Th SP11 09

3D Subsurface Temperature Model of Europe for Geothermal Exploration

J. Limberger* (Utrecht University) & J.D. van Wees (TNO Utrecht and Utrecht University)

SUMMARY

For the assessment of geothermal resources in Europe we constructed a digital 3D temperature model of the European crust and sedimentary basins, incorporating publicly available temperature data. Using European crustal thickness models and indirect parameters such as surface heat flow measurements, temperatures were calculated for regions where data are scarce.

Our temperature model of Europe has a horizontal grid resolution of 10x10 km and extends to a depth of 10 km below ground level. The model covers Europe up to the Russian border and includes Turkey and Iceland.

Introduction

Predicting subsurface temperatures is a crucial part in the exploration phase of the development of a geothermal system. Together with flow rate, temperature controls the amount of energy that can be utilized for direct heating and even more for power production, preferring temperatures larger than 200°C. Therefore, the first step for the assessment of geothermal resources across Europe in the framework of the EU funded project GEOELEC, was the development of a 3D temperature model of the subsurface. As a starting point, we compiled publicly available temperature data from wells and national databases. One of the challenges is the unequal spatial distribution of subsurface temperature data across Europe. Most of the available temperature information is limited to areas that have been explored for hydrocarbons (e.g. the Netherlands) and temperature data from wells strongly decrease with depth. In Europe, few temperature measurements are available at depths greater than 5 km. To cope with the lack of temperature data, indirect measurements such as the surface heat flow Q_s can be used to model the subsurface temperature as is shown in equation 1 for 1D heat conduction:

$$T(z) = \frac{-A}{2k} z^2 + \frac{Q_s + Ah}{k} z + T_0 \quad (1)$$

Here, the temperature at depth $T(z)$ is related to the layer thickness h , thermal conductivity k , the radiogenic heat production A and the surface temperature T_0 .

Methodology

For our model we adopted a 3D conductive model for the lithosphere (cf. Bonte et al., 2012), incorporated existing temperature information and used an approach similar to Beardsmore et al. (2010) to populate the model with thermal properties and boundary conditions. To discriminate between the thermal conductivity of sediments deposited in basins and the crystalline rocks in the basement, a two layer model was used based on the sediment thickness from the crustal model of Tesauro et al. (2008). Different values for the thermal conductivity were assigned to each layer. Following the work of Pollack and Chapman (1977), it was assumed that 40% of the surface heat flow originates from radiogenic heat production in the upper crust. Using the surface heat flow data from Artemieva (2006), the local heat production in every 3D grid cell was derived and values for the basal heat flow of the lithosphere (Q_m) were obtained by subtracting the sum of the total crustal heat production from the surface heat flow. Subsequently, the basal heat flow was applied as boundary condition for the bottom of the model. For the vertical edges of the model, zero horizontal heat flow was assumed. For the top of the model average annual surface temperatures were used from the World-Clim-Global Climate Database (Hijmans et al. 2005).

Results and conclusions

Our derived temperature model of Europe has a horizontal resolution of 10x10 km and a vertical resolution of 250 m and extends to a depth of 10 km below ground level. The model covers Europe up to the Russian border and includes Turkey and Iceland. Figure 1 shows two depth slices of the temperature at a depth of 5 km and 10 km, respectively. A pronounced difference in temperature can be observed between the northeastern and southwestern part of Europe. Here, the Trans-European Suture Zone (TESZ) forms a boundary between the cold Precambrian terranes in the northeast and the hotter Phanerozoic terranes in the southwest. At 5 km depth the average temperature is 111°C, but temperatures can be as low as 30°C in the areas of the Baltic Shield and can be higher than 200°C in volcanic areas such as Italy and Iceland. At 10 km depth the average temperature is 201°C but varies from 50°C to 650°C.

The use of indirect parameters such as heat flow measurements in combination with models of the crust allowed us to constrain temperatures for regions in Europe where data are scarcely available. The model could be improved by dividing the crust into more layers with specific thermal properties, however this requires more detailed crustal models.

Figure 1 Depth slices taken from the 3D temperature model at depths of 5 km (left) and 10 km (right) below ground level.

Acknowledgements

The research has been partially funded by the IEE programme GEOELEC (www.geoelec.eu).

References

- Artemieva, I.M. [2006] Global 1 x 1 thermal model TC1 for the continental lithosphere: Implications for lithosphere secular evolution. *Tectonophysics*, **416**(1–4), 245–277.
- Beardsmore, G.R., Rybach, L., Blackwell, D. and Baron, C. [2010] A Protocol for Estimating and Mapping Global EGS Potential, Geothermal. *Resources Council Transactions* **34**, 301–312.
- Bonté, D., Van Wees, J.D. and Verweij, J.M. [2012] Subsurface temperature of the onshore Netherlands: new temperature dataset and modelling. *Netherlands Journal of Geosciences*, **91**(4), 491–515.
- Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. and Jarvis, A. [2005] Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, **25**(15), 1965–1978.
- Pollack, H.N. and Chapman, D.S. [1977] On the regional variation of heat flow, geotherms, and lithospheric thickness. *Tectonophysics*, **38**(3–4), 279–296.
- Tesauro, M., Kaban, M.K. and Cloetingh, S.A.P.L. [2008] EuCRUST-07: A new reference model for the European crust. *Geophysical Research Letters*, **35**(5), 1–5.