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Sill intrusion driven fluid flow and vent formation in volcanic basins: Modeling rates of volatile release and paleoclimate effects

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Evidence of mass extinction events in conjunction with climate change occur throughout the geological record and may be accompanied by pronounced negative carbon isotope excursions. The processes that trigger such globally destructive changes are still under considerable debate. These include mechanisms such as poisoning from trace metals released during large volcanic eruptions (Vogt, 1972), CO_2 released from lava degassing during the formation of Large Igneous Provinces (LIPs) (Courtillot and Renne, 2003) and CH_4 release during the destabilization of sub-seafloor methane (Dickens et al., 1995), to name a few. Thermogenic methane derived from contact metamorphism associated with magma emplacement and cooling in sedimentary basins has been recently gaining considerable attention as a potential mechanism that may have triggered global climate events in the past (e.g. Svensen and Jamtveit, 2010). The discovery of hydrothermal vent complexes that are spatially associated with such basins also supports the discharge of greenhouse gases into the atmosphere (e.g. Jamtveit et al., 2004; Planke et al., 2005; Svensen et al., 2006). A previous study that investigated this process using a fluid flow model (Iyer et al., 2013) suggested that although hydrothermal plume formation resulting from sill emplacement may indeed release large quantities of methane at the surface, the rate at which this methane is released into the atmosphere is too slow to trigger, by itself, some of the negative δ13C excursions observed in the fossil record over short time scales observed in the fossil record. Here, we reinvestigate the rates of gas release during sill emplacement in a case study from the Harstad Basin off-shore Norway with a special emphasis on vent formation.

The presented study is based on a seismic line that crosses multiple sill structures emplaced around 55 Ma within the Lower Cretaceous sediments. A single well-defined vent complex is interpreted above the termination of the main sill in the region. We use a 2D, hybrid FEM/FVM model that solves for fully compressible fluid flow to quantify the thermogenic release and transport of methane and to evaluate flow patterns within these systems. Additionally, vent formation in the model is implemented by simple fracture criteria that modify the permeability structure when the fluid pressure exceeds a threshold determined by the lithostatic pressure. The model with fracture formation is able to reproduce a single vent complex at the observed location above the main sill tip. This is very different from hydrothermal plume formation elsewhere in the region and occurs over short time scales (hundreds of years) and results in fluid focusing in that region. The rate of degassing and the resulting negative δ13C excursion from the vent model is then compared to models where only hydrothermal plume formation results in gas transportation. Lastly, variations in the amount of gas liberated in the system are investigated based on kerogen type and other mineral reactions such as limestone decarbonation and halite breakdown in the affected source rock.