Location of anomalously hot temperatures due to heat refraction

Abstract. To explain temperature differences at a given depth, several mechanisms can be invoked. Outside volcanic areas, variations in mantle heat flow can trigger differences in crustal temperatures, but they only act over several tens to hundreds of kms. At a smaller scale, temperature differences at shallow depths can only be explained by crustal heterogeneities and/or fluid flows. When fluid motion is negligible, heat transfer processes – and thus subsurface temperatures – are basically controlled by thermal properties of rocks (thermal conductivity and heat production rates). Because of the heterogeneous nature of the crust, one can say that heat refraction occurs everywhere as soon as the working scale is comparable with typical lengths of crustal bodies (layer thicknesses, granitoids sizes, etc).

Theoretical and numerical results from thermal modelling of heat refraction allow to quantify simple effects due to crustal heterogeneities, and thus may be compared with real data (heat flow measurements and/or temperature profiles). However, some subtle additional parameters, like the geometry of the heterogeneity, appear to play a significant role in the interpretation of field data. In particular, an anomalous conductive body with a small aspect ratio (width over depth) will not disturb the underlying isotherms even if a high surface heat flow is measured (e.g. heat flow anomaly in Manitoba). On the opposite, one may easily miss a large-scale temperature anomaly when a large aspect ratio insulating body is considered, because surface heat flow is only affected locally, at the very edges of the heterogeneity (e.g. sedimentary basins, ash-flow calderas).

Heat refraction effects occur in a number of geological systems, but they may lead to distinct signatures :

- Close to quartz-rich faulted zones, a lateral conductivity contrast of 1.5 to 4 results in an anomalous surface heat flow
- Heat refraction effects due to lateral conductivity contrasts are enhanced at depth (evidenced in ash-flow calderas)
- In large sedimentary basins, shallow temperature anomalies at not correlated with anomalous surface heat flow

High heat flow in Manitoba :

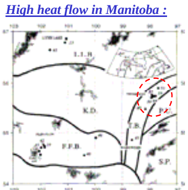


Figure 1. Heat flow values in the eastern Trans Hudson Orogen (in $mW.m^{-2}$). Diamonds correspond to previously published data (Drury, 1985; and references therein). Geological domains are delineated : *LLB*: Lynn Lake Belt; *K.D.* Kisseynew Domain; *FFB*: Flin Flon Belt; *TB*: Thompson Belt; *PU*: Pikwitonei Uplift; *SP*: Superior Province. Inset : *HC*: Hearne Craton; *SP*: Superior Province; *G*: Grenville Province.

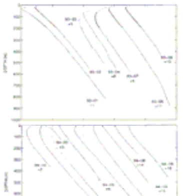


Figure 2. Measured temperature profiles. For clarity, temperature profiles are shifted as indicated. *Top*: profiles from the Flin Flon Belt and from Wabowden (see Table 1). *Bottom*: profiles from the Thompson area.

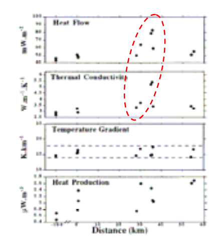
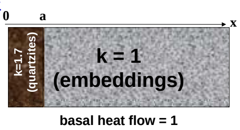


Figure 3. Heat flow, thermal conductivity, temperature gradient and heat production profiles along the Thompson belt. Origin corresponds to borehole 94-11 (see Table 1). Temperature gradients do not vary much and high heat flow values are due to large values of thermal conductivity.

Model:



Analytical solution:

$$\phi_{x<a}(x) = \sum_{n=0}^{\infty} \alpha_n + \frac{\alpha_n (k-1) cosh(k_n x)}{k sinh(k_n a) + cosh(k_n a)} \quad (2)$$

and

$$\phi_{x>a}(x) = \sum_{n=0}^{\infty} \alpha_n + \frac{\alpha_n (1-k) sinh(k_n a) exp(k_n(a-x))}{k sinh(k_n a) + cosh(k_n a)} \quad (3)$$

where

$$k_n = \frac{(2n+1)\pi}{2}, \qquad \alpha_n = \frac{4}{\pi}\frac{(-1)^n}{(2n+1)} \quad (4)$$

Results:

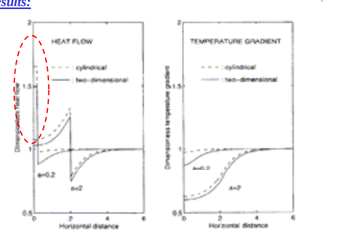


Figure 4. Surface heat flow and temperature gradient variations due to heat refraction by a conductor of thermal conductivity contrast of 1.7. The dimensionless half-width or radius *a* is indicated.

After Guillou-Frottier et al., 1996

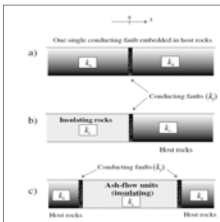
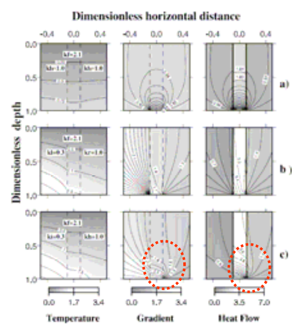


Fig. 7. Sketch of the three models used for studying heat refraction effects around faults: (a) a single fault embedded in an infinite plate of "normal" conductivity; (b) same as the previous case but the medium on the left is insulating; (c) the insulating medium is of finite size (caldera case) and the embedding medium (plate) is infinite.



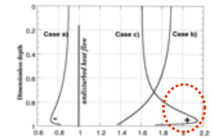
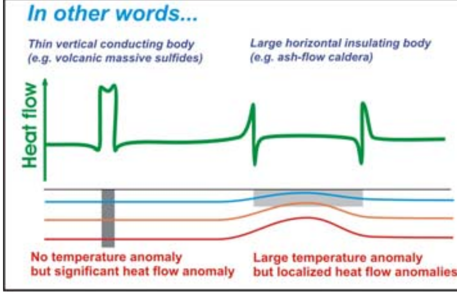


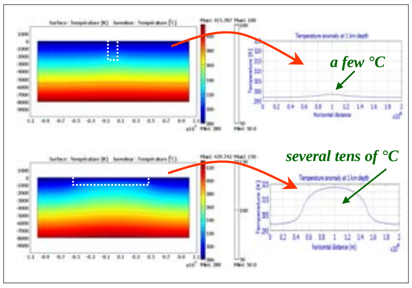
Fig. 9. Details of the vertical heat flow profiles at the outer edge of the conducting fault for the three cases of Fig. 7. Note the anomalous positive heat anomaly at depth, for case (c).

The finite size of the insulating body (the ash-flow unit, case c) promotes external heat escape through the conducting faults

After Guillou-Frottier et al., 2000

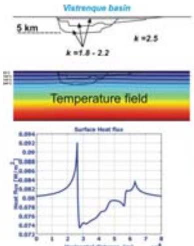
In other words...

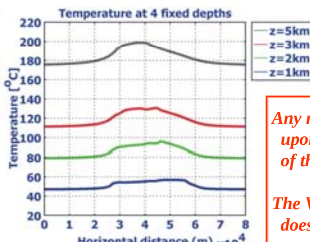




Vistrenque basin (south-east of France)

South of France, the apparent temperature anomaly does not appear in the surface heat flow map. One data, located in the Vistrenque basin (close to Nimes fault), indicates 120°C at 3 km depth. Due to the thick sedimentary cover, the account for insulating sediments easily explains such anomalous temperatures.

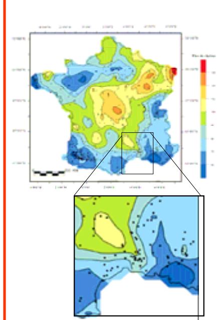




Any model must however rely upon representative values of thermal conductivities.

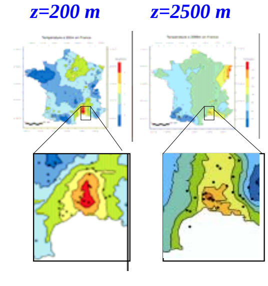
The Vistrenque example (left) does not hold as soon as conductivity values for sediments are enhanced by 30%.

Surface Heat Flow



Subsurface temperatures

z=200 m *z=2500 m*



Even at large scale, there is no clear relationship between surface heat flow and underground temperatures, probably because of heat refraction effects.

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References

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