Mapping the geothermal potential of a borehole heat exchanger in Kuujjuaq, Québec, Canada.

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ABSTRACT

Inuit communities of Nunavik, Northern Québec, strongly rely on fossil fuels for building's space heating. Diesel furnaces are spread in all the 14 Inuit villages, totalizing 12,000 inhabitants and situated along the coast of the Ungava Peninsula. A feasibility study has been carried out in Kuujjuaq, the capital of Nunavik, to evaluate the possibility of using low-enthalpy geothermal energy as a renewable and sustainable heating source. The present contribution highlights the geothermal potential of a borehole heat exchanger (BHE) calculated with the G.POT method. This method is based on a simplified heat transfer model taking into account ground thermal properties and a wide range of installation design parameters. The main constraints of the surveyed area are related to the low underground temperature, with discontinuous permafrost depending on the local geological conditions, and high building heating needs with over 8,500 heating degree day below 18°C. Different borehole characteristics were analyzed, according to the technologies available in the area. A geothermal potential of 3.8 MWh/y has been calculated for a 100 m deep borehole installed in the town center and it is highly influenced by the threshold temperature of the heat carrier fluid. This result is low if compared to common applications in the south, but the high cost and the adverse environmental effects of fossil fuels currently used allow to consider shallow geothermal energy as a possible solution for the area of Kuujjuaq.

GEOLOGICAL SETTING & THERMAL PROPERTIES

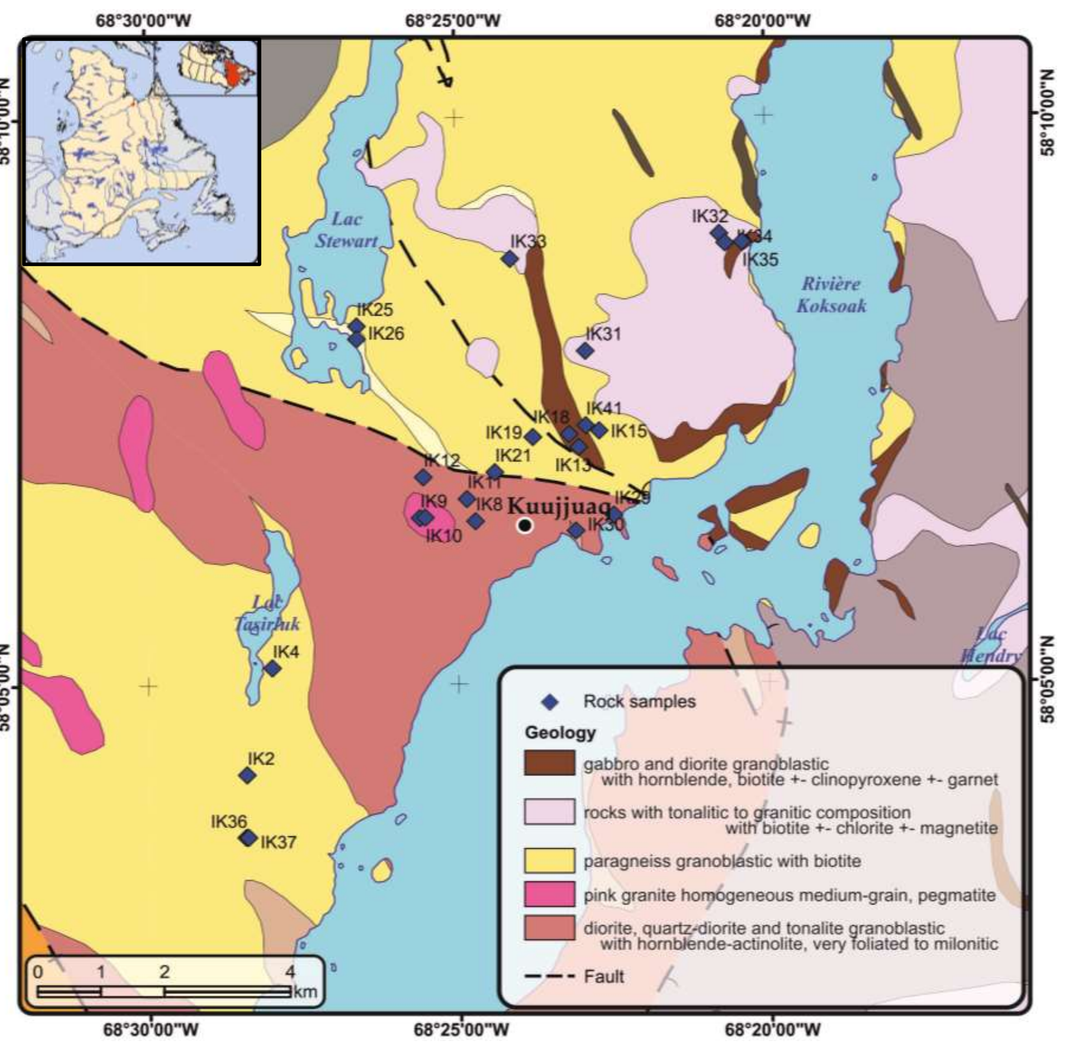

Figure 1 - Geological map

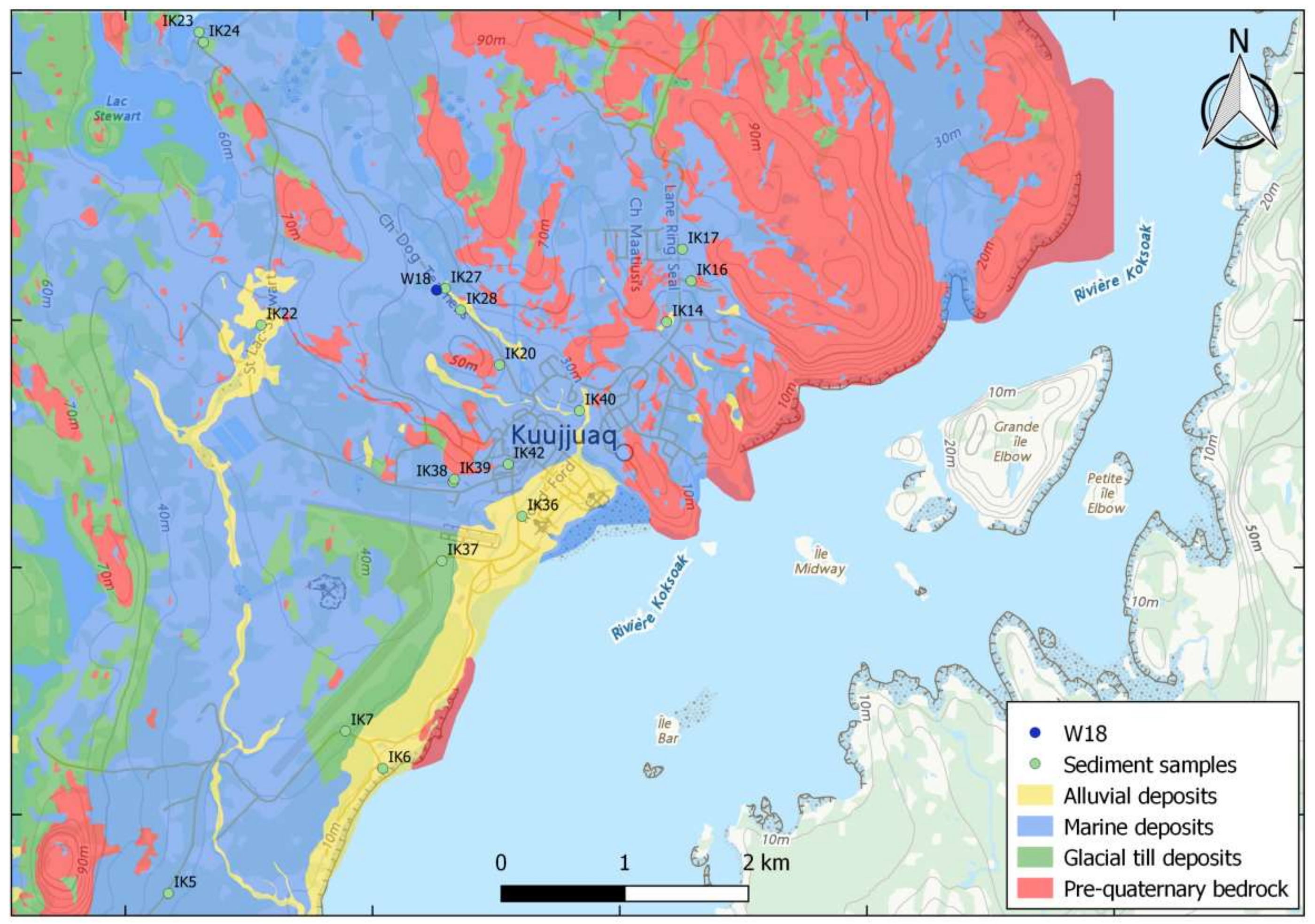

Figure 2 - Map of the quaternary sediments

Kuujjuaq (58.10°N, -68.42°E) is located in the west part of Southeastern Churchill Province, part of the Canadian Shield (Fig. 1). The main lithological units present in Kuujjuaq and surroundings are diorites and gabbros from "Complexe de Kaslac" (1.8 Ga), tonalitic gneisses of "Pluton de Kuujjuaq" (1.8 Ga) and granoblastic paragneisses of the "Suite de la Baleine" (Archean to Paleoproterozoic) (Simard et al., 2013).

The quaternary sediments mainly consist of littoral and pre-littoral sediments alternating to intertidal deposits related to different cycles of transgression and regression of the Iberville sea (Fig. 2). From a geo-morphological point of view, two small parallel valleys can be highlighted in the territory of Kuujjuaq, both of them southward degrading to the Kosoak River whose estuary outlets in the Ungava Bay around 50 km in the NNE direction. Glacial till deposits often cover bedrock outcrops and it is common to find them underlying the marine sediments. Alluvial coarse grained materials are only found along the small streams of the above mentioned valleys (Fortier et al., 2011).

Thermal conductivity and heat capacity were analysed in the laboratory by a needle probe for the unconsolidated quaternary sediments and by a heat flow meter for the rock samples (Fig. 3, Raymond et al., 2017).

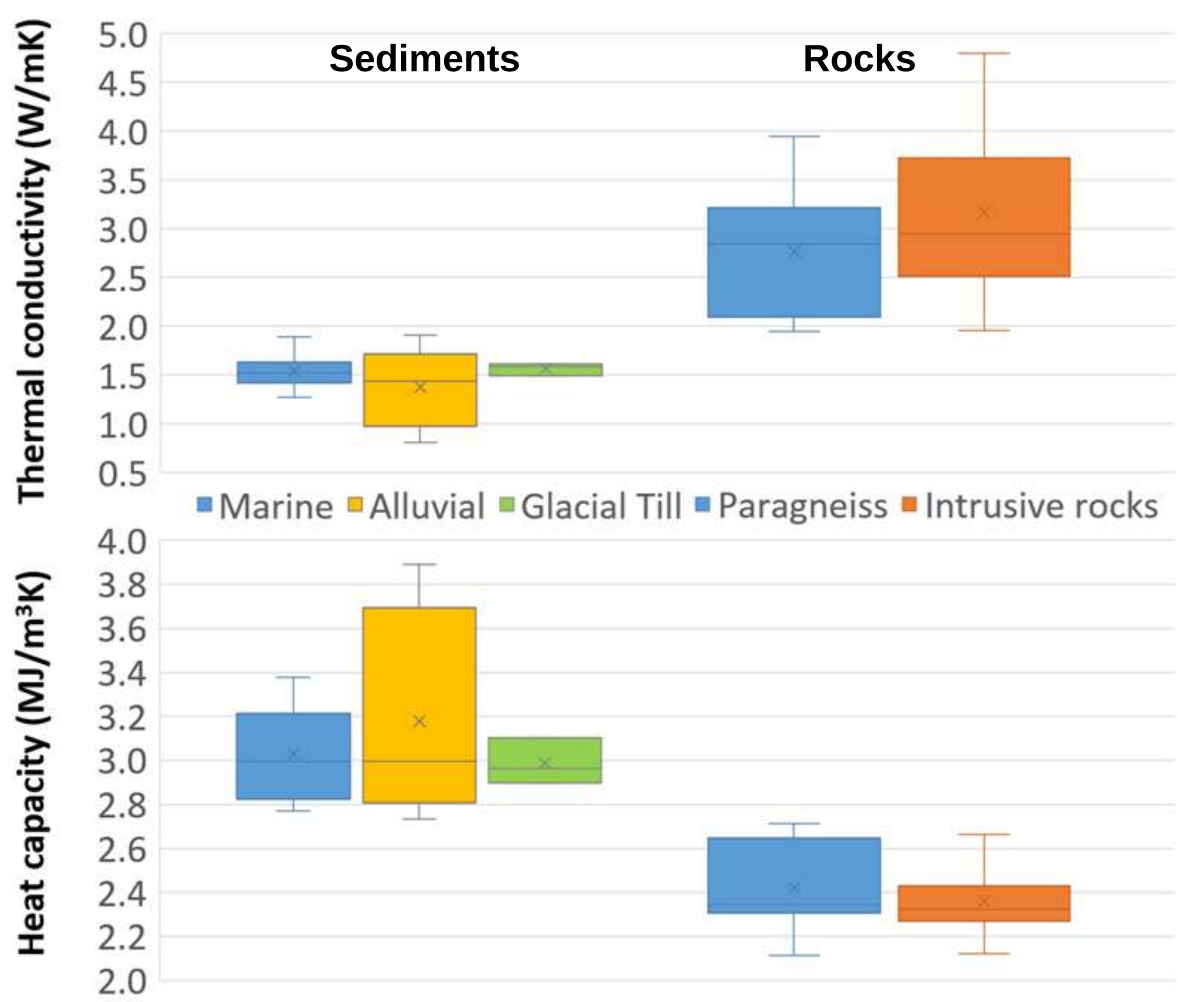

Figure 3 - Thermal conductivity and heat capacity of quaternary sediments and rock samples in saturated conditions

GROUND TEMPERATURE & THERMAL LOADS

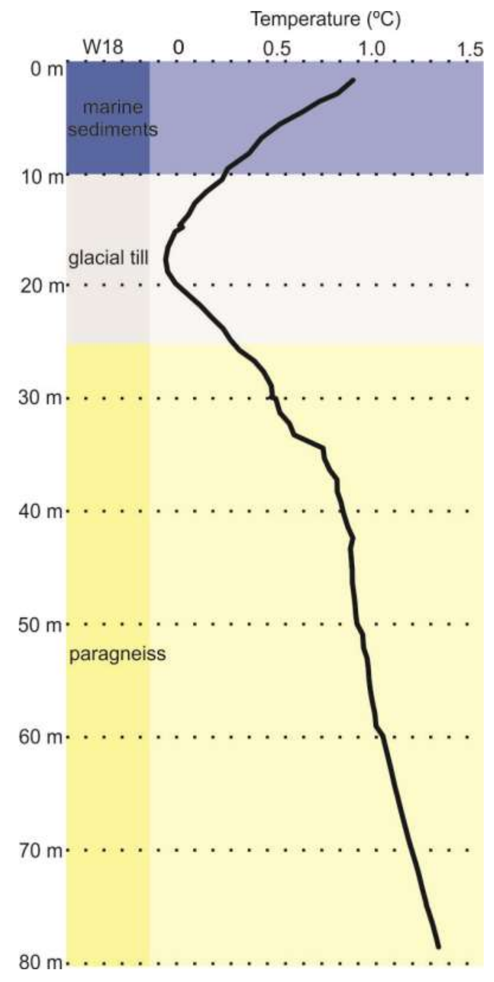

Figure 4 – T-depth profile in W18

The shallow underground temperature in the study area is slightly higher than 0°C and the vertical geothermal gradient is very low (Fig. 4). This is a limiting factor for the efficiency of geothermal applications. The average undisturbed ground temperature over the length of the borehole (T_0) was estimated in 1.0 °C, 1.75 °C and 2.75 °C over the first 100, 200 and 300 m. The total annual demand for space heating and domestic hot water of a typical semi-detached house in Kuujjuaq is around 43 MWh/y (Fig. 5).

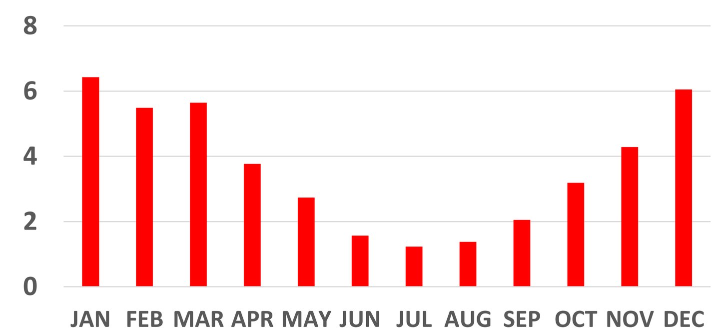

Figure 5 – Annual thermal loads (MWh)

METHODOLOGY

The G.POT (Casasso and Sethi, 2016) method was adopted for the estimation of the geothermal potential (Q_{BHE}). This method provides an empirical relationship (Eq. 1) involving thermal properties of the ground and the BHE, and operational/design parameters of the plant (Tab. 1). It allows the estimation of the maximum sustainably exchangeable energy of a BHE in a homogeneous porous medium.

$$\bar{Q}_{BHE} = \frac{0.0701 \cdot (T_0 - T_{lim}) \cdot \lambda \cdot L \cdot t'_c}{-0.619 \cdot t'_c \cdot log(u'_s) + (0.532 \cdot t'_c - 0.962) \cdot log(u'_c) - 0.455 \cdot t'_c - 1.619 + 4\pi\lambda \cdot R_b}$$

With: $u'_c = \rho c \cdot r_b^2/(4\lambda t_c)$, $u'_s = \rho c \cdot R_b^2/(4\lambda t_s)$, $t'_c = t_c/t_y$ **Equation 1**

Parameter	Symbol	Value	Unit
Threshold fluid temperature	T_{lim}	-3	°C
Borehole depth	L	100/ 200/ 300	m
Undisturbed ground temperature	T_0	1.0/ 1.75/ 2.75	°C
Borehole radius	r_b	0.038	m
Simulated lifetime	t_s	50	years
Length of the heating season	t_c	270	days
Borehole thermal resistance	R_b	0.1	mK/W

Table 1 – Parameters adopted for the application of the G.POT method in Kuujjuaq

Ground thermal conductivity (λ) and heat capacity (ρc) maps were realised according to the laboratory analyses shown in Fig. 3 and considering the presence and thickness of quaternary deposits.

RESULTS & DISCUSSION

Three different maps of geothermal potential has been drawn (Fig. 6) to compare three different BHE lengths. Due mainly to the reduced range of variation of thermal conductivity values, the small surface considered and the minimal altitude differences, values of geothermal potential are very homogenous.

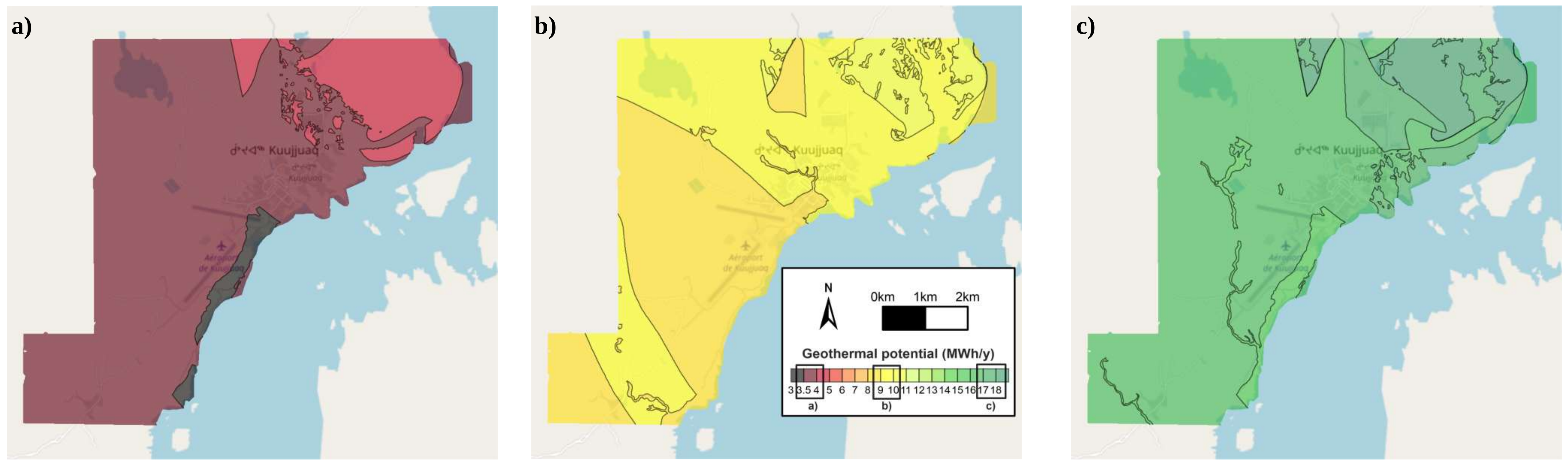

Figure 6 – Shallow geothermal potential in Kuujjuaq according to different BHE lengths: a) 100 m; b) 200 m; c) 300 m.

BHE length (m)	Geothermal Potential (MWh/y)	BHEs required	Total drilled length (m)
100	3.7	12	1200
200	9.0	5	1000
300	16.5	3	900

Table 2 – BHE to be drilled in Kuujjuaq to cover 43 MWh/y

The geothermal potential increases more than linearly with the length of the borehole, thanks to the higher temperatures reached and the lower influence of shallow less conductive quaternary deposits. In the municipal territory, the potential ranges from 3.4 to 4.2 MWh/y in the 100 m case; from 8.6 to 10.0 MWh/y in the 200 m case; from 15.8 to 18.2 MWh/y in the 300 m case. The energy demand of a typical semi-detached house in Kuujjuaq (43 MWh/y, Fig. 5) can be fulfilled by 12, 5 and 3 boreholes respectively, with total drilled lengths decreasing from case 1 to 3 according to the increasing potential (Tab. 2).

REFERENCES

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