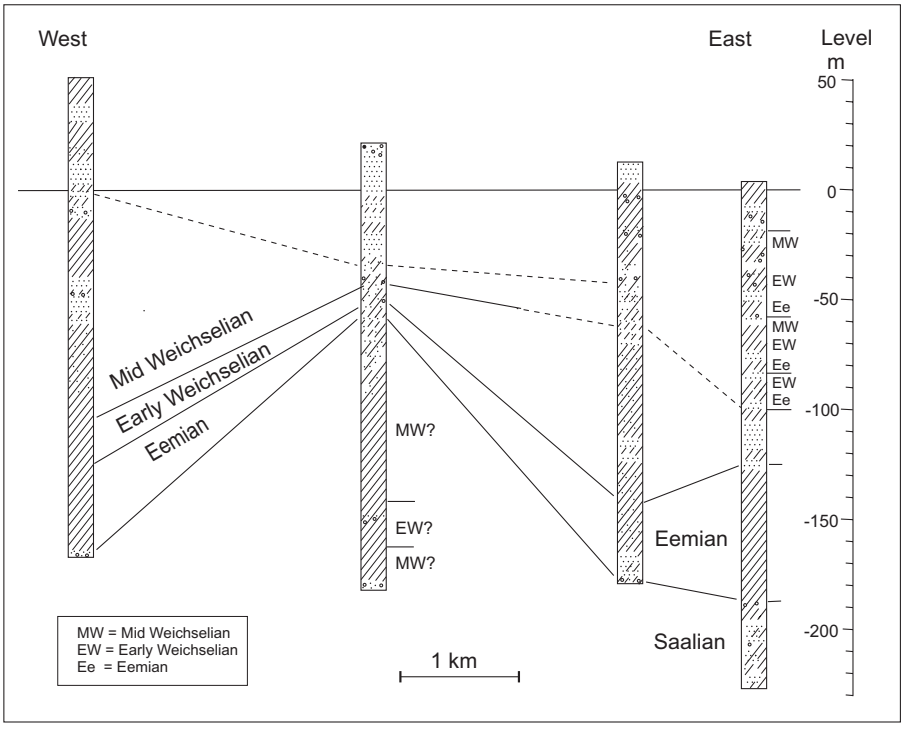

Fig. 3. Stratigraphy of Pleistocene deposits in the Frederikshavn area based on the foraminfera bio-zones of Knudsen (1985). Location of wells, profile 2, is shown in Fig. 1.

coast of Kattegat.

3 Gas migration

The carbonate crusts/methane seepage sites are found in shallow waters (0–30 m) where glacigene marine deposits are covered by thin layers of Holocene sandy sediments. Migration of gas was thought to occur along fractures in the compact clayey cap-rock covering the reservoirs (Laier et al., 1992). Fractures created as a result of tectonic activity along the Fenno-Scandian border zone. However, the distribution of seeps/carbonate crust sites does not simply follow the patterns of deep faults of the area.

On acoustic profiles the glacigene marine deposits appear as steep ridges, which were most likely formed as result of glacial tectonics during the expansion of the Scandinavian ice sheet prior to the Late Glacial Maximum ca. 20 ka. Before that, open marine conditions existed in the Kattegat area during most of the Weichselian time. It is not known to what extend or to what depth the advancing glacier affected the marine deposits. Probably the layers that were affected show some similarity with the internal structure of the glacigene deposits, partly exposed in coastal cliffs of the west-coast of northern Denmark. These cliffs reveal a composite-ridge system of imbricated sheets of sediments most likely displaced by glacial activity from flat-lying strata beyond the ice mar-

gin (Sadolin et al., 1997). The sheets are composed of alternating layers of clays and sand. A few mud diapirs are also observed. Studies of foraminifera in cutting samples from old gas exploration wells of the Frederikshavn area indicated that the glaciers probably affected even the deeper layers, as some of the bio-zones varied in thickness over short distances. Furthermore, the order of bio-zones was sometimes reversed, Fig. 3.

Assuming that the deeper layers were pushed to near vertical position in some areas, then methane generated in the clayey sediments would easily migrate in adjacent sandy layers which could extend to quite near the surface.

4 Conclusion

Gas seeps occur in areas where glacigene marine deposits are found at shallow sub-bottom depth. Migration of gas preferably occurs where marine deposits was affected by glaciers to great depths.

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