Heat Flow, Depth - Temperature Variations and Stored Thermal Energy for Enhanced Geothermal Systems (EGS) In Canada

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While previously examined only for Alberta (Majorowicz and Moore, 2008), the potential for the Enhanced Geothermal System (EGS) concept, as outlined by the MIT report (Tester et al., 2006), is examined here for all of Canada. Enhanced (or Engineered) Geothermal Systems are engineered reservoirs that have been created to extract economical amounts of heat from low permeability and/or porosity geothermal resources. Temperatures greater than 150 °C at depths less than 7km are required. To evaluate target areas for potential EGS heat mining across Canada we have constructed detailed heat flow and depth-temperature maps to determine the geothermal resource base in conduction dominated systems (sedimentary basins and crystalline basment). We also determined the quantity of thermal energy (heat content available from deep hot rocks). We evaluate thermal energy availability for 3 depth slices (3-4 km; 6-7 km and 9.5-10.5 km) in a 4 km by 4 km grid.

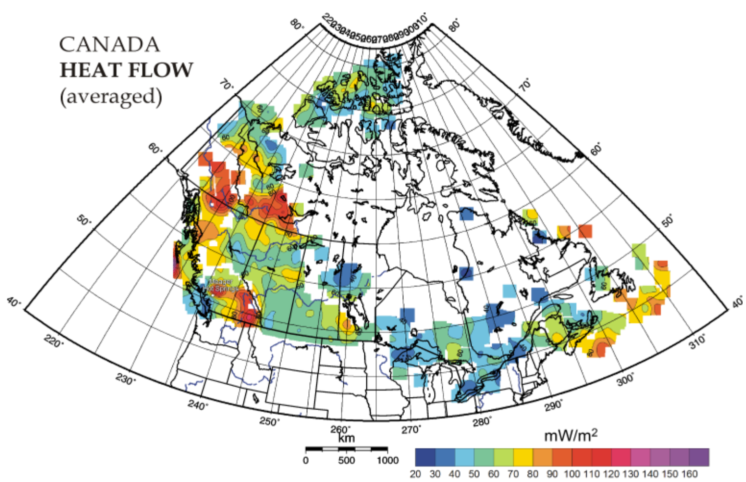

Figure 1. Contour map of heat flow (in mW/m^2) in Canada.

Earlier Canadian heat flow compilations were completed by Jessop (1990) and Jessop et al. (2005). We use the same data as for the North America Heat Flow Map edited by Blackwell and Richards (2004). However, as Figure 1 illustrates there are large regions of Canada with sparse or no data. To better honor this distribution we generated a new map, presented here, that does not extrapolate contours through areas with no available data (heat flow values are available for only ~40% of Canada's landmass). In addition, new smoothing and averaging techniques were used which allowed filtering out anomalous data. The final database consists of 3085 locations, the majority of which are heat flow estimates from well temperatures in the Western Canada Sedimentary Basin (WCSB). Based on the heat flow pattern shown in Figure 1, the national average is calculated here to be 64 mW/m^2 +/- 16 mW/m^2.

Heat flow patterns are used to calculate depth-temperature profiles. Thermal blanketing effect of relatively low thermal conductivity sediments makes deep basin areas of the WCSB, with relatively high heat flow, attractive for geothermal development (up to some 200 ^{o}C), as well as very high heat flow areas of the Canadian Cordillera. Temperature data for high heat flow zones of the northern part of the WCSB allow well constrained T-z modeled synthetic geothermal gradients (Fig.2). At 10 km depth we can expect EGS temperatures in the 150 to 200 ^{o}C range across most of Canada, excepting some areas of the shield. At these depths temperatures in the 200-300 ^{o}C range are estimated for large regions of the Cordillera and the WCSB.

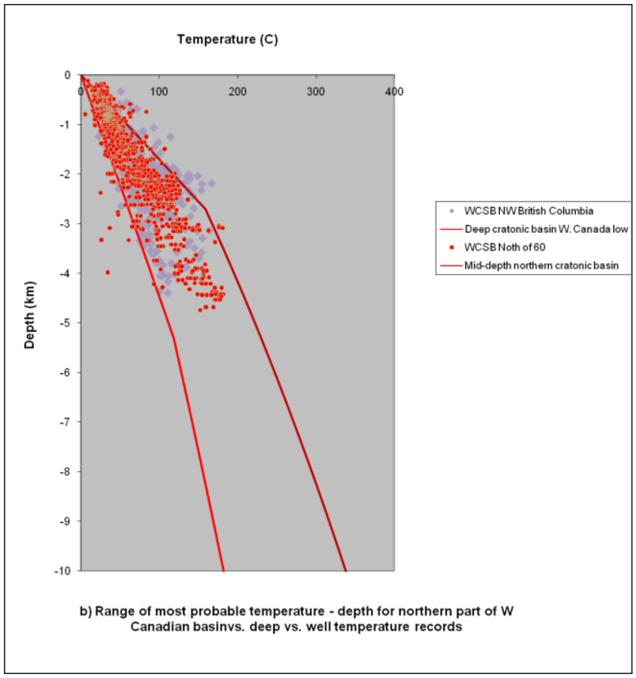

Figure. 2. Observed temperature data from deep wells in the northern part of the WCSB vs. range of possible values from modeled synthetic geotherms.

To understand the magnitude of the thermal energy or heat content of the rock available for heat 'farming' we use an experiment in which a 4X4km area of 1km thick rock volume at known average temperature are considered through Canada. The quantity of thermal energy present if rock slices of 1 km thickness and 4x4 km areas was calculated. In fig 3 we show heat content for the 3-4km depth range across Canada.

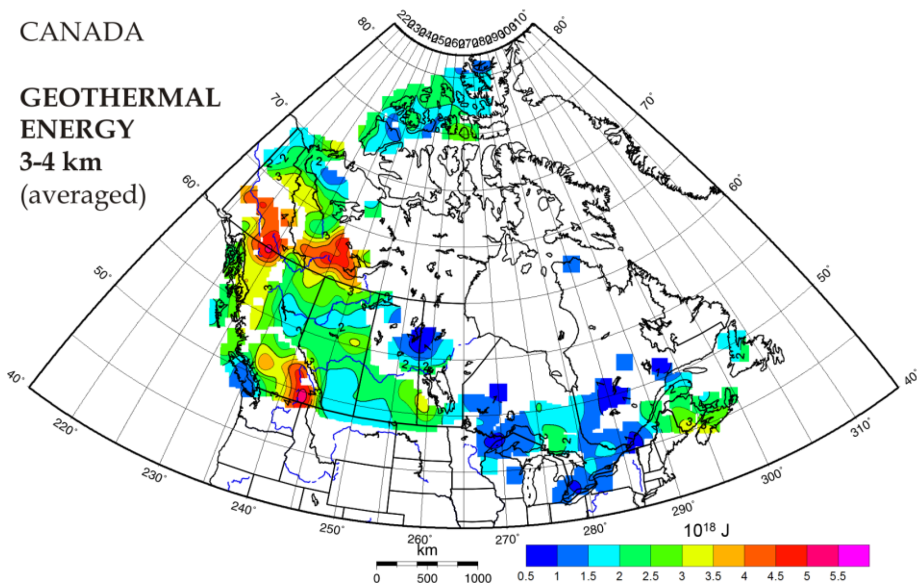

Figure 3. Heat content variations for the 3-4km depth range.

We then summed the total in-place heat content calculated for all of Canada's territory which is 9984670 km^2. for the depth intervals 3-4 km, 6-7 km and 9-10km we have integrated geothermal energy content to be mined/harvested at 1.4* 10^{24}J, 2.9*10^{24}J and 4.7*10^{24}J respectively. Given this, the potential for geothermal energy to provide significant renewable energy supply for Canada is huge. The actual accessible and usable geothermal energy resource however will be significantly smaller than the in-place resource. The estimate for "conservative" production used by MIT (Tester et al., 2006) is 0.02 of in-place thermal energy. Using a similar value gives us 1 x10^{17} J = 0.1 quads for the same rock volume as above. This would still provide a significant contribution towards Canadian energy consumption; requiring only 100 developments to meet Canada's current energy demand. Only a portion of the rock heat content can be mined /harvested for thermal and electrical energy and it very much depends not only on temperature but also on possibility of generation of enough of water flow through hydraulically enhanced cracks in the rock. To see what power can be produced with the use of water as a high heat capacity carrier we calculated available thermal power and related electrical power (for a binary power system conversion rates given in Tester et al., 2006 are used). For the feasible temperature cooling of rock mass by 100 °C at specific heat capacity of water 4000 J/(kg °C), flow rate 100 kg/s (triplet system with one well injecting water and two producing wells) for the factor-thermal to electrical 0.15 * MWth the available power of electrical EGS production we calculate to be 6 MWe.

CONCLUSIONS

Our results show that Canada has significant potential for EGS development. The best EGS prospects are in western Canada due to higher overall heat flow. The most promising targets for EGS are in Cordillera with especially interesting areas in the southern BC, in the southern part of Yukon and in the Mackenzie basin. This northern high geothermal energy content area spreads southward towards NE BC part of the WCSB and north western Alberta.

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