Evaluation of thermal proprieties of SLL sedimentary basin: measurements in laboratory and well logs approach

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Introduction

Generating electricity from deep geothermal resources has been proved in many countries (France, Germany, USA…). This clean and renewable energy is promoted today worldwide: some projects have already been installed while others are currently studied.

In Quebec, we also aim at having an electric power plant which uses deep geothermal resources to produce electricity. This project is now at the phase of exploration. We try to find the best place to install such a power plant. Unfortunately, heat flow studies have been mostly done at the scale of Canada or for North America (Grasby et al., 2011). Others few studies and models have been done recently to a smaller scale but lack of thermal conductivity determination (Raymond et al. 2012).

Our main goal is to assess the subsurface temperature and heat flow at a scale allowing a better resolution. Our second goal consists of reducing the uncertainty of the temperature predictions at depth. The St. Lawrence Lowlands (SLL) sedimentary basin has been chosen for the study area where new analytical methods have been applied to improve temperature predictions.

Geological setting

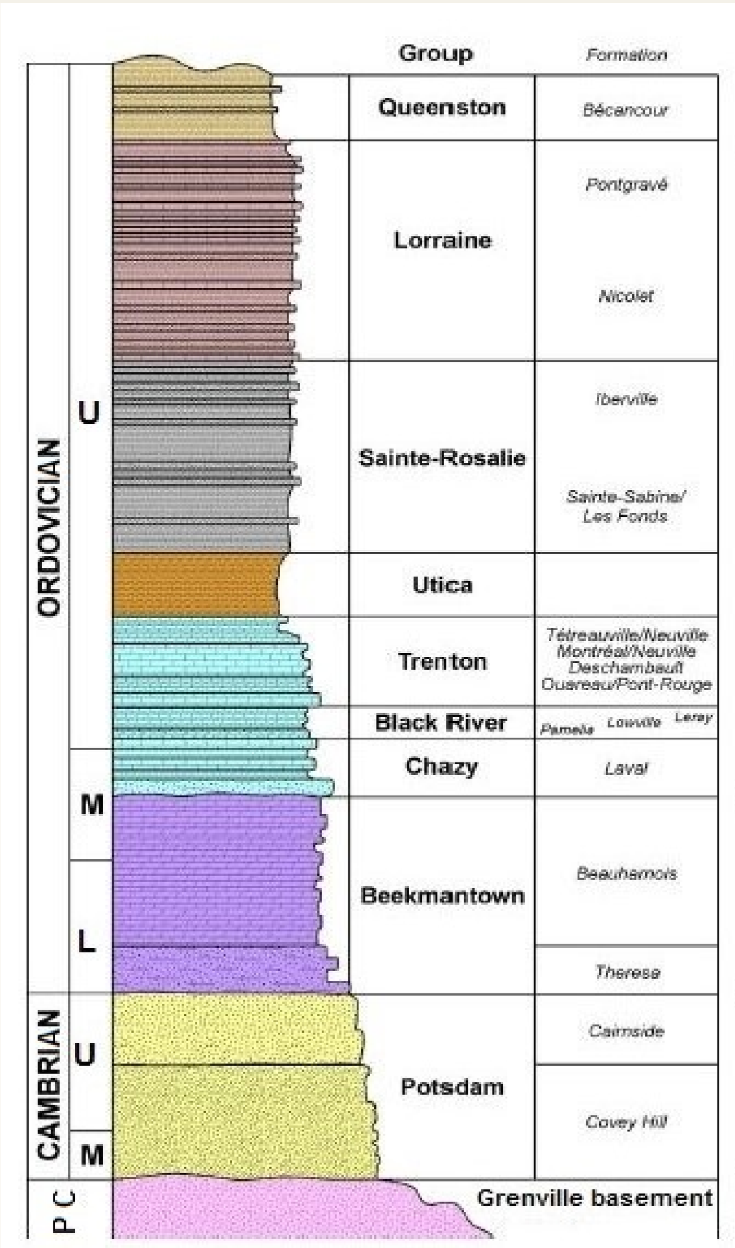

Figure 2: Stratigraphic column (Hofma 1972, Globensky 1987, SaladHersi et al. 2003 et Comeau et al. 2004).

The SLL basin is a sedimentary basin located in Quebec (East Canada). This large synclinal, oriented Northeast-Southwest, contain the majority of the urban area of the province (figure 1). The upper units of the basin are dominated by finite sedimentation (Groups of Queenston, Loraine, St Roalie, and Utica). Known as insulating rocks, the shale of such groups may be a good trap of heat. Thus, they constitute the potential caprocks (figure 2). In the opposite, the lower units such as Beekmantown (limestone) and Potsdam (sandstone) are dominated by heat conducting minerals (respectively dolomite and Quartz). Previous Studies (Bédard et al., 2013; Tran Ngoc et al., 2013; Tran Ngoc et al., 2014) additionally show interesting porosity and permeability values for both units. With such mineralogy and petrophysical proprieties, the two geological formations are potential geothermal reservoirs at depth where temperature buildup may be sufficient.

Finally, the Precambrian basement, essentially composed of metamorphic rocks, can be a target for enhanced geothermal system.

Methodology

Field Works:

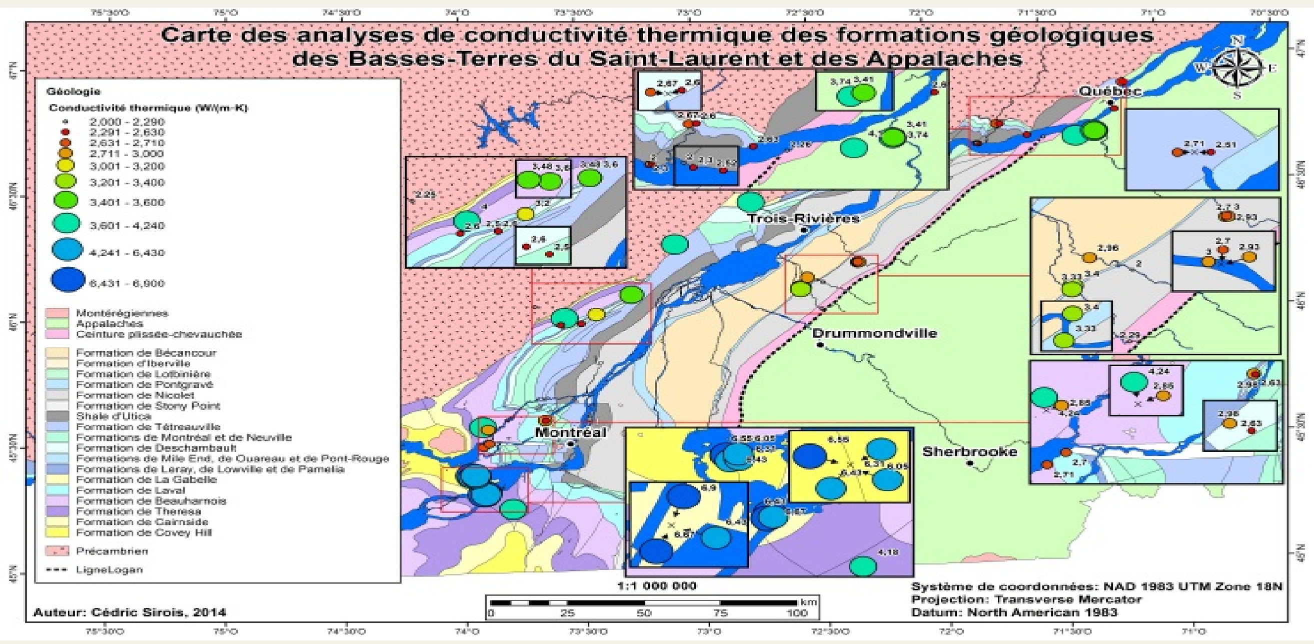

Figure 3. Samples locations and thermal conductivity values

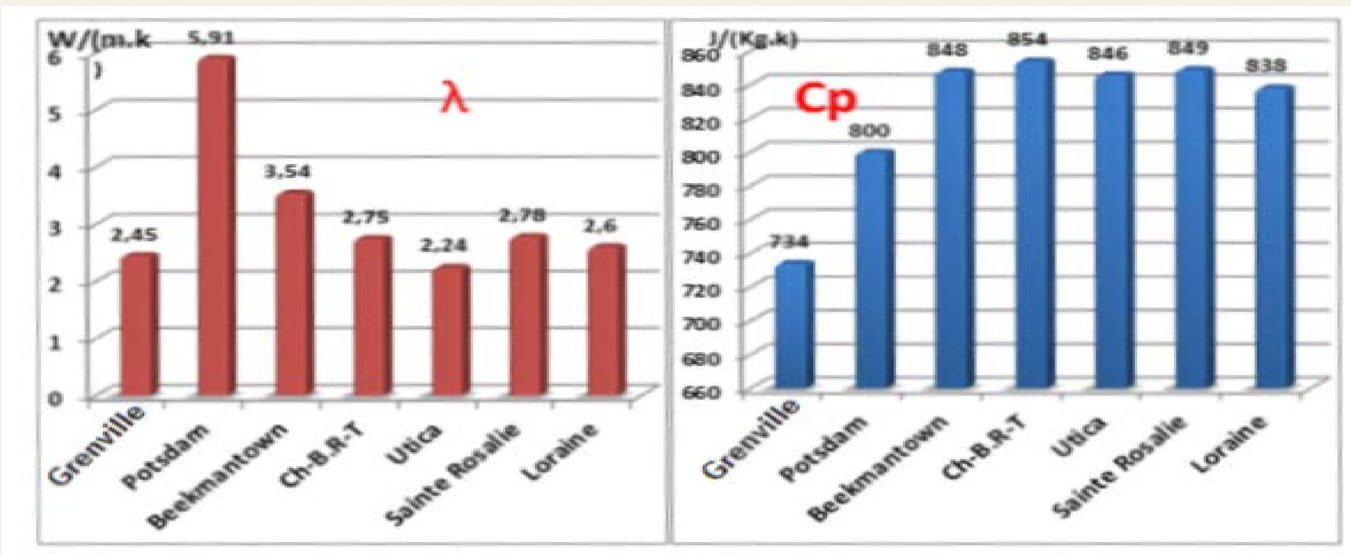

Figure 4. Average of thermal capacity and conductivity for each group

At the beginning, an approximate estimation of the thermal proprieties of the different units has been aimed. The thermal conductivity and heat capacity was evaluated using surface samples. Thus, a sampling campaign has been realized in the summer 2014. More than 45 samples were collected. Thermal conductivity was measured with a needle probe while heat capacity was estimated using microscopic observations. Positions and thermal conductivity of each sample are presented on Figure 3.

In order to evaluate the thermal characteristics of each group, we decided to calculate the average of thermal conductivity and heat capacity of the basin units (Figure 4). Thermal conductivity results showed that the Potsdam group represents the best heat conductor, following by the Beekmantown group. An average near 6 W/(m.k) for Potsdam and an average of 3.5 W/(m.k) for Beekmantown have been recorded. The other groups showed generally moderate values of thermal conductivity going from 2.24 to 2.78 W/(m.k) (figure 4).

Inferring thermal proprieties from well logs:

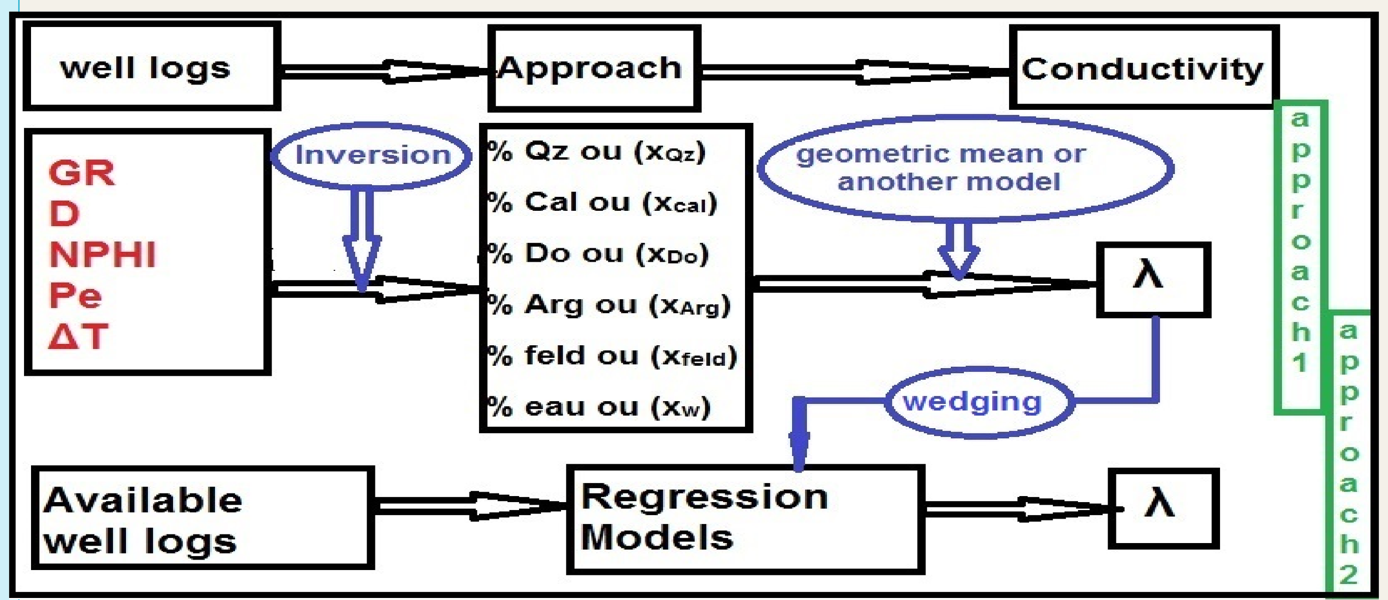

Figure 5. Indirect methods to infer thermal conductivity from well logs

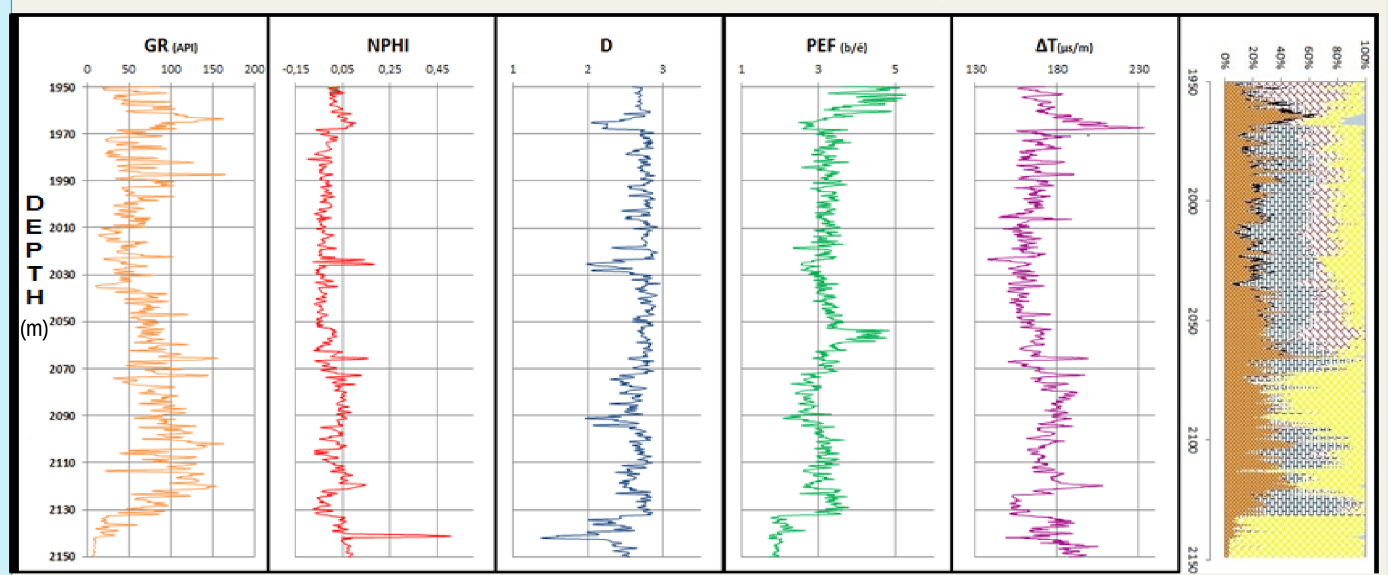

Figure 6. Used well logs and stratigraphic column reconstituted

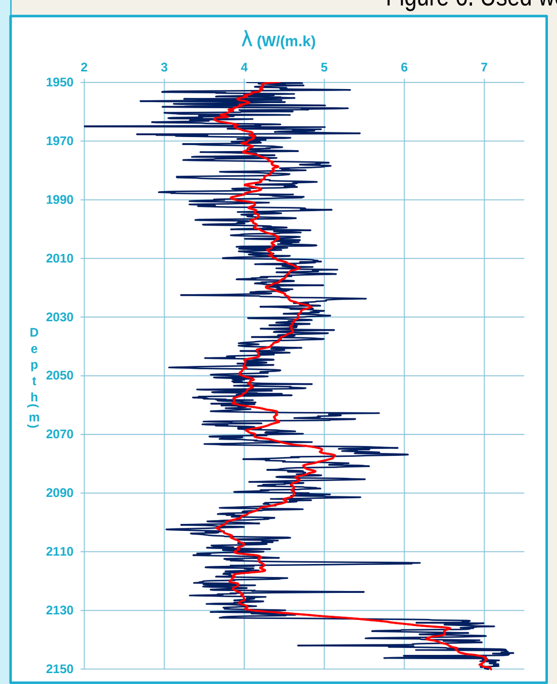

Figure 7. Example of a thermal conductivity profile

Thermal conductivity profiles were determined in wells to take into account the heterogeneities inside the geological formations using two approaches. The first consists to inverse the well logs data in order to get the mineralogical composition at each depth. Then, a geometric mean was used to infer the thermal conductivity (figures 5, 6 and 7). This approach is the most accurate, but it needs complete well logs. It can only be applied to a limited amount of wells where different type of well logs is available. The second approach, which is less accurate but is more flexible, consist to find empirical relations between the thermal conductivity and petrophysical proprieties such Gamma Ray, Density and Neutron porosity (figure 5).

formations	relations	N	R^2	Rms (w/(m.k))
clay Formations	λ= 2.44 + 0.03/Φ²-3.03/Vp	3010	0.64	0.17
Limestone Formations	λ= 6.31 -0.4* Vsh -0.017*ρ -15.38/Vp	2699	0.57	0.32
Sandstone Formations	λ=6.95 -0.026* Gr-9.50* Φ	1988	0.93	0.33
Theresa	λ=15.55 -0.014*Gr -13 *Φ-1.43*D -1.05*Vp	155	0.73	0.35
Basement	λ=5.03-0.02*Gr6.33*Φ+0.31*Vp	3066	0.95	0.2

Validation of equations

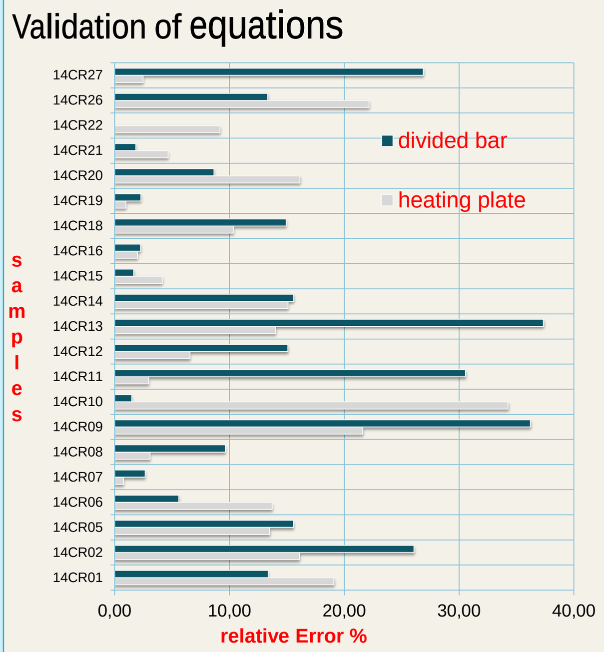

Figure 8: Relative Error between estimated and measured thermal conductivity

We then evaluated if our models predictions for thermal conductivity were satisfactory. Estimated values and direct measurements, at the same depth, were compared. For such purpose, more than 45 cores have been collected. The thermal conductivity of these samples was then measured using two methods: steady-state divided bar and transient heat plate.

Relative errors between inferred and measured thermal conductivities are given (figure 8). Errors range between 0.8% and 35%. The high errors recorded for some sample are due to the bad quality of samples, the occasional absence of one or more important well logs and the larger resolution of the well logs. In fact, estimation using well logs has a resolution of about 10- 30 cm, while measurement resolutions have a scale of a few cm with the divided bar and a few mm with the transient heating plate.

Profile temperature, heat flow and temperature gradient:

- Temperature profiles were determined with thermal conductivity values inferred form well logs of SLL basin (75 wells), by numerically solving the Poisson's equation:
- $\lambda \nabla^2 T + A = 0$. The thermal conductivity profiles were corrected for pressure and temperature effects. We use the equation of Fuchs (2014) for pressure:
- $\lambda(P) = (1.095\, C.T_{1atm}$-0.172)*$P^{0.0088.TC-0.0067}$ and the relation given by Clauser (2006) for temperature effects:
- $\lambda(T) = \frac{\lambda_0}{a+T\left(b-\frac{c}{\lambda_0}\right)}$ a = 0.99;b=34.10^{-4}; c=39.10^{-4}.
- With these profiles, we calculated first the temperature gradient and then the surface heat flux.
- We then prepared maps for both heat flux and temperature at different depths: 1 Km; 2.5 Km; 4 Km and 5Km.

Results

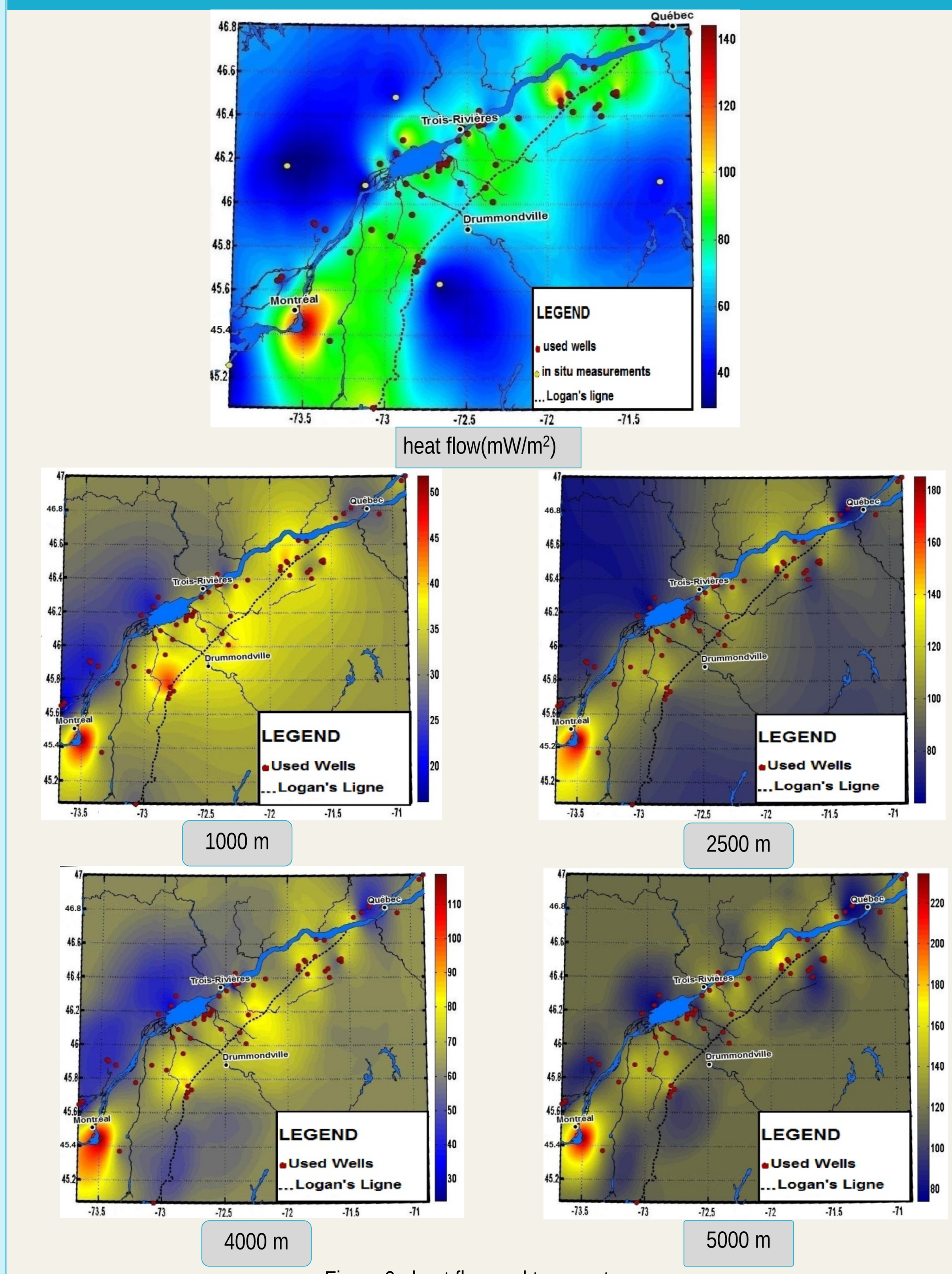

Figure 9: heat flow and temperature maps

Conclusions

Using well logs, we arrive at more accurate predictions of temperature at depth (figure 9). Heat flow map show estimations ranging from 40 mW/m² to 140 mW/m² for the SLL basin. The high values are observed between the Logan fault and the ST. Lawrence River. Some Highest values are located near the Logan fault and are well justified. Others, like near Montreal, are poorly supported by a low amount of data. Compared to other research, we found that heat flow is slightly overestimated in this study. This is due to the pressure correction.

When comparing the 4 maps, we can note that the temperature is more uniform at depth: local variations are less visible at 5 km depth.

The next steps consist to continue the investigation in the most favorable areas along the Logan Line.

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