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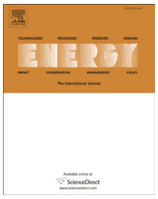

Salt intrusions providing a new geothermal exploration target for higher energy recovery at shallower depths

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ABSTRACT

Direct use of geothermal energy can present challenges of financial feasibility in a low-enthalpy setting. The average temperature gradients in sedimentary basins make it necessary to reach larger depths for meaningful heat production, thus increasing the drilling cost. Therefore, full realization of geothermal projects in low-enthalpy environments has been difficult and not widely deployed. The concept of harvesting the positive temperature anomalies caused by the increased heat conductivity of salt bodies could enable access to higher temperatures at a shallower depth, thus reducing the necessary depth of drilling. In a potential site in NE Netherlands, temperature differences of up to 25 °C close to the top of a salt body are modeled. Substantiating this concept we show that the energetic benefits can result to up to 40% more energy extracted, while the temperature recovery of the field is only prolonged by 13%. This opens up new possibilities for geothermal applications in sedimentary basins.

1. Introduction

The use of geothermal energy for industrial or domestic purposes has been the subject of scientific focus in various different contexts [1–3]. However, direct use of energy from low-enthalpy geothermal sources can present challenges for financial feasibility, especially in areas where shallow, high temperature conditions are absent. The average geothermal gradient in sedimentary basins and the economic competition with fossil fuels are the main reasons for these challenges. In sedimentary basins, drilling has been identified as the highest cost contributor for geothermal projects [4–7], whereas the possible thermal energy output is largely determined by local temperature gradients and reservoir characteristics [8]. The above-mentioned challenges could be overcome by harnessing the energy channelled through the high heat conductivity of salt bodies [9], giving rise to locally higher temperatures at shallower depths, thus reducing drilling costs. This principle could outline potential geothermal targets through regional models using data generated by the hydrocarbon industry. Uncertainty remains pertinent despite high data availability in mature hydrocarbon basins [10]. Nonetheless the use of such data has been exemplified in different geothermal contexts before as a means to identify geothermal potential [11]. In this paper we substantiate the concept of harvesting the positive thermal anomalies caused by the heat conductivity of salt in the Eemshaven area in the NE Netherlands.

Salt bodies have a lower density than most rocks below 500 m burial depth [9]. When pressure levels exceed the formation strength, salt behaves in a visco-plastic way [12]; through this process, called halokinesis, salt flows towards the surface creating various structural shapes [13]. After halokinesis took place in Permian (Zechstein) evaporite sequences in the North of the Netherlands [14,15], several salt intrusions and domes have formed [13].

In sedimentary basins away from tectonic plate margins and in the absence of significant crustal extension, the heat flow maintains its average continental plate values [16]. In such settings the geothermal gradient is dominated by conductive processes [17,18] if significant vertical heat convection through fracture systems is absent [19]. The importance of conduction in the temperature distribution has also been identified in regional studies within the Southern Permian Basin (SPB) [20,21]. Consequently, stratigraphic intervals with high conductivity are of major importance for the temperature field.

The thermal conductivity of salt is two to four times higher than

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that of non-evaporitic sediments [22–25]. Heat is preferentially channeled through the salt, creating positive temperature anomalies around the top of a dome and negative ones at its base [19,20,22,26–28].

Higher temperatures found at shallower depths could contribute to a more economically viable utilization of direct use geothermal heat, especially in the low enthalpy context of the Netherlands, which has an average geothermal gradient of 31.3 °C/km [29]. Salt bodies have been found to influence the temperature gradient of existing nearby gas production wells in the greater southern Permian Basin [19,25,26,28,30], as well as within the Netherlands [29]. Modelling of salt intrusions in Northern Germany, within the same basin, has also linked them to increased temperature levels [21].

However, most studies examine an areas of tenths [26,31], hundreds [21,25,28–30] and sometimes thousands [18] of km with the underlying layer geometry sometimes based on large regional models. Such models are very insightful and identify temperature field anomalies on a larger scale. Nonetheless studies at a smaller scale could highlight details that are either missed or not pronounced in large regional studies. Using high resolution 3D seismic data for the geometry modelling and constraining the simulations with a temperature map as a lower boundary can increase the resolution of the temperature field. Such smaller scale models can help bridge the gap between the large scale regional models and models targeted at field development.

In this research we substantiate the concept of harvesting higher temperatures at a shallower depth due to the increased heat conductivity of salt bodies. The energetic benefits and possible economic impact of a direct-use geothermal installation is showcased. To this end, 3D seismic data were used to delineate a salt body located in the North of the Netherlands above the currently producing Groningen gas field. Based on structural interpretation we have constructed a geological model of the salt body, covering an area of 5 km^2 at depths ranging from 1.6 to 2.0 km. At these depths, temperatures of ca. 65 °C are predicted based on the average geothermal gradient. Using the geological model the specific temperature field has been calculated, using five thermal conductivity scenarios for the lithostratigraphic units. Furthermore, the effect of the computed temperature field on the performance of a conceptual geothermal aquifer positioned at the top of the salt structure is analysed. Lastly, a comparison is made with an aquifer positioned in a standard geothermal gradient for the basin.

1.1. Background

The operator of the Groningen gasfield (NAM), provided the 3D Pre-Stack Depth Migrated (PSDM) reflection seismic data which were used for seismic interpretation. Crossline and inline interval is 25 m, the vertical sample interval is 4 m and the data reach to a depth of 4 km. The available seismic data extends over an area of 27 km by 26 km, but interpretation focusses on the harbour area where there is demand for heat (Fig. 1). Seismic interpretation was carried out on top and base horizons of the main geological units using Petrel (Schlumberger) supported by 3D autotracking (Fig. 2a).

Furthermore, borehole lithostratigraphic data from 63 nearby wells (see Appendix A), publicly available from NL Olie-en Gasportaal [32], were used to further constrain the geological model. To aid the interpretation of the salt, seismic attributes of Instantaneous Phase (Fig. 2b), Amplitude Contrast, Relative Acoustic Impedance, Variance and Chaos were computed from the original seismic dataset.

2. Structural model

2.1. Geology

In the area of interest a salt ridge was identified with a thickness of up to 1500 m (Fig. 3c). Within this area, the top of the salt exhibits a depth range between 1,600 m and 2,000 m covering circa 5 km^2 (Fig. 3b). The geometry of the salt dome tightly matches the regional model by Strozyk et al. (2014) for the Groningen High region. Furthermore, the shape of the salt ridge correlates strongly to the fault orientation in the underlying Rotliegend (Fig. 3d). The salt structure is up to circa 1,000 m thicker above the faulted Rotliegend basement, while it drops to its normal stratigraphic

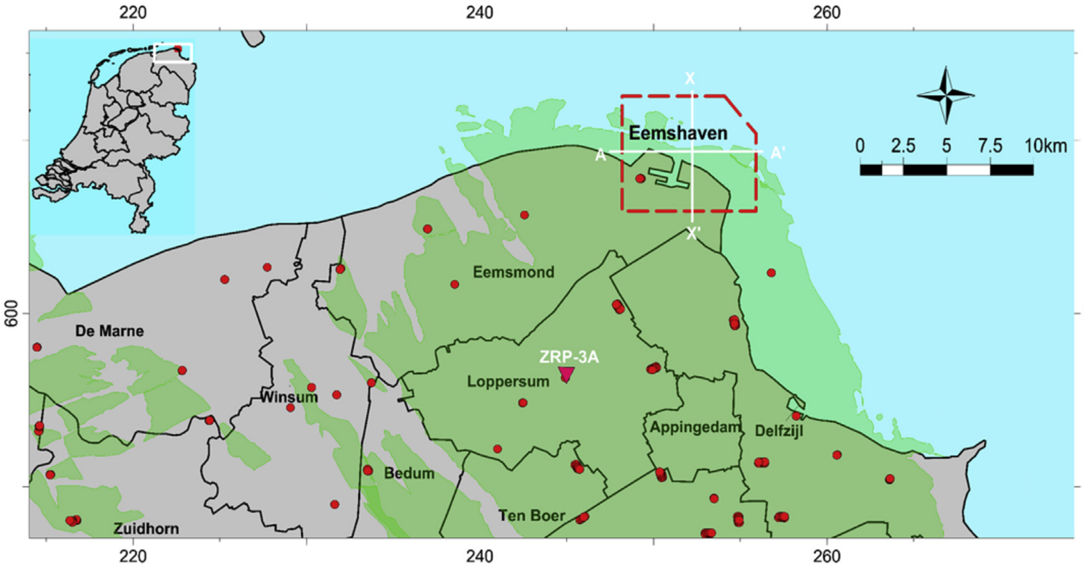

Fig. 1. Study area in the North of the Netherlands. Axes are based on RD-New system coordinates, converted to distance (km). Red dots depict surface locations of existing gas wells, the black lines depict municipal borders and the coast line and gas fields are indicated in light green. The dotted red line outlines the area of interest around the Eemshaven port, where demand for geothermal heat is present. The cross section X-X′ is presented in Fig. 2, and cross section A-A′ in Fig. 3. Distributed Temperature Sensing (DTS) data of the ZRP-3A well are presented in Fig. 6. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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