Geophysical Research Abstracts
Vol. 14, EGU2012-6942, 2012
EGU General Assembly 2012

Geothermal Studies of the Outokumpu Deep Drill Hole, Finland: Vertical variation in heat flow and palaeoclimatic implications

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Detailed geothermal studies of deep drill holes provide insights to heat transfer processes in the crust, and allow separation of different factors involved, such as palaeoclimatic and structural conductive effects as well as advective fluid flow effects.

We present high resolution geothermal results of the 2,516 m deep Outokumpu Deep Drill Hole in eastern Finland drilled in 2004-2005 into a Palaeoproterozoic formation with metasedimentary rocks, ophiolite-derived altered ultramafic rocks and pegmatitic granite. The down-hole temperatures have been logged five times after end of drilling and extend to day 948 after drilling. The hole is completely cored (79% core coverage) and thermal conductivity measurements were done at 1 m intervals. The geothermal results on temperature gradient, thermal conductivity and heat flow density yield an exceptionally detailed data set and indicate a significant vertical variation in gradient and heat flow density. Heat flow density increases from about 28-32 mW m-2 in the uppermost 1000 m to 40-45 mW m-2 at depths exceeding 2000 m. The estimated undisturbed surface heat flow value is 42 mWm-2.

We present results on forward and inverse transient conductive models which suggest that the vertical variation in heat flow can mostly be attributed to a palaeoclimatic effect due to ground surface temperature (GST) variations during the last 100,000 years. The modelling suggests that the average GST was about -3...-4°C during the Weichselian glaciation. Holocene GST values are within ± 2 degree from the present average GST in Outokumpu (5°C).

The topographic hydraulic heads and hydraulic conductivity of crystalline rocks are low which suggests that advective heat transfer in the formation is not significant. The slow replacement of fresh flushing water by saline formation fluids is observed in the hole, but it does not generate significant thermal disturbances in the logs. On the other hand, free sluggish thermal convection is present in the large diameter (22 cm) borehole, and temperature variations in the range of few mK to 0.01 K occur over times of minutes to tens of minutes. Theory suggests that convection cells are about as tall as the drill hole diameter, and thus the free convection is expected to generate only local thermal 'noise'not affecting the general geothermal results.

Reference: Physics of the Earth and Planetary Interiors 188 (2011) 9–25 (doi:10.1016/j.pepi.2011.06.002)