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# Topography effects on the surface heat flow and subsurface temperature

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## Abstract

The surface heat flow of a planet is a fundamental measure for its overall energy balance, and is somewhat indicative of its total radionudlide inventory and its internal dynamics. However, this quantity depends not only on the heat flow from the deep interior (core, mantle) into the crust, but also from the the radiogenic heat that is produced in the crust. Furthermore, the topography and the thermal properties of the near surface layers influence the heat flow. Therefore, it is not straightforward to determine the global surface heat flow from single measurements, unless a correction for topography effects is applied. Here, we study the effect of several generic geological features such as basins, craters, shield volcanos, grabens and ridges, on the heat flow at the surface, and determine the subsurface temperatures. It will be shown that the influence of the topography is substantial.

## Digital formats

The global surface heat flow of a planet is characteristic for the state of a planet's interior and its thermal history. Obviously the global heat flow can only be determined if either an unreasonably large number of measurements distributed across the globe can be performed, or if one or a few local measurements are somewhat representative for the whole planet. On Earth, this is hardly the case, because the surface heat flux varies between 30 and ¿ 100 mW/m$^2$ and differs especially between the continental ( 57 mW/m$^2$ average) and the oceanic crust (100 mW/m$^2$ average). There are two main reasons: (1) the two crust types have quite different average thicknesses (10 km for oceanic, 40 km for continental crust) and therefore different insulation effects, and (2) both crust types differ in mineral content, especially with respect to radionuclides. The decay of radioactive isotopes provides an additional heat source which creates an additional contribution to the surface heat flow. Obviously, the crust thickness and its heat source density influence the measured surface heat flow significantly.

A further complication is created by the topography in the vicinity of the measurement location. Several generic geologic features will be studied in a numerical finite element model, e.g. basins, craters, shield volcanos, grabens and ridges. Particularly interesting is the effect of additional layers of a low thermal conductivity material, such as dust fillings in craters. The model computes the heat flow density and the temperature for every grid point in the crust and at the surface.

The examples shown here consider two different models of sections through a generic crust (see figures 1 and 2), with a flat lower crust boundary, a valley on the left hand side and a ridge on the right hand side (they might be misinterpreted as a bowl–shaped crater and a pancake–shaped hill, but the underlying model is a two–dimensional one, no axial symmetry). The width of the model domain is 100 km, and the thickness is 20 km. Both models assume a heat flow of 50 mW/m$^2$ at the lower boundary, a constant temperature at the surface, and thermal properties that are typical for crust rocks. The second model includes a thin layer of sediment filling on the floor of the valley on the left hand side. Such sediments are typically loose and have a lower thermal conductivity then solid rock and act as a thermal blanket. Figure 1 shows the vertical component of the heat flow for the simple model without the additional sediment filling. The heat flow is substantially increased in the valley, while the valley ridges close to the surrounding plateau show a strong reduction of the heat flow compared to the 50 mW/m$^2$ which are induced into the model at the crust base. The ridge on the right shows the opposite effect: a heat flow reduction on its top and a significant local increase at its base. Figure 2 shows the vertical heat flow component for the second model which includes a sediment filling in the valley. For better comparison the color coding has been forced to be identical to figure 1, therefore extremely large values are blanked out and appear white. The heat flow at the valley floor is almost choked to 0, but enforces an extremely enhanced heat flow where the sediment layer is confined by the valley walls. Figure 3 shows the temperature distribution for this model. It can be seen that the sediment layer leads to a very accentuated temperature increase below it. The imprint can be seen all through the crust, and the temperatures at the valley base, i.e. immediately below the sediment layer, are much higher than

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elsewhere close to the surface.

Though these generic models are still very simple, they already show the importance of such studies: 1) Obviously, heat flow measurements are substantially influenced by the topography in their surrounding and by no means representative for a global average. On the other hand, sophisticated models of the actual topography around the measurement location can help to correct for the topography effect. 2) Even when no measurements are considered, such studies can be of importance for the understanding of the Martian surface; especially where the depths of stable ice layers is of importance.

It should be mentioned that the effects of topography and heat source density in the crust have been studied already by [1, 3, 2], but only for the Moon and Asteroids, and using a different numerical approach.

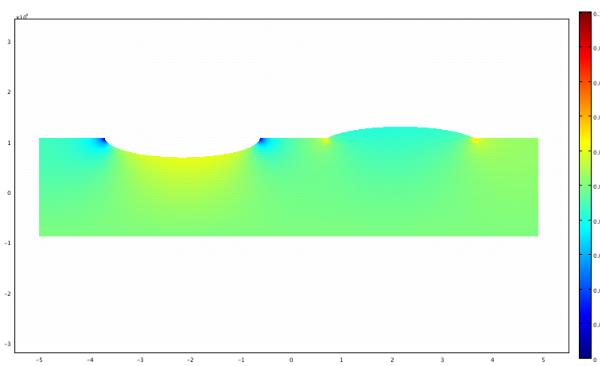

Figure 1: Cross section through a generic crust with a graben or canyon on the left hand side and a ridge on the right hand side. Colors denote vertical heat flow density. The heat flow into the domain (bottom) is uniform. The topography influences the heat flow and causes substantial variations.

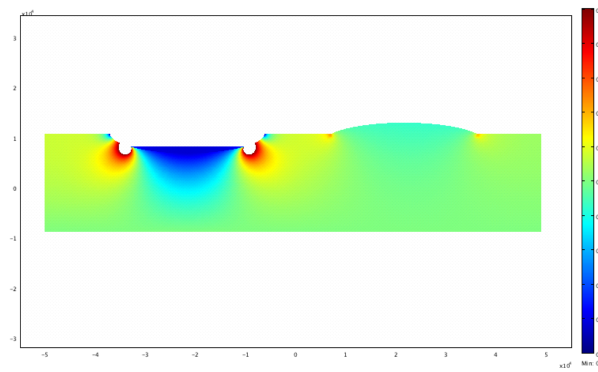

Figure 2: Cross section through a generic crust with a graben or canyon on the left hand side and a ridge on the right hand side. In addition to the model shown in fig. 1, the graben is now partly filled with a low thermal conductivity material such as dust. Colors denote vertical heat flow density. The heat flow into the domain (bottom) is uniform. The topography influences the heat flow and causes substantial variations.

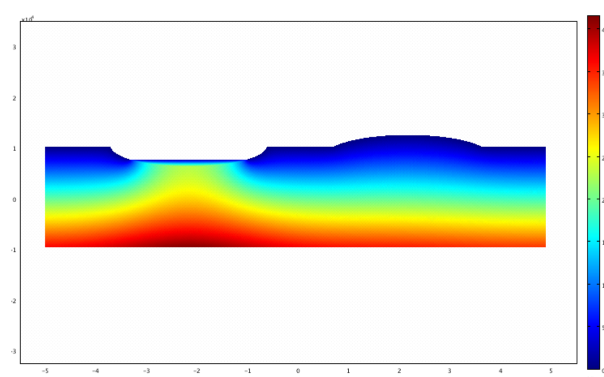

Figure 3: Cross section through a generic crust with a graben or canyon on the left hand side and a ridge on the right hand side. The graben is now partly filled with a low thermal conductivity material such as dust, as in fig. 2. Colors denote temperature. The temperature reveals strong local variations, which will have an influence on, for example, the depth level of near surface water ice.

## Bibliography

### References

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[3] Warren, P. H. and Rasmussen, K. L., (1984), *LPI Contributions*, 540, 18+