Are polygonal fault systems a fluid source for gas hydrate developmnent on the mid-Norwegian Margin

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Introduction

Bottom simulating reflectors that indicate the presence of gas hydrates exist on the mid-Norwegian margin north of the Storegga Slide (Bugge et al., 1987; Mienert et al., 1998) and in some areas underneath the landslide close to the northern sidewall (Bouriak et al., 2000; Berndt et al., subm.). As gas hydrates may have profound effects on continental slope stability (McIver, 1982, Kvenvolden, 1993) the occurrence of gas hydrates potentially poses a risk to deep-water hydrocarbon exploration of the near-by Ormen Lange field. Therefore, a detailed geological and geophysical evaluation of the Storegga gas hydrate system is timely. In particular it is necessary to understand the different processes that control distribution and quantity of natural gas hydrates in this area. The landward boundary of gas hydrate occurrence is controlled by the interception of the base of the gas hydrate stability zone with the sea floor (Mienert et al., 2000). Landward of this line the pressure is too low for the gas hydrates to be stable. Here, we present evidence that fluid supply from polygonal fault systems and Tertiary dome structures is another control on gas hydate occurrences.

Polygonal fault systems

The mid-Norwegian Margin is a passive margin covered by Mesozoic and Cenozoic sedimentary successions of more than 10 km thickness within the late Cretaceous/early Tertiary Vøring and Møre basins. The late Cenozoic sediment comprise the Miocene to early Pliocene Kai Formation with fine grained hemi-pelagic sediments and the Pliocene to Holocene Naust formation with partly hemi-pelagic contourite deposits and partly

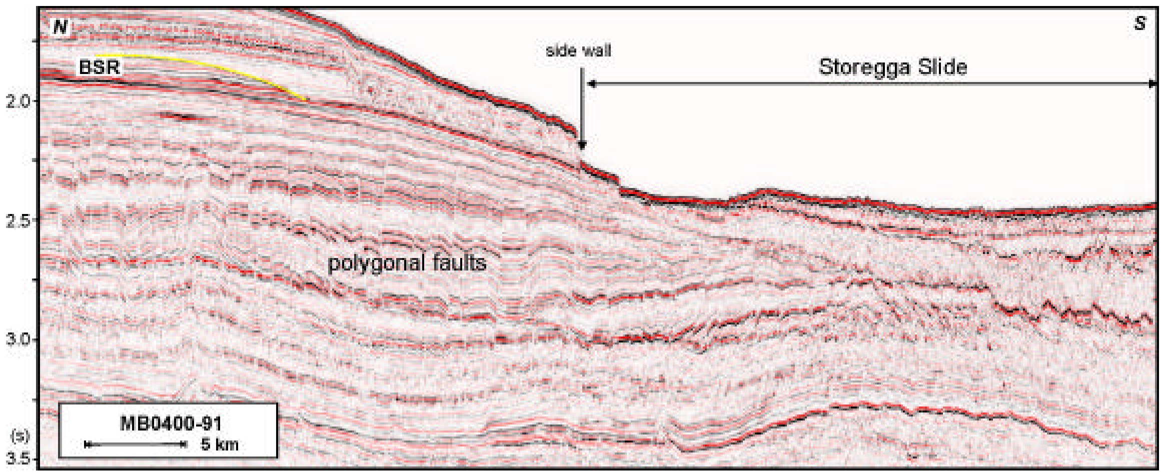

Figure 1: *Migrated multi-channel seismic line showing polygonal faults on the northern sidewall of the Storegga Slide underlying a gas hydrate related BSR (for location see Figure 2.*

glacigenic debris flows. The Kai formation exhibits polygonal fault systems (Figure 1) similar to those that are well studied in the central North Sea. Systematic mapping of these fault systems in 2- and 3-D seismic data shows that they occur at three stratigraphic levels. They are found in Eocene and Oligocene strata near the Ormen Lange Dome in the southern part of the mid-Norwegian margin, in Plio-/Pleistocene strata near the transition between the Vøring and Møre basins, and in the western parts of the Vøring Basin they partly crop out and partly they cut Oligocene and Miocene strata. The fact that the faults are layer-bound implies that they are not the result of tectonic activity but rather the result of sediment contraction and fluid expulsion from the host sediments (Cartwright and Lonergan, 1996). Possible driving mechanisms for such fluid expulsion include Rayleigh-Taylor instabilities and syneresis of colloids (Dewhurst et al., 1999). The amount of fluid expulsion generally is significant. Verschuren (1992) estimated that similar rocks from the southern North Sea shrunk by up to 60 volume percent.

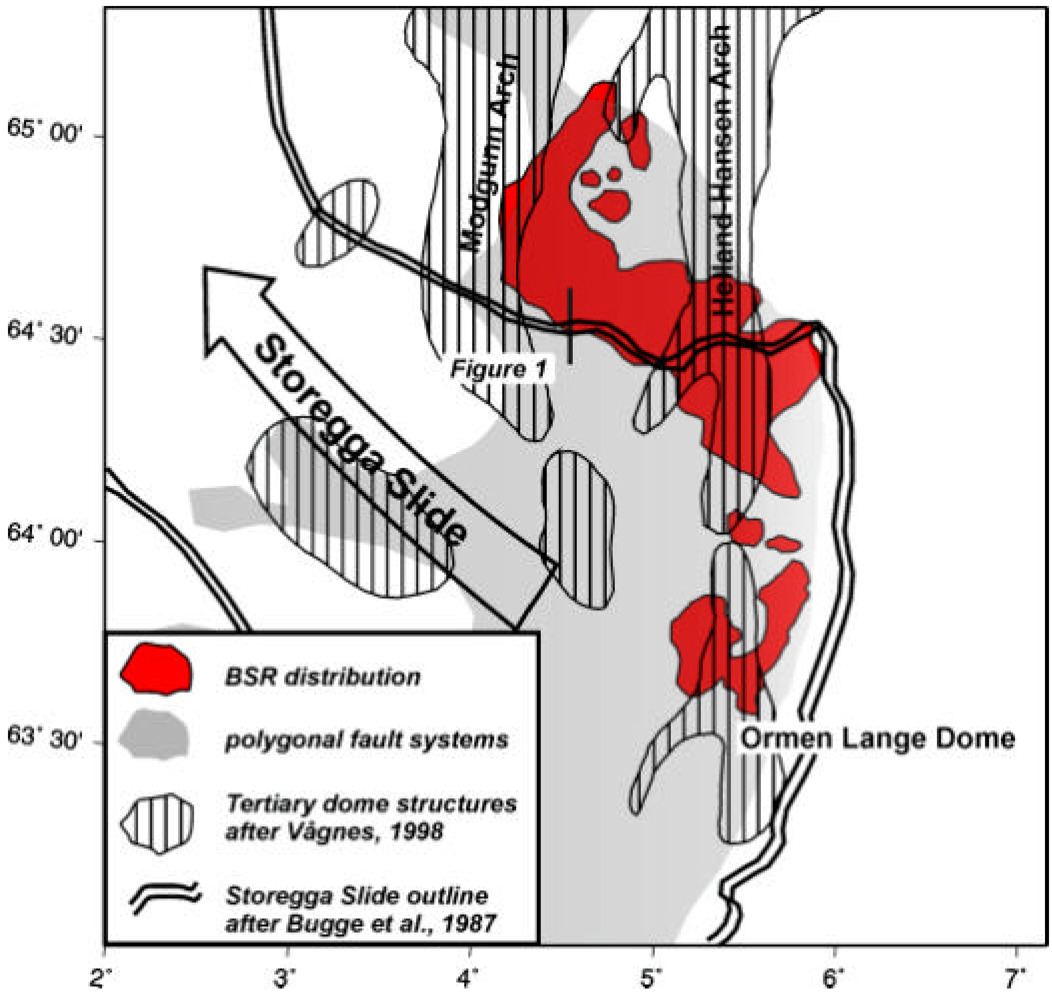

Figure 2: *Distribution of gas hydrates in relation to polygonal faults and other geological controls.*

Commonly seismic wipe-outs, which are indicative of fluid escape, occur above the fault systems. As these wipe-outs frequently do not reach the surface, they allow dating of compaction-related faulting that gives rise to fluid expulsion. Outcropping of faults and evidence for fluid expulsion in the overburden imply that faulting and compaction start shortly after deposition and continues after the faulted sediments are buried by subsequent sedimentation. Fluid flow from the polygonal fault systems is an ongoing process today (Berndt et al., subm.).

Natural gas hydrates

Natural gas hydrates are compounds of water and hydrocarbon gases, predominantly methane. The water molecules form a rigid lattice of cages with each of the cages containing one gas molecule (Kvenvolden, 1993). Gas hydrates are only stable at high pressures and low temperatures that are typically found in continental margin sediments and in permafrost soils. The exact stability conditions depend furthermore on the geochemical composition of both the pore water and the hydrocarbon (Sloan, 1998). Their chemical structure determines the amount of water and gas that is bound in hydrates. At standard temperature/pressure conditions one cubic meter of gas hydrate consists of 0.8 cubic meter of water and 164 cubic meter of gas (Kvenvolden, 1993). In most geological settings this requires substantial fluid flow in order to supply the required amount of pore fluids by advection.

Relationship between gas hydrates and polygonal fault systems

The polygonal fault systems are widespread on the mid-Norwegian margin (Figure 2). Gas hydrates on the other hand are much less frequent. They occur exclusively in areas in which polygonal fault systems are present. The fact that we observe fluid flow-related pipes rising from the top of the polygonal fault systems, i.e. the boundary between the gas hydrate bearing Naust formation and the fluid expelling Kai formation, implies that a steady supply of pore fluids exists into the gas hydrate bearing sediments. Moreover, there is no seismic evidence for fluid flow from deeper stratigraphic level. This suggests that the pore fluids that are expelled from polygonal fault systems are the main fluid source for formation of gas hydrates at shallow stratigraphic levels. The Ormen Lange Dome and the Helland-Hansen Arch, two Tertiary dome structures with hydrocarbon potential in the study area, might represent another source for fluids in particular light hydrocarbons. However, indicators for fluid flow from these dome structures and upward are much less wide-spread than indicators for fluid flow from the polygonal fault systems.

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