Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Fractured Anhydrite as a Geothermal Source in a Low Enthalpy Context (Southern Permian Basin, Netherlands)

Alexandros Daniilidis and Rien Herber

Geo-Energy Department, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

a.daniilidis@rug.nl

Keywords: Geothermal energy; Direct use; Fractured Anhydrite, Geology;

ABSTRACT

Increased heat flow associated with the presence of salt domes could be beneficial for geothermal energy applications in a low enthalpy environment. Anhydrite layers within such salt domes could be a potential geothermal target. These layers are known to undergo brittle deformation, which in turn can lead to the generation of a fracture network, able to facilitate fluid flow. We investigate the suitability of such an anhydrite layer in the Southern Permian Basin (The Netherlands) by means of seismic interpretation and seismic attributes. Our results reveal the presence of an anhydrite layer and evidence of brittle deformation and fracturing on the macro scale. Lastly, we identify future steps for a more comprehensive resource assessment of such a concept.

1. INTRODUCTION

Direct use of energy from low enthalpy geothermal sources can present challenges of economic feasibility, especially so in areas where volcanic activity is absent. Drilling has been identified as the main cost contributor (Barbier, 2002; Goldstein et al., 2011; Johnston, Narsilio, & Colls, 2011) in geothermal projects located in sedimentary basins. In addition to drilling costs, local temperature gradients and reservoir permeability have the largest influence on power output (van Wees et al., 2012), which indirectly affects economic feasibility. The above-mentioned challenges could be overcome by harnessing heat accumulated due to the increased heat conductivity of salt bodies (Geluk, Paar, & Fokker, 2007), which are less costly to reach because of their presence at shallower depths.

Salt bodies have been found to influence the temperature gradient of existing nearby gas production wells in the southern Permian Basin in the Netherlands (Bonte, Van Wees, & Verweij, 2012). Modelling of salt intrusions in North Germany, within the same basin, has linked them to increased heat flow (Agemar, Schellschmidt, & Schulz, 2012). In the low enthalpy subsurface environment of the Netherlands, which has an average geothermal gradient 31.3°C/km (Bonte et al., 2012), the higher heat flow values found at shallower depths could contribute to an economically more viable utilization of geothermal heat.

The Southern Permian Basin has been extensively studied for hydrocarbon exploration (Doornenbal et al., 2010) and is known to feature salt layers that function as a reservoir seal. As a result of halokinesis, Permian (Zechstein) evaporite sequences in the North of the Netherlands (De Jager & Geluk, 2007; van Gent, Back, Urai, Kukla, & Reicherter, 2009) have formed several salt intrusions and diapirs. In addition, formation of the domes and diapirs has been found to cause fracturing of the anhydrite and or carbonate caprocks present on top of the (Zechstein) salt layers (Geluk et al., 2007). Brittle deformation resulting in boudinage and accompanying generation of neck fractures in anhydrite layers in a halite matrix have also been documented in lab experiments that applied deformation stress (G. Zulauf et al., 2009; G. Zulauf et al., 2010; J. Zulauf, Zulauf, Hammer, & Zanella, 2011).

Fractured formations such as anhydrite layers can be considered as equivalents of porous media (Caine, Evans, & Forster, 1996) since fractures act as conduits, thus creating an effective permeability. An example of such a setting is the Zechstein caprock interval located in the Dutch offshore which contains a proven gas field (G16-FA), currently in production. Thus, the combination of higher heat flow, creating a heat-buffer at the top of the diapir in shallower depths, together with effective permeability of an existing fracture network, could prove to be an economically appealing source of geothermal energy (Figure 1). Since the feasibility of geothermal energy production from a fractured anhydrite layer located on top of a salt structure has not been researched before, we investigate this option, with an eye to improve economic feasibility. In our research project, 3D Pre-Stack Depth Migrated (PSDM) seismic data were used to delineate salt bodies located in the North of the Netherlands, overlying the currently producing Groningen gas field, which is expected to remain in production until 2068 (TNO, 2012). Structural interpretation is carried out for a salt ridge covering an area of 5.2km^2 in a depth ranging from1.6 to 2.0 km. At this depth, temperatures of ca. 65°C are predicted. In addition, anhydrites thicknesses of 50m have been suggested by lithostratigraphy of nearby borehole drilling logs. Future efforts towards a comprehensive resource assessment at the area of interest are outlined.

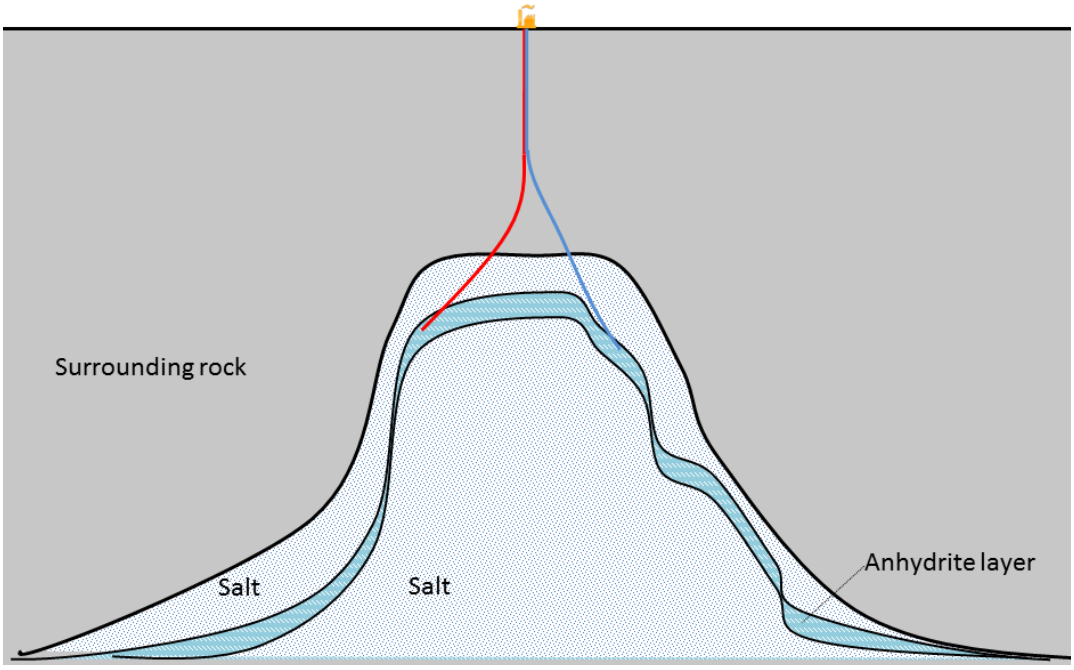

Figure 1. Conceptual drawing of the anhydrite layer as reservoir target for a geothermal doublet. The blue line represents the injector and the red line, the producer.

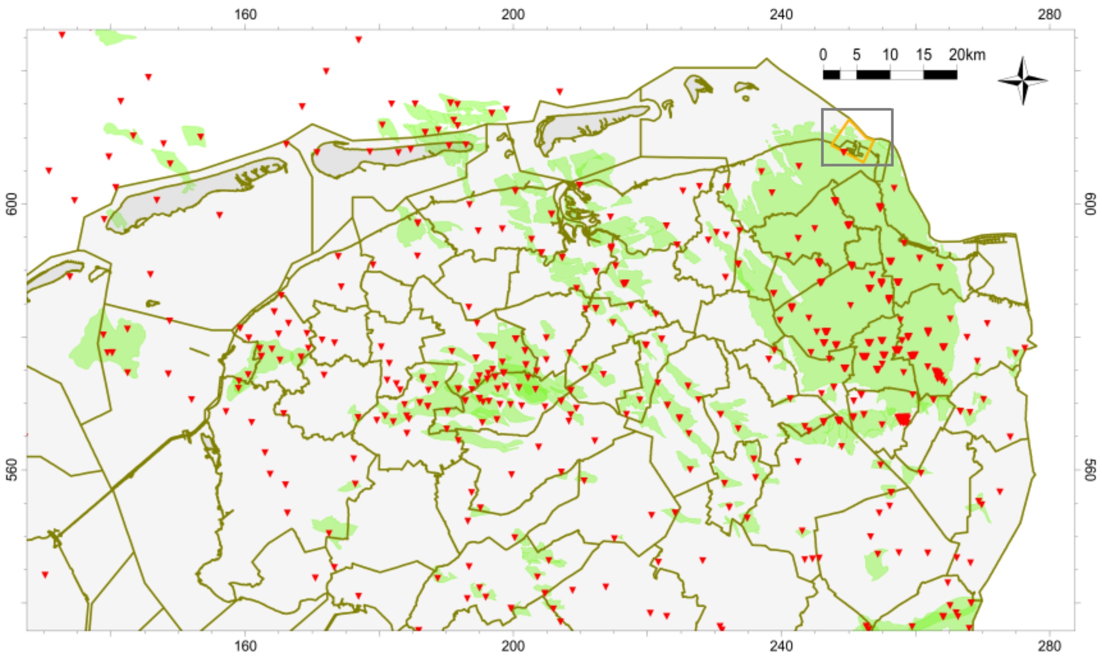

Figure 2. Study area in the North of the Netherlands. Axes are based on RD-New system coordinates, converted to distance (km). The red inverted triangles depict well locations, the black lines depict municipal borders, the orange polygon shows the geothermal license area, the dashed square the area of interest and available seismic cube and the light green represents gas fields. The largest gas field on the NE is the Groningen gas field.

2. METHODS

3D Pre-Stack Depth Migrated (PSDM) reflection seismic data, provided by NAM, were used for seismic interpretation. Crossline and inline interval is 25m, the vertical sample interval 4m and seismic data reach to a depth of 4km. The seismic data extend over an area of 27km by 26km in the North of onshore Netherlands. Seismic interpretation was carried out for top and base horizons of the geological intervals using Petrel (Schlumberger). Every 6th line was interpreted (both cross and inlines) using five times vertical exaggeration. Subsequently seismic traces were auto-tracked in 3D using manual interpretation as seed.

Furthermore, borehole lithostratigraphic data and logs from wells (63 in total, see Appendix A), publicly available from NLOG, were used to further constrain the geological model. To aid the interpretation, seismic attributes like Instantaneous Phase, Amplitude Contrast, Relative Acoustic Impedance, Variance, Chaos and 3D curvature were computed from the original seismic dataset.

3. RESULTS

Through structural interpretation we identified a salt ridge in the area of interest with a thickness of up to 1000m (Figure 3). Within the geothermal license area, the upper part of the structure covers a depth range between 1.6 and 2.0 km in an area of 5.2 km^2 (Figure 4). The presence of an anhydrite layer was interpreted within the salt dome. This layer was correlated with well logs in the area and identified as the ZEZ3A formation. Lithostratigraphy of nearby well logs suggested ZEZ3A anhydrite thicknesses of circa 50m, which is in agreement with the seismic signature of the data (Figure 5).

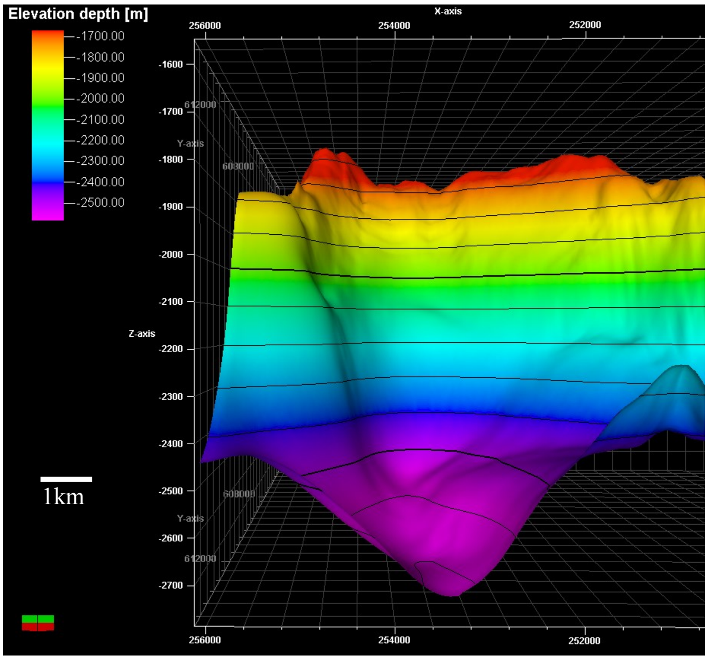

Figure 3. Top of the salt structure interpreted from 3D PSDM seismic data (view from North) within the geothermal license area. The structure reaches a peak height of 1000m below sea-level. Scale is set for the front side of the structure.

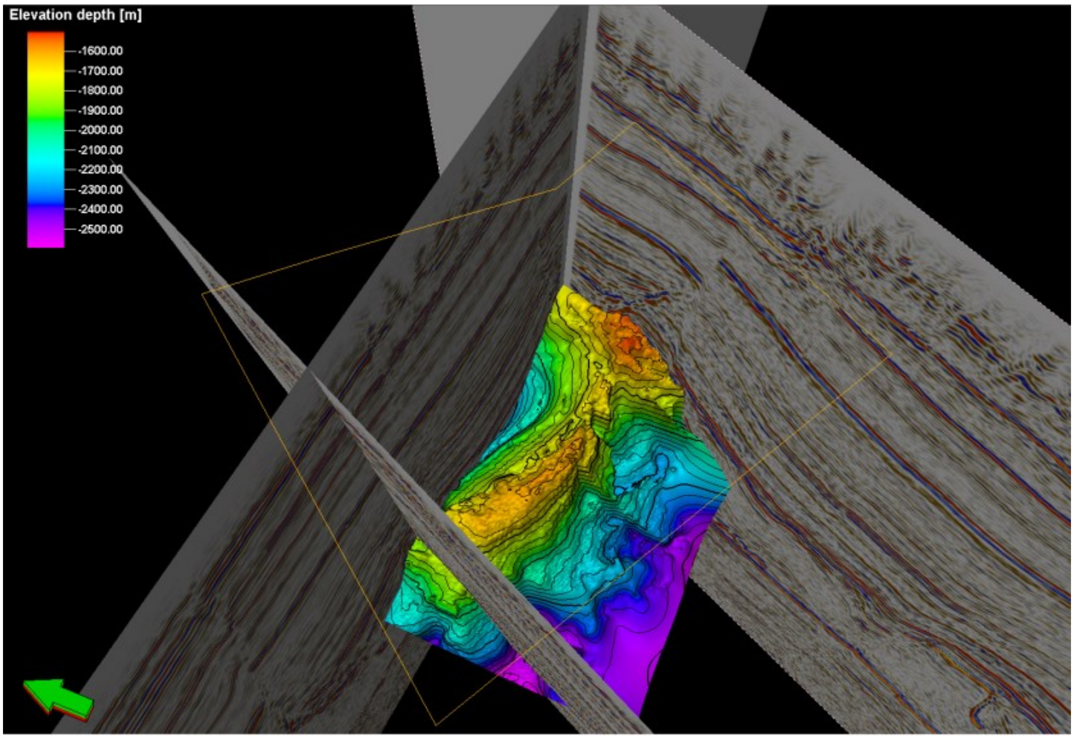

Figure 4. Interpreted anhydrite layer within the salt structure in relation to the geothermal license area (orange polygon) and three arbitrary seismic lines. The licensed area only covers a small part of the structure but does include the more relevant top part of the structure. The latter reaches a depth of about 1550m on the NE side. The green arrow indicates North.

The seismic signature of the layer shows characteristics of brittle deformation, namely boudinage and fracturing (Figure 5). This result is in accordance with the experimental work of Zulauf et al. (2011). The top part of the anhydrite layer is conformable to the overall relief of the salt dome. The fractured nature of the formation results in a rougher surface relief compared to that of the dome (Figure 3).

Attribute analysis of the original reflection seismic signal reveals the presence of extensive lateral discontinuities throughout the anhydrite layer (Figure 7b, c & d). Especially the RMS amplitude and variance attributes, together with structural analysis (edge detection) indicate the presence of discontinuities in the top part of the layer (Figure 7b & c). From an economic feasibility perspective, the top part of the structure is also the most interesting one for a doublet installation, since it is should hold a heat buffer at lower depth. However, density and orientation patterns of the fractures from seismic data are only indicative and a more detailed meso- and micro-scale fracture analysis is called for.

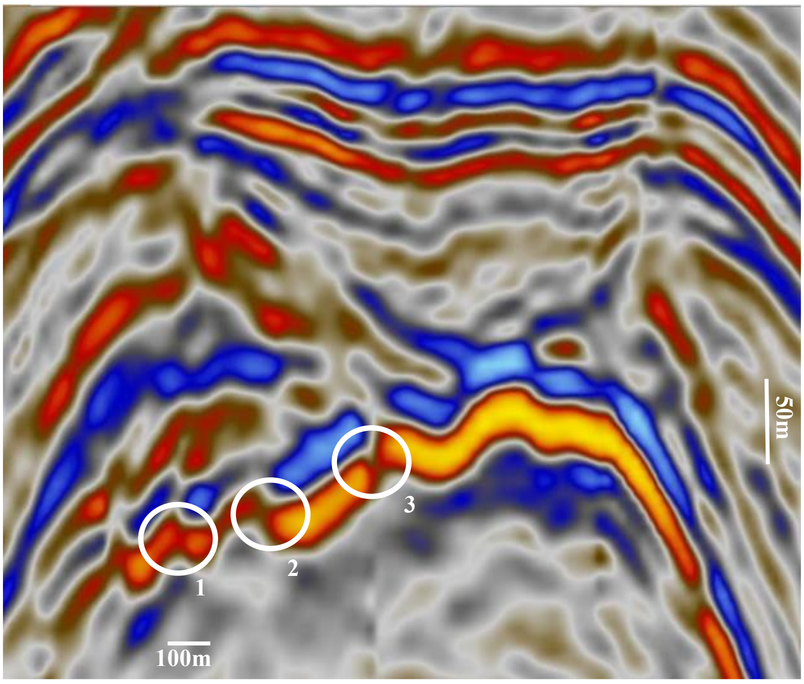

Figure 5. Reflection seismic (depth domain, 5 times vertical exaggeration) depicting fracturing (1,2,3) and boudinage (1,2) of the anhydrite layer within the salt structure on a macro scale. Red signifies sharp transitions from lower to higher acoustic velocity.

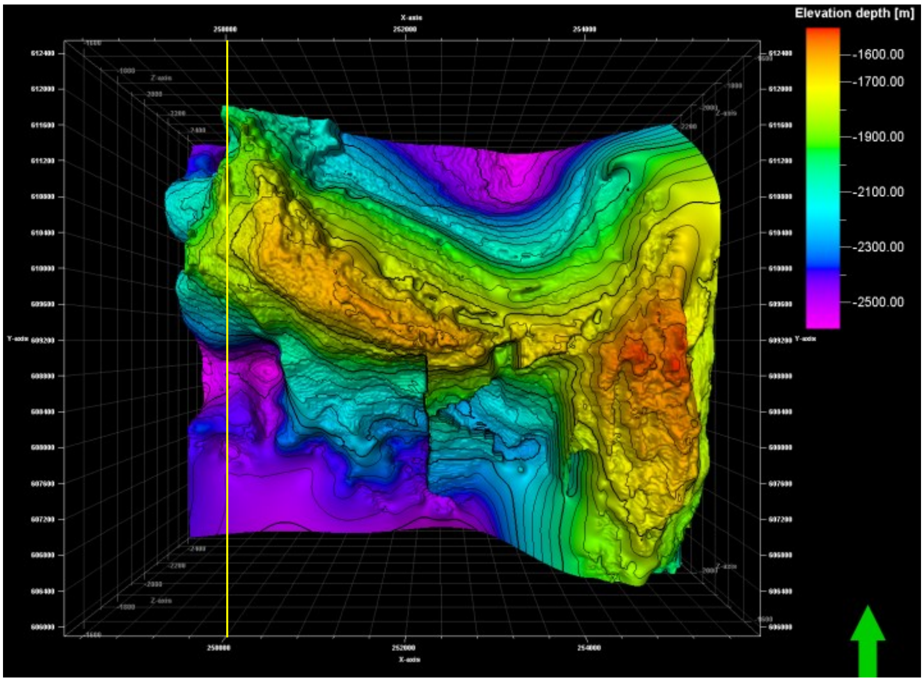

Figure 6. Depth map of the anhydrite layer within the dome. The yellow line represents the seismic crossline presented in Figure 5 and the green arrow the North.

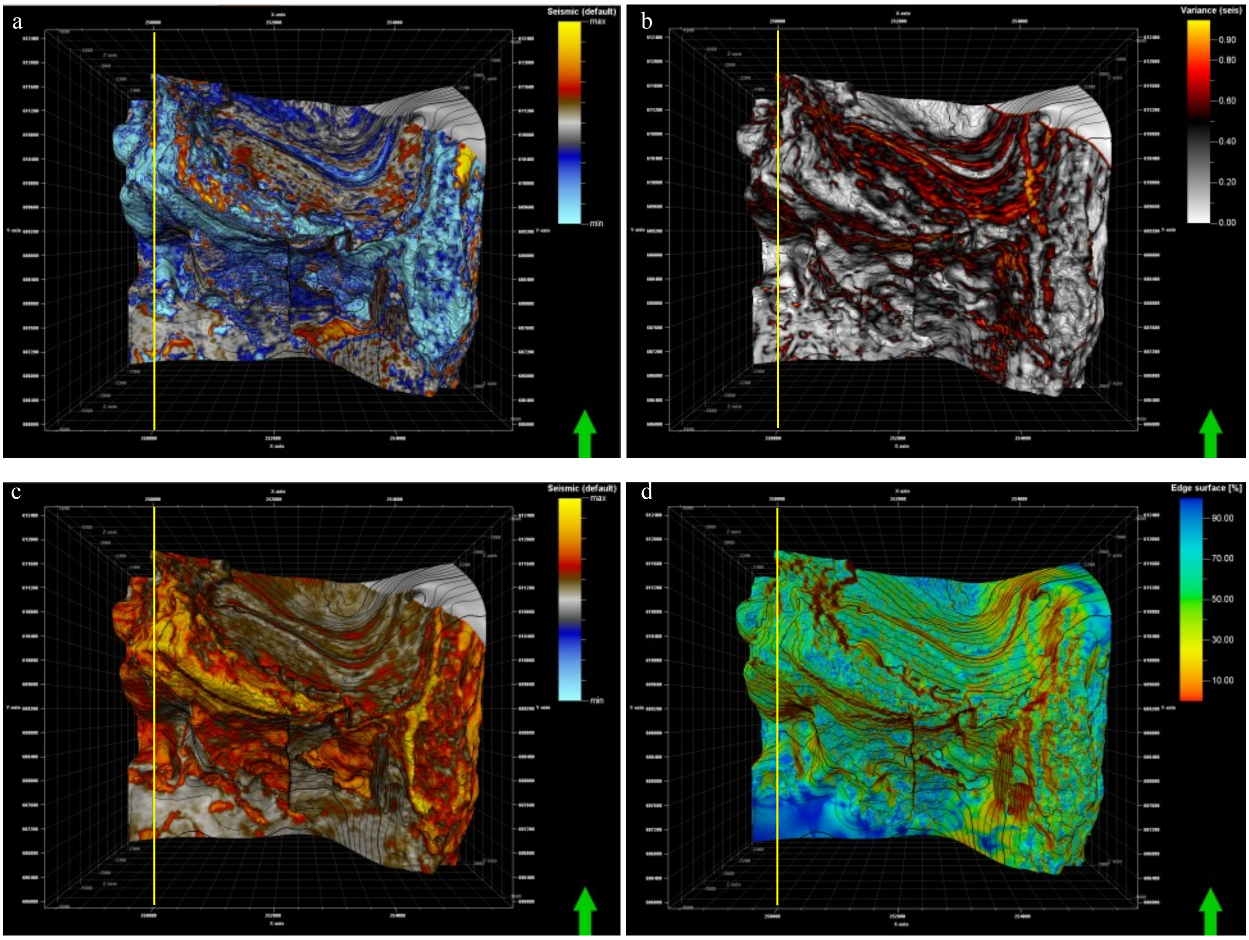

Figure 7. Seismic attributes of (a) relative acoustic impedance, (b) variance, (c) RMS amplitude and (d) edge detection structural analysis of the anhydrite layer within the salt structure. Relative acoustic impedance is the running sum of regularly sampled amplitude values, variance is the estimation of signal variance, and RMS amplitude is measured over a specified window (20m around the interpreted horizon). Relative acoustic impedance and variance data suggest a dense presence of horizontal discontinuities in the seismic signature. Variance and edge detection show discontinuity orientation along the elongated sides of the structure; indications of a second, less dense orientation perpendicular to the first one can also be observed. The yellow line represents the seismic crossline presented in Figure 5.

4. DISCUSSION AND CONCLUSION

We postulate that using a fractured anhydrite layer for geothermal energy production can be beneficial for the economics of a geothermal installation. This can be especially important for project implementation in a low enthalpy context, such as in Southern Permian Basin (The Netherlands). The increased heat flow, in principle facilitated through a salt dome (Agemar et al., 2012; Bonte et al., 2012) can reduce the drilling costs.

The presence of an anhydrite layer in the area of interest is validated by means of seismic interpretation and available well logs. The layer forms a dome structure which can act as a heat buffer, while the thickness in the area is circa 50 m. Brittle deformation characteristics, such as boudinage and fracturing are confirmed on the macro scale and agree with previous lab observations (J. Zulauf et al., 2011). Seismic attributes and structural analysis of the interpreted layer have identified directional discontinuities within the anhydrite layer. These results exhibit the necessary qualities for considering fractured anhydrite as an economically feasible geothermal energy source, as suggested by our conceptual drawing (Figure 1).

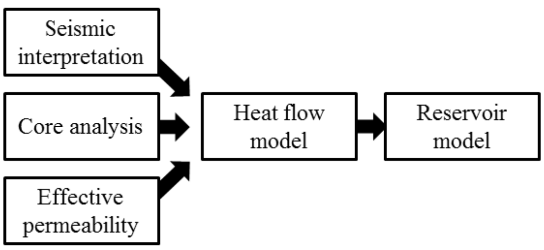

Figure 8. Workflow for a comprehensive evaluation of fractured anhydrite as geothermal energy source

Nevertheless, the permeability characteristics of the fractures or fracture network cannot be derived at this scale of observation. A core analysis is needed to establish the presence and characteristics of a fracture network at the meso- and micro- scales.

Furthermore, heat flow modeling on the specific geological setting and reservoir simulation making use of the fracture characteristics should further substantiate the resource assessment. The workflow design for such a comprehensive evaluation of fractured anhydrite as geothermal energy source is depicted in Figure 8. Efforts towards this are already on-going at the time of writing.

ACKNOWLEDGEMENTS

The authors would like to thank NAM for providing the 3D PSDM seismic data and Schlumberger for providing an academic license for Petrel.

APPENDIX A

List of wells used: UHM cluster, UHZ-01, HND-01, BIR cluster, FRM cluster, DZL cluster, BRW cluster, AMR cluster, LMR cluster, ZND cluster

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