Boreholes, orebodies, and heat refraction : Implications for heat flow density studies and paleoclimatic reconstructions

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Implications for heat flow density studies and paleoclimatic reconstructions

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Summary

Although thermal conductivity in crustal rocks does not vary much, there may be exceptions near some ore deposits. Because boreholes that are used in heat flow density studies as well as in paleoclimatic reconstructions are generally drilled for mineral exploration, it is worth understanding the effects of heat refraction at depth, near these thermal conductors.

At the surface, the constant temperature condition tends to smooth refraction effects related to narrow conductive bodies, whereas at depth, where this condition has less effect, lateral heat transfer could significantly distort the temperature field.

* When several boreholes are used to estimate the heat flow values, there the chances of a biased determination are small. On the other hand, when a single borehole is used, the heat flow estimate might be in error. Synthetic examples of thermal refraction show that perturbations can be recorded away from the conductor. Perturbations are shown to be higher above the inclined sides of the orebody.

* Examples of inversion of ground surface temperature history from synthetic temperature profiles disturbed by a thermal conductor show that heat refraction effects can also lead to apparent warming or cooling signatures depending on the position of the borehole.

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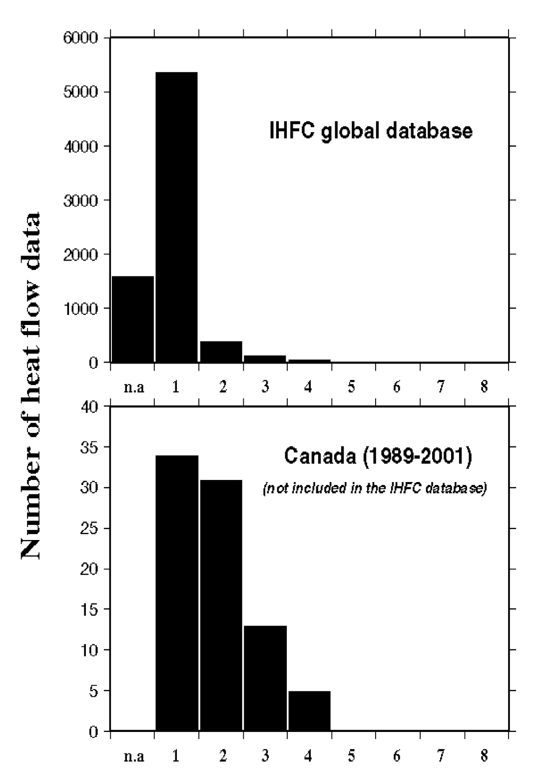
Heat flow data



•Heat flow data presently available through the I.H.F.C. database.

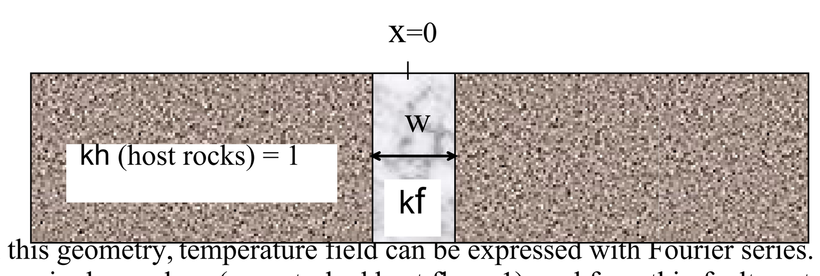
•Note that most terrestrial heat flow values are deduced from only one single temperature profile.

•Heat flow data acquired in Canada during several heat flow campaigns between 1989 and 2001 (Mareschal et al., 2000, and references therein).

•These data, not included in the IHFC database, show that more than half of the estimated heat flow values are determined with 2 or more temperature profiles.

Heat refraction near a conductor

The case of a single conductor (conductivity kf) embedded within « normal » rocks (conductivity kh) has been developped in Guillou-Frottier et al. (1996), and detailed for depth-dependence in Guillou-Frottier et al. (2000). Analytical solutions are easily obtained for a rectangular geometry (dimensionless width = w) :



•With this geometry, temperature field can be expressed with Fourier series.
In dimensionless values (unperturbed heat flow=1), and for a thin fault centered at the horizontal distance x=0, we have, within the fault :

T(x,z) = sin(qmz) (am f(x) + m) with f(x) = cosh(qmx) ,

qm = (2m+1). /2 , and m= [8 (-1)m / 2(2m+1)2]. (kh /kf) ,

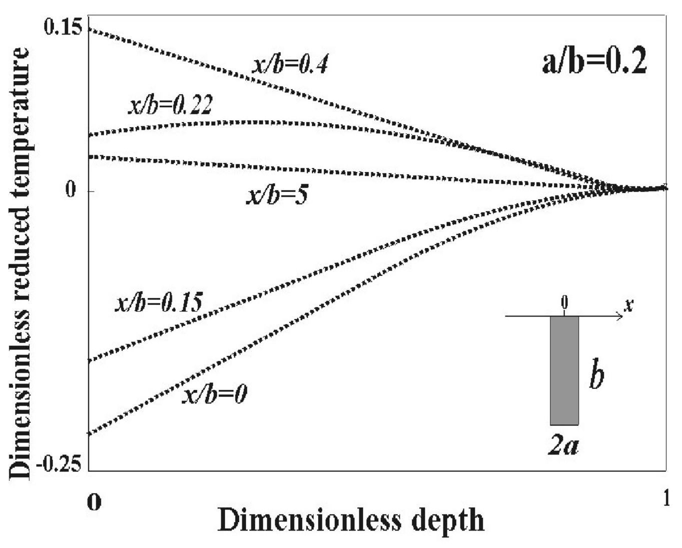
and Fourier coefficient am is determined by continuity of temperatures and horizontal heat flow through the interfaces x = ± w/2.

•Within the host rocks, a similar expression is deduced, with f(x)=exp(-qm|x|), and other coefficients (see Guillou-Frottier et al. (2000) for details).

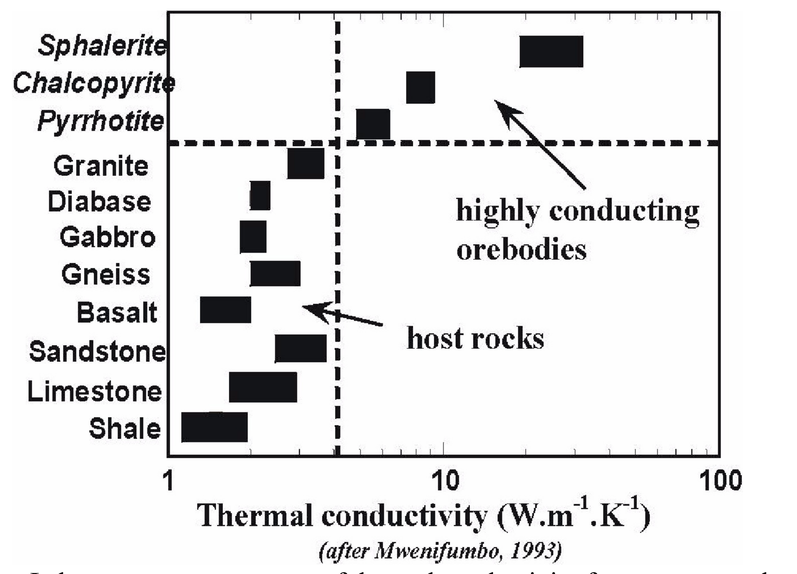
Results for a conductor (kf = 2 kh) of aspect ratio a/b=0.2 (see sketch). Note the various curvatures depending on the position of the temperature profile versus the conductive fault.

•Here, the constant temperature gradient has been removed from the temperature profile.

•Note the strong distortion at the edge of the external side of the fault (x/b = 0.22), as well as the two opposite signatures within and outside the conductor.



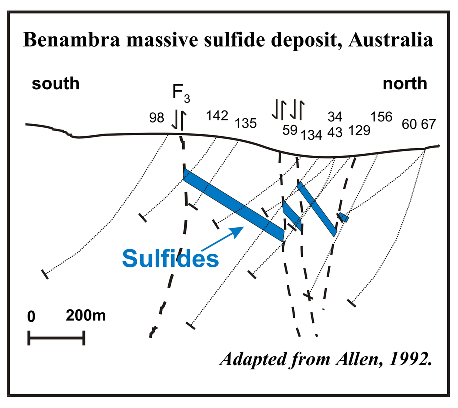
Thermal conductivity data

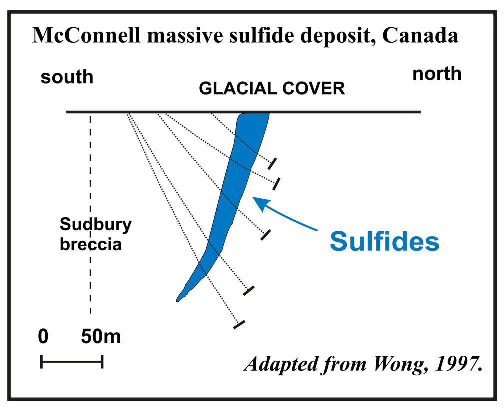


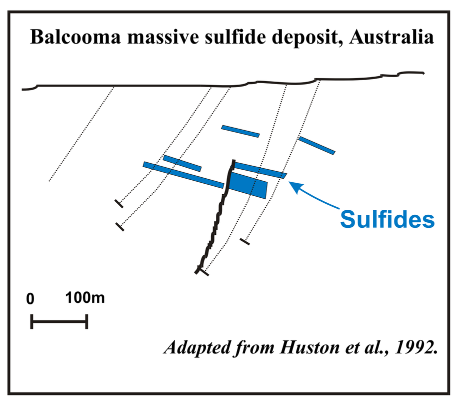
•Laboratory measurements of thermal conductivity for common rocks give values ranging between 1 and 7 W/m/K. However, for some volcanic massive sulfide deposits, the high content of pyrite, chalcopyrite and sphalerite can lead to a high bulk conductivity.

•In the Iberian pyrite belt, measurements within the « Masa Valverde » deposit give thermal conductivities from 15 to 23 W/m/K over a thickness of about 60m.

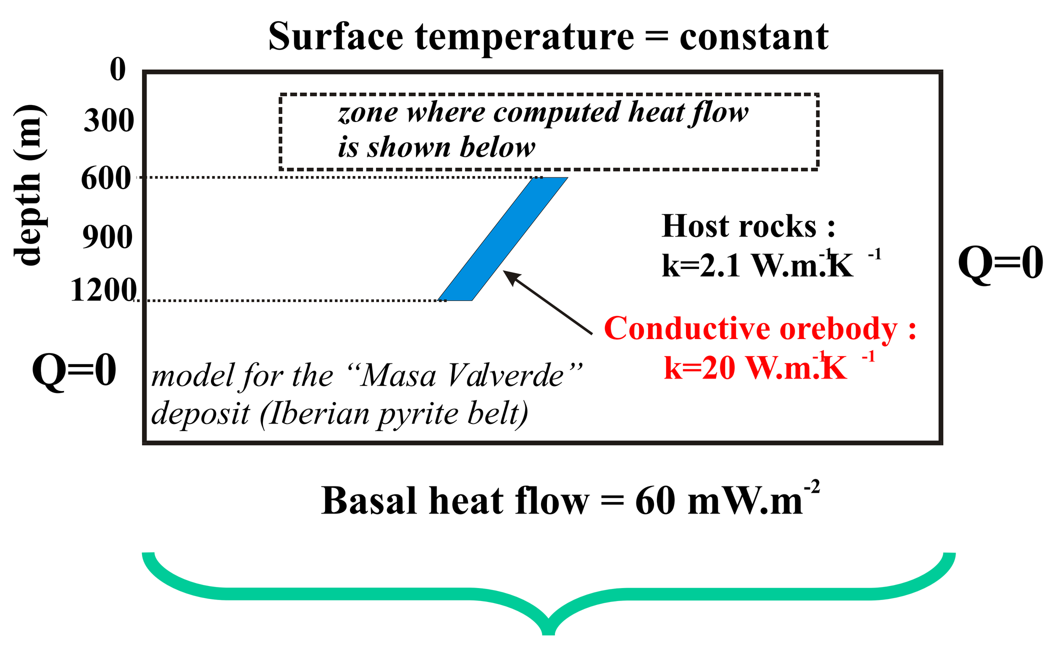
Orebodies and boreholes locations

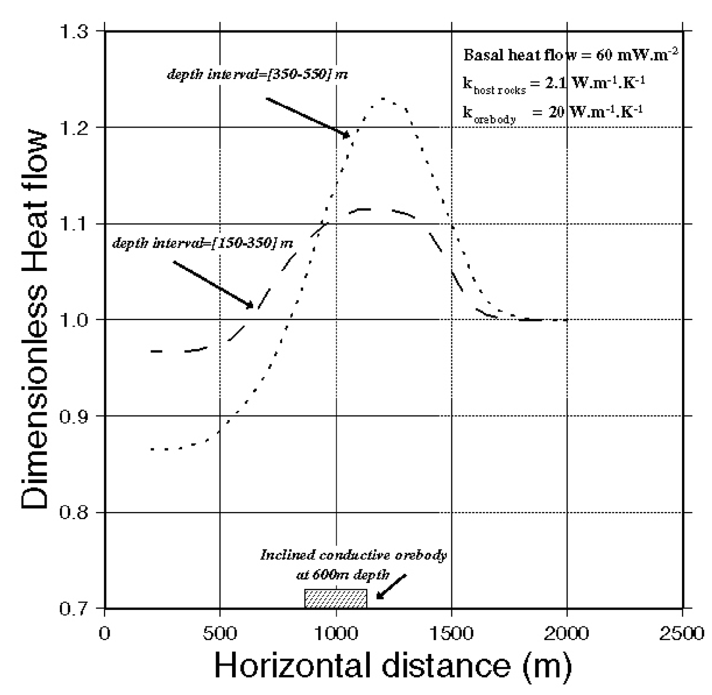






Theoretical modelling





Because boreholes are often drilled above the inclined sides of the orebody, we have used a finite-element model presented by Gable et al. (1996) - dedicated to the « Masa Valverde » modelling - to decipher the heat flow perturbation near the inclined orebody.

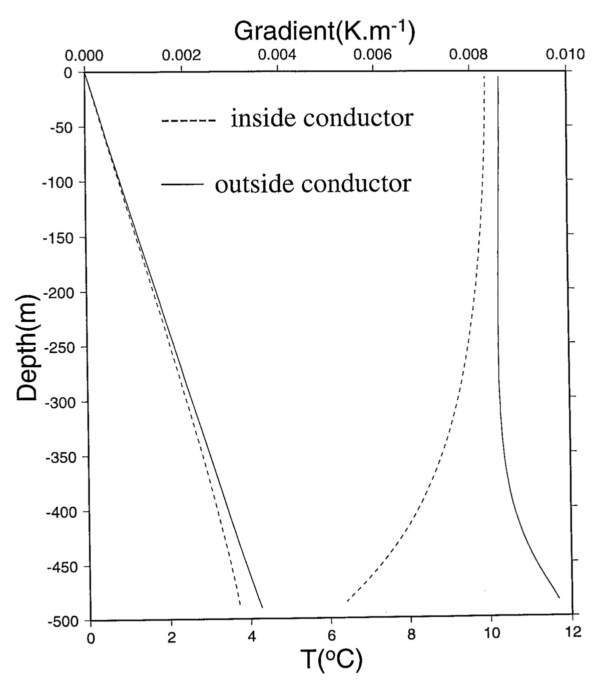
It is worth noting that the heat flow estimates, made at a« reasonable » depth range [350-550m] yield almost 40% of variation between the lowest and the highest estimates of the « equilibrium » heat flow above the inclined side.

Ground surface temperature history inferred around a conductive body

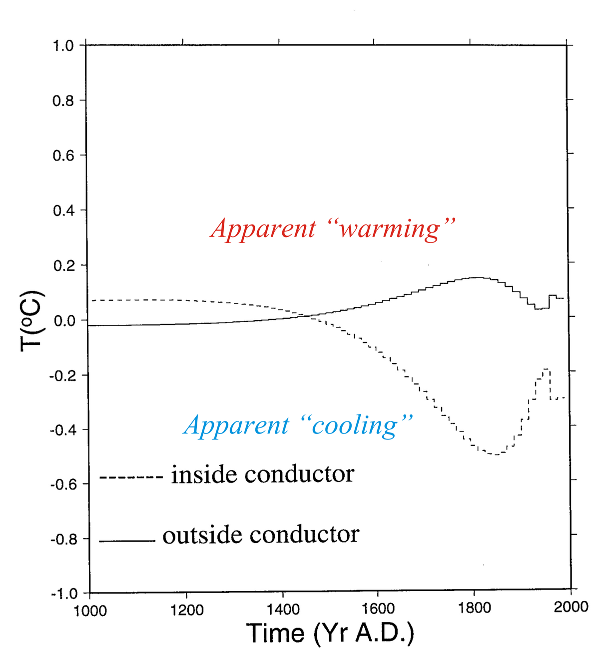
•Synthetic temperature and thermal gradient profiles, as deduced from theoretical modelling described on the left.

•These profiles (with realistic dimensions) have been inverted with the singular value decomposition method (Mareschal and Beltrami, 1992).

•Results are shown on the right.



Inverted profiles : G.S.T.H.



Inferred Ground Surface Temperature History (G.S.T.H.) from the previous theoretical profiles.

An apparent warming signature appears for the profile located outside the conductor, and an apparent cooling signature (-0.5°C) could be assimilated to the Little Ice Ages effects, for a profile located within the conductor.

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References :
-Gable R. et al., Geothermal exploration of deep polymetallic orebodies, 3rd Symposio Sulfuros Polimetalicos de la Faja Piritica Iberica, Huelva, Spain, 21-23 February 1996.
-Guillou-Frottier L. et al., High heat flow in the Trans-Hudson orogen, central Canadian Shield, Geophys. Res. Lett., 23, 3027-3030, 1996
-Guillou-Frottier L. et al., Genetic links between ash-flow calderas and associated ore deposits as revealed by large-scale thermo-mechanical modeling, J. Volcanol. Geotherm. Res., 102, 339-361, 2000.
-Mareschal J-C. and H. Beltrami, Evidence for recent warming from perturbed geothermal gradients : examples from eastern Canada, Clim. Dyn., 6, 135-143, 1992.
-Mareschal J-C. et al., Heat flow and deep thermal structure near the southeastern edge of the Canadian Shield, Can. J. Earth Sci., 37, 339-414, 2000.
-Mwenifumbo C.J.., Temperature logging in mineral exploration, J. Appl. Geophys., 30, 297-313, 1993.