Using Basin Modeling for Geothermal Energy Exploration in The Netherlands*

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Abstract

The petroleum geology of the West Netherlands Basin (WNB) and Roer Valley Graben (RVG) in the Netherlands has been studied in detail by several authors over the years (Zijerveld et al., 1992; Geluk et al., 1994; Van Balen et al., 2000). A lot of the geological research was focused on conventional oil and gas exploration. However, the focus of exploration currently shifts towards unconventional energy such as geothermal energy or shale gas. For geothermal purposes new questions with regard to porosity/permeability and temperature of sandstone aquifers and the related thermal conductivity have surfaced that were not answered by the previous studies. For example, more detailed knowledge of eroded thicknesses and the influence of the erosion on the geological framework is important for predicting porosity or permeability in sandstones and shales.

Geothermal energy in the Netherlands can be used for a number of applications, such as heating of greenhouses or office buildings. To assess the amount of energy that can be extracted from the earth using current technology, a tool was developed that displays available sandstone reservoirs, depth, temperature, and flow properties of the layers (www.thermogis.nl). So far, the generated information is based on the present-day burial and a temperature gradient for the entire Netherlands. Temperature and porosity measurements are, however, only available at public well locations. The determination of these parameters on a regional level requires their estimation between the wells. Instead of an interpolation between the measured temperature and porosity values, we apply 3D basin modeling using PetroMod from Schlumberger to include the effect of present and past burial.

Within this study (Figure 1) a burial anomaly map was created using the reconstructed thicknesses from the erosion maps and running a forward basin model. The burial anomaly is mainly related to the Late Cretaceous inversion event. In some areas the difference in burial compared to present-day is more than 1500 m, indicating that significant differences in rock properties could occur. The burial anomaly is restricted to the northern part of the study area where highest values coincide with large inverted faults.

Geologic History

Between the Late Permian and Early Triassic, the study area was characterized by thermal subsidence following the orogenic collapse of the Variscan Orogen and minor fault activity as attested by a thick homogeneous sedimentation in the RVG, the WNB and surrounding areas (Zijerveld et al., 1992; Winstanley, 1993). During the Late Jurassic/Early Cretaceous the RVG and WNB strongly subsided while the surrounding blocks and platforms were uplifted (Zijerveld et al., 1992; Geluk et al., 1994). This was related to major rifting activity and subsidence was controlled by the reactivation of pre-existing Variscan faults as normal faults. During the Late Cretaceous/Early Tertiary several inversion events removed most of the sediments deposited during the Late Jurassic/Early Cretaceous (Winstanley, 1993). In the RVG the major phase of uplift and erosion occurred already in the Campanian and later inversion events had only little effect. This can be seen in well logs and biostratigraphic analyses of the Late Cretaceous sediments in the southern part of the graben. They show a Late Maastrichtian to Danian age and therefore represent chalk deposition after the major inversion phase (Luijendijk et al., 2011). In the WNB the later inversion events had more influence; the Late Maastrichtian to Danian sediments are not observed. Whether most erosion occurred during the Campanian or Latest Cretaceous/Early Tertiary cannot be deduced from the stratigraphic record (De Jager, 2003).

Method

The four main erosion phases were included into the basin model (Saalian, Kimmerian, Sub-Hercynian, and Laramide). To determine the amount of erosion during these phases 1D models were created based on well data and calibrated against temperature and vitrinite reflectance using also the structural setting of the well. Erosion maps were then created by constructing original thickness maps for each eroded layer using interpolation and then subtracting the present-day thickness. Paleo-heat flow maps were created for the model using the in-house developed tectonic heat flow calculation tool PetroProb and the heat flow calibration tool from PetroMod. These maps were calibrated against present-day temperature, vitrinite reflectance, and tectonic subsidence. The evolution of the sediment-water interface temperature used for the model was defined using the standard model from PetroMod with a refined curve for the Tertiary and Quaternary. The refined curve was determined using geochemical and geobiological proxies (Donders et al., 2009; Verweij et al. in press). The water depth is necessary to determine the depth below sea floor through time and the temperature at the top of the sediments if only surface temperatures are available. The water depth was determined from the sedimentological descriptions of Van Adrichem Boogaert and Kouwe (1993) and from micropaleonto-logical studies. The water depth at a certain time was kept constant for the whole area as no more detailed information was available. To achieve an accurate model of the porosity and permeability of the reservoir layers, user-defined porosity-depth correlations were used for sandstone and shale and the respective mixtures. These correlations are based on a selection of porosity measurements from wells and are calibrated against a different set of measurements in the model. The definition of the lithology is based on the description of the groups, formations, and members from Van Adrichem Boogaert and Kouwe (1993). To achieve a more detailed view the lithology of three horizons was specified using the stratigraphic information from the wells.

Results

Within this study a burial anomaly map was created using the reconstructed thicknesses from the erosion maps and running a forward basin model. The burial anomaly is mainly related to the Late Cretaceous inversion event. In some areas the difference in burial compared to present-day is more than 1500 m, indicating that significant differences in rock properties could occur. The burial anomaly is restricted to the northern part of the study area where highest values coincide with large inverted faults (Figure 2).

One scenario of the model was calculated without erosion to compare the porosity with and without erosion and to check how much the burial anomaly influences the physical parameters of the layer. Figure 3 shows the difference in porosity of a pure sandstone layer and a 75% shale, 25% silt layer between the two scenarios. The difference in porosity can be up to 15%. Shale rich layers show higher differences in porosity than pure sandstone layers. The difference in porosity is positively correlated to the burial anomaly; however the burial anomaly needs to exceed 300 m to change the porosity significantly. Figure 3 shows porosity/depth extractions of three different well positions for both scenarios. The wells are situated in areas with burial anomalies of different magnitude, 1300 for well JUT-01, 600 for well ARV-01, and 250 for well WAS-23. In the last well almost no influence of the burial anomaly on the porosity is visible. The same observation was made for the other physical properties such as permeability and thermal conductivity.

Acknowledgements

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Figure 1. Position of the study area (brown line).

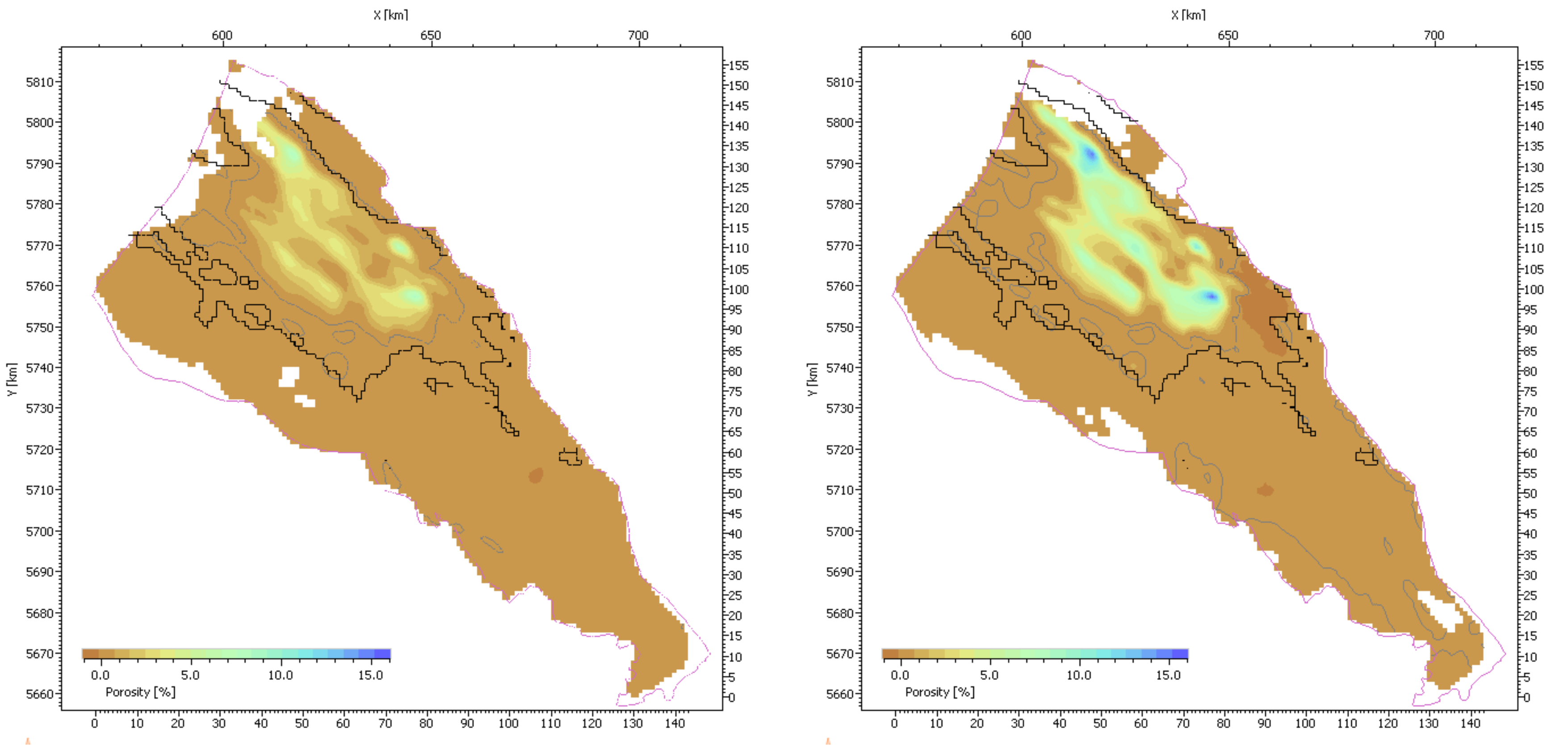

Figure 2. Influence of the burial anomaly on the calculated porosity of a sandstone and a shale rich layer.

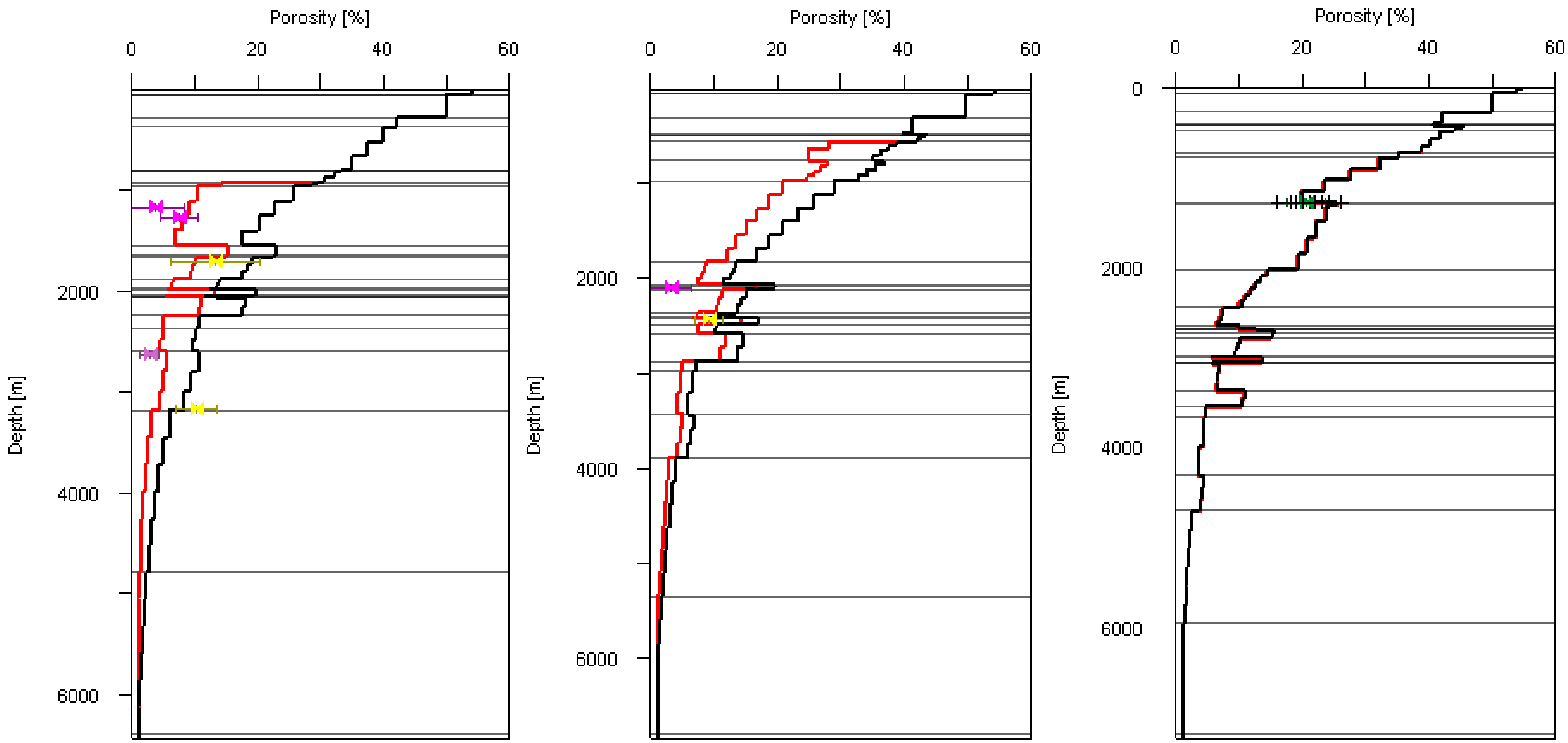

Figure 3. Comparison of different porosity-depth curves (red with erosion, black without) for the location of well JUT-01 (a, ~1300 m burial anomaly), well ARV-01 (b, ~600 m burial anomaly) and well WAS-23 (c, ~250 m burial anomaly).