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Comparative analysis of methane-seepage structures on the Vestnesa Ridge and in the Nyegga area on the Norwegian-Barents-Svalbard Margin - a model for their formation

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The flow of fluids through marine sediments is one of the most dominant and pervasive processes in continental margins. These processes control the evolution of a sedimentary basin and its seafloor environment, and have implications for hydrocarbon exploration and seabed ecosystems. Many seep sites at the seafloor are associated with large but complex faunal communities that have received significant attention in recent years. However, there is a need for a better understanding of the driving mechanism of fluid flow in various geological settings, the accumulation of fluids in the subsurface and their focused flow through conduits and/or faults to the seabed. Hundreds of gas-seepage sites occur in the Nyegga area on the mid-Norwegian margin and on the Vestnesa Ridge offshore western Svalbard. Seismic data shows that fluid flow structures, so-called chimneys, pierce through hemipelagic marine clays and extend over a depth of more than 600 m. The seafloor expressions of these structures are mostly small depressions with a diameter of up to 600 m and a depth of up to 20 m. However, new high-resolution 3D seismic data shows that there is a pronounced difference in acoustic character between seepage structures in the Nyegga area and on the Vestnesa Ridge. Chimneys in the Nyegga area appear as nearly-vertical columnar zones of complete acoustic transparency with occasional amplitude anomalies at the chimney wall and mostly high seafloor-reflection amplitudes. In contrast, chimneys on the Vestnesa Ridge show as upwards-meandering contorted structures with discontinuous reflectors at the chimney walls, and have variable amplitude anomalies throughout the structure and at the seafloor. Recent observations of methane flares in the water column imply that the Vestnesa Ridge vent system is active now. On the contrary, the age of the Nyegga chimneys is dated to approximately 10-15 ka before present. Moreover, velocity analysis shows that the chimneys at Nyegga contain a high-velocity material. Considering observations of hydrate-filled fractures in sediment samples from bottom coring and by analogy of observation in boreholes in the Ulleung Basin, we argue that chimneys at Nyegga are hydrate-filled fracture systems. Chimneys develop by hydraulic fracturing at the base of the hydrate-stability zone or occasionally deeper. The seal breach allows gas-laden fluids to migrate upward along the fractures (possibly reaching the seafloor). Gas hydrates form within fractures, clogging them and thus sealing off the fluids. New overpressures might develop underneath clogged fractures or at the origin of the chimney structure. Subsequently, new fractures develop and allow fluids to migrate until clogged by hydrates. As a consequence, multi-fractured vertical structures develop with fractures that are filled with hydrates. In the Nyegga area, the chimneys have developed into a mature state; they are possibly dead or at least dormant. Here, hydrate formation within fractures causes blanking, which explains the observed acoustic transparency. Fluid migration might be reactivated if new overpressures develop. On the Vestnesa Ridge, chimneys are in its infancy, and are active. Only some fractured networks have developed as indicated by the seismic expression of chimneys in this area. This formation model implies that the flow of gas-laden fluids to the seabed and possibly into the hydrosphere is episodic and occurs in blowouts. Large quantities of methane could be released spontaneously over a short period of time interrupted by longer dormant periods.