GEOLOGICAL SURVEY OF CANADA
OPEN FILE 6167

Geothermal Maps of Canada

S.E. Grasby, J. Majorowicz, and M. Ko

2009

Natural Resources Canada | Ressources naturelles Canada

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 6167

Geothermal Maps of Canada

S. E. Grasby, J. Majorowicz, and M. Ko

2009

Available from
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario K1A 0E8

Grasby, S.E., Majorowicz, J., and Ko, M.
2009: Geothermal Maps of Canada, Geological Survey of Canada Open File 6167, 35p.

Open files are products that have not gone through the GSC formal publication process.

Abstract

In order to better define spatial variability, and variability with depth, of geothermal energy potential in Canada, a series of depth-temperature maps have been produced, along with derivative products. These maps illustrate temperature fields across Canada for specific depth intervals for both shallow (50 to 300 m depth) and deep (3500 to 10,000 m depth) geothermal systems. Derivative maps include energy storage for specified depth intervals, in addition to a heat flow map, which are constrained by data limitations.

Introduction

Geothermal energy is a largely unrecognized and undervalued potential energy resource in Canada. However the high cost of non-renewable energy resources and concerns over impacts of CO_2 emissions have increased interest in renewable energy potential in Canada. The National Geothermal Program (1975-1985) accumulated a significant amount of data that documented many areas of high geothermal energy potential in Canada (Jessop et al., 1991) and as recently summarized by Jessop (2008a,b). Previous work shows that high heat flow regions of western and northern Canada could provide usable geothermal energy (Jessop et al., 1991; Jones et al., 1985; Majorowicz et al., 1985; Blackwell and Richards, 2004; Ghomeshei et al., 2005) for space heating and electrical production. In addition recent work shows the potential of low temperature geothermal systems over most of the country (Majorowicz et al., 2009).

In order to define better the variability of geothermal potential in Canada, both spatially and with depth, a series of Geothermal Maps have been produced. These maps provide a broad overview of depth-temperature fields and heat flow that can be used to help refine areas of highest geothermal potential in Canada.

Three sets of maps are presented: 1) shallow thermal fields related to heat exchange systems (50 to 300 m depth), 2) deep thermal fields related to direct use and electrical generation potential (3500 to 10,000 m depth), and 3) derivative maps which include heat flow, and derived energy potential maps, in addition to maps of other areas of resource potential (volcanic belts, thermal springs, Tertiary intrusions). Where appropriate depth intervals were chosen to match depth-temperature maps produced for the United States (MIT, 2007).

Data Resources

Temperature data used in constructing depth-temperature maps are derived from high-precision temperature logs (some with multiple temperature-depth logs) from wells across Canada. Temperature records are derived from several existing published data files as well as unpublished and proprietary data sets. As such only the derivative maps are presented here.

Temperature – depth data sources used in this mapping effort include:

1. Temperature data measured north of 60 deg. N in Canada by Earth Physics Branch of Energy Mines and Resources (A. Taylor, A. Judge, M. Burgess and V. Allen) and published in a series "Canadian Geothermal Data Collection" – Geothermal Series, EMR Earth Physics, Branch between 1973 and 1981 (Earth Physics Branch EMR, 1974, 1975, 1976, 1977, 1979, 1981) as listings and graphic plots of temperature vs. depth.

2. Temperature logs across Canada (mainly eastern Canada and British Columbia data) from the data base of the International Heat Flow Commission (IHFC and NOAA Borehole Temperatures and Climate Reconstructions Database, 2002). These data were collected by the University of Michigan and provided by several Canadian and US researchers (A. Jessop, K. Wang, J.-C. Mareschal, J. Majorowicz, W. Gosnold). Names of data providers, logging dates, locations and temperature – depth pairs are given in that data base: (http://www.geo.lsa.umich.edu/climate/NAM.html).

3. Unpublished logs recorded in the time period between 1991-2006 in the Western Canadian Sedimentary basin by Northern Geothermal Consultants, Edmonton and EMR Earth Physics Branch and – GSC Calgary. These data are in GSC Calgary Canadian temperature data collection (Jessop et al. 2005).

All data collected were from high precision temperature – depth logs taken by thermistor probes commonly calibrated to an accuracy of 0.003 °C, and attached to an electrical cable. In some cases, temperature data were measured by data loggers where records of temperature and pressure are recorded by a computer in the logger lowered into the well on a steel wire. The probes are lowered into the wells and temperature records are taken for depth intervals starting from where the well is filled with water. The wells logged were usually drilled for mineral prospecting and hydrogeology observational networks. These wells are in thermal equilibrium attained years after the initial drilling disturbance. Temperatures for the depth of particular maps were taken either directly from temperature readings, or interpolated from data points above and below using a calculated thermal gradient between the points. In some cases for shallow wells, a single site has multiple logs, or logs taken at several wells at location within 20-30 m radius (e.g. Alberta groundwater observational wells). These data are averaged for the site.

Methods

All map data was interpolated using inverse distance weighting methods. This provided a more exact and less generalized depiction of the data where local variation can be determined from neighbouring data points. Data for shallow thermal systems, energy sinks and temperature differences maps were interpolated for all of Canada south of the permafrost boundary. All data for deep thermal systems, heat flow and thermal energy maps were constrained to a 50 km block surrounding each data point. White areas represent regions without data. All maps included in this report were constructed using ESRI ArcMap Version 9.2.

<u>Shallow thermal fields</u>

Data from shallow systems is represented at 50m intervals from 50m to 300m depths. Areas north of the permafrost line are not considered. Boundaries identifying discontinuous permafrost (T = 0 to -2 °C) and continuous permafrost (T< -2 °C) are shown.

<u>Deep thermal fields</u>

Temperature data for non-shallow systems were available for 3500m, 6500m and 10,000m depths. Thermal gradients were estimated for intermediate depths and used to create the maps displaying temperature at 4500m, 5500m and 7500m depths.

Derivatives

Thermal Energy Sinks represent a calculation of thermal energy exchangeable during the cooling (heat flux into the ground) and heating (heat flux out of the ground) season in the upper 50m of land surface, south of the permafrost line (as in Majorowicz et al. 2009). Heat flux from the ground is represented as positive energy gain, whereas heat flux into the ground as negative. The annual variation in heat flux is measured in units of $J*E^{15}$ per km^2 from 50m.

Heat energy within deep geothermal systems were derived from temperature logs and parameters including changes in temperature with depth, volume, heat content and density of surrounding rock (Majorowicz and Grasby in prep). Temperature differences relative to minimum, mean, and maximum annual surface temperature and temperature measurements at 50 m depth were derived from Environment Canada data (Majorowicz et al. 2009). Temperature logs for non-shallow systems were also used to create a map displaying depth to 150 °C. Due to data constraints, real temperature readings at 150 +/-5 °C and between 3.5 km and 7.5 km depths were used to interpolate data in locations where measurements were not available. Depths greater than 7500 m were considered economically impractical for geothermal prospects and were not included in assessing the depth to 150 °C.

Potential thermal anomalies may be marked by the occurrence of thermal springs and volcanoes. These are restricted to the Western Canada Cordillera. Thermal spring locations are based on a compilation by S.E. Grasby. Volcano locations are derived from Hickson (1992). Early research on the Coryell Syenite showed hot dry rock geothermal potential associated with Tertiary Plutons (Jessop, 2008b). These features are also mapped, as extracted from Wheeler (1996).

The resultant series of new geothermal maps constructed are listed in Table 1.

Table 1 –Geothermal Maps of Canada presented in this report.

Shallow Temperature Fields (depth of temperature field in metres)	
Figure 1	50
Figure 2	100
Figure 3	150
Figure 4	200
Figure 5	250
Figure 6	300
Deep Temperature Fields (depth of temperature field in metres)	
Figure 7	3500

Figure 8	4500
Figure 9	5500
Figure 10	6500
Figure 11	7500
Figure 12	10000
Derivative maps	
Figure 13	Data control points
Figure 14	Heat Flow
Figure 15	Thermal Energy Sink-cooling season (50 m depth)
Figure 16	Thermal Energy Sink –heating season (50 m depth)
Figure 17	Mean Annual Thermal Energy (50 m depth)
Figure 18	Temperature difference (50 m depth relative to annual minimum surface temperature)
Figure 19	Temperature difference (50 m depth relative to annual mean surface temperature)
Figure 20	Temperature difference (50 m depth relative to annual maximum surface temperature)
Figure 21	Heat Energy 3-4 km
Figure 22	Heat Energy 6-7 km
Figure 23	Heat Energy 10 km
Figure 24	Depth to 150 °C
Figure 25	Thermal Spring Locations
Figure 26	Volcano Locations
Figure 27	Tertiary Intrusive Rock

Acknowledgements

Amanda Niosi provided GIS and technical support for map production. Funding support to complete these maps through an EcoEnergy grant is greatly appreciated.

References

Blackwell, D. D., and Richards, M. (2004) Geothermal map of North America: Explanation of resources and applications: Geothermal Resources Council Transactions, v. 28, p. 317–320.

Ghomshei, M.M., MacLeod, K., Sadlier-Brown, T.L., Meech, J.A. and Dakin, R.A.,2005, Canadian Geothermal Energy Poised for Takeoff: Proceedings World Geothermal Congress, 4p.

Hickson, C. (1992) Canadian Cordillera: Volcano Vent Map and Table. *In* Volcanoes of North America (C. Wood and J. Kienle eds.). Cambridge University Press, 354 p.

Jessop, A M (2008a) Review of National Geothermal Energy Program: phase 1 - geothermal potential of sedimentary basins. Geological Survey of Canada, Open File 5690, 146 pages.

Jessop, A.M. (2008b) Review of National Geothermal Energy Program, Phase 2 - geothermal potential of the Cordillera. Geological Survey of Canada, Open File 5906, 86 pages.

Jessop, A.M., Ghomeshei, M.M., and Drury, M. (1991) Geothermal Energy in Canada: Geothermics, v. 20, no. 5/6, p**.** 369-385.

Jones, F. W., Lam, H.L., and Majorowicz, J. A., 1985, Temperature distributions at the Paleozoic and Precambrian surfaces and their implications for geothermal energy recovery in Alberta: Canadian Journal Earth Sciences, v. 22**,** p. 1774-1780.

Majorowicz, J.A. and Grasby, S.E. (in prep) Enhanced Geothermal Energy Resources in Canada.

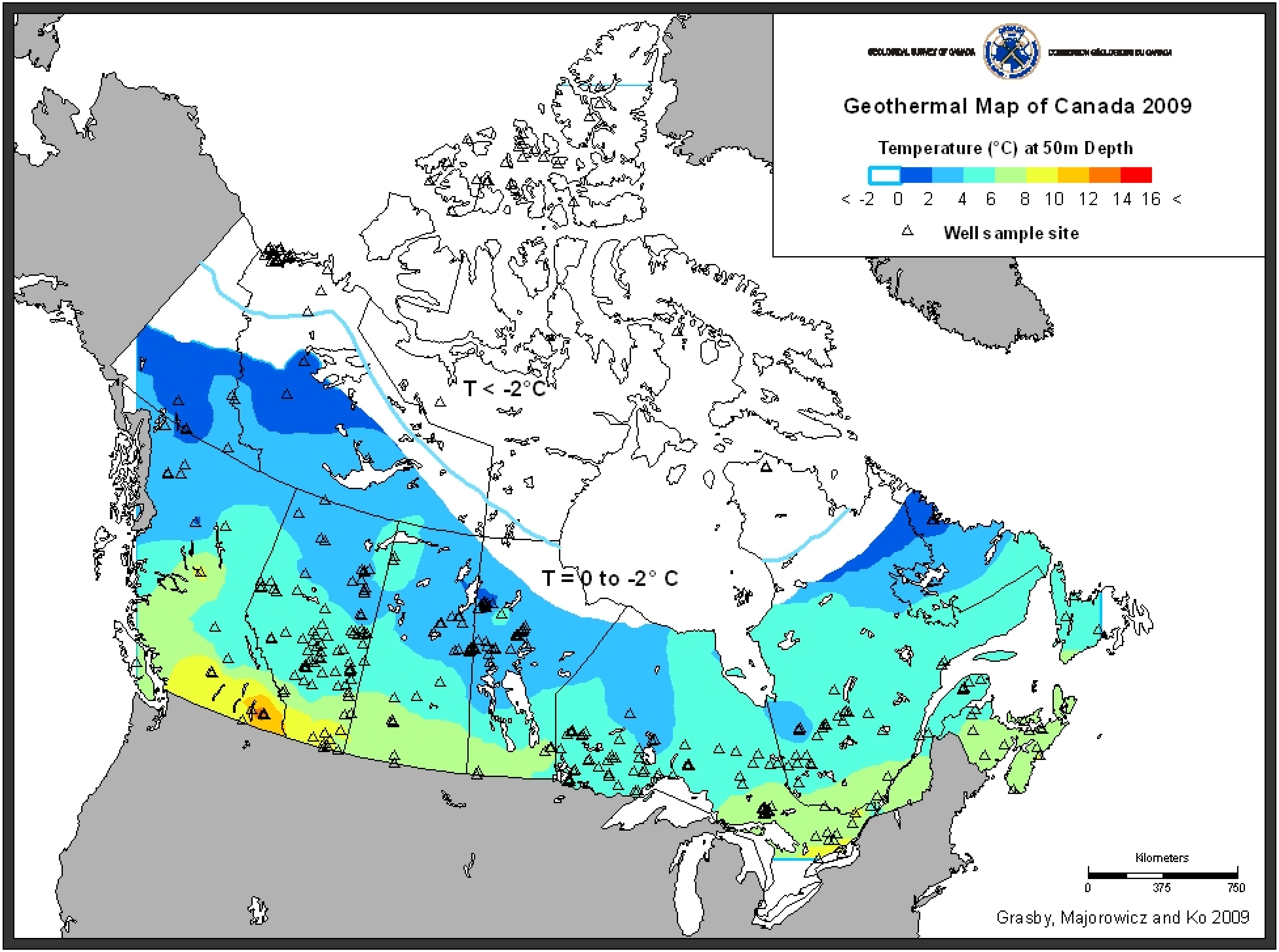
Majorowicz, J.A., Grasby, S.E., Skinner, W.R. (2009) Estimation of shallow geothermal energy resources in Canada – Heat gain and heat sink. Natural Resources Research.

Majorowicz, J.A., Jones, F.W., Lam, H-L., Linville, A. and Nguyen, C.D., 1985, Topography and subsurface temperature regime in the western Canadian Sedimentary Basin: Implications for low-enthalpy geothermal energy recovery: Geothermics, v. 14, no, 2/3, p. 175-187.

MIT (2007) Report on The Future of Geothermal Energy, 2007, http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

Wheeler, J.O. (1996) Geological Map of Canada. 1:5,000,000 scale.

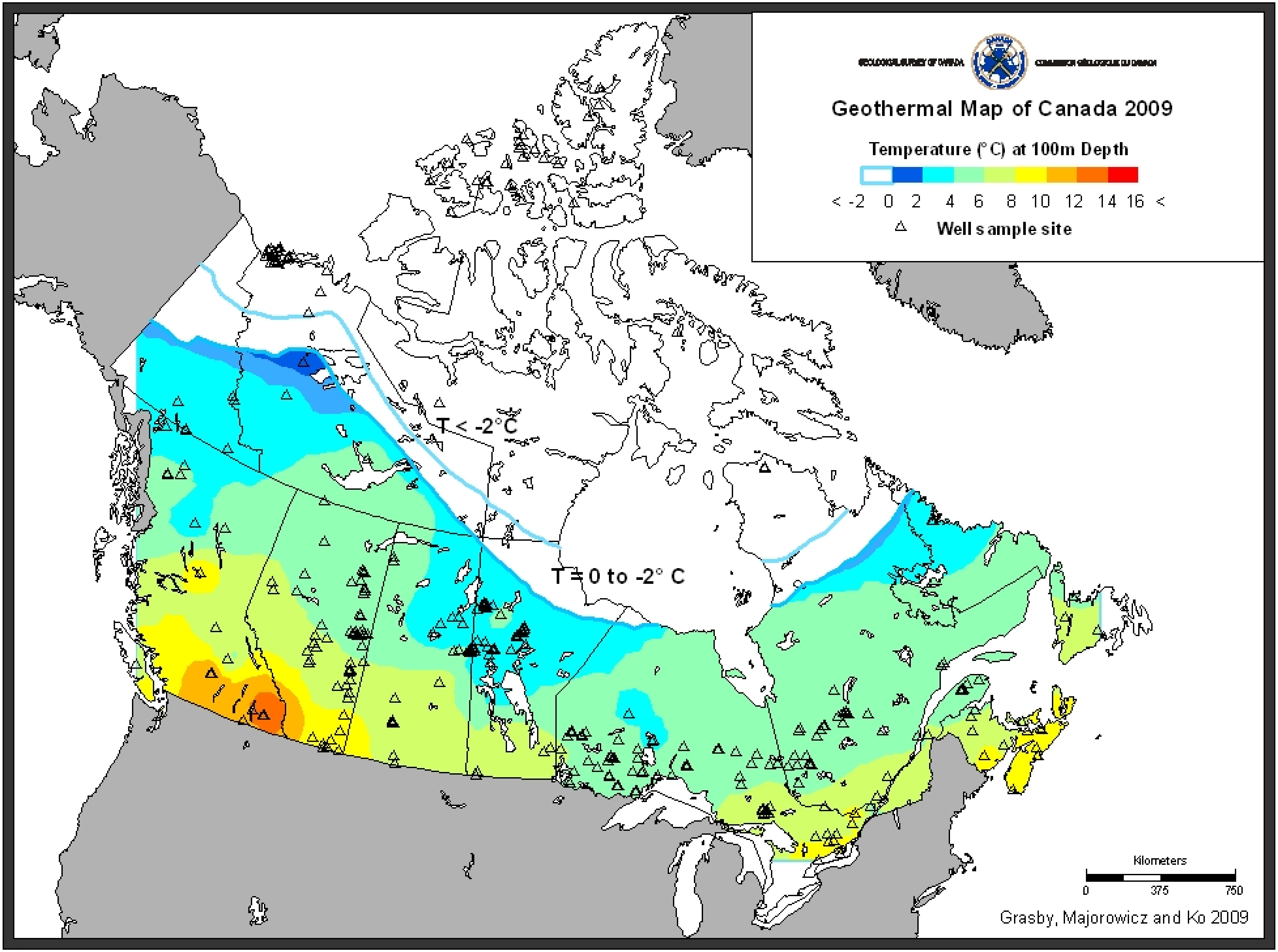
Natural Resources Canada | Ressources naturelles Canada



Canada

Figure 1

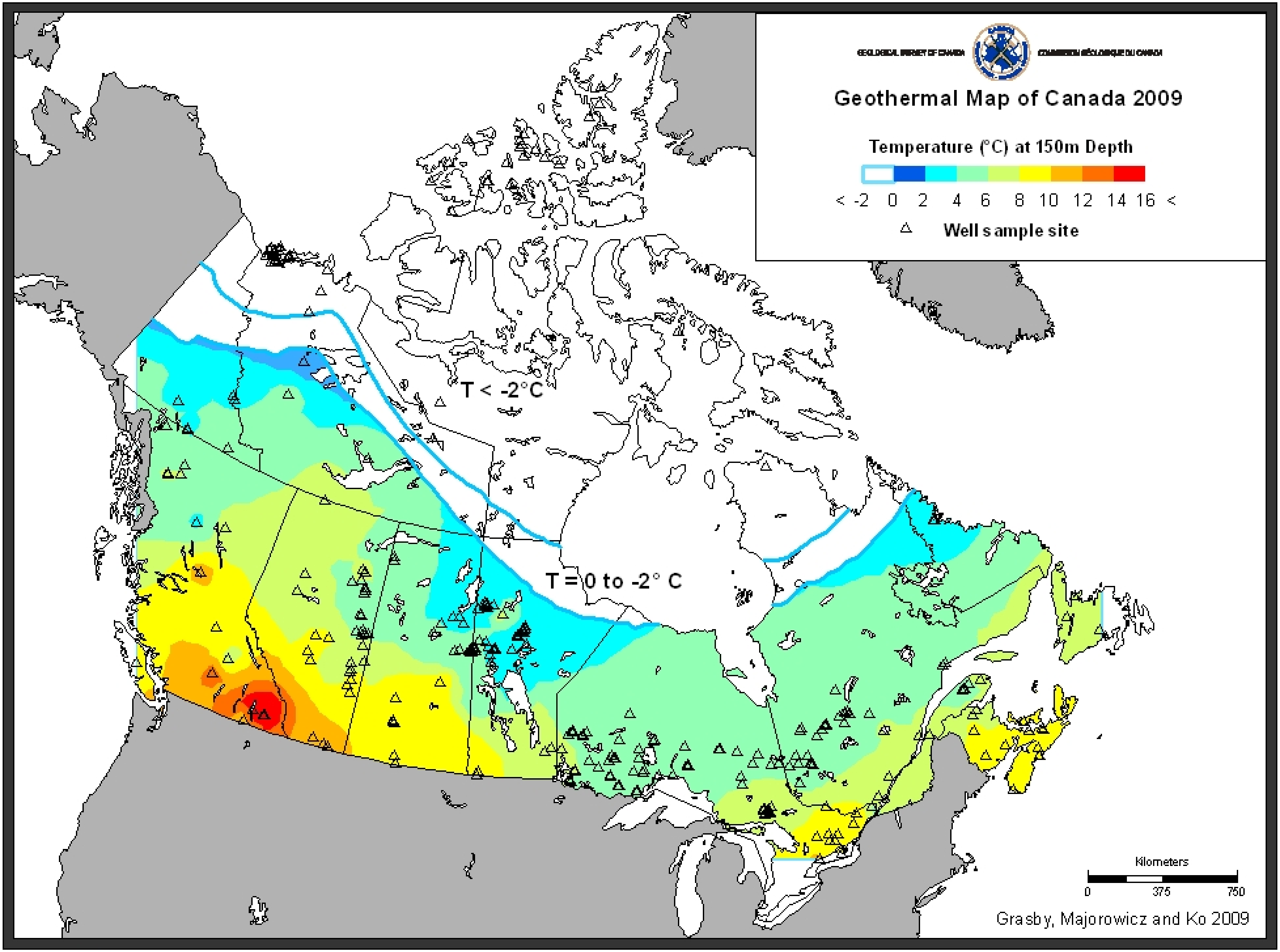
Natural Resources Canada | Ressources naturelles Canada



Canada

Figure 2

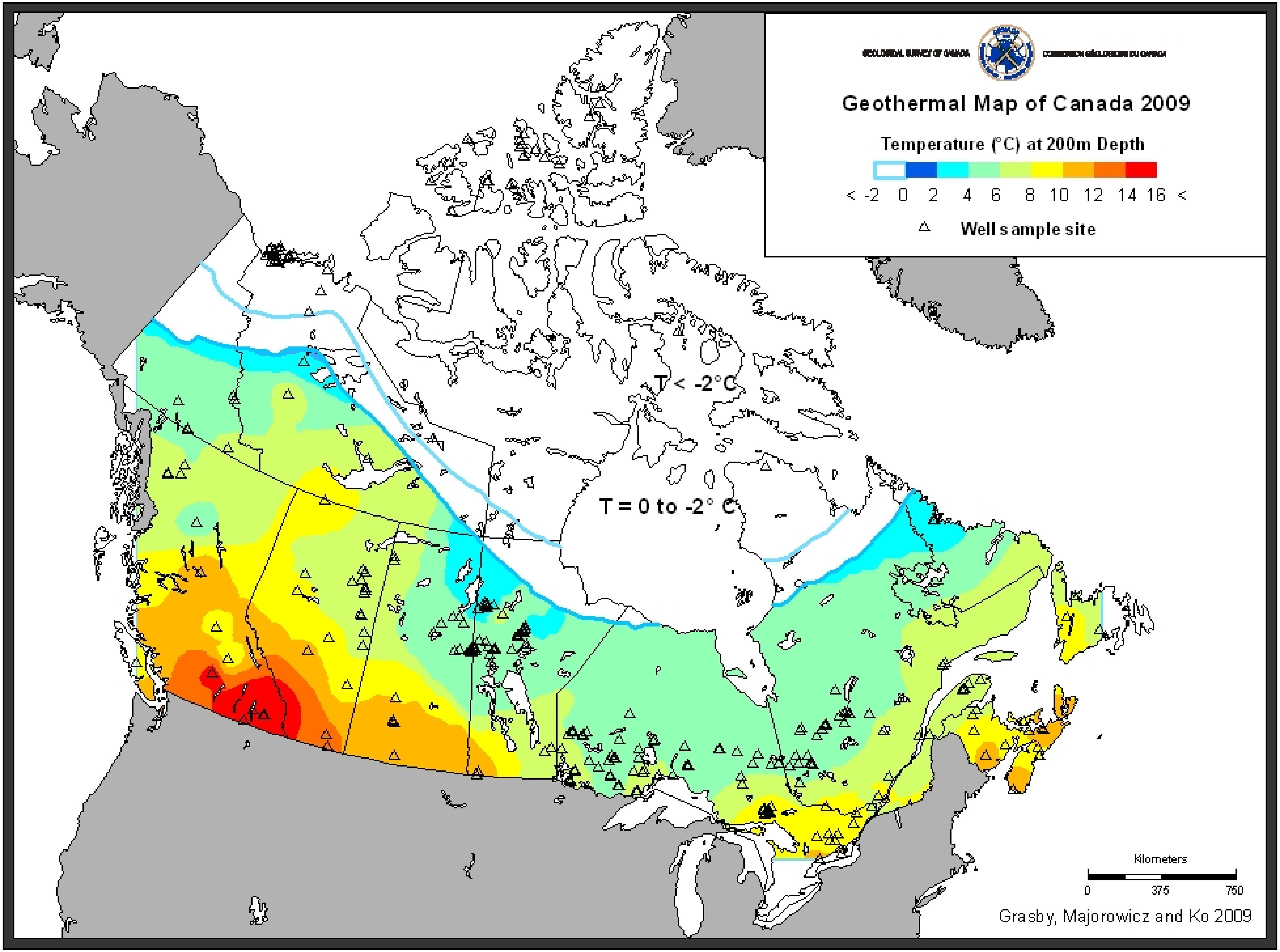
Natural Resources Canada / Ressources naturelles Canada



Canada

Figure 3

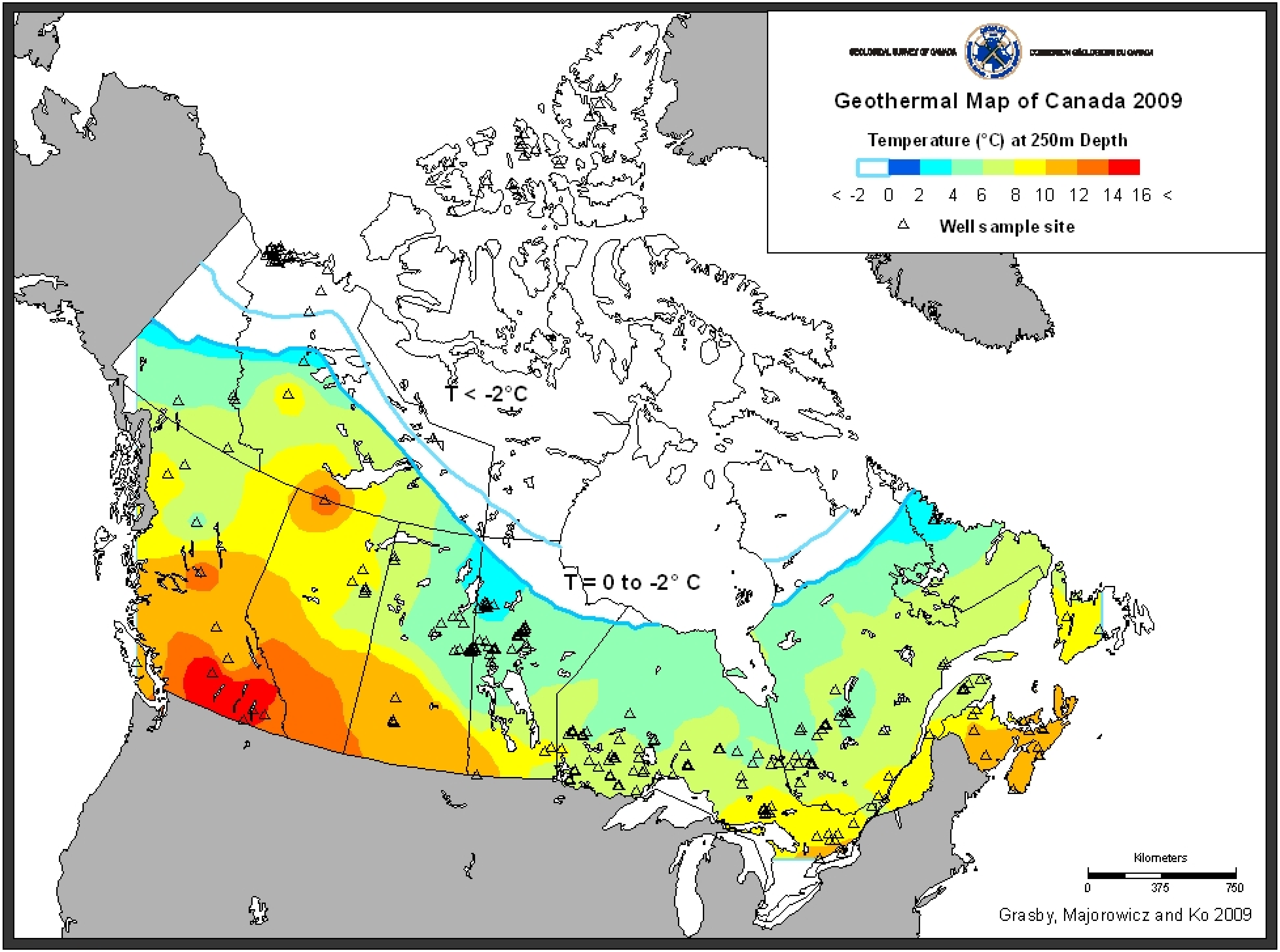
Natural Resources Canada | Ressources naturelles Canada



Canada

Figure 4

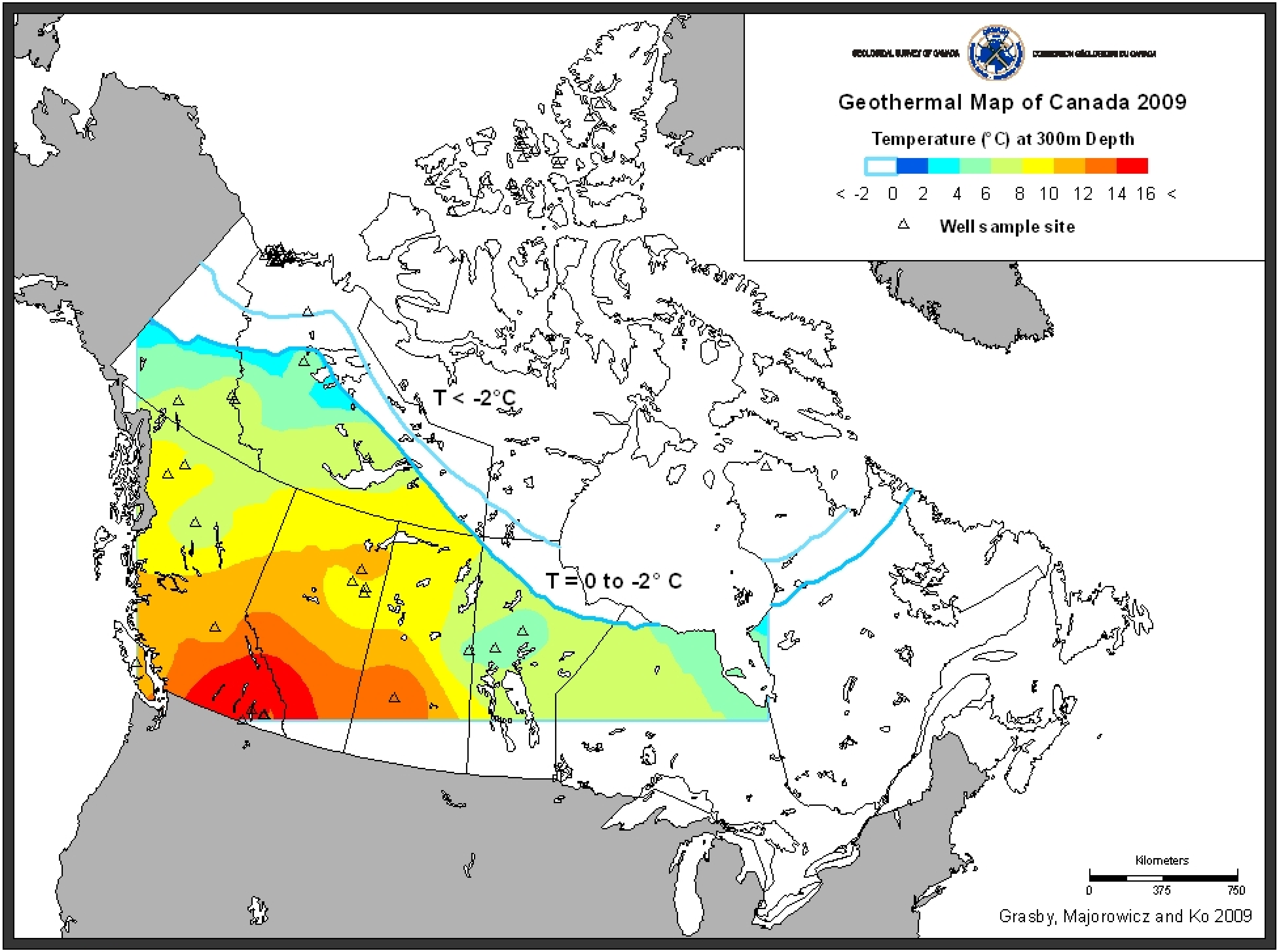
Natural Resources Canada | Ressources naturelles Canada



Canada

Figure 5

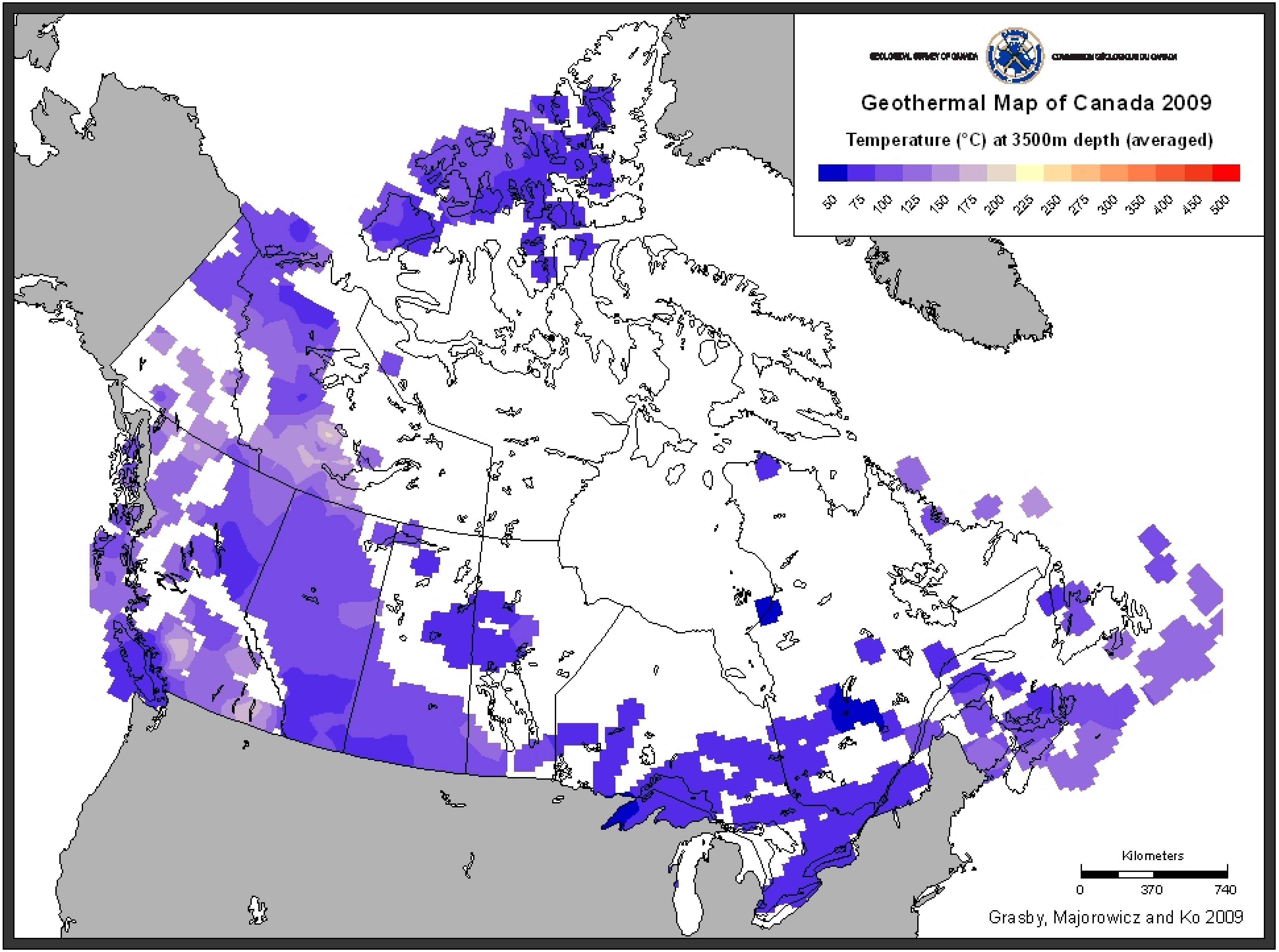
Natural Resources Canada / Ressources naturelles Canada



Canada

Figure 6

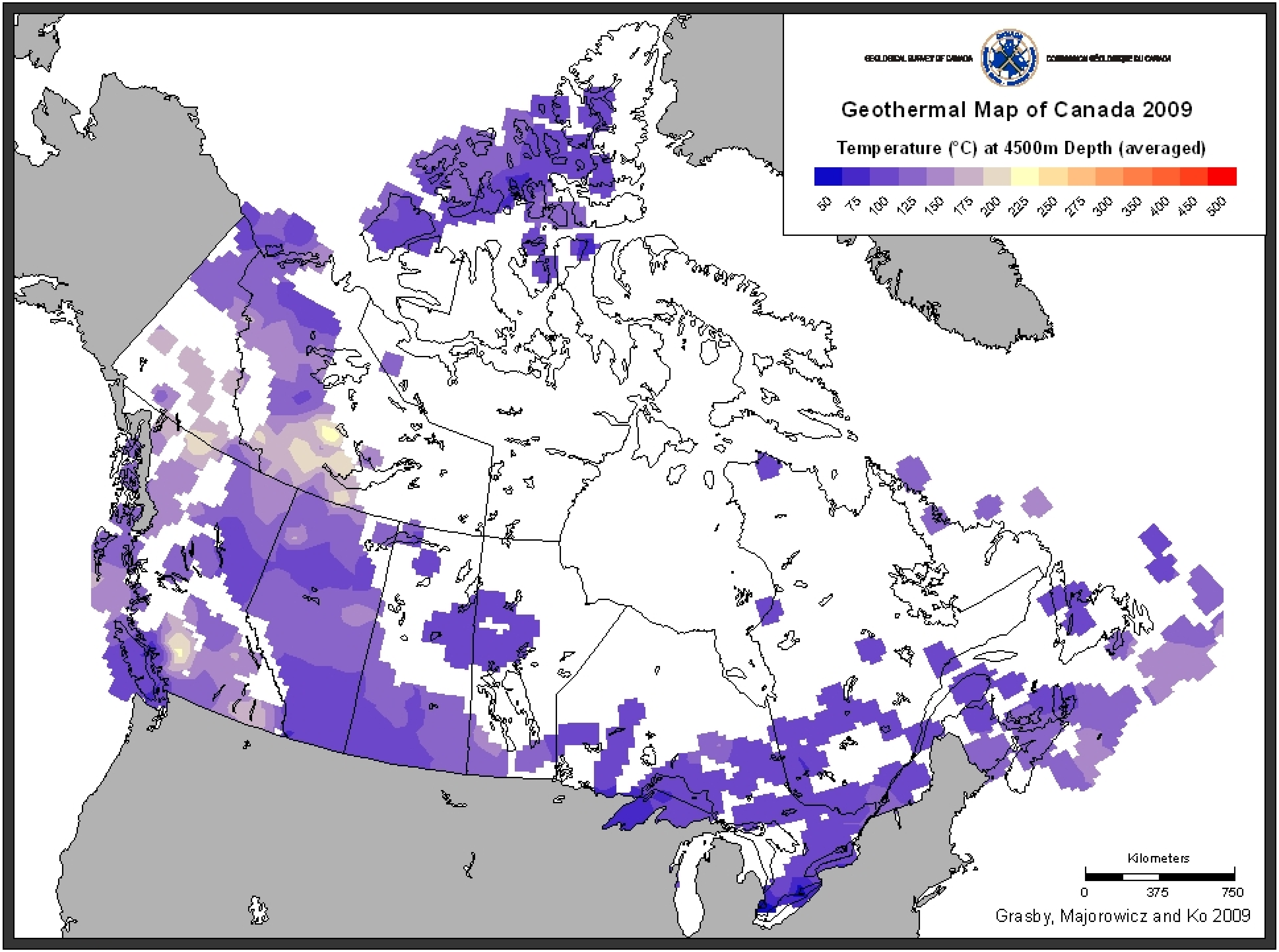
Natural Resources Canada Ressources naturelles Canada



Canada

Figure 7

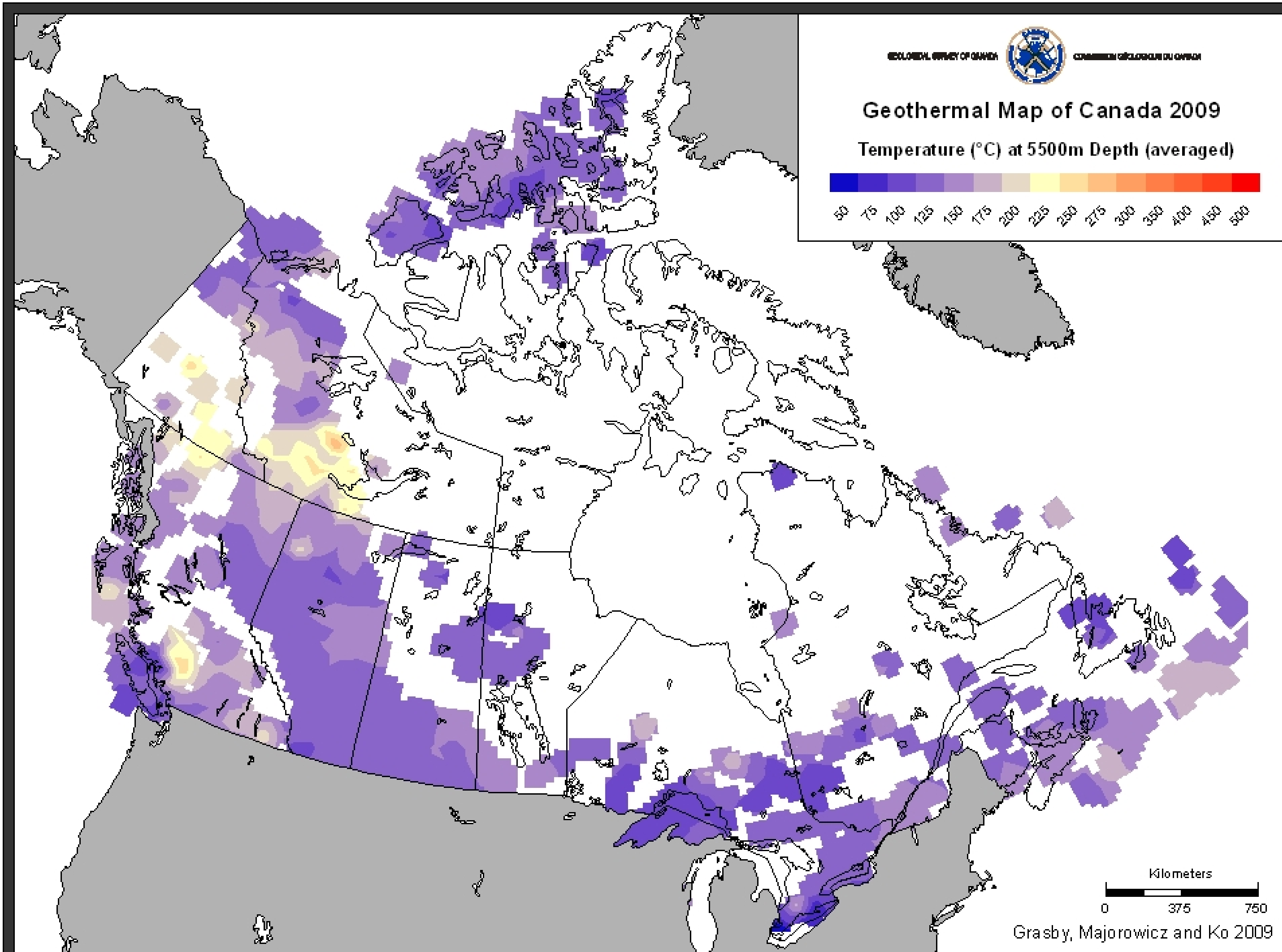
Natural Resources Canada Ressources naturelles Canada



Canada

Figure 8

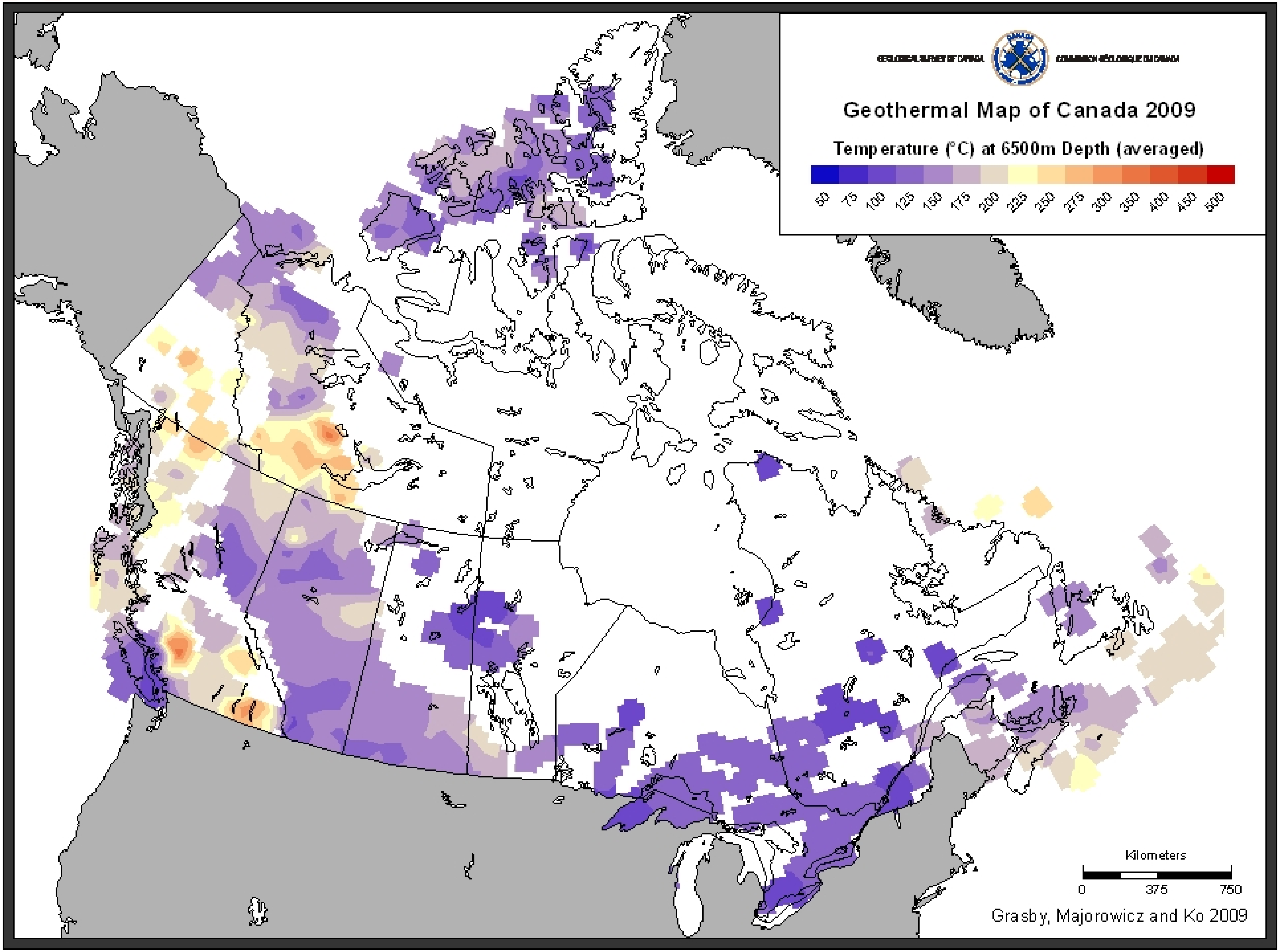
Natural Resources Canada
Ressources naturelles Canada



Canada

Figure 9

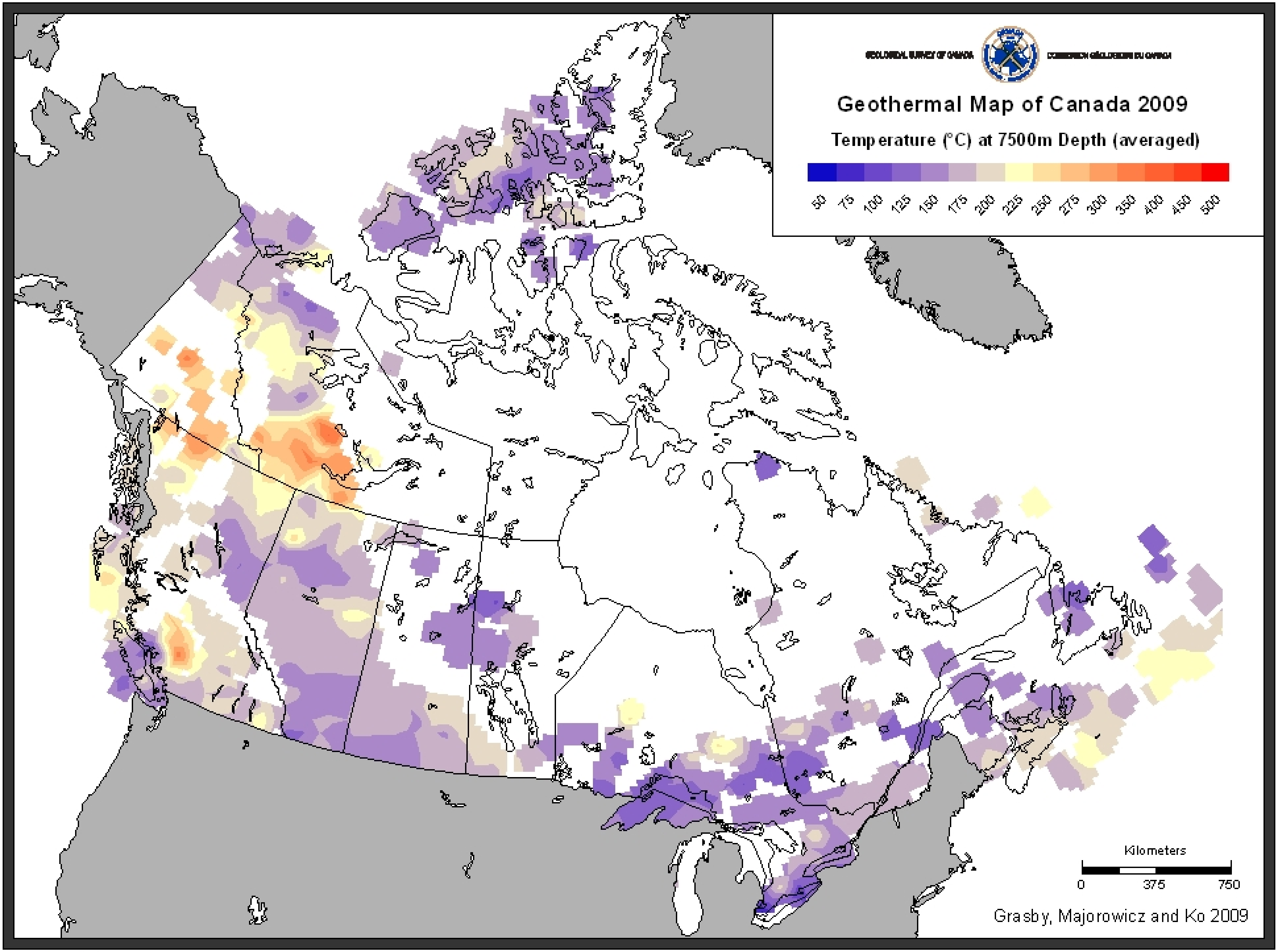
Natural Resources Canada | Ressources naturelles Canada



Canada

Figure 10

Natural Resources Canada / Ressources naturelles Canada



Canada

Figure 11

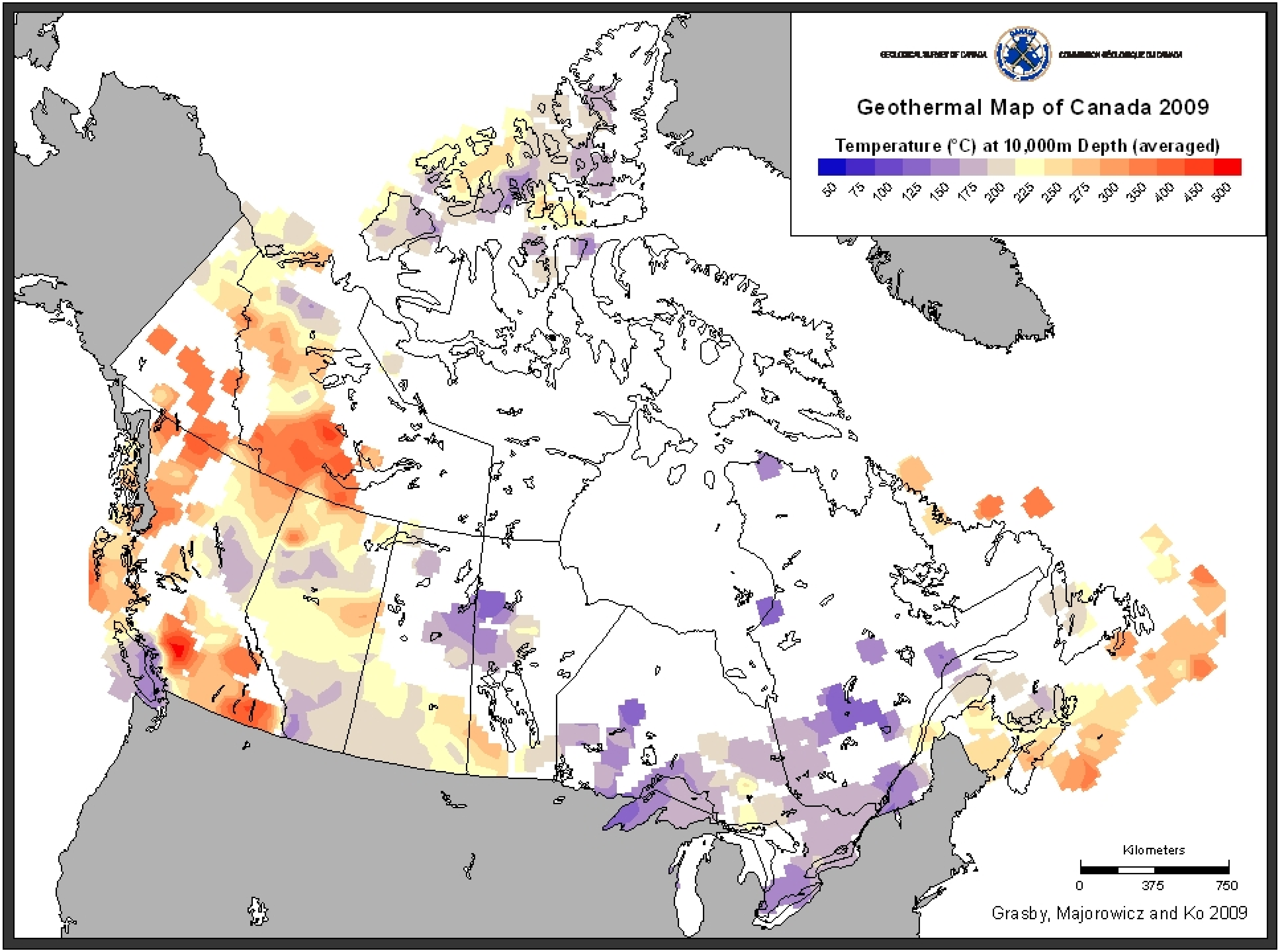
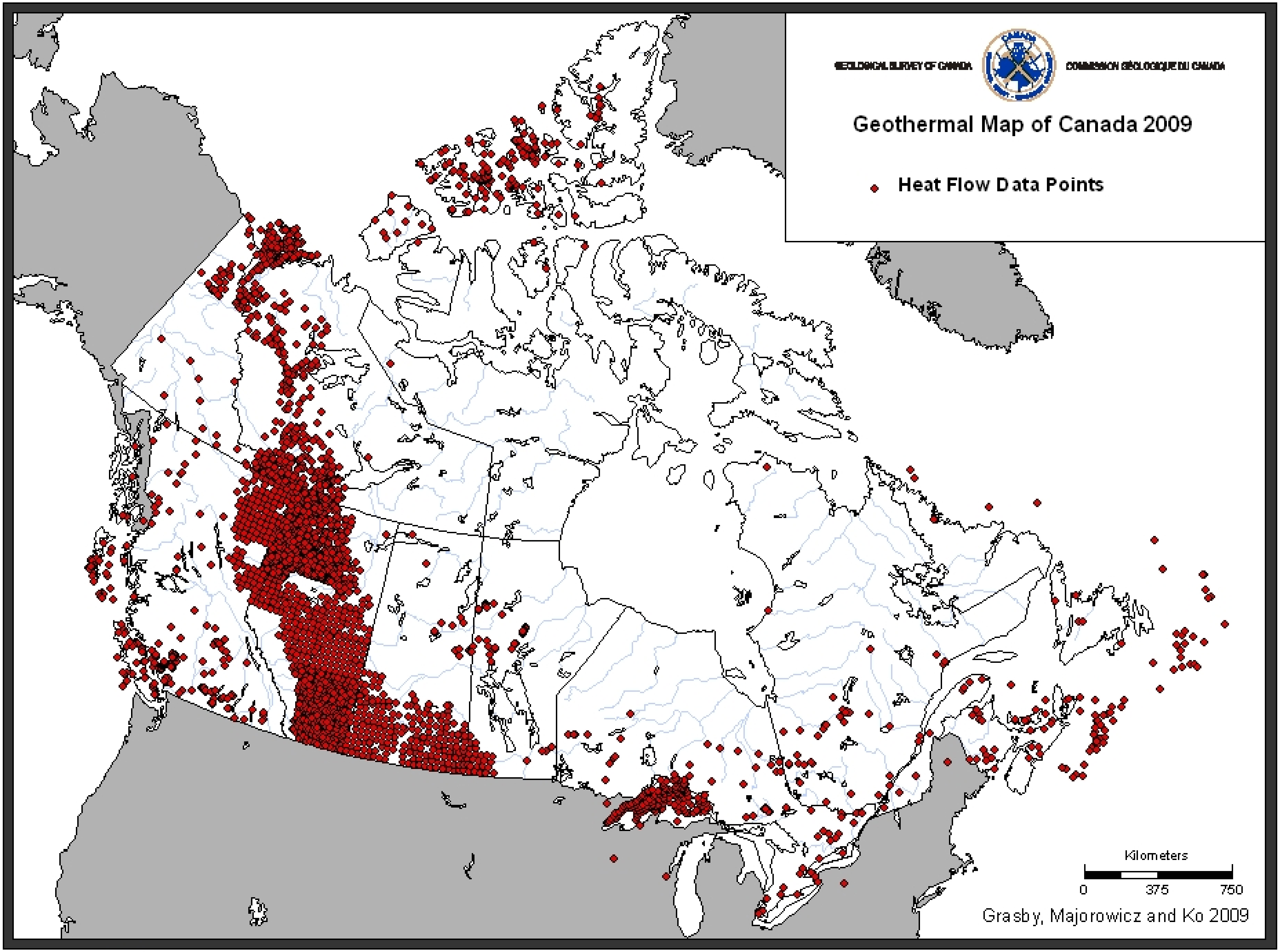

GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA
Geothermal Map of Canada 2009
Temperature (°C) at 10,000m Depth (averaged)
50 75 100 125 150 175 200 225 250 275 300 350 400 450 500
Kilometers
0 375 750
Grasby, Majorowicz and Ko 2009

Figure 12

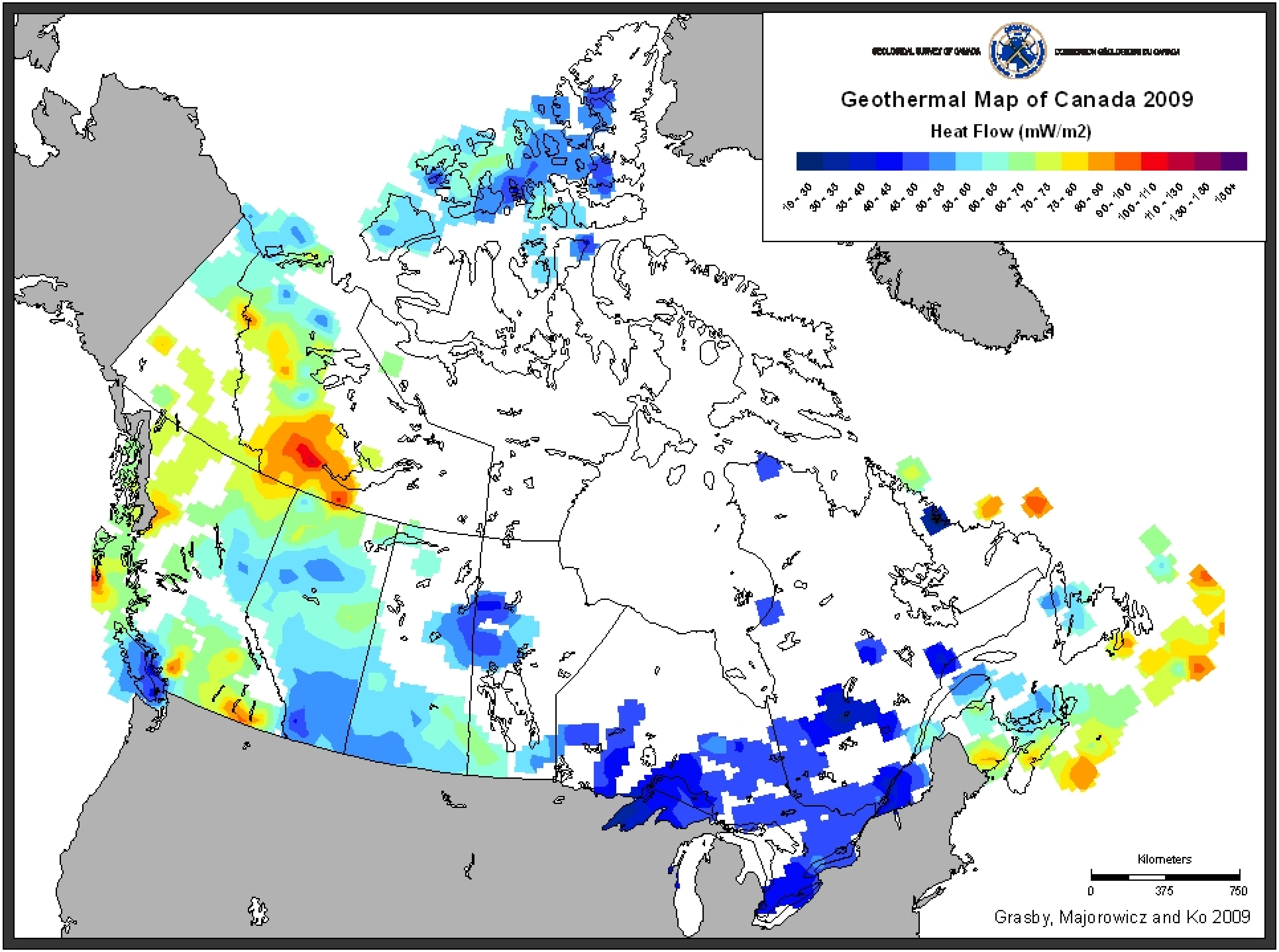
Natural Resources Canada | Ressources naturelles Canada



Canada

Figure 13

Natural Resources Canada | Ressources naturelles Canada



Canada

Figure 14

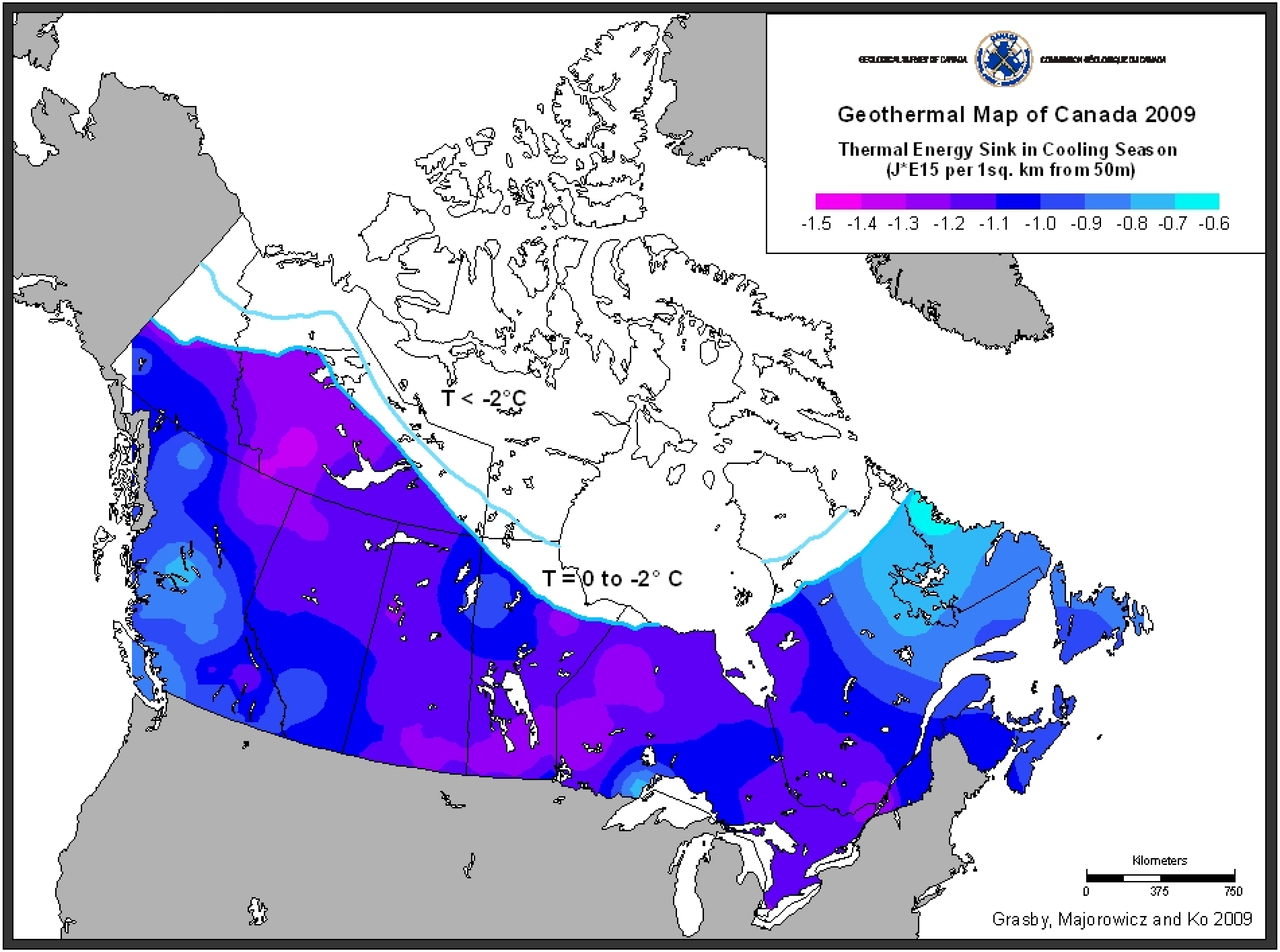

Geothermal Map of Canada 2009
Thermal Energy Sink in Cooling Season
(J*E15 per 1sq. km from 50m)
-1.5 -1.4 -1.3 -1.2 -1.1 -1.0 -0.9 -0.8 -0.7 -0.6
T < -2°C
T = 0 to -2° C
Kilometers
0 375 750
Grasby, Majorowicz and Ko 2009

Figure 15

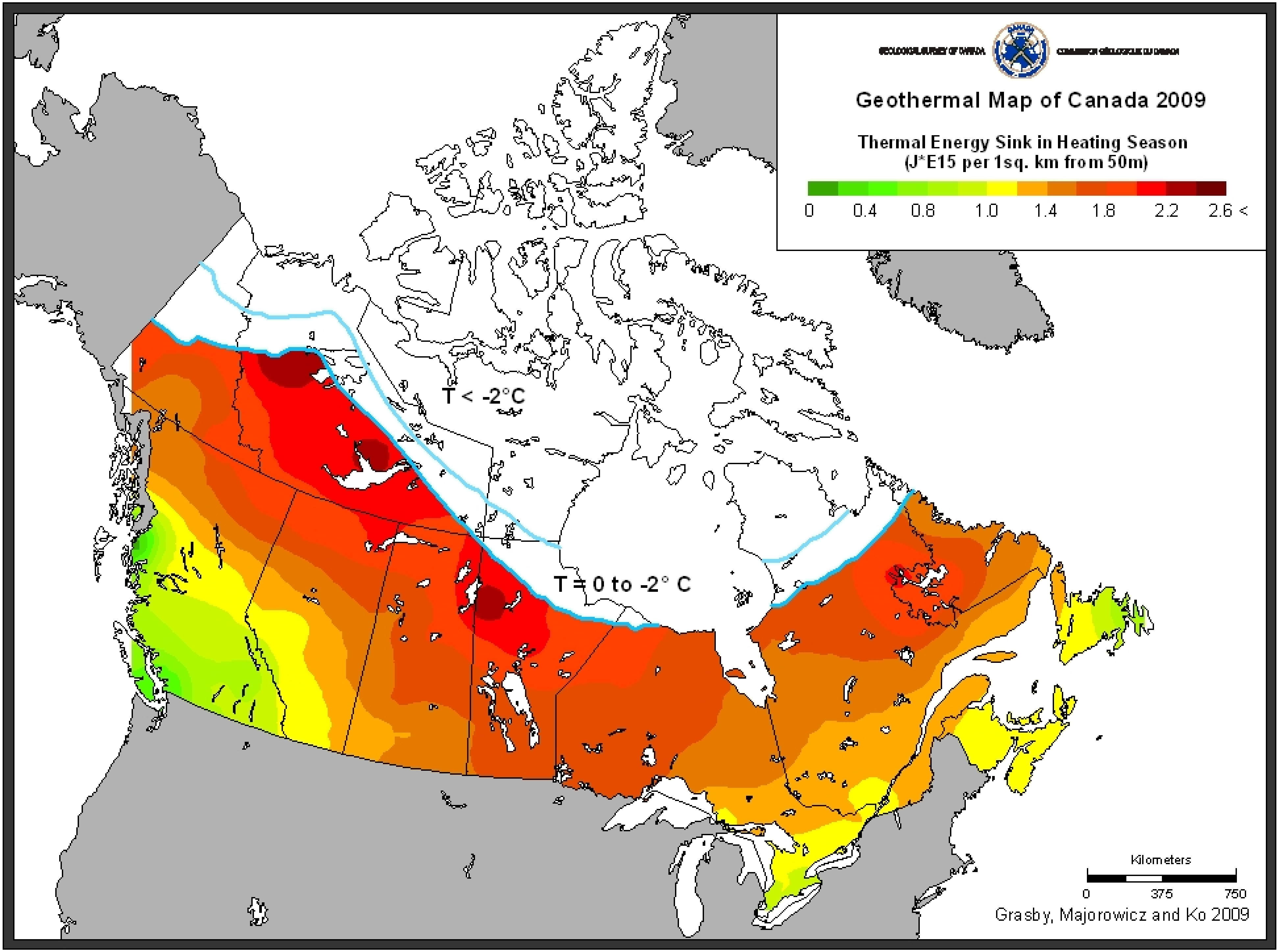
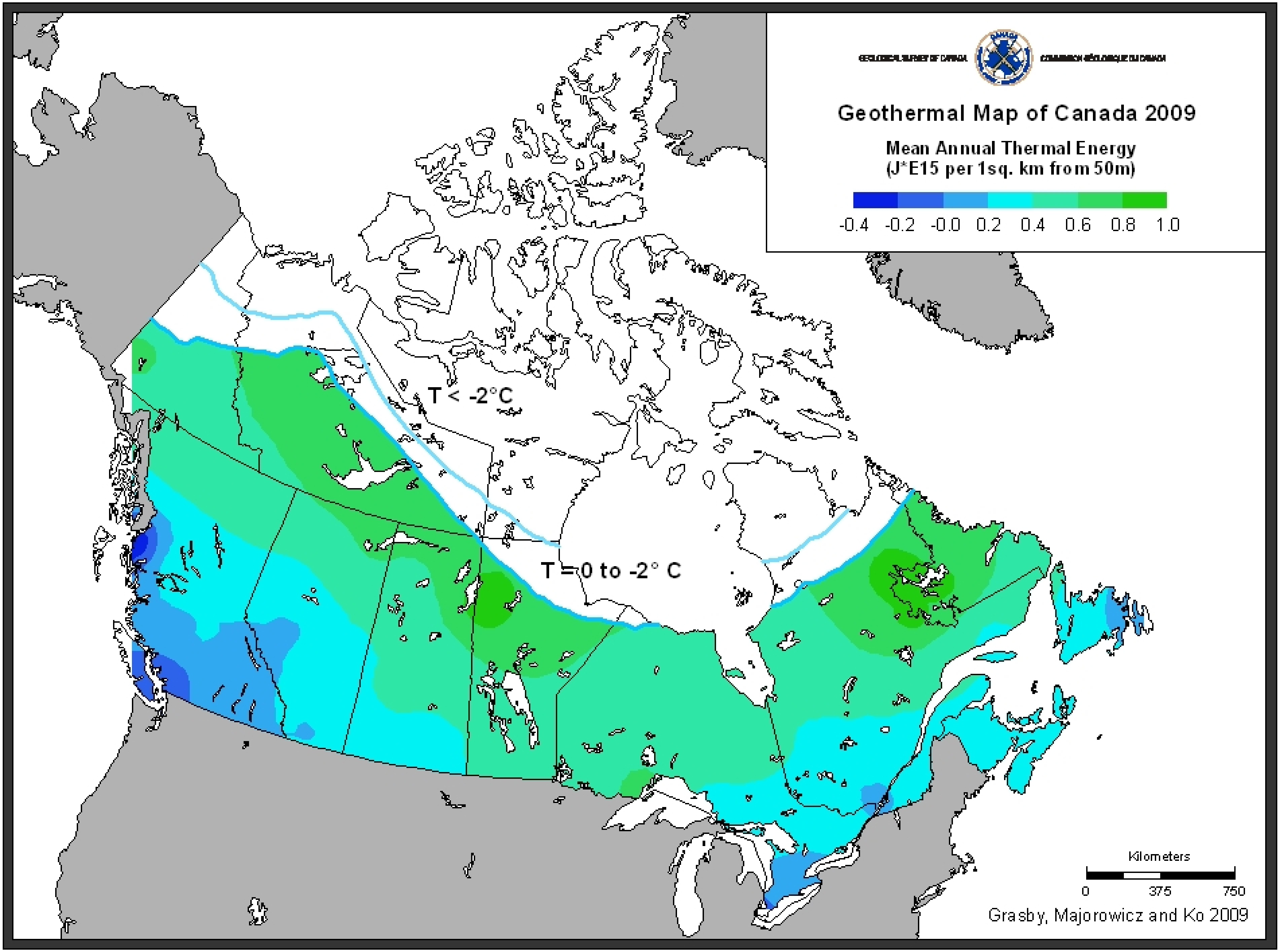

GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA
Geothermal Map of Canada 2009
Thermal Energy Sink in Heating Season
(J*E15 per 1sq. km from 50m)
0 0.4 0.8 1.0 1.4 1.8 2.2 2.6 <
T < -2°C
T = 0 to -2° C
Kilometers
0 375 750
Grasby, Majorowicz and Ko 2009

Figure 16

Natural Resources Canada | Ressources naturelles Canada



Canada

Figure 17

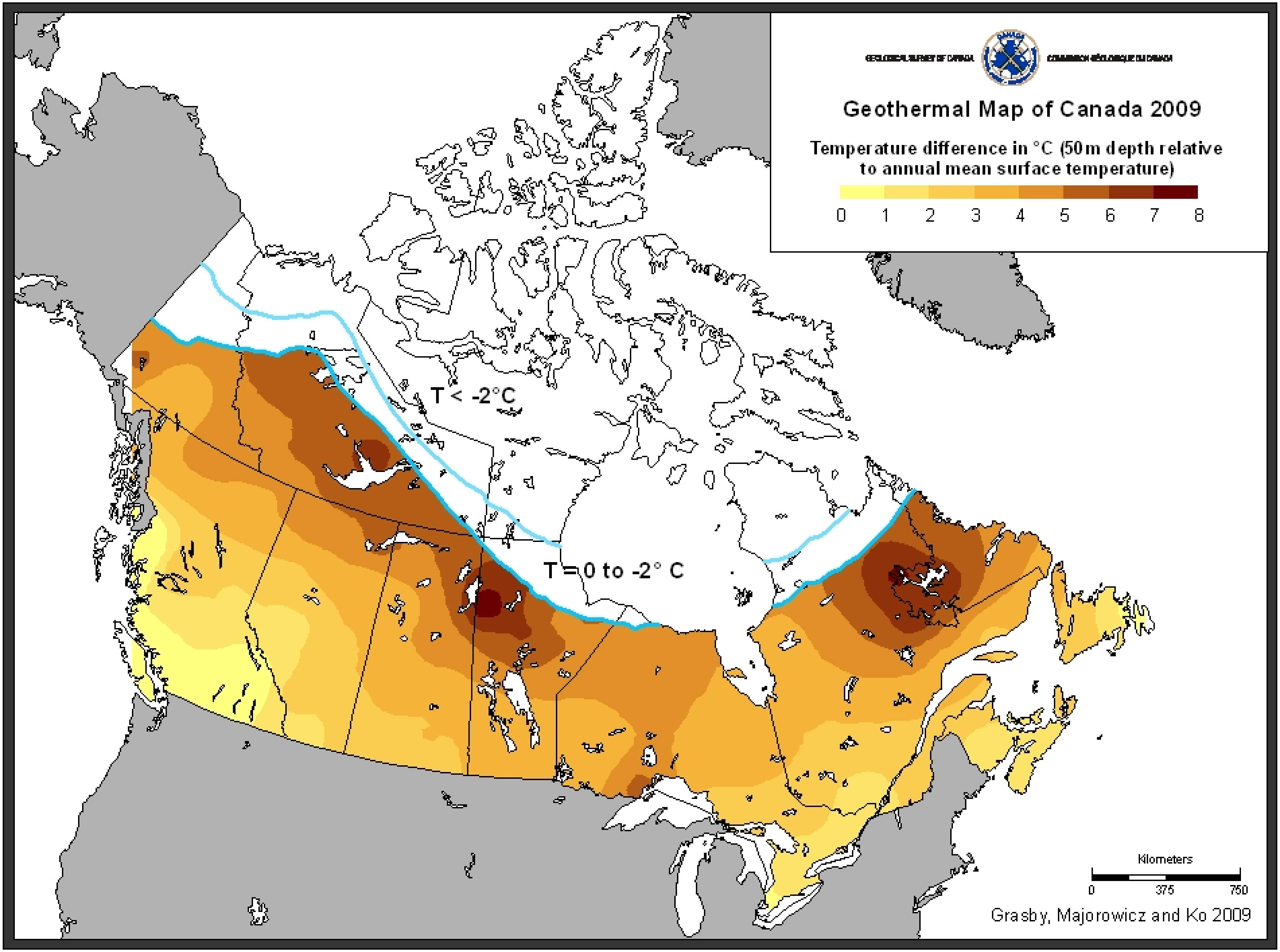

GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA
Geothermal Map of Canada 2009
Temperature difference in °C (50m depth relative to annual mean surface temperature)
0 1 2 3 4 5 6 7 8
T < -2°C
T = 0 to -2° C
Kilometers
0 375 750
Grasby, Majorowicz and Ko 2009

Figure 19

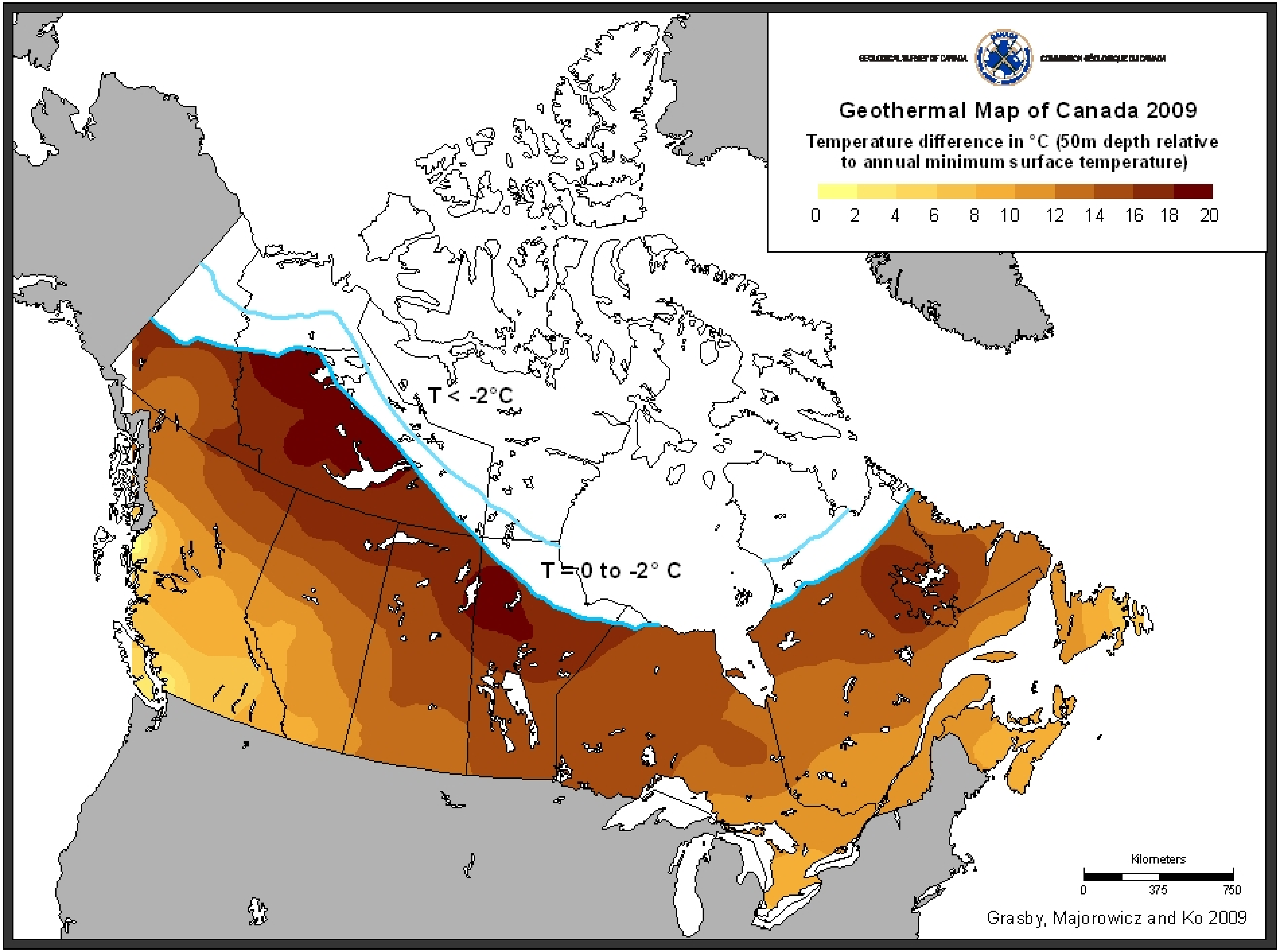
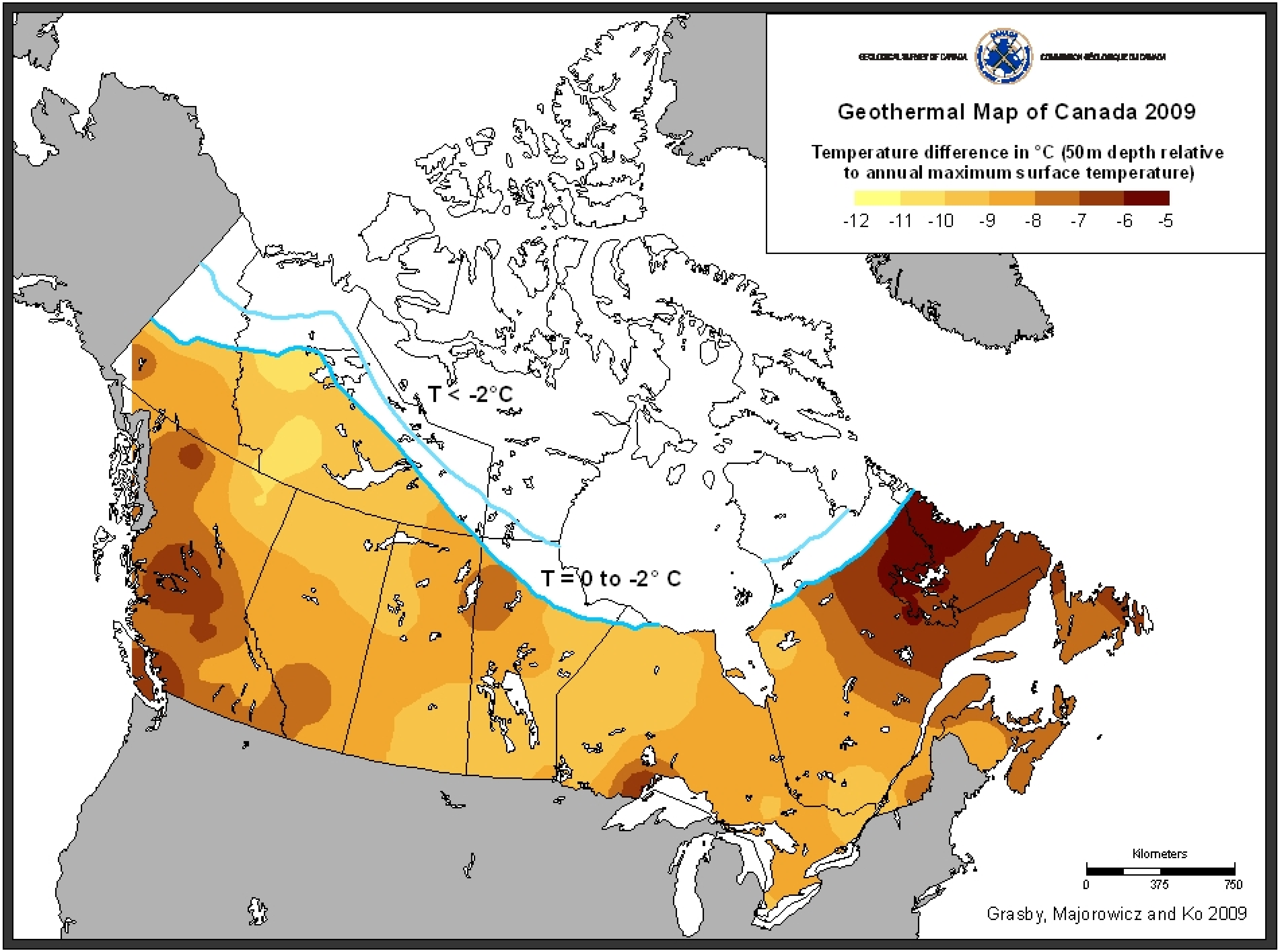

GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA
Geothermal Map of Canada 2009
Temperature difference in °C (50m depth relative to annual minimum surface temperature)
0 2 4 6 8 10 12 14 16 18 20
T < -2°C
T = 0 to -2° C
Kilometers
0 375 750
Grasby, Majorowicz and Ko 2009

Figure 18

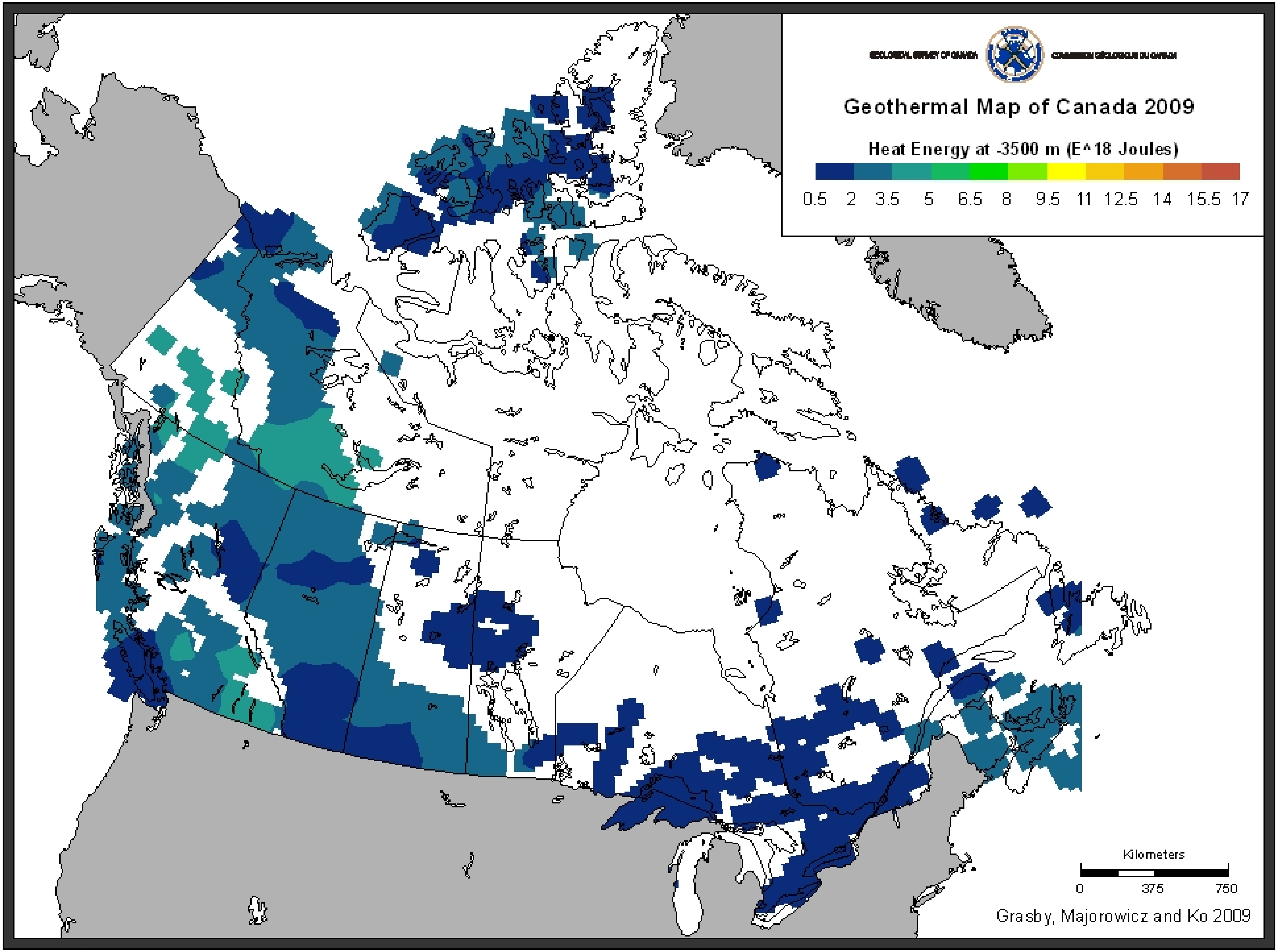
Natural Resources Canada   Ressources naturelles Canada



Canada

Figure 20

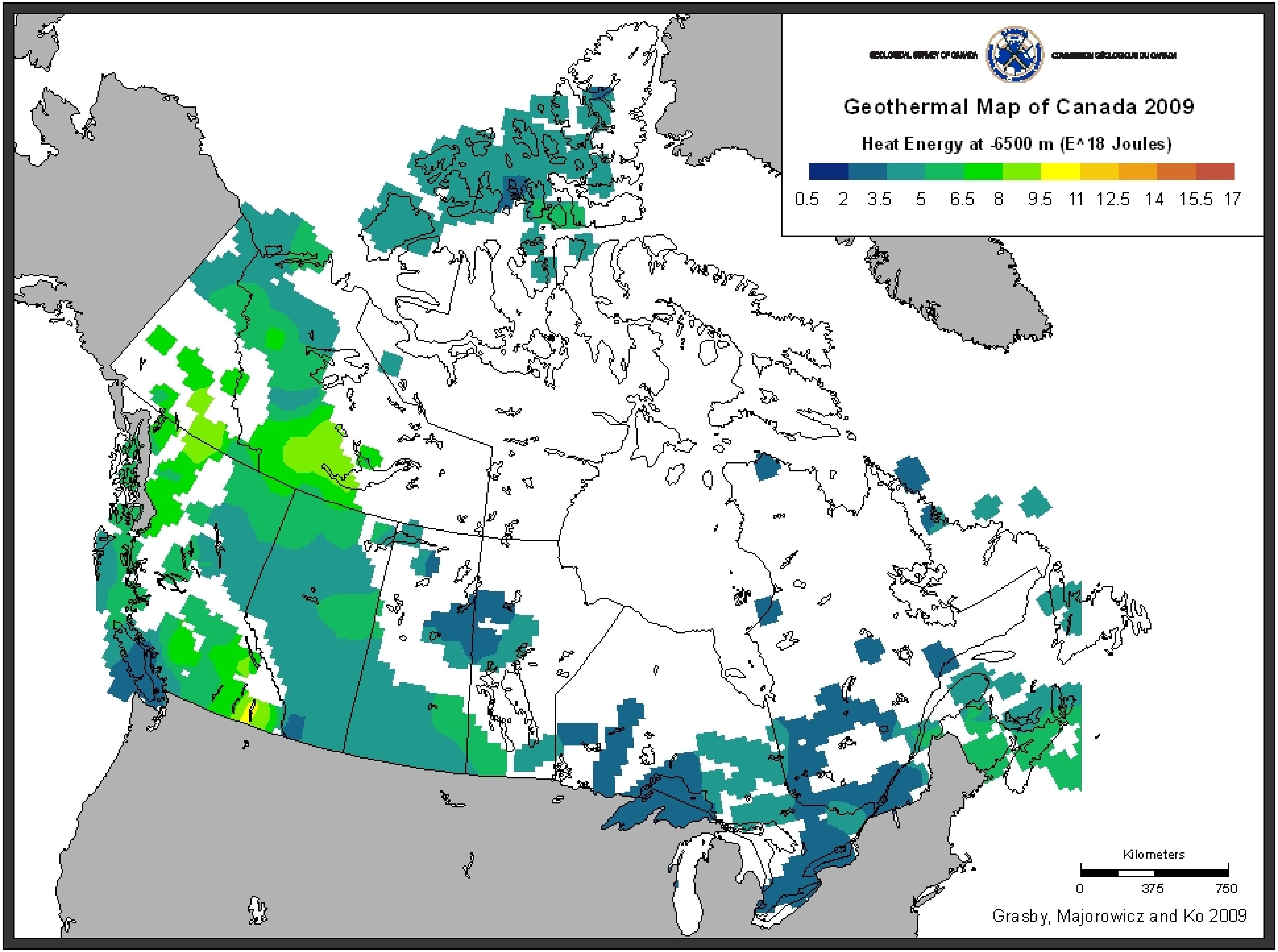
Natural Resources Canada   Ressources naturelles Canada



Canada

Figure 21

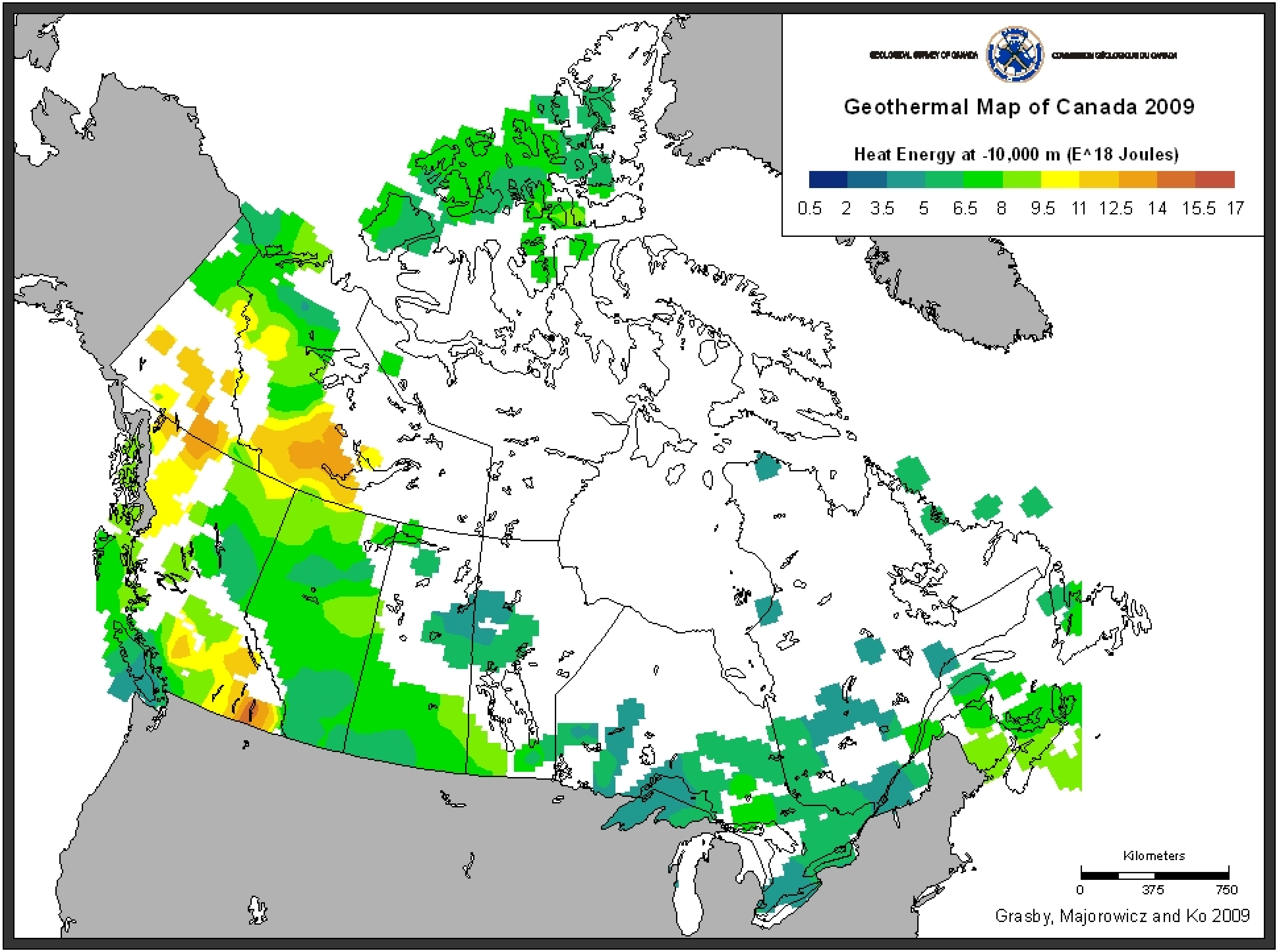
Natural Resources Canada Ressources naturelles Canada



Canada

Figure 22

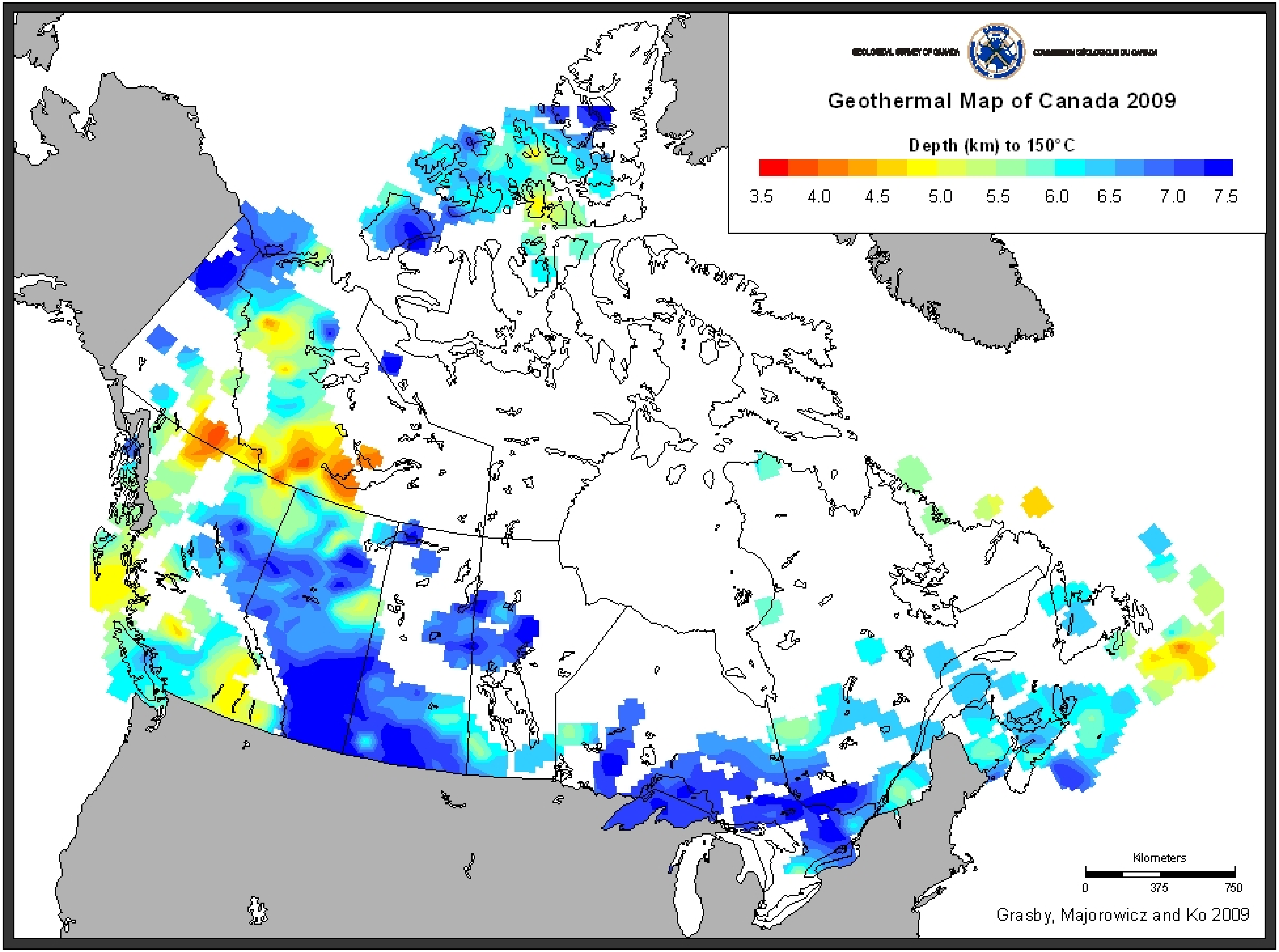
Natural Resources Canada Ressources naturelles Canada



Canada

Figure 23

Natural Resources Canada Ressources naturelles Canada



Canada

Figure 24

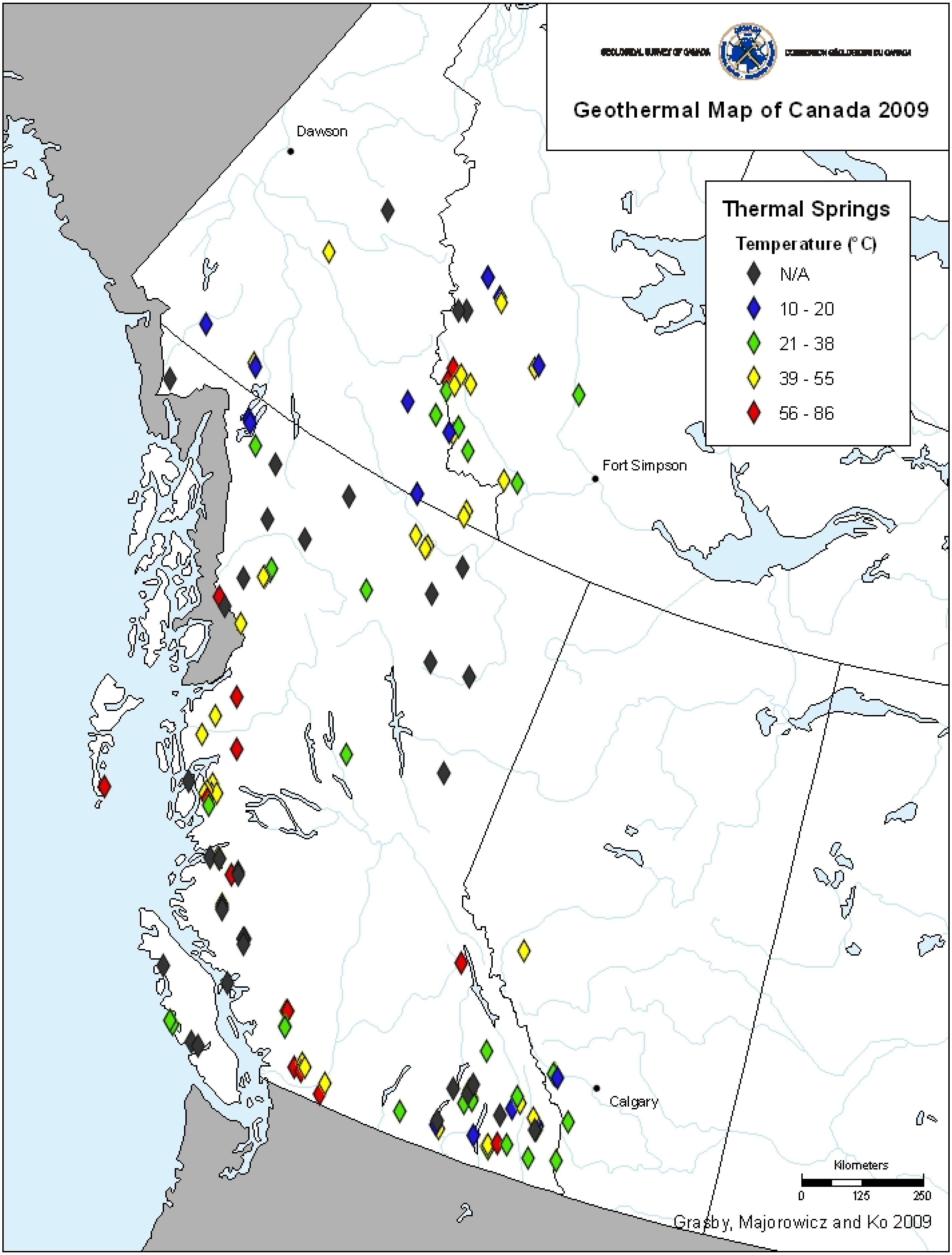

GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA
Geothermal Map of Canada 2009
Thermal Springs
Temperature (°C)
N/A
10 - 20
21 - 38
39 - 55
56 - 86
Dawson
Fort Simpson
Calgary
Kilometers
0
125
250
Grasby, Majorowicz and Ko 2009

Figure 25

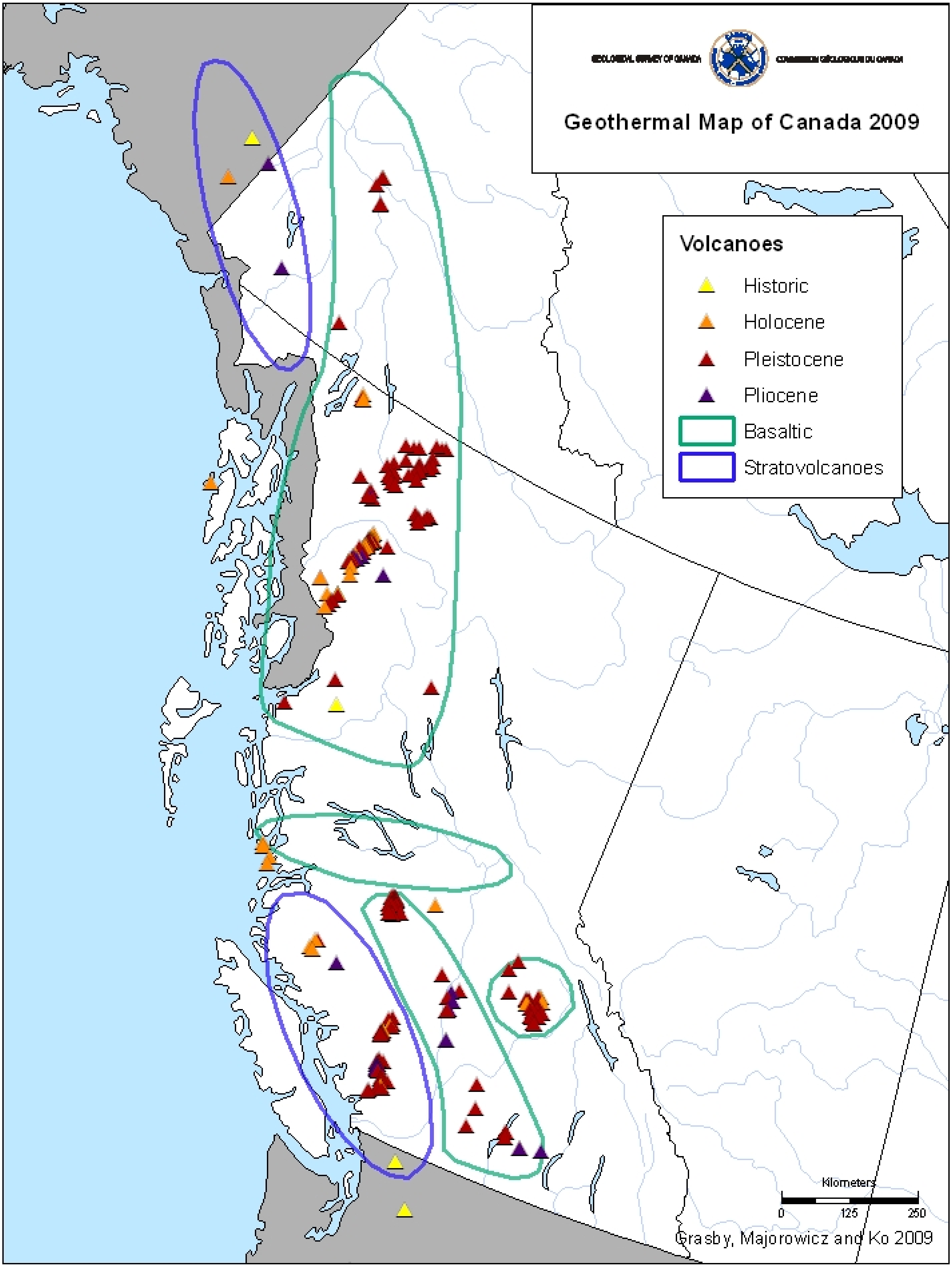
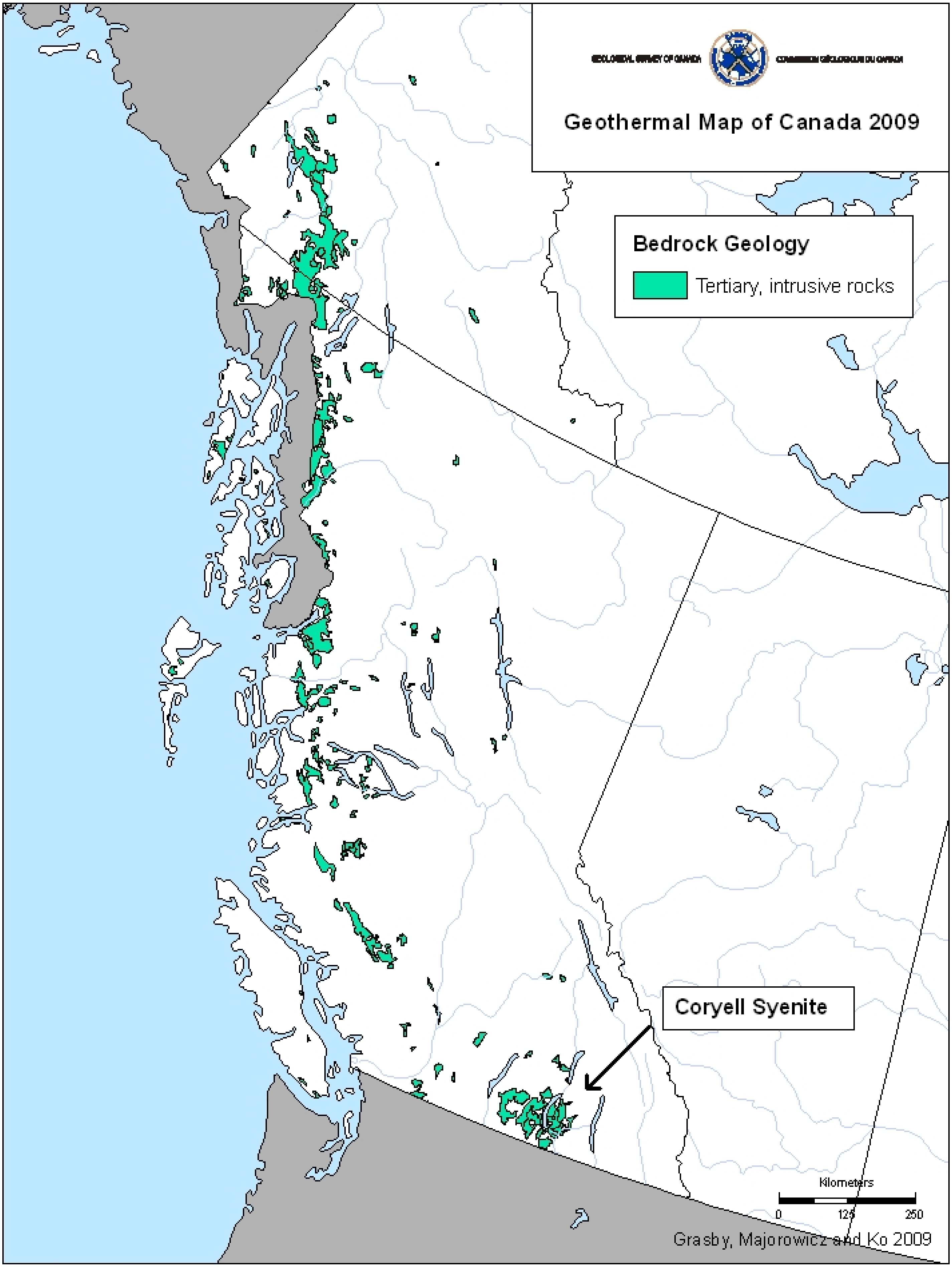

Geothermal Map of Canada 2009
Volcanoes
Historic
Holocene
Pleistocene
Pliocene
Basaltic
Stratovolcanoes
Kilometers
0
125
250
Grasby, Majorowicz and Ko 2009

Figure 26

Natural Resources Canada / Ressources naturelles Canada



Canada

Figure 27