

An Assessment of Deep Geothermal Resources in Norway

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ABSTRACT

The Geological Survey of Norway is currently conducting the largest heat flow study of the Norway mainland ever carried out since the 1970's. In the framework of the Kontiki (NGU-StatoilHydro) and HeatBar (NGU-NFR-StatoilHydro) projects, we measured temperatures in 15 deep drill holes located in the Oslo Region, mid-Norway, Nordland and Finnmark. In contrast with previous heat flow studies, most of our drill holes reach depths exceeding 800 m, allowing for corrected geothermal gradients from paleoclimatic effects and, consequently, for estimating temperatures well below the deepest level reached by the drill holes. The data were primarily used to calculate the relative amount of heat flow produced in the different units of the Norwegian basement and to extrapolate this information to the offshore areas.

In the present contribution, we focus on the geothermal potential of the Norway mainland. Using our calculated heat flow values, recently published thermal properties of a wide range of rocks in Norway and results from previous geological and geophysical studies, we computed underground temperatures at different depths. Relatively low temperatures are predicted down to 5 km in central and northern Norway, restricting the geothermal potential of these regions to the use of "low temperature fields" (i.e. < 100 °C) for house or, eventually, district heating only. In the Oslo Region, the most populated region of Norway, our calculations point towards much more favorable conditions. We show that, depending mainly on the thickness of the Cambrian-Ordovician cover and, to some extent, on the concentration of radioactive content in the underlying basement, "medium temperature geothermal fields" (i.e. 100-200°C) could potentially be operated for electricity production in the near future. These preliminary conclusions sound promising but still need to be confirmed by more focused studies.

1. INTRODUCTION

Based on heat flow data collected in shallow drill holes (i.e. less than 300m depth) and lake measurements by means of gravity probes, Norway has been viewed until recently as a "cold spot" in terms of geothermal gradients and surface heat flow (Haenel et al. 1979). According to the previous data collection, average heat flow values were ~40 to 50 mW/m², characteristic of cratonic regions (Fig. 1).

In 2004, NGU (i.e. Geological Survey of Norway) and StatoilHydro initiated the Kontiki project followed in 2005 by the HeatBar project with additional support from the Research Council of Norway (i.e. NFR). One of the main goals of both projects was to determine more reliable heat flow values, the previous ones were suspected to contain strong paleoclimatic signals that were not corrected.

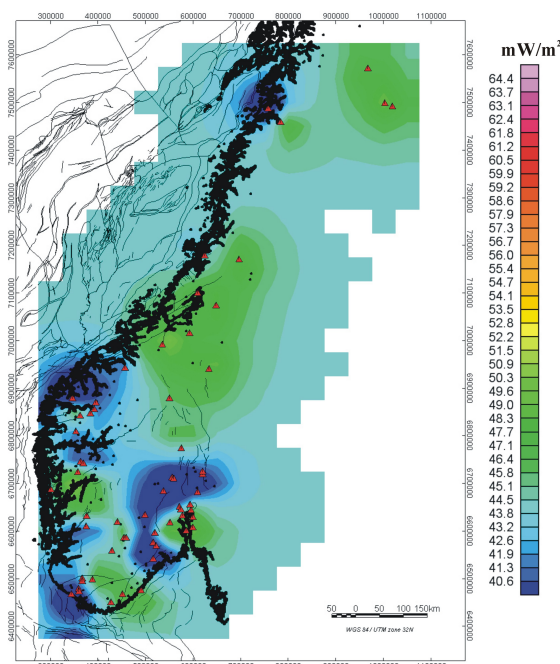


Figure 1: Heat flow map of Norway according to data collected in the 70s (Haenel et al. 1979). Note the relatively low values (40 to 50 mW/m²). Most heat flow values were determined from shallow mining wells (i.e. less than 300 m depth) and lake measurements and uncorrected for the potential influence of paleoclimatic variations.

2. THE MODERN HEAT FLOW DATABASE OF NORWAY

In the framework of the Kontiki and HeatBar (NGU-NFR-StatoilHydro) projects, we measured temperatures in 15 deep drillholes located in the Oslo Region (SE Norway), mid-Norway, Nordland (northern Norway) and Finnmark (Arctic Norway). In contrast with previous heat flow studies, most of the new drill holes reach depths exceeding 800 m, allowing for the identification of paleoclimatic signals in the geothermal gradients and removing them. In addition, we made a dense sampling of core material from the wells in order to measure the thermal conductivity of the rocks penetrated in the wells. This allowed for high-resolution heat flow profiles (Pascal et al. 2008, Slagstad et al. 2009). Finally, geochemical analyses have been conducted on different basement units (Slagstad 2008) in the vicinity of the drill holes with the aim of determining the relative proportion of heat generating elements (i.e. potassium, uranium and thorium) and calculate the part of the heat originating in the crust.

The modern heat flow map of Norway is shown in Figure 2. The results demonstrate that heat flow values fall in the

range of ~ 50 to ~ 70 mW/m^2 in excellent agreement with values obtained in the neighboring country of Sweden (Eriksson and Malmquist 1979). In detail, heat flow reaches its lowest value in northern Norway and its maximum in southern Norway in the Oslo Region. Heat generation data shows that there is a positive correlation between heat production in the basement (i.e. down to < 1 and up to ~ 4 mW/m^3 in northern Norway and the Oslo Region respectively, Slagstad 2008) and heat flow.

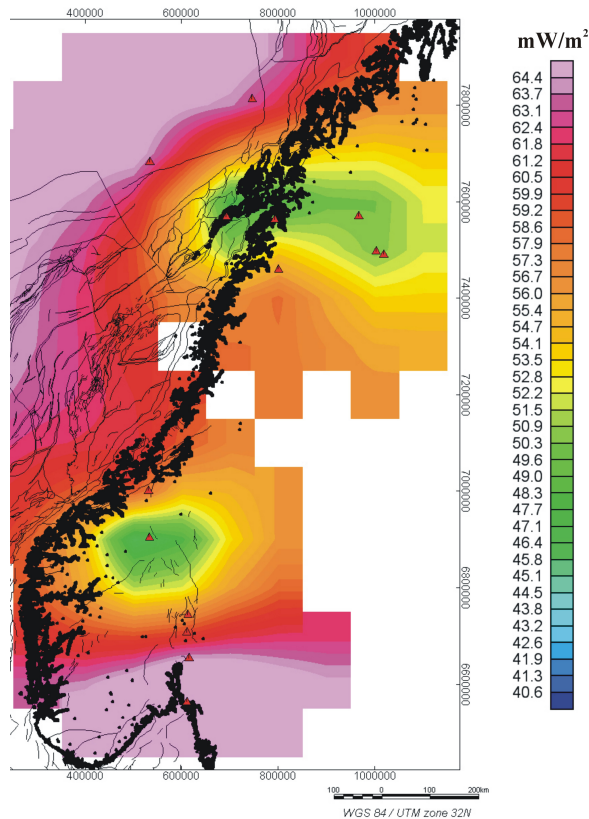


Figure 2: Modern heat flow map of Norway. Note that the newly determined heat flow values exceed by 10 to 20 mW/m^2 the previously ones (Fig. 1).

3. IMPLICATIONS FOR GEOTHERMAL PROSPECTING

The increasing demand for energy and the urgent need for “clean” and renewable energy sources has drawn back to the agenda geothermal prospecting in most western countries and its interest is being actively raised in Norway too. In order to estimate the geothermal potential of Norway we used our newly established heat flow database.

Firstly, we selected the wells presenting the most stable heat flow values, thus potentially undisturbed by fluid circulations or undetected paleoclimatic signals (Pascal et al. 2009). After this first screening, we took the heat flow values determined from the deepest parts of the wells and corresponding thermal conductivities. As a first attempt we computed temperatures down to 5 km depth below the surface for each selected well, based on these two datasets. Figure 3 shows that temperatures higher than 100°C are predicted in most places and higher than 130°C for two localities.

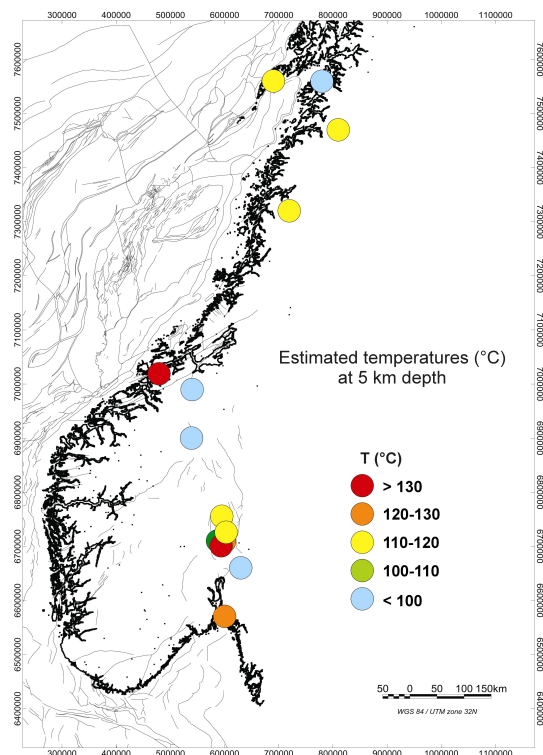


Figure 3: Estimated temperatures at 5 km depth below the surface.

Secondly, we attempted to estimate the error bars associated with our determined temperatures. Being aware of the lack of information well below the deepest levels reached by the drill holes (i.e. ~ 1000 m), we restricted the analysis to the most influential parameter, namely thermal conductivity and made it vary in a reasonable range for basement rocks (i.e. 2.5 to 4 W/m.K).

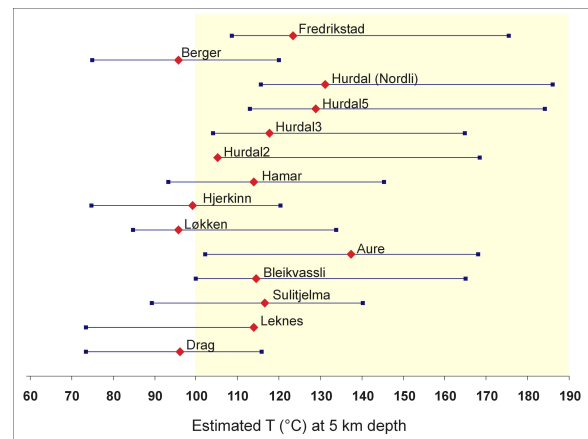


Figure 4: Estimated temperatures at 5 km depth below the surface for each selected heat flow site in Norway, localities depicted from north (Drag) to south (Fredrikstad). Error bars were determined by varying thermal conductivity values inside a reasonable range for basement rocks. Note the gradual increase in predicted temperatures from north to south.

The results (Fig. 4) confirmed the visual impression given by Figures 2 and 3. The Oslo Region in southern Norway, which is also and fortunately the most populated one, appears to have the best potential in terms of geothermal

prospecting. In detail, the analysis suggests that it is not unreasonable to expect temperatures $>150^{\circ}\text{C}$ in areas where granites with high heat production have been detected (i.e. Fredrikstad) or where a relatively significant cover of sediments is still present (i.e. Hamar), insulating thermally the underlying basement.

4. CONCLUSION

Geothermal prospecting in Norway is still in its infancy and more geological and geophysical studies are crucially needed before economically sustainable targets are found. Nevertheless, the progress made in the past five years, mainly in the framework of the Kontiki and HeatBar projects, sheds new light and hope for the geothermal state of Norway. Our main finding is that heat flow and temperature values below the surface are not desperately low as claimed by previous studies.

REFERENCES

- Eriksson, K.G. and Malmquist, D.: A review of the past and the present investigations of heat flow in Sweden, V. Cermak and L. Rybach (eds.), *Terrestrial heat flow in Europe*, p. 267-277, Springer-Verlag, Berlin (1979).
- Haenel, R. Grønlie, G., and Heier, K.S.: Terrestrial heat-flow determination in Norway and an attempted interpretation, in V. Cermak and L. Rybach (eds.), *Terrestrial heat flow in Europe*, p. 232-240, Springer-Verlag, Berlin (1979).
- Pascal, C., Barrère, C., Davidsen, B., Ebbing, J., Elvebakk, H., Gernigon, L., Olesen, O., Roberts, D., Siedlecka, A., Skilbrei, J.R., Slagstad, T., and Wissing, B.: HeatBar progress report 2008, Basement heat generation and heat flow in the western Barents Sea – importance for hydrocarbon systems, NGU Report 2008.072, 64 pp. (2008).
- Pascal, C., Elvebakk, H., and Olesen, O.: An assessment of deep geothermal resources in Norway, *Proceedings, Norwegian Winter Meeting, Bergen* (2009).
- Slagstad, T.: Radiogenic heat production of Archaean to Permian geological provinces in Norway, *Norwegian Journal of Geology*, 88, 149-166 (2008).
- Slagstad, T., Balling, N., Elvebakk, H., Midttømme, K., Olesen, O., Olsen, L., and Pascal, C.: Heat flow measurements in Late Palaeoproterozoic to Permian geological provinces in south and central Norway and a new heat-flow map of Fennoscandia and the Norwegian-Greenland Sea, *Tectonophysics*, 473, 341-361 (2009).