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Petroleum implications of sill intrusions: Hydrothermal vent complexes

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Hydrothermal vent complexes are commonly associated with sheet intrusion in volcanic basins, and the formation of these vent complexes is intimately related to the emplacement of sill complexes. We are currently completing an integrated seismic, field and theoretical study on the petroleum implications of sill intrusions. One aspect of this study has been to get new understanding of the formation and long-term impact of hydrothermal vent complexes based on geological/geophysical interpretation and analyses combined with theoretical studies and numerical modeling.

We have mapped several hundred hydrothermal vent complexes on seismic data in the Møre and Vøring basins, and studied more than 10 vent complexes in the field in the Karoo basin, South Africa. In addition, a detailed petrophysical and geological analysis program has been completed in well 6607/12-1 in the Vøring Basin. This well was drilled more than 2 km into a vent complex in 1986. In cross-section, the hydrothermal vent complexes consist of an upper and a lower part. The upper part is commonly eye- or crater-shaped. It consists of an inner zone with brecciated sediments and pipes, and an outer zone of structurally deformed, inward-dipping, strata. Sand-rich vent complexes represent positive erosional remnants in the field, with numerous sediment pipes and dikes suggesting mobilization of sediments towards the paleosurface. The lower part of the vent complexes is commonly not observed in the field, but is identified on seismic data as a chimney-like structures with disturbed character. The diameter of the upper part is typically 0.5 to 5 km, but craters >10 km in diameter exist. The lower part has a smaller diameter, and continues normally down to the upper termination of interpreted sill intrusions. Several observations suggest that the hydrothermal vent complexes are re-used for fluid migration long time after their formation: 1) disturbed seismic data ('seep anomalies') and mounds above the vent complexes; 2) asphaltene veins within vent complexes in the Karoo basin; and 3) anomalous oxygen and carbon isotope values above the vent complexes.

The upper part of the hydrothermal vent complexes was formed at the paleosurface at the time of intrusive magmatic activity (i.e., near the Paleocene/Eocene transition in the Møre and Vøring basins, and in the Jurassic in the Karoo basin). It may extend more than hundred meters into underlying strata, and is typically a few hundred meters thick. The upper part of the vent complexes is located below the top-Paleocene time-horizon in a few places in the Møre Basin, which suggest an early phase of intrusive magmatism. This activity is tentatively dated at 60 Ma when the magmatism started in the NE Atlantic.

The conditions necessary to generate fluid overpressure sufficient to cause hydrothermal venting are described by a dimensionless parameter, ***Ve***, reflecting the relative rates of heat and fluid transport. Numerical modeling of the temperature and fluid pressure fields around a magmatic sill shows that boiling of pore fluids may cause gas to rise explosively towards the surface shortly (a few years) after sill emplacement. A vent complex is more likely to be formed when the magma is intruded in low permeability strata, whereas no vent complexes are formed when the local permeability around the sill is high.

We propose the following integrated model for the formation of hydrothermal vent complexes in a volcanic basin: (1) Intrusion of magma leads to heating and local boiling of pore fluids in the intruded sediments; (2) Fluid phase separation may lead to an explosive hydrothermal eruption at the paleosurface, forming a hydrothermal vent complex. The explosive rise of fluids towards the surface cause brecciation and fluidization of sediments migrating towards the surface; and (3) Re-use of the hydrothermal vent complex fracture system by fluid migration during final cooling of the sill complex and later burial of the basin.