Geometries of igneous intrusions in inner Isfjorden, Svalbard: implications for fluid flow and CO_2 storage

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Sills and dykes of the Early Cretaceous High Arctic Large Igneous Province (HALIP) can be found in on-shore outcrops in Franz Josef Land, northern Greenland, the Canadian Arctic, on the Siberian De Long Islands and Svalbard. Seismic, magnetic and gravity data also suggest an extensive offshore extent of the HALIP which, if paleotectonic reconstructions are applied, was sourced from a mantle plume located near the Alpha Ridge (Maher, 2001, Nejbert et al., 2011).

On Svalbard, HALIP rocks are represented by the doleritic sills and dykes of the Diabasodden Suite (DBS, Nejbert et al., 2011). The DBS is regionally extensive across Svalbard, and is particularly well exposed and easily accessible in the inner parts of Isfjorden in Central Spitsbergen.

Drilling, fieldwork and seismic acquisition carried out as part of an ongoing reservoir characterization program for the Longyearbyen CO_2 Laboratory project has identified several igneous intrusions in the Triassic target aquifer. Well data show a substantial (~60 bar) sub-hydrostatic pressure regime in the reservoir at the planned injection site. The gently dipping reservoir reaches the surface just 15 km from the well-site, which should allow pressure communication with the surface. The observed under-pressure must thus originate from local compartmentalization caused by the presence of lateral flow barriers (faults, lateral pinch-outs, permafrost, igneous intrusions or a combination thereof). In this contribution we collate a range of available data sources in order to constrain the geometry of igneous features in inner Isfjorden. The aim of this exercise is to (1) accurately model these intrusions as part of the ongoing CO_2 storage project and (2) contribute to the general understanding of the DBS magma plumbing system.

Within the inner Isfjorden study area, the DBS typically consists of 1-100 m thick sills and up to 15 m thick dykes. Individual sills can normally be traced laterally for 10-15 km, although some may extend up to 30 km. Subordinate dykes are often poorly exposed and covered by scree, but are typically traceable over distances of up to 4 km. In the study area the erosion-resistant sills typically form mountain plateaus, protecting the underlying rocks. A detailed study of the Botneheia mountain, using field data and LiDAR data, indicates minor thickness variation along the sill length (Fig. 1).

Onshore and offshore 2D seismic data indicate the presence of discontinuous, layer-transgressive and high-amplitude reflectors which are interpreted as sills. A saucer-shaped geometry is illustrated by a similar high-amplitude reflector (Fig. 2a), typical for igneous intrusions in sediments as seen in other provinces such as the South African Karoo Basin or the Norwegian Møre and Vøring basins. High-resolution multibeam bathymetry also captures curved resistant ridges on the seafloor, interpreted as possible inclined rims of saucer-shaped intrusions (Fig. 2b, c). An up to 100 m high and 600 m wide stock-like system near Kapp Thordsen may represent a feeder system. Fieldwork also suggests possible saucer-shaped geometries at Wallenbergfjellet and parts of southern Dickson Land, in addition to numerous layer-transgressive dykes.

Due to their 3D geometry saucer-shaped intrusions have the potential to compartmentalize a reservoir if their layer-transgressive margins cross the boundary between an underlying reservoir and an overlying seal.

While 3D seismic would be required to provide unequivocal rendering of sub-surface intrusion geometries on Svalbard, fieldwork has revealed that the target aquifer in the study area contains extensive layer-transgressive intrusions. A 5 m thick doleritic dyke at Botneheia cuts through the entire target aquifer and is ca. 3 km long. Such dykes have been shown, particularly if unweathered, to act as baffles and barriers to migrating fluids (Perrin et al., 2011). Fieldwork further suggests that while the fractured contact zones of intrusions typically exhibit evidence of past fluid flow (e.g. calcite veins), fractures within the intrusions themselves appear impermeable to fluid circulation. Subsequent deformation during Tertiary compressional tectonics formed additional fractures.

Furthermore, 268 submarine pockmarks have been identified on the 5 m gridded bathymetry data in the study area. They typically reach 80-120 m in diameter and 3-4 m in height. Their preferential distribution along the sub-cropping base of the inclined, sheet-like intrusions suggest that the fluid flow is controlled by both lithology and the presence of intrusions. Interestingly, pockmarks are also clustered along the subcrop of the Wilhelmøya Subgroup, part of the target aquifer of the Longyearbyen CO_2 Lab project.

Based on the present data set we conclude that igneous intrusions may affect the size of the accessible target aquifer for CO_2 storage on Svalbard. Their accurate representation in a reservoir model is therefore crucial.

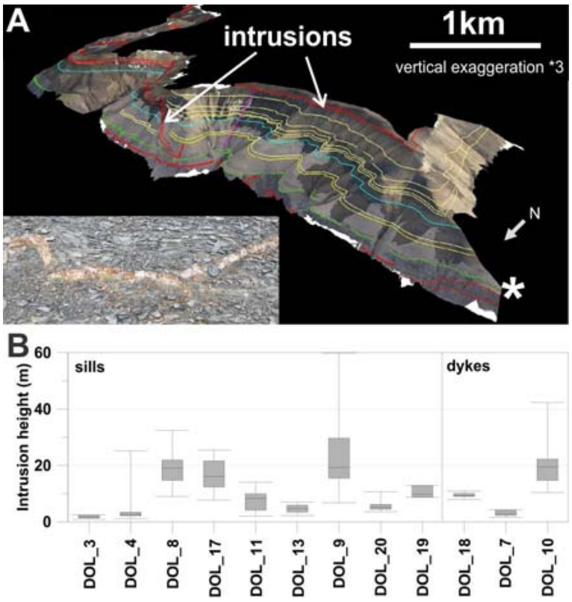

Fig. 1 – (a) LiDAR scan of Botneheia, with igneous intrusions highlighted in red. Note particularly the transgressive intrusion linking the upper and lower sills. The inset photograph shows thin (ca. 10 cm) sills, similar to those penetrated in the borehole, occurring just above the major sill (location marked with white star). (b) Box-whisker plots illustrating the thicknesses of twelve igneous bodies at Botneheia.

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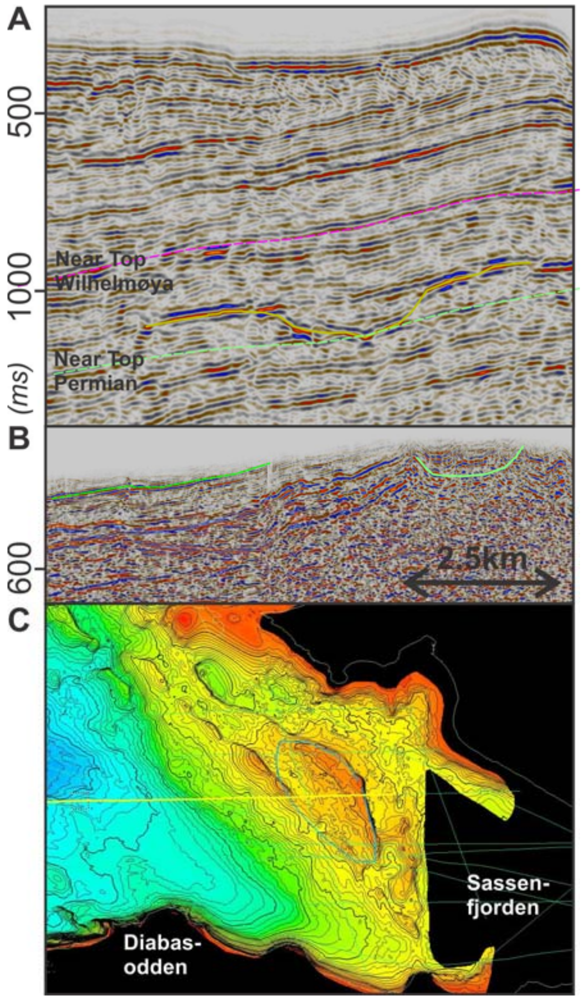

Fig. 2 – (a) Example of a saucer-shaped seismic reflector on 2D line ST8815-214 located 10 km from Longyearbyen on strike to the targeted aquifer. The inclined rim transects approximately 260 m of stratigraphy. The Wilhelmøya Subgroup is the uppermost part of the target aquifer. (b) A poorly-defined saucer-like geometry in Sassenfjorden, corresponding to a curved positive relief feature on the seabed (c).

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