# Enhanced Geothermal Systems (EGS) Potential in the Alberta Basin

*Prepared by*

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*ISEEE Research Paper*

*(Research sponsored by the Alberta Energy Research Institute)*

July 2008

**Title:** Enhanced Geothermal Systems (EGS) Potential in the Alberta Basin

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## Disclaimer



## Acknowledgments

The authors would like to thank the Alberta Energy Research Institute for its support for the research that is the focus of this report.

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# Executive Summary

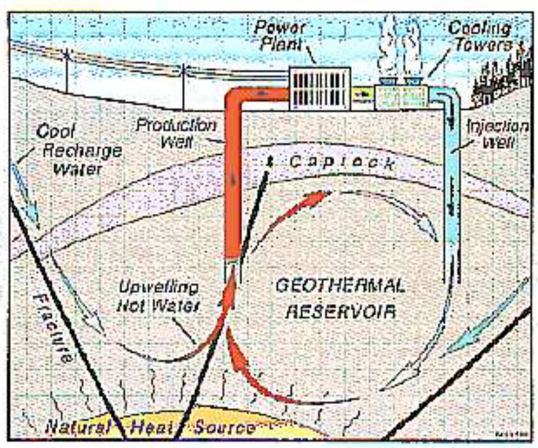
**Background**

This report surveys the potential heat resources estimated at various depths within the geographic boundaries of the Province of Alberta, Canada. The study was designed to evaluate deep heat resources that might support the development of Engineered Geothermal Resources (EGS) for either electric power generation or native steam load. This study produced a series of maps that estimate a range of subsurface temperature isoquants. These are extrapolated to extreme depths and suggest a process for estimating the heat potential in the Province.

Increased demands on energy systems generally have prompted both public and private parties to examine alternative energy and energy efficiency opportunities. Geothermal power, literally a byproduct of tapping hot water or rock areas in the earth's crust, offers the potential for direct power or steam production as well as fuel substitution.

Access to heat resources is possible literally anywhere on earth, although the heat values available will vary greatly, depending on a variation of depth, rock type, available water and the ability to move water through interstitial cracks. Figure 1 below illustrates this relationship for traditional hydrogeothermal resources where re-injection of water can be used to sustain or supplement steam generation.

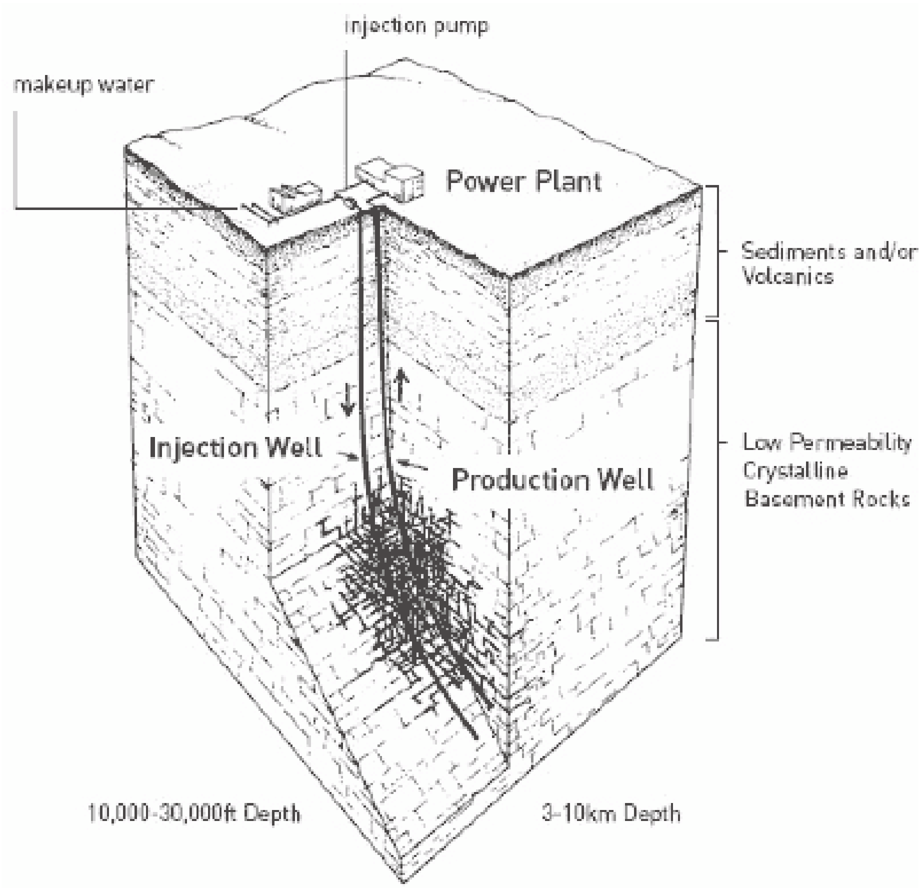
**Figure 1**




Source: Nevada Geothermal Corp., http://www.nevadageothermal.com/i/maps/caprock.gif

Understanding the extent and relative heat levels available on a large scale, however, has not been undertaken until very recently with the publication of the MIT report on exploiting deep geothermal potential which must be "engineered" in order to develop power production potential. This is illustrated in Figure 2 showing the extreme depth and reservoir stimulation needed to extract heat from deep geologic zones.

**Figure 2**




Source: MIT, The Future of Geothermal Power, 2004

Much of the accessible hydrogeothermal resources have been tapped and utilized either for electric power production or steam generation where co-generation facilities can be economically justified. Electric production is a function of generation capital cost, corresponding capacity factor and access to nearby transmission interconnects. Because of the nature of the power produced, the output is typically utilized as a base-load component in the dispatched electricity market.

**EGS Potential**

The U.S. Department of Energy has broadly defined Enhanced (or Engineered) Geothermal Systems (EGS) as engineered reservoirs that have been created to extract economical amounts of heat from low permeability and/or porosity geothermal resources. This includes all geothermal resources that are currently not in commercial production and require stimulation or enhancement. EGS excludes high-grade hydrothermal but includes conduction dominated, low-permeability resources in sedimentary and basement formations, (as well as geopressured, magma, and low-grade, unproductive hydrothermal resources).

Depth and rock relationships

Geothermal wells explore and exploit a continuum of heat available under the earth's surface. Most of the current applications develop heat from shallow depths where heat exchange can take place, such as the use of geothermal heat pumps for buildings or hydrogeothermal resources where a natural heat source combined with available underground or pumped water is exploited for the steam or extreme heat potential which can be used for instance in transference to fluids which extract and use that heat to turn turbines and provide electric power. Geothermal heat pumps are typically employed in shallow depths (< 300m), while depending on local conditions, hydrogeothermal systems can tap heat or steam resources to depths approaching 3Km. At depths below 3Km the rock or compressed sedimentary layers must usually be stimulated (hydrofracing) in order to create pore space where water can be pumped in order to create a heat flow system.

The categories of available resource generally follow this sequence, in increasing depth from surface.

a. Low Grade Geothermal Heat
b. Hydrogeothermal Resources
c. Hot Wet Rock
d. Hot Dry Rock
e. Hot Fractured Rock
f. Engineered or Enhanced Geothermal System

In addition, co-produced hot water from oil and gas production can be treated as an unconventional EGS resource. When fully developed, EGS will recover thermal energy contained in subsurface rocks by creating or accessing a system of open, connected fractures through which water can be circulated down injection wells, heated by contact with the rocks, and returned to the surface in production wells to form a closed loop.

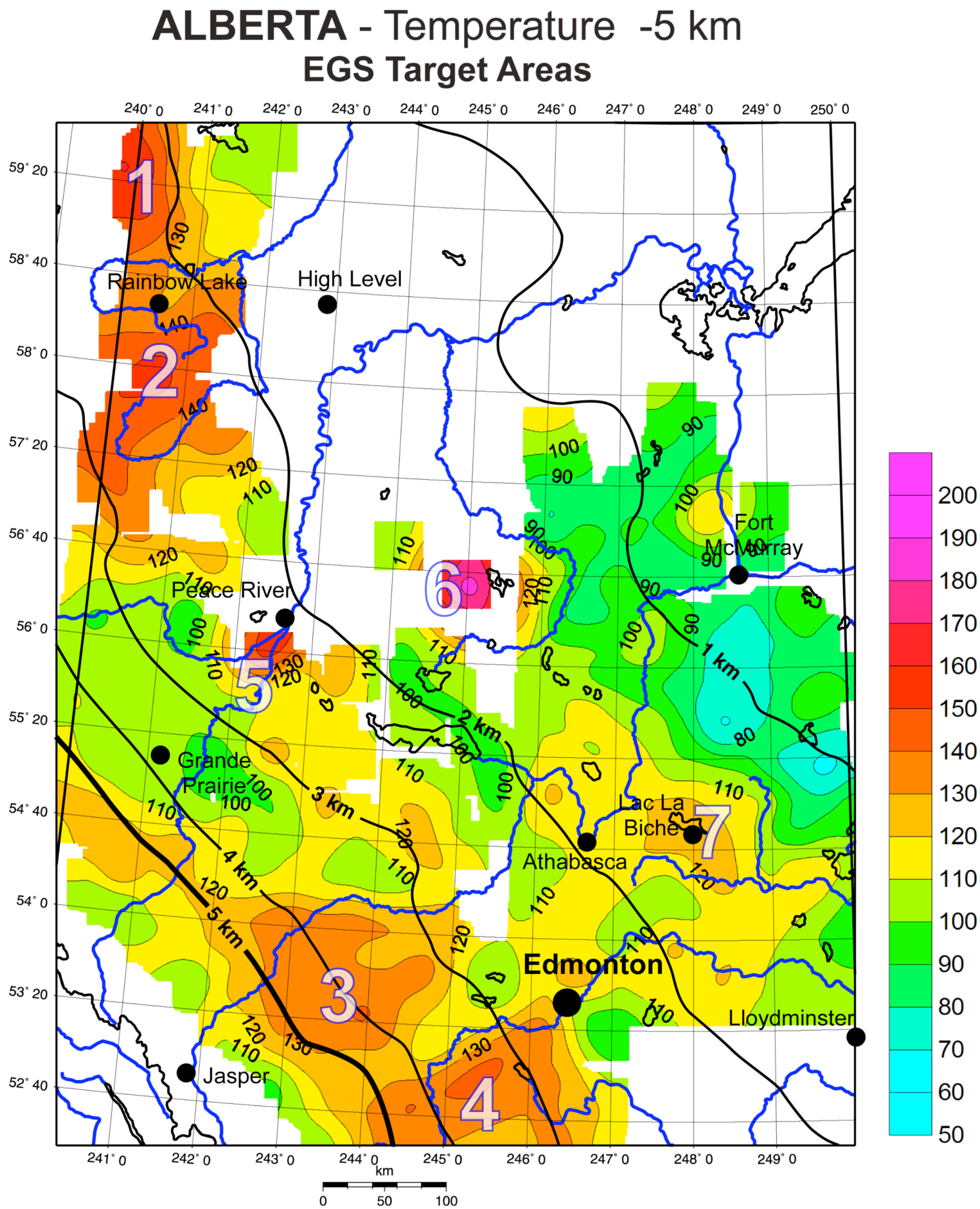
The EGS System requires introduction of water into rock of limited permeability (either tight sediment or basement) in a controlled fracture setting so that this water can be withdrawn in other wells for heat extraction. As an example, in the US, an area that appears to be very favorable is in east Texas and northern Louisiana where the low permeability tight formations of the Jurassic period exist with temperatures over 350 °F (177°C) that are currently exploited as tight gas systems.

The most favorable EGS resources will be a function of heat content, drilled depth and stimulation potential. The best resources are estimated to be less than 7 km in depth and with temperatures >150°C. In the continental USA, for instance, there are estimated to be at least 17 million kilometers with these requirements, with a thermal energy potential of 8,600,000 x $10^{18}$ Joules. EGS systems are not fully implemented but various research sites around the world confirm the potential of the resource including Rosemanowes in Germany, Soultz-sous-Forêts in France and Cooper Basin in Australia. Because the technology and drilling techniques are thought to be an extension of existing drilling patterns and costs, but are not yet fully validated, estimates of development costs are necessarily imprecise.

Components of Direct EGS development cost would include -drilling wells that reach hot temperatures >150°C, fracturing and/or horizontally drilling wells to develop high water flow and/or acquire make-up water, installing infrastructure, roads, piping, and power line routing, and building power stations.

Figure 3, shown below, illustrates the areas of central and northern Alberta which seem to show good potential for EGS from temperature maps based on the AEUB temperature data set. The grading of areas suggests the priority of future research and ultimately access to higher value resources, as well as the relative proximity to developed load centers. The zones with 150 $^{o}$C temperature at 5km depth are all in the north western part of Alberta north and south of Rainbow Lake. (target areas 1 and 2). Target areas 3 and 4 also have anomalies close to 140-150 $^{o}$C . These high temperature zones are sustained through deeper depth and are visible in maps of temperature at larger depths of 7km and 10km. At 10km these areas reach above 200 $^{o}$C. It is also true for the area of Lac La Bische in the shallower part of the basin (Target area 7).

**Figure 3**



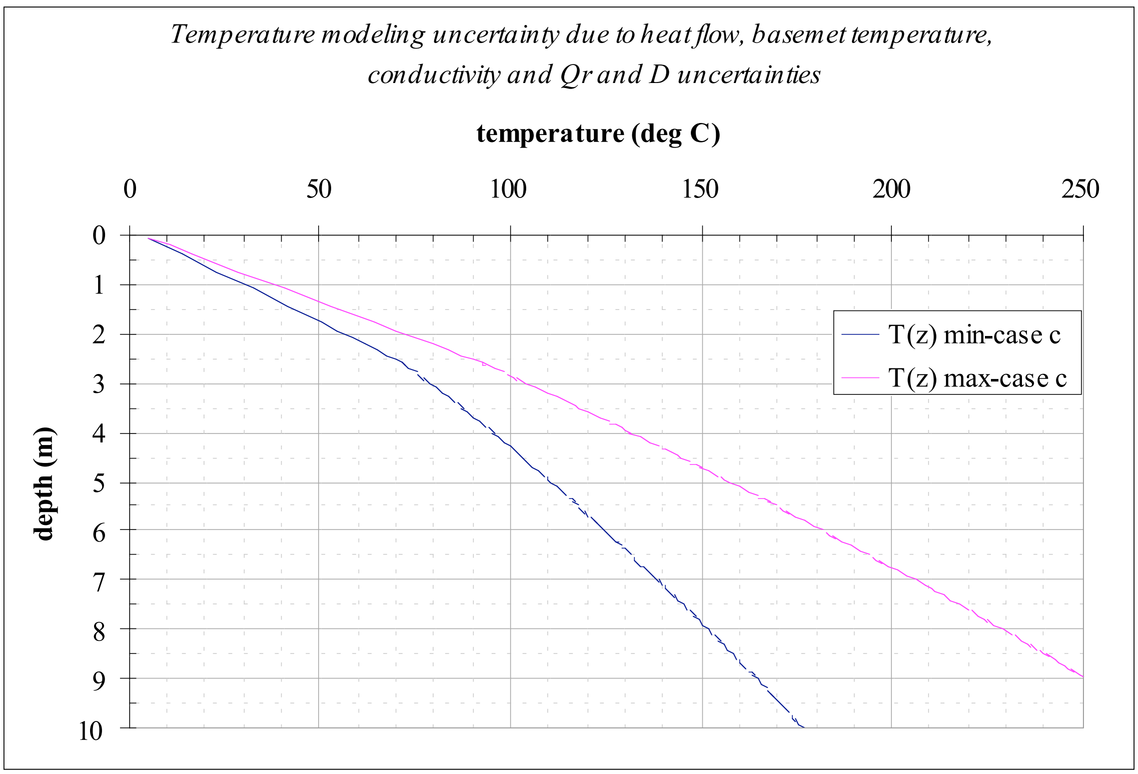
ALBERTA - Temperature -5 km
EGS Target Areas
Rainbow Lake
High Level
Peace River
Fort McMurray
Grande Prairie
Lac La Biche
Athabasca
Edmonton
Jasper
Lloydminster
1
2
3
4
5
6
7
1 km
2 km
3 km
4 km
5 km
km
0
50
100
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50

*Measurement Uncertainty*

Major gaps in data appear in the north central region of the Province and reflect the lack of drilling activity in that area. The temperature zones at depth levels below the data are approximate. The calculation of minimum and maximum bounds of temperatures for different assumption on heat flow, conductivity and basement temperature (these are quantities with at least 10% uncertainty) is shown in Figure 4 below which combines bounds of confidence for fixed quantities of heat flow, thermal conductivities and temperature at the basement.

The temperature zones calculated and contoured for chosen depth levels down to 10k depth reflect a confidence interval of some 9 $^{o}$C at 2km and as high as 50 $^{o}$C at 10 km.

**Figure 4**



**Temperature and quantity at depth**

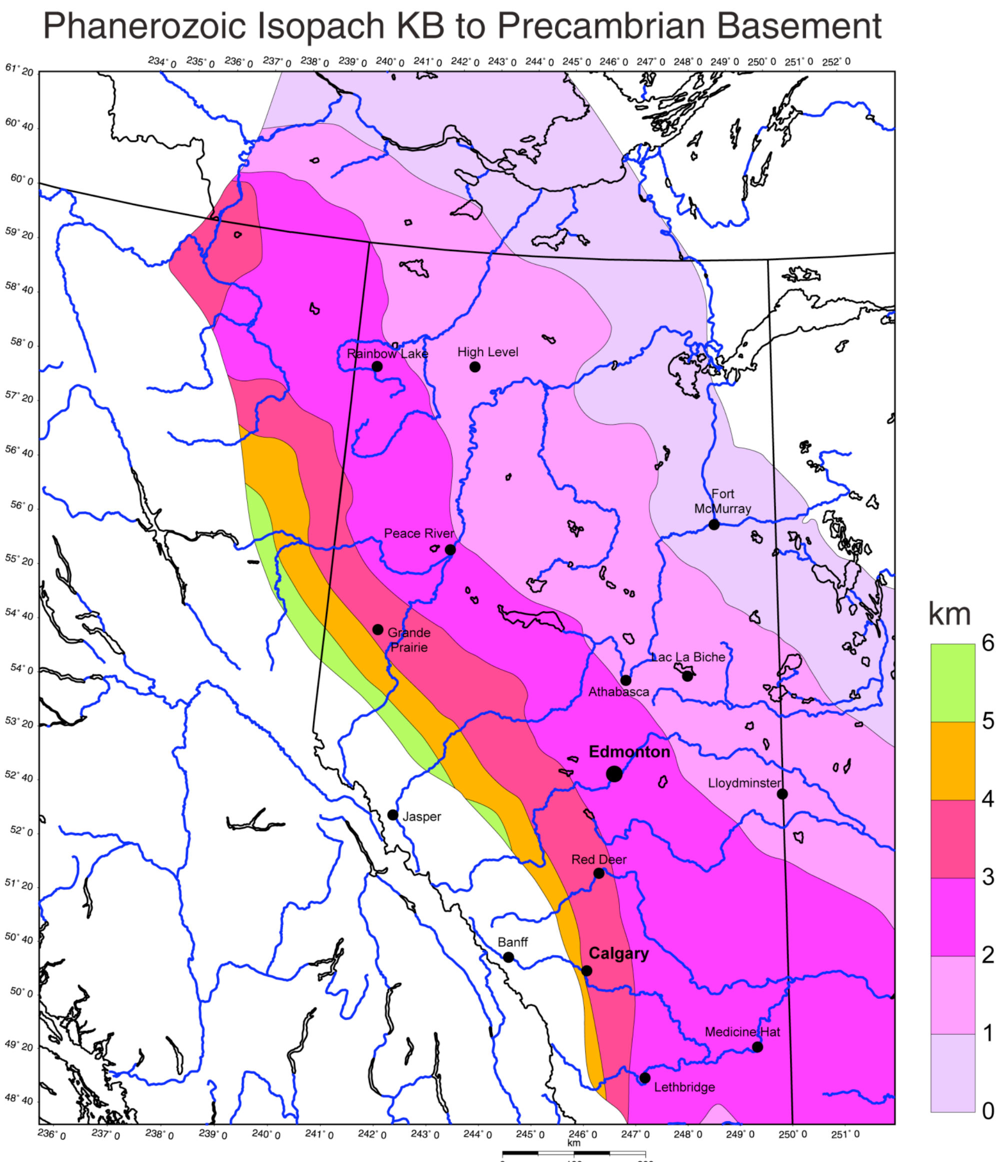
Maps of temperature at depth are constructed from the AEUB temperature data, based on them heat flow calculations and modeling calculations in this report. Temperatures at depths 1km and 2km are in large part within the western part of the Alberta basinal sediments (eastern parts are below the top of the crystalline basement at these depths), temperatures at 5km are almost all within crystalline rocks underlying basinal sedimentary succession (except very western deepest part of the basin (>5km)). Temperatures below 7km depth levels are all within crystalline rocks of the granitic crust.

The illustrative amount of energy from a 1km slice of rock in a 100 $km^2$ 'target' area is more than Canada's annual energy consumption. The actual accessible and usable energy resource will be smaller, but still extremely valuable. For future exploration, target areas can be determined from temperature maps and other information (rock parameters etc.). The analysis of the temperature maps shows that we can reach usable temperature zones that average 150 $^oC$ for large areas of the north western Alberta and central eastern Alberta as well as elsewhere from average depth of 7km (Map 7) and smaller areas from 5km depth down to 50 $^oC$ producing large amounts of energy. Temperature of 150 $^oC$ can be reached for the north western part at depths as low as 5km. At a depth of 10km we have large areas of temperatures >200 $^oC$. At 250 $^oC$ the total amount of energy represented by the 200$km^2$ area is greater than 100 quads.

**Implications**

The first highlights of the analysis of the EUB temperature data from well tests show that we have few hot spots in Alberta with heat flow as high as in the basins of the western US. The region of Lac La Biche is one example. Some high values North of Fort MacMurray are suggested by the available data. These , however, are based on data from very shallow wells (few hundred meters) and not always confirmed by also shallow precise temperature logs in Alberta Energy observational wells. The most interesting regions are found in the extreme Northwest region of Alberta, where there is a deep and extensive blanket of sediments with corresponding softer overlying rock to drill through in order to obtain EGS-like temperatures (>150 $^oC$). The lowest heat flow is apparent in the Rocky Mountain foothills. While the basin sediments here are relatively thick, the rate of increase of temperature with depth is low with corresponding low heat gradient. The general trend of the basement formations is shown in Figure 5 below. Since much of the principal heat available for transfer is contained in the basement rock, its surface proximity and the implied sedimentary "blanket" are critical to decisions on well locations and power transfer facilities in the future.

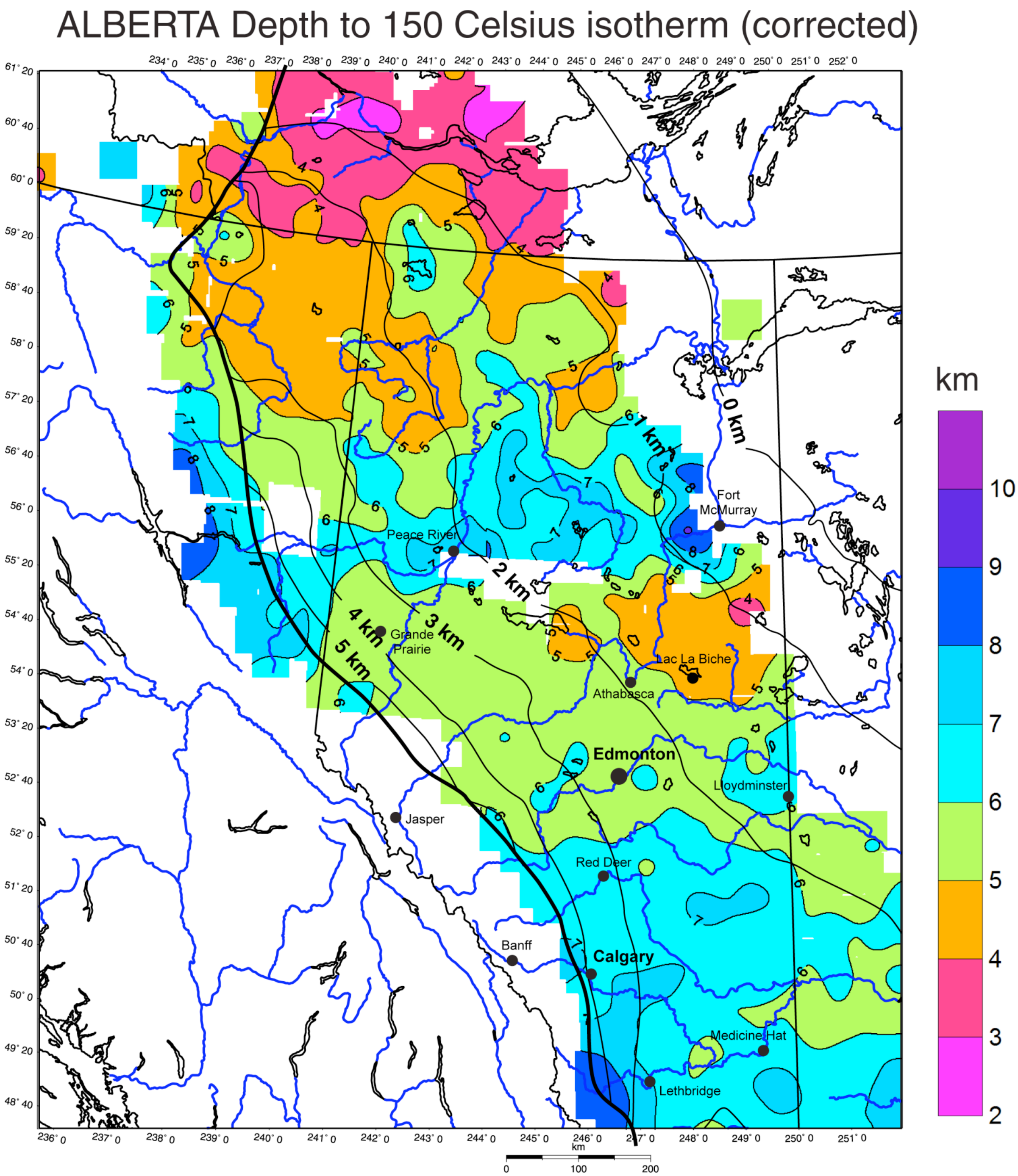
**Figure 5**
**Schematic of Phanerozoic Isopach**
**showing depth to basement**




Source: NRCan, Majorowicz, 2007

When viewed as a pan-Albertan map of depth to reach a minimum of 150 $^{o}$C based on heat flow calculated from the BHT data base of the University of Alberta, a pattern of resource distribution reveals a slightly larger distributed area than first revealed either by well data or previous geologic reports. The least favorable areas are those of southern Alberta and Peace River Arch where we would need to drill 6-8km to reach 150 $^{o}$C. This is apparent in Figure 6 shown below.

**Figure 6**
**Schematic of depth to 150 °C**



**Conclusions and Recommendations for Further Work**

This preliminary research suggests a more abundant geothermal resource may be present than previously assumed in Alberta if EGS technology is able to be demonstrated and ultimately used not only for steam heat but electricity generation. This technology will also allow access to more moderate heat zones, making them accessible for heat redistribution (for in-situ operations for instance) and for displacement of some current fuel sources such as natural gas used for steam heat generation.

The mapping exercise used here is preliminary and relies on published data from several sources. It is revealing in several areas, first and foremost in identifying a significant heat resource available within the Province. However, even a cursory examination of the mapping illustrates gaps and areas of potentially inconsistent results. The broad interpretations in some areas underline the need for further assessment and investigation to gain confidence in the extent and depth of the underlying resource. We feel that the next step in data collection should involve a collaborative effort with industry to return to old wells and well logs to extract more accurate and timely data.

In terms of future power generation, the geographic areas we have identified are not convenient or adjacent for use in high-demand power centers such as cities. However, there are power system proposals such as the Northern Lights Transmission line and the Edmonton-West coal power corridor that would provide access to transmission interconnection, capacity and distribution, making this source of power production economic and useful for dispatch. Our data suggest that wide distribution of useful heat value resources are available at moderate depths which have already been reached in oil and gas drilling operations.

Such synergies will only be seen as desirable when clearer analysis of costs and risk factors are explored. For instance, a new transmission system from the Fort McMurray area will only be attractive to investors when there is excess electric power generated in the region which has a market for delivery. Similarly, the Alberta power market must be capable of absorbing new supplies of base load electric energy to support more remote geothermal development. Nonetheless, power of this type, i.e. baseload, is forecast to be competitive with other existing baseload resources such as pulverized coal or light water nuclear reactors. Developing synergistic relationships with other power system operators such as transmission and distribution, or other large load centers such as oil sands operations, will result in earlier investment and ultimately earlier access to this resource.

Other synergistic opportunities are beginning to be explored and may provide additional incentive to include Geothermal EGS in Alberta's power portfolio. These include combining geothermal drilling and exploration with future carbon capture and sequestration schemes, sharing costs and diminishing the overall cost for either technology in the process. Future geothermal power conversion technologies can be used to dry biomass crops, reducing the cost of this co-power opportunity. In addition, since the life-cycle impacts and costs of geothermal systems are lower than other renewable energy resources, development of this source can provide carbon offsets as well as so-called green credits which can support the creation and liquidity in the coming carbon trading markets.

We believe *prospective* regions should be analyzed in greater detail, in finer grain research in the future. For instance, areas around the North Saskatchewan River may prove to be productive, with estimated heat flow values >80 mW/m. As mentioned previously, combining mid-range EGS heat potential with in-situ operations in the oil sands development areas may provide opportunities for fuel substitution for natural gas.

There are current proposals for new baseload power generation in Alberta that range from new IGCC level coal plants to large nuclear facilities. Geothermal power based on Engineered Geothermal Systems may be able to reduce or substitute for these proposed power sources at competitive prices while providing a side benefit of lower GHG emissions and ultimately tradable credits on carbon markets.

This technology has many possible applications within the Alberta and greater Canadian energy portfolio and should be the subject of a coordinated and multi-faceted on-going research program. This should include enhanced mapping, new well data recording requirements and support for alternative energy resources. Ultimately, developing this resource can provide the model for efficiently and economically diversifying Alberta's energy portfolio, balancing native load and simultaneously providing a dynamic and robust export product.

# Enhanced Geothermal Systems (EGS) Potential in the Alberta Basin

**Jacek Majorowicz**[1]
**Michal C. Moore**[2]

Summary

This report surveys the potential heat resources estimated at various depths within the geographic boundaries of the Province of Alberta, Canada[3]. The study was designed to evaluate deep heat resources that might support the development of Engineered Geothermal Resources (EGS) for either electric power generation or native steam load.

This preliminary research suggests a more abundant geothermal resource may be present than previously assumed in Alberta if EGS technology is able to be demonstrated and ultimately used not only for steam heat but electricity generation. This technology will also allow access to more moderate heat zones, making them accessible for heat redistribution (for in-situ operations for instance) and for displacement of some current fuel sources such as natural gas used for steam heat generation.

In terms of future power generation, the geographic areas we have identified are not convenient or adjacent for use in high-demand power centers such as cities. This data suggest that wide distribution of useful heat value resources are available at moderate depths which have already been reached in oil and gas drilling operations.

Background and Study Methods

This research work was supported by a grant from the Alberta Energy Research Institute to the Institute for Sustainable Energy, Environment and Economy at the University of Calgary. The data and conclusions shown here are the responsibility of the authors and do not necessarily reflect the goals or policies of the University or the Institute.

The study used published data from public regulatory agencies as well as unpublished bottom hole temperature (BHT) data available in industry files stored either at the University of Calgary or the University of Alberta libraries. The results are presented by developing a series maps of predicted heat isoquants throughout the Province.

The primary objective of this research has been to identify the location and extent of deep geothermal resources. However, the development of maps and field data has, by definition, created an estimate of resources by heat content which may prove valuable for

[1] ISEEE, University of Calgary and University of North Dakota
[2] University of Calgary, Institute for Sustainable Energy, Environment and Economy
[3] The work was sponsored by the Alberta Energy Research Institute (AERI) and by the Institute for Sustainable Energy, Environment and Economy (ISEEE) at the University of Calgary

assessment of a wide range of uses other than power generation, including steam and natural gas fuel substitution.

**Study Objectives**

The work evaluated potential areas for the Engineered Geothermal Systems (EGS) in Alberta by using existing published data in the form of well logs and bottom hole temperature data (BHT) obtained from oil industry well logs on file with the Alberta Energy and Utilities Board (AEUB) and in Provincial University libraries. The study has produced a series of maps that estimate a range of subsurface temperature isoquants. We extrapolate these to extreme depths and suggest a process for estimating the heat potential in the Province. The report concludes with an assessment of further information and research needs as well as suggestions for the development of long-term test facilities. The data included here are based on:

- Determination of the magnitude and distribution of the EGS resource in Alberta
- Evaluation of the existing temperature data base (heat flow map of N. America heat flow data for Alberta, published geothermal gradient data, conductivity estimates; ground surface temperature data; EUB temperature data base).
- Calculation of depth to temperatures >150°C both in sedimentary and crystalline rock areas
- Construction of maps of depth to temperatures >150°C
- Determination of hot spot areas based on the analysis of the new map of the depth to temperatures >150°C and depth less than 7 km

The final report recommendations are based on:

- Estimation of available energy from deep geothermal sources
- Determination of 2-3 'target' areas in Alberta for future drilling and EGS demonstration projects that show the most promise.

**Background**

Increased demands on energy systems generally have prompted both public and private parties to examine alternative energy and energy efficiency opportunities. Geothermal power, literally a byproduct of tapping hot water or rock areas in the Earth's crust, offers the potential for direct power or steam production as well as fuel substitution.

Access to heat resources is possible literally anywhere on earth, although the heat values available will vary greatly, depending on a variation of depth, rock type, available water and the ability to move water through interstitial cracks. Figure 1 below illustrates this relationship for traditional hydrogeothermal resources where re-injection of water can be used to sustain or supplement steam generation.

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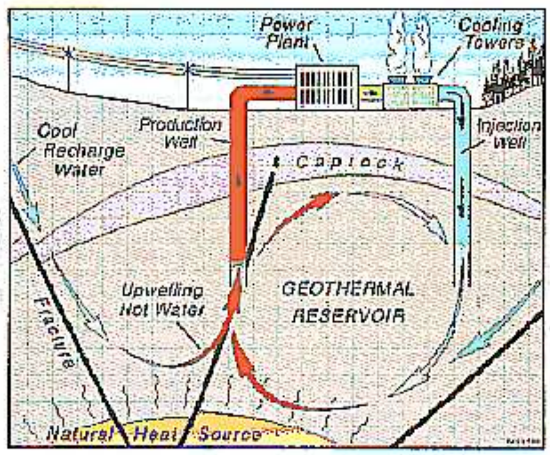
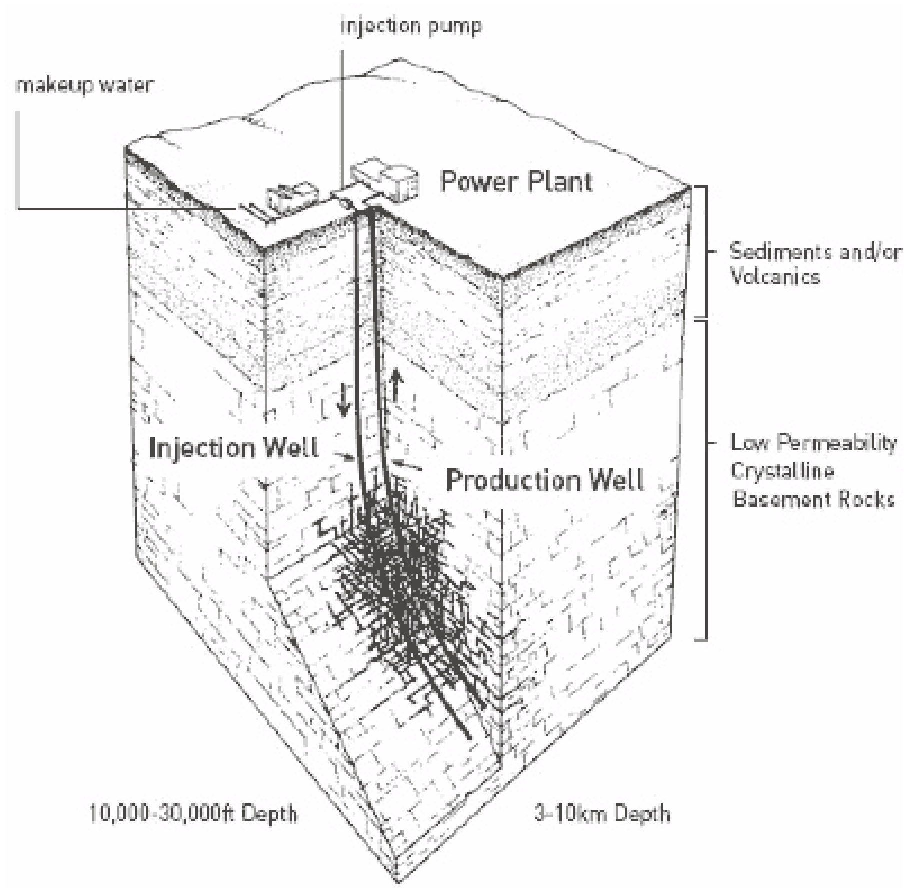



Source: Nevada Geothermal Corp., http://www.nevadageothermal.com/i/maps/caprock.gif

Traditional hydrogeothermal[4] resources have been exploited in various degrees for centuries, although power production systems are relatively recent phenomena.[5] Understanding the extent and relative heat levels available on a large scale, however, has not been undertaken until very recently with the publication of the MIT report on exploiting deep geothermal potential which must be "engineered" in order to develop power production potential. This is illustrated in Figure 2 showing the extreme depth and reservoir stimulation needed to extract heat from deep geologic zones.

[4] For example, the British Columbia Geothermal Resources Act emphasizes hydrogeothermal or low temperature geothermal resources as the Earth's natural heat and all substances that get added value from it including: steam, water, water vapour, and, all substances dissolved in the steam, water or water vapour obtained from a well.
For the purpose of the Act, it does not include: water at less than 80°C at the surface or hydrocarbons.
[5] See The Status of Geothermal Power 1995-2000, Geothermics, Vol. 30:1, pg 1-27, February 2001, and The Status and Future of Geothermal Electric Power, C. Kutscher, NREL, 2000, NREL/CP-550-28204

**Figure 2**

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Most of the Canadian geothermal development work has been concentrated in British Columbia. For instance, in 1975, BC Hydro drilled 18 test holes at Meager Mountain, 45 kilometers northwest of Pemberton. This work was followed by three deep exploratory wells between 1980 and 1982. Another deep exploratory well was completed by Pacific Geopower in July 1995. To date, the Meager Mountain area is the most significant geothermal energy discovery in Canada, shown in Figure 3.

**Figure 3**


Source: Geopower.ca

South of the Meager Mountain area is Mount Cayley, where the federal government drilled five shallow wells in 1977 and found evidence of geothermal gradients similar to those at Meager Mountain.

**NRCan Geothermal Research**

A broad program to develop pan-Canadian geothermal data was begun in the 1980s, consisting of a compilation of maps generated largely from oil and gas well data. The program was suspended due to budget cuts in the late 1990s and was recently re-funded to bring the original data into a compiled format.

This program[6] can be summarized as:

It assessed possibilities in geothermal energy in Canada in so-called traditional hydrogeological resources. These would be confined mainly to aquifers in sedimentary cover. The program also assessed the possibility of using steam in some volcanic areas of British Columbia. The effort is largely focused on identifying and qualitatively assessing traditional hydrogeothermal resources.

[6] Source: NRCan and personal communication, Alan Jessop, project manager

The first data available are in the form of maps and profiles including:

Mapping of heat flow data from existing sources (published) for all of Canada as part of the Decade of North American Geology series (DENAG).

Construction of regional heat flow maps like a map of thermal gradients in Western Canadian Sedimentary basin (Majorowicz, Jessop, Jones joint publications).

Canadian heat flow map as part of North America heat flow map (ed. Blackwell and Richards).

Calculated temperature depth profiles (geotherms) for major tectonic units (Drury, Jessop, Judge & Lewis publications).

Published maps of temperature at Paleozoic discontinuity and Precambrian basement based on the data set compiled by University of Alberta (Jones, Lam & Majorowicz).

Maps assessing so-called shallow geothermal potential (Majorowicz and Grasby, GSC Calgary, Canada). It consists a series of maps down to -250m at 50m intervals and maps of surface winter and summer average temperatures. The heat content in that interval was calculated.

**EGS Potential**

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<u>Depth and rock relationships</u>

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The EGS System requires introduction of water into rock of limited permeability (either tight sediment or basement) in a controlled fracture setting so that this water can be withdrawn in other wells for heat extraction. As an example, in the U.S., an area that appears to be very favorable is in east Texas and northern Louisiana where the low-permeability tight formations of the Jurassic period exist with temperatures over 350°F (177°C) that are currently exploited as tight gas systems.

The most favorable EGS resources will be a function of heat content, drilled depth and stimulation potential. The best resources are estimated to be less than 7 km in depth and with temperatures >150°C.[8] In the continental USA, for instance, there are estimated to be at least 17 million kilometers with these requirements, with a thermal energy potential of 8,600,000 x $10^{18}$ Joules.[9] EGS systems are not fully implemented but various research sites around the world confirm the potential of the resource including Rosemanowes in Germany, Soultz-sous-Forêts in France and Cooper Basin in Australia. Because the technology and drilling techniques are thought to be an extension of existing drilling patterns and costs, but are not yet fully validated, estimates of development costs are necessarily imprecise.[10]

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[7] MIT Report. 2007; http://www1.eere.energy.gov/geothermal/egs_technology.html
[8] Ibid, MIT Report
[9] Source David Blackwell, personal communication and estimates in MIT Report, Ibid.
[10] A recent report estimates lower drilling costs and resource recovery. See Thorsteinsson, H. et al, "The Impacts of Drilling and Reservoir Technology Advances on EGS Exploration", PROCEEDINGS, Thirty-Third Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, January 28-30, 2008

Components of Direct EGS development cost would include: drilling wells that reach hot temperatures >150°C; fracturing and/or horizontally drilling wells to develop high water flow and/or acquire make-up water; installing infrastructure, roads, piping, and power line routing; and building power stations.

**Research Collaboration**

Using the MIT report as an incentive, a group[11] of academic and government research personnel from the University of Calgary and the Geological Survey of Canada (GSC) sponsored a day-long forum in Calgary on June 22, 2007 to hear a technical report on subsurface mapping in the U.S. and the construction of a cost-estimation model for the MIT report. This was followed by the delivery of a report from the original author of the Canadian research program, which has recently been funded to support the assembly of a report containing the original field mapping and interpretation by the GSC.[12] The group agreed on the need to identify the resource extent and its heat potential (maps). This research[13] is the first element of that objective.

**Previous Work - The MIT Report**

The most recent serious effort to investigate the EGS potential in North America was sponsored by the US Department of Energy[14]. This report found significant opportunities that were represented by further research in EGS. They reported that:

"Geothermal energy from EGS represents a large, indigenous resource that can provide base-load electric power and heat at a level that can have a major impact on the United States, while incurring minimal environmental impacts. With a reasonable investment in R&D, EGS could provide 100 GWe or more of cost competitive generating capacity in the next 50 years. Further, EGS provides a secure source of power for the long term that would help protect America against economic instabilities resulting from fuel price fluctuations or supply disruptions. Most of the key technical requirements to make EGS work economically over a wide area of the country are in effect, with remaining goals easily within reach. This achievement could provide performance verification at a commercial scale within a 10- to 15-year period nationwide."

EGS is one of the few renewable energy resources that can provide continuous base-load power with minimal visual and other environmental impacts. Geothermal systems have a small footprint and virtually no emissions, including carbon dioxide. Geothermal energy has significant base-load potential, requires no storage, and, thus, it complements other renewable energy resources – solar (CSP and PV), wind, hydropower – in a lower-carbon

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[11] The group included a wide range of Canadian and American research personnel and spent the balance of forum discussing the nature and structure of a future program that would build on historically derived data and develop a future research and policy program that would explore the potential of all levels of geothermal energy to supplement and diversify Canadian energy supplies.

[12] A. Jessop, Mapping Alberta Geothermal Resources, NRCan, personal communication, results unpublished,2007

[13] This work is sponsored by a grant from the Alberta Energy Research Institute (AERI).

[14] Ibid, MIT report

energy future. In the shorter term, having a significant portion of our base load supplied by geothermal sources would provide a buffer against the instabilities of gas price fluctuations and supply disruptions, as well as nuclear plant retirements.

At this point, the main constraint is creating sufficient connectivity within the injection and production well system in the stimulated region of the EGS reservoir to allow for high per-well production rates without reducing reservoir life by rapid cooling".[15]

**Field Data Methods**

The methodology employed in this research project is based on collection, analysis and interpretation of existing data sources, which are diverse and represent different eras of data requirement and geographic distribution. All data used are aggregated to an appropriate level to maintain individual well anonymity and represent field data that have not been independently validated. However, anomalous data entries or statistical outliers have been screened and eliminated in the data survey in order to present a more uniform analysis.

Temperature data points (some 100k temperatures from pressure-flow tests) were obtained from AEUB data files and analyzed towards heat flow. Heat flow data were also calculated from previously published geothermal gradient and thermal conductivity averages for 1-3 township-range areas. These were based on bottom hole temperature (BHT) data base compiled by the University of Alberta during the GSC 1980-90th geothermal energy program (Majorowicz and Jessop, 1981).

Uncertainty and Estimation

These maps are based on discontinuous data sources with varying degrees of control on collection and validation. As a consequence there are gaps in the primary data which have not been independently validated. Since the majority of wells used for observation are primarily serving the oil and gas industry, the depth is less than that which would be necessary for EGS operations. Consequently, the maps represent a series of estimates and extrapolation to depth.

The calculations that underlie the heat flow and temperature at depth isoquants have an implied error range. This is explored in more detail below.

The point temperature measurements, which are the majority of available data, are at large level of uncertainty due to measuring errors and mainly due to disturbance of drilling (circulation of fluid in the well bore during drilling). Bottom Hole Temperatures or BHTs are especially unreliable in those cases where there is a delay; i.e. the measurements taken hours after drilling process circulation ceases show cooler than normal temperature levels. It is assumed here that temperature observations in shut-in holes like the ones provided to us by AEUB are expected to be more reliable because of

[15] Op cite, Executive Summary of report

the long time of stabilization. They are generally in good agreement with the independent temperature measurements made for heat flow determinations as noted by Anglin and Beck (1965, Can. J. Earth Sci.) and Majorowicz and Jessop, (1981, Tectonophysics).[16]

Estimates of heat flow and temperature at depths below the observations are subject to uncertainties, both in terms of assumed geolithic characteristics as well as temperature gradients, and are thus usable primarily as indicators of a range of temperature by depth and geographic location that defines useable temperature resources in industrial processes. Temperature calculations at depths well below the measured values (bottom hole temperatures, shut-in holes, test temperature records, continuous temperature logs) depend on the assumption of heat generation model. In Alberta, heat generation has been studied from the basement rocks reached by deep drillings (Jones and Majorowicz, 1987). Uncertainty in assuming heat input from below the upper crustal, highly radiogenic layer is also important The crust contributes approximately half of the observed near surface heat flow and the other half or more comes from below (Lachenbruch (1971), Pollack and Chapman (1977).[16]

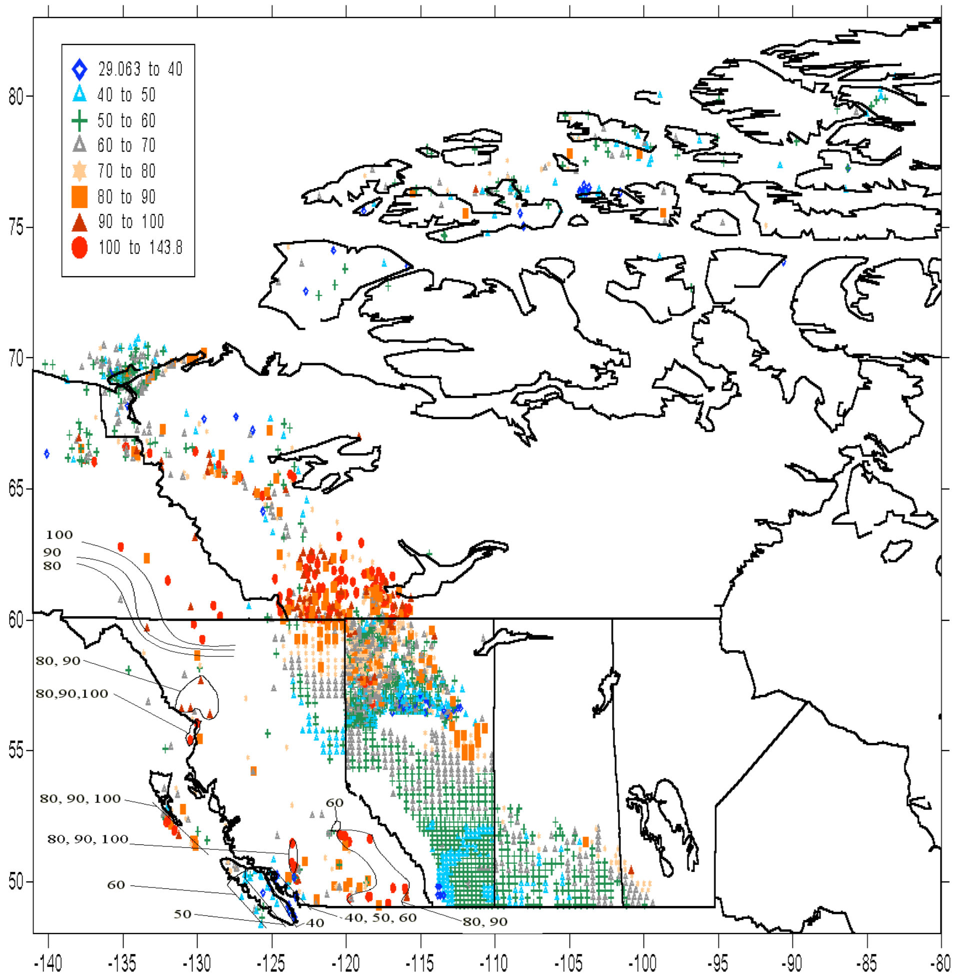
Mapping and Interpretive Data

The maps of heat flow and temperature at chosen depth level up to 10km shown below are mainly based on the AEUB data base from shut-in wells observations. These data are the data of our choice in analyzing heat energy underground in the Province for the reasons discussed above. This database available to us through a courtesy of AEUB , covered large part of Alberta. It is, however, missing parts of the province including southern Alberta. Those parts were covered by the most recent heat flow mapping based on BHTs heat flow estimates done for Canada as part of the Heat Flow Map of North America (Lewis, Majorowicz and J-C Marschal, Heat Flow of N. America Canadian Editors). The heat flow values from that map are shown here for Western Canada (Figure 4).

[16] Anglin and Beck, 1965, CJESci. and Majorowicz and Jessop, 1981, Tectonophys.
Jones and Majorowicz, 1987, GRL
Lachenbruch, 1971, JGR;
Pollack and Chapman, 1977, EPSL

**Figure 4**

Western Canadian heat flow values included in the Heat Flow Map of North America




(compilation from: Lewis, Majorowicz and J-C Marschal, Heat Flow of N. America Canadian Editors).

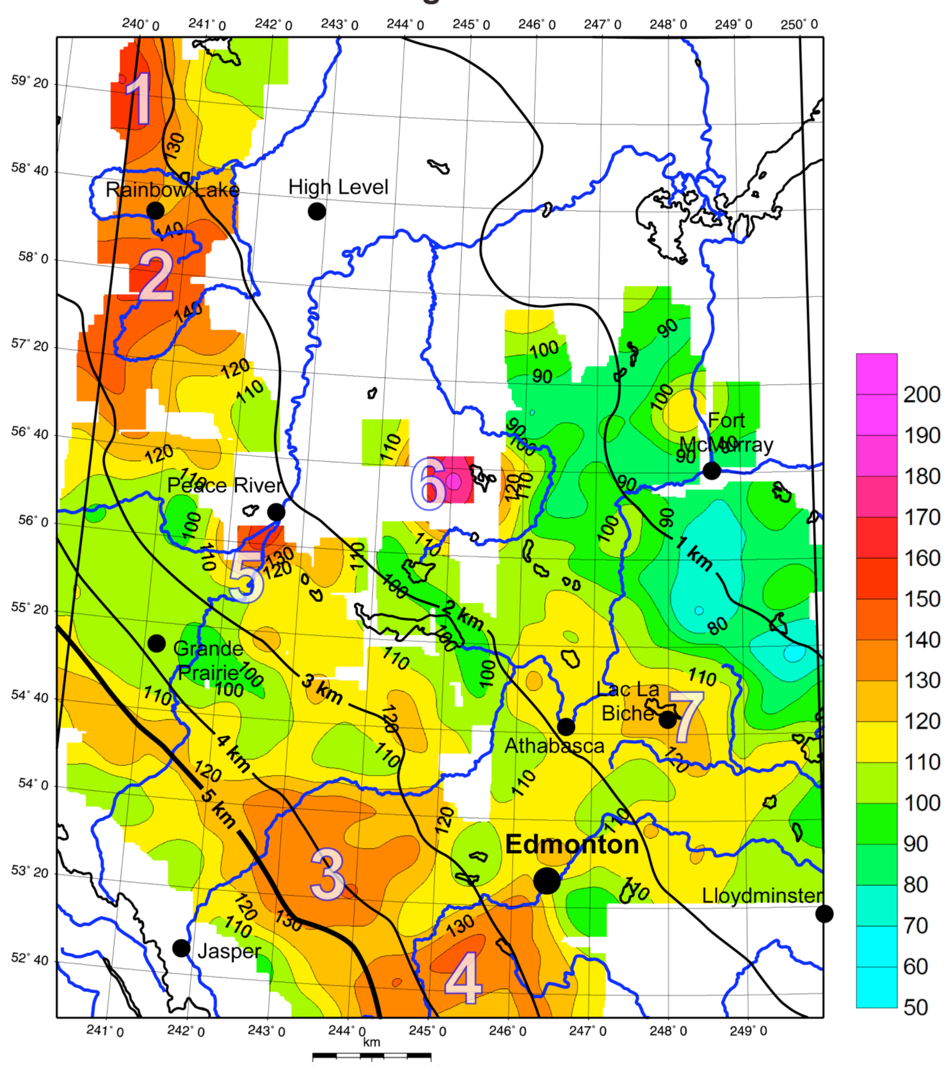
Mapping of deep geothermal resources in North America is only recently available on a large scale. The data for Canada are incomplete and available only in localized circumstances which is illustrated in Figure 4 above. Most of the data available track either closely to known volcanic activity or are associated with faulting structures or deep sedimentary basins. In Alberta, most of the data are obtained from existing oil and gas operational wells and inferred at depth, which is shown by heat range in the legend. The data shown in this plot are consistent with recent data produced in the MIT report (Tester et. al. 2006) and illustrate the fact that the heat flows are concentrated primarily in western areas.

Figure 5, shown below, illustrates the areas of central and northern Alberta which seem to show good potential for EGS from temperature maps based on the AEUB temperature dataset. The grading of areas suggests the priority of future research and ultimately access to higher-value resources, as well as the relative proximity to developed load centers. The zones with 150 $^{o}$C temperature at 5 km depth are all in the northwestern part of Alberta and north and south of Rainbow Lake. (target areas 1 and 2). Target areas 3 and 4 also have anomalies close to 140-150 $^{o}$C. These high-temperature zones are sustained through deeper depth and are visible in maps of temperature at larger depths of 7 km and 10 km. At 10 km these areas reach above 200 $^{o}$C. It is also true for the area of Lac La Biche in the shallower part of the basin (Target area 7).

**Figure 5**

## **ALBERTA** - Temperature -5 km

### EGS Target Areas



Most existing data on heat flows, depth to heat range and areal extent are compiled from well data, and more specifically from original drilling records that include bottom hole temperatures. Using this data (in Alberta records this data is compiled as so-called "Industrial Data") we can locate the major areas of previous well activity. Not all of the wells drilled produced usable or even consistent data. Additionally, many areas of the Province show no well ativity while others are highly concentrated, with the consequence that redundant and often more reliable data is available. Large gaps such as the area west of Edmonton imply a need for different measurement techniques such as seismic refraction to extend and validate the isopact maps included in this report.

Heat flow is a function of thermal conductivity and thermal resistance. These describe heat transfer within a material once heat has entered the material with the rate of change of temperature with displacement in a given direction or plane from some reference point.

Thermal conductivity, k, is an intrinsic property of materials which describes their ability to conduct heat to adjacent materials or to the environment. For non-homogeneous materials, the term "relative thermal conductivity" is often used because the thermal conductivity of these materials depends on the relative thickness of the layers and their orientation with respect to heat flow.

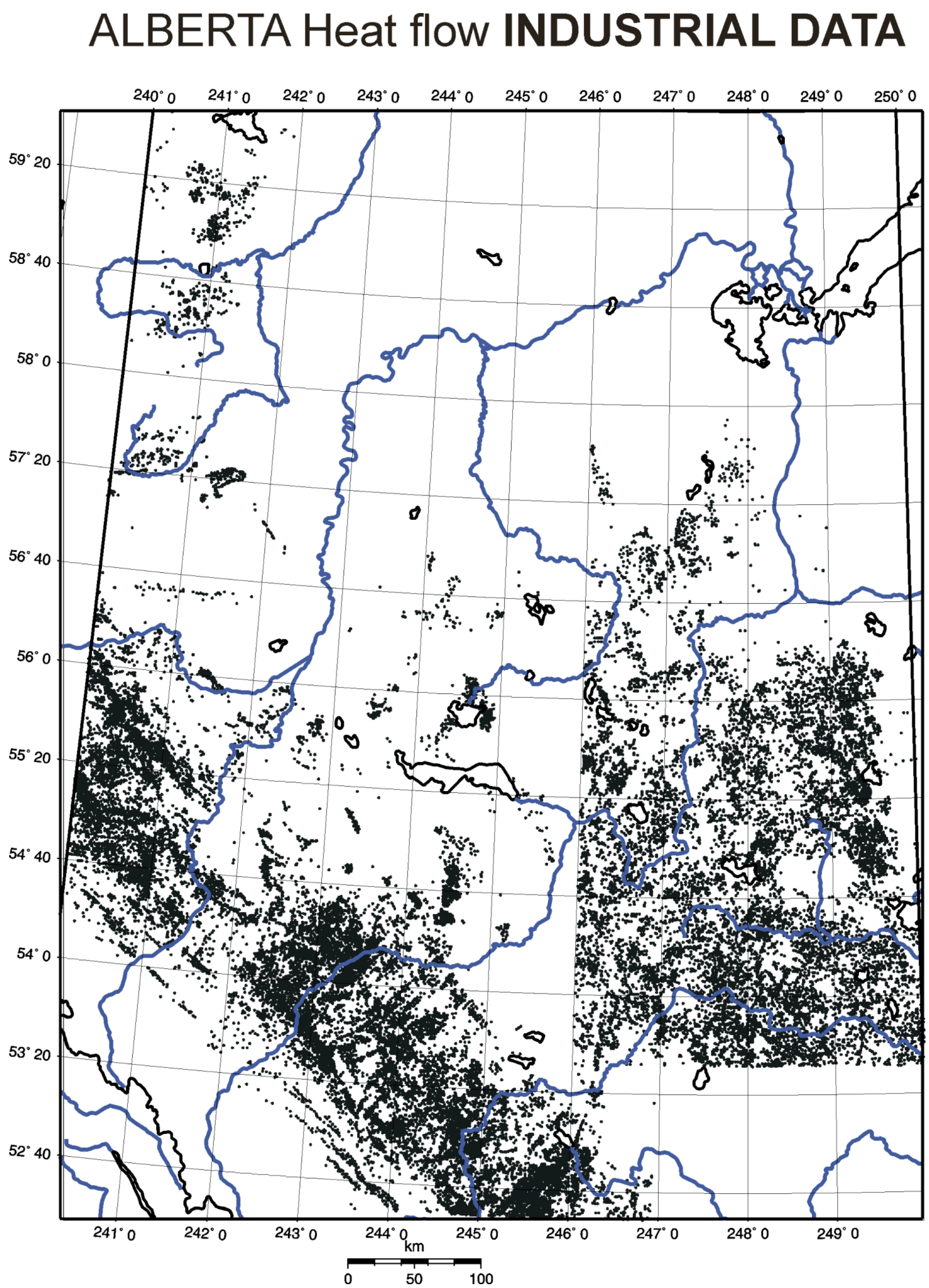
For a one dimensional, steady state heat flow the rate is expressed by Fourier's equation:
Where:

k = thermal conductivity, W/m-K in degrees Kelvin
Q = rate of heat flow, W
A = contact area
d = distance of heat flow
$\Delta T$= temperature difference

Using published data these relationships have been used to construct a series of heat isoquant maps that illustrate the heat potential estimated to be available at depth within the Province. The source of that data is illustrated in Map 1 below.

Map 1 is constructed from the locations of the temperature records taken from the files of the Alberta Energy and Utilities Board and is used to show the range of observations correlated by Bottom Hole Temperature (BHT) throughout the Province, without reference to well type or depth.

**Map 1 - EUB temperature data file's locations**

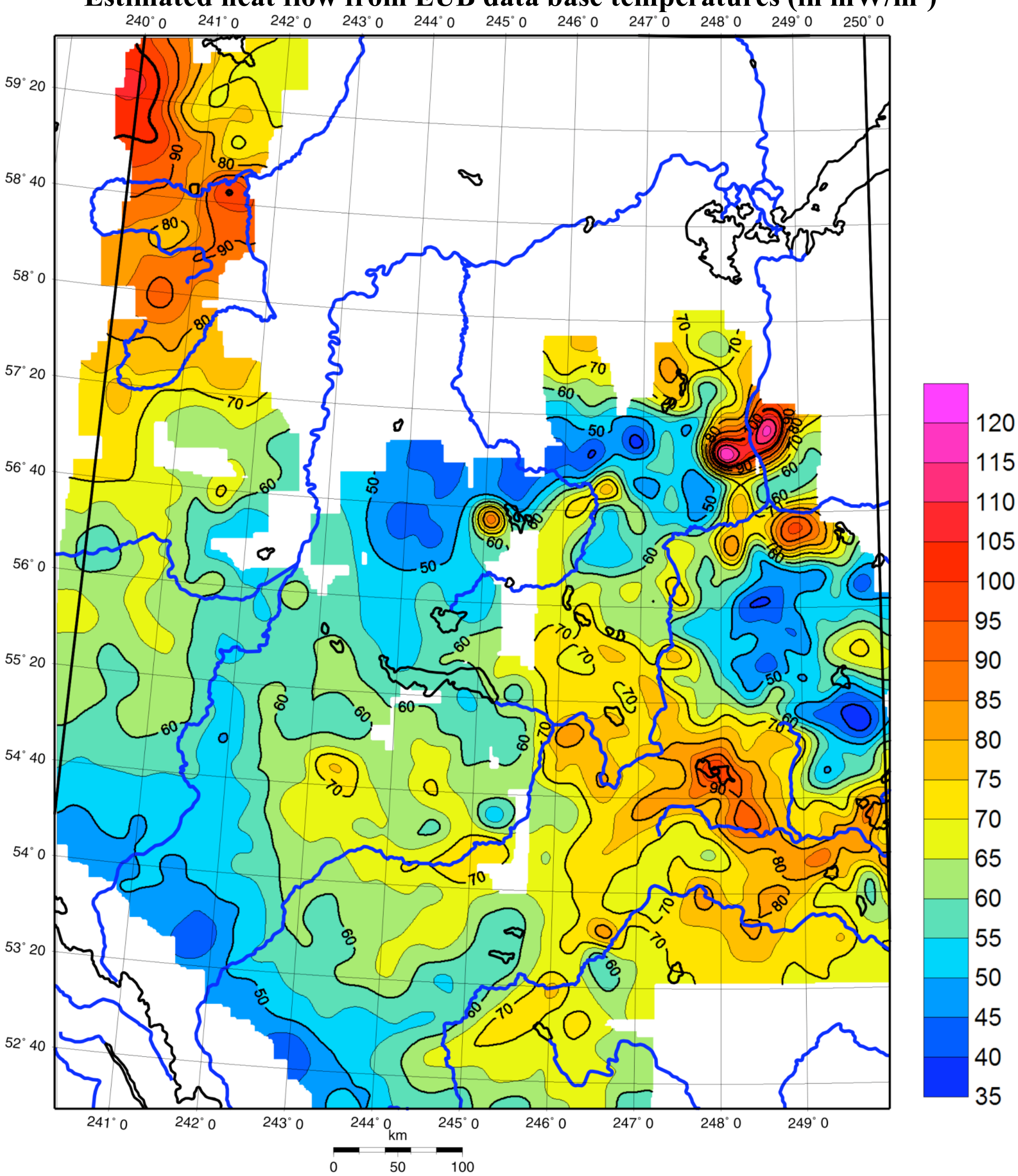



Source: AEUB, 2007

## Heat Flow

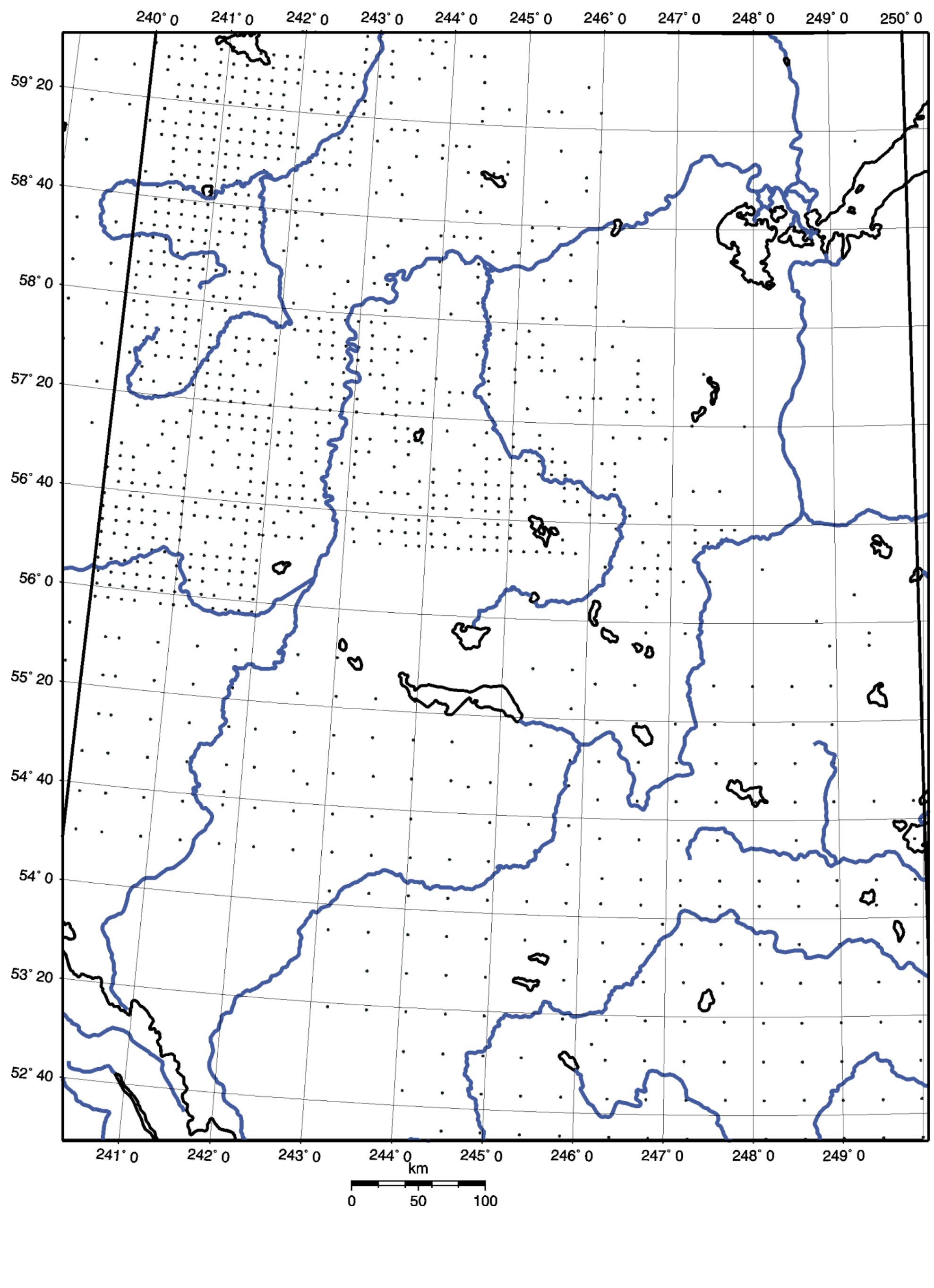
The following maps illustrate heat flow at depth, which is a function of gradient and proximity to basement rocks with residual heat, or in the case of formations close to magmatic resources (such as the Meager Creek Volcanic formations) the conductive presence of the intrusive heat source. Map 2 is used to extrapolate and illustrate temperature resources at a depth of up to 5 km throughout the central-northern part of the province. The southern part of the province has lower heat flow than in the central and northern part where higher heat flow zones are found (see Figure 4) for reference.

**Map 2**
**Estimated heat flow from EUB data base temperatures (in mW/m$^2$)**



The location of BHT sources is shown in Map 3 below, which formed the basis for extrapolating the potential and creating the heat isoquants shown in Map 4 following.

**Map 3**
**Heat flow locations based on the University of Alberta BHT data base collection**
**(used in Blackwell Richard's (Ed.) Heat Flow Map of North America[17]).**

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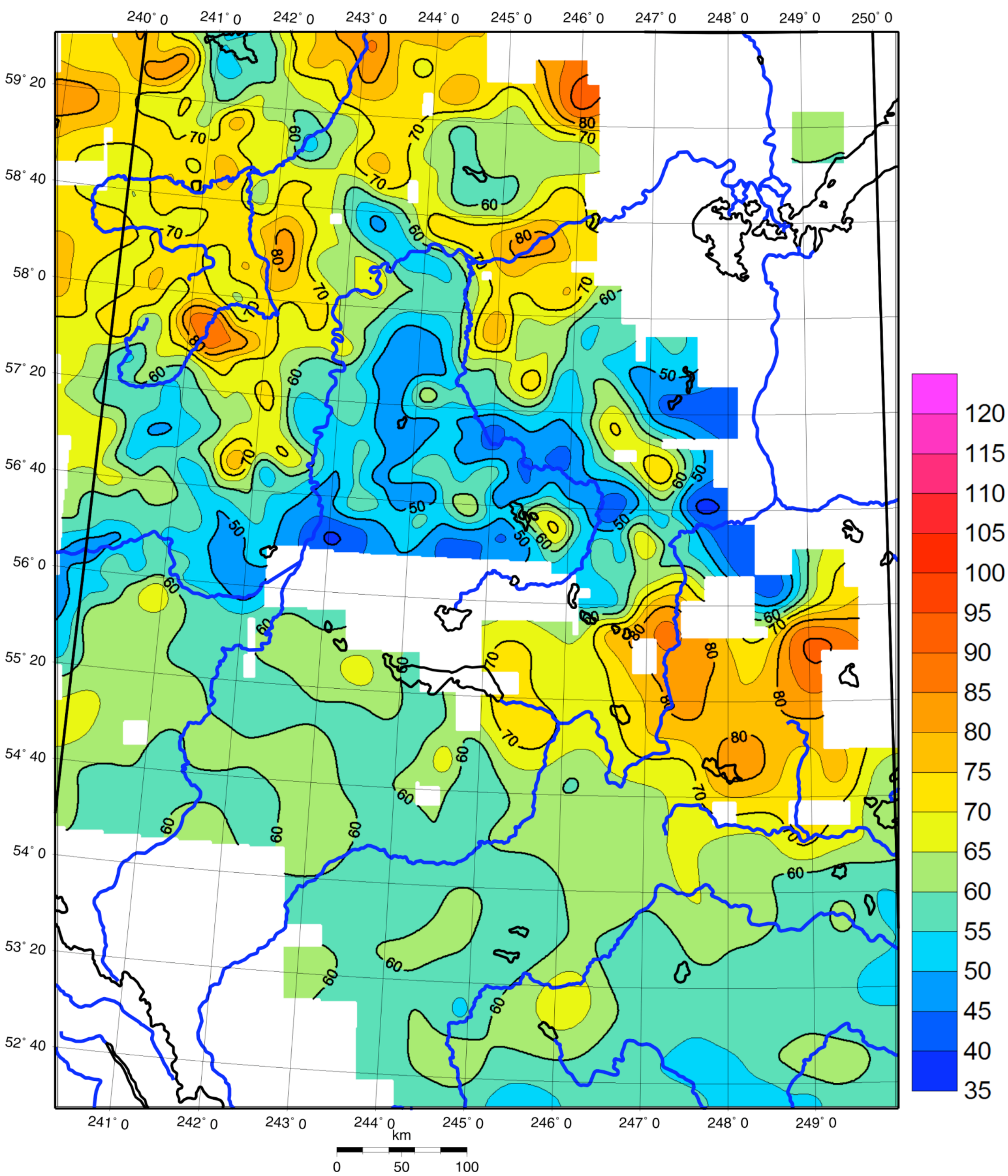
[17] Ibid.

Map 4 shows the University of Alberta BHT data based average heat flow for the Province (in mW/m$^2$) drawn using same contour interval as heat flow map based on EUB data. The result illustrates the dispersed power potential.

**Map 4**
**Estimated heat flow for the same area as EUB data (Map2)**




Source: University of Alberta bottom hole temperature data project which formed part of the basis for the Blackwell (Ed) Heat Flow Map of North America[18] in mW/m$^2$

[18]Blackwell, D. and Richards, M.(2004), Geothermal Map of North America; Explanation of Resources and Applications", Geothermal Resources Council Trans., 28:317-320

## Interpretation of Heat Flow and Power Potential

Heat flow maps are the necessary element of calculation for temperature at depths where there are no measured data. This is mainly the case of EGS assessment, as temperatures 150-200 $^{o}$C are mainly achievable at high depths and mainly below the sedimentary cover (though some 150 $^{o}$C temperatures are within the deep part of the Alberta basin).

The knowledge of heat flow Q and of variation of thermal conductivity K with depth allows calculation of temperature at depth. Heat flow values and assumed thermal conductivity, as well as knowledge of near-surface temperatures at the base of the Phanerozoic sediments (about 0.5 km – 5,0 km depth range for the study area), permits a calculation of temperature at depth profiles for the upper parts of crystalline crust below sedimentary succession of the northeast Alberta basin.

Assumption 1: Heat flow is constant with depth (except for cases of heat flow reduction with depth due to radioactive heat flow contribution).

Assumption 2: Basement heat flow Qo is correlated statistically with heat generation of the basement Ao in the form

$$Qo=Q_r + DAo \qquad (1)$$

Assumption 3: It is assumed that heat generation for the crystalline crust decreases with depth according to:

$$A(z) = A_o \exp(-z/D) \qquad (2)$$

and that temperature variation with depth in the crystalline crust can be calculated using equation:

$$T(z) = T_b + Q_r z K^{-1} + A_o D^2 K^{-1}(1-\exp(-z/D)), \qquad (3)$$

where $Q_r$ is the reduced (deep) heat flow, Ao is top of the basement heat generation, $T_b$ is temperature at the crystalline basement surface and D is in kilometres. D is a slope of the heat flow/heat generation relationship obtained for the Canadian craton of which includes WCSB and Alberta basin in particular are a part of.. Thermal conductivity K for the crust and upper mantle for Canadian craton is given by Jessop (1990, Thermal Geophysics, Elsevier, Table 11). Typically, conductivity for crystalline rocks is 3.2 W/mK while it is around 2 W/mK for the sediments. Typical heat generation values for the study area are $A_o$=1 -5 $\mu W/m^3$ for the low and high heat flow regions respectively (based on existing data from the study area in publications (Burwash and Burwash, 1989; Jones and Majorowicz, GRL, 1987).

It is established from hundreds of heat flow/heat generation data points that

D=9.6 km and Qr=33mW/m**2 for the Canadian craton.

We use the approach described by Dave Blackwell (2007) in his temperature assessment down to 10 km for the USA as a reference point of departure.

Heat generation is calculated for the basement from heat flow at the basement surface $Q_o$.

$Q_o$ is calculated from heat flow at the surface Qs (based on measured temperatures and assumed heat conductivity of sediments and probable heat generation within sediments As=1$\mu$W/m$^3$).

$$Qo=Q_s-As*d_s \qquad (4)$$

Where $d_s$ is sedimentary thickness and $A_s$ is heat generation of sediments, $Q_s$ is heat flow at the surface.

Heat generation Ao of the basement can be calculated from heat flow –heat generation relationship (Blackwell, 2007, MIT report).

$$A_o = (Q_o-Qr)/D \qquad (5)$$

This relationship is well explained by the model of exponential decrease of heat generation with depth within entire crystalline crust (Lachenbruch, 1970, JGR).

**Maps and Data**

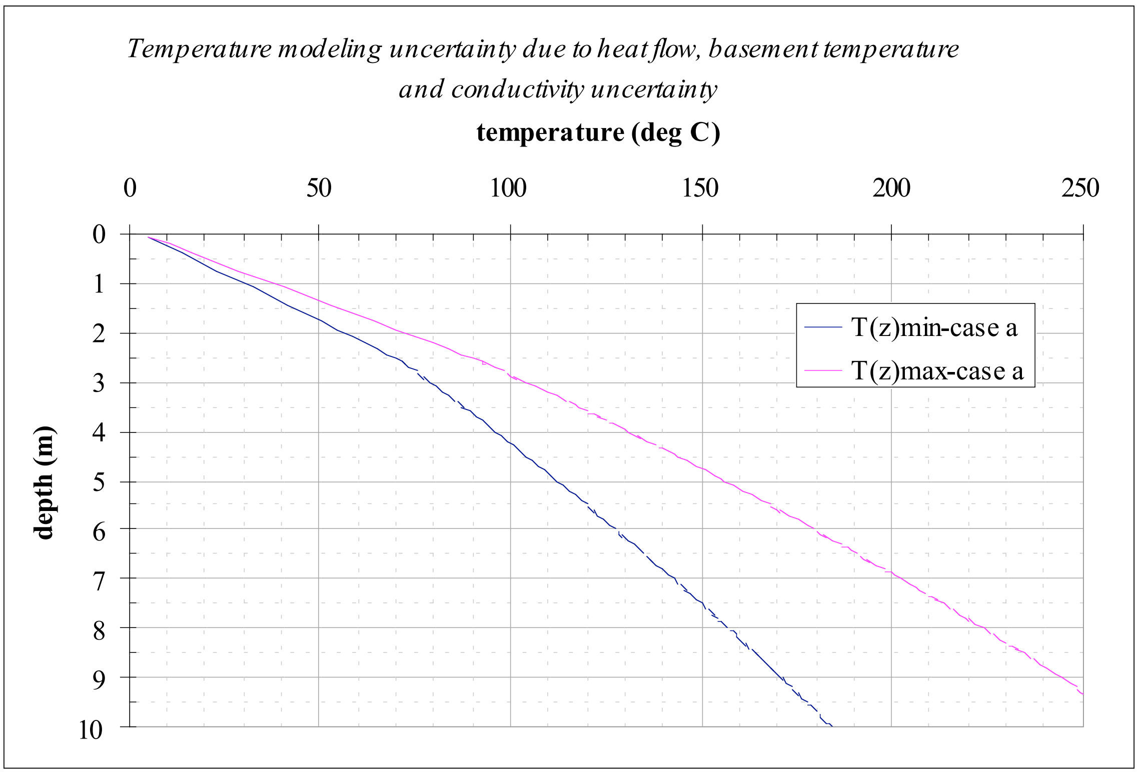
The data available from this study are presented in a series of maps showing successive heat isoquants at depths of 1, 2, 5 and 10 km below surface. These depths allow a rough correlation with the Blackwell maps of North America and show the estimated extension of the resource through the Province roughly trending from southeast to northwest following the sedimentary basin.

*Measurement Uncertainty*

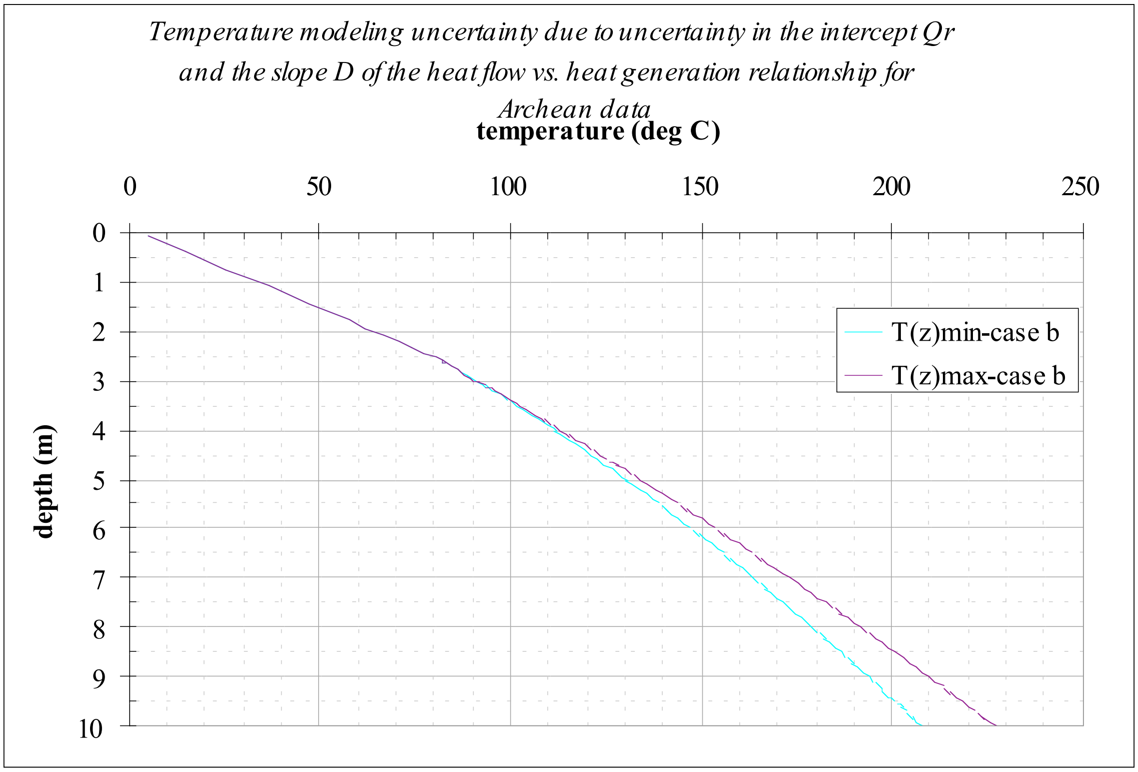
Major gaps in data appear in the north-central region of the Province and reflect the lack of drilling activity in that area. The temperature zones at depth levels below the data are approximate. The calculation of minimum and maximum bounds of temperatures for different assumption on heat flow, conductivity and basement temperature (these are quantities with at least 10% uncertainty) is shown in Figure 6. In Figure 7 we show bounds of confidence for fixed quantities of heat flow, thermal conductivities and temperature at the basement, however, with uncertainties on heat flow-heat generation relationship (reduced heat flow $Q_r$ and slope D (equation 1). In Figure 8 we show temperature bounds (minimum and maximum) for the combined effects as shown in Figures 6 and 7.

The temperature zones calculated and contoured for chosen depth levels down to 10k depth reflect a confidence interval of some 9 $^oC$ at 2 km and as high as 50 $^oC$ at 10 km. The difference between the minimum and maximum bounds at these depths will be 15 $^oC$ and 75 $^oC$ respectively as shown below in Figure 7.

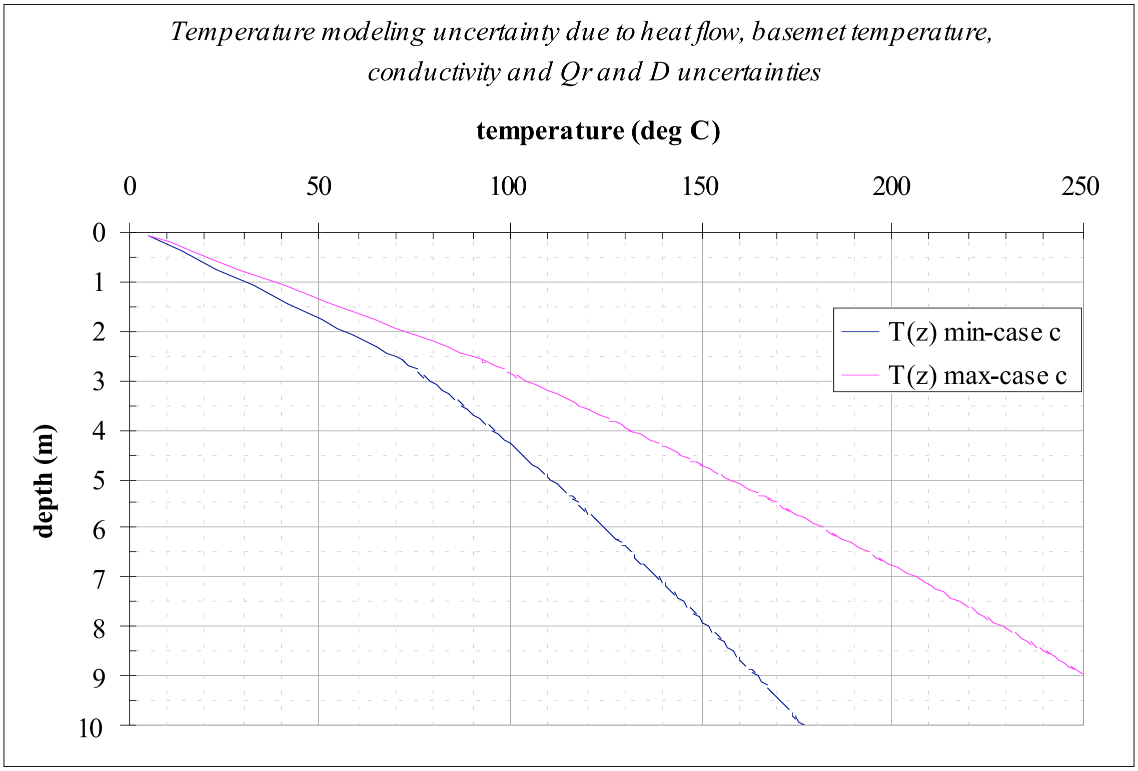
**Figure 6**



## Figure 7



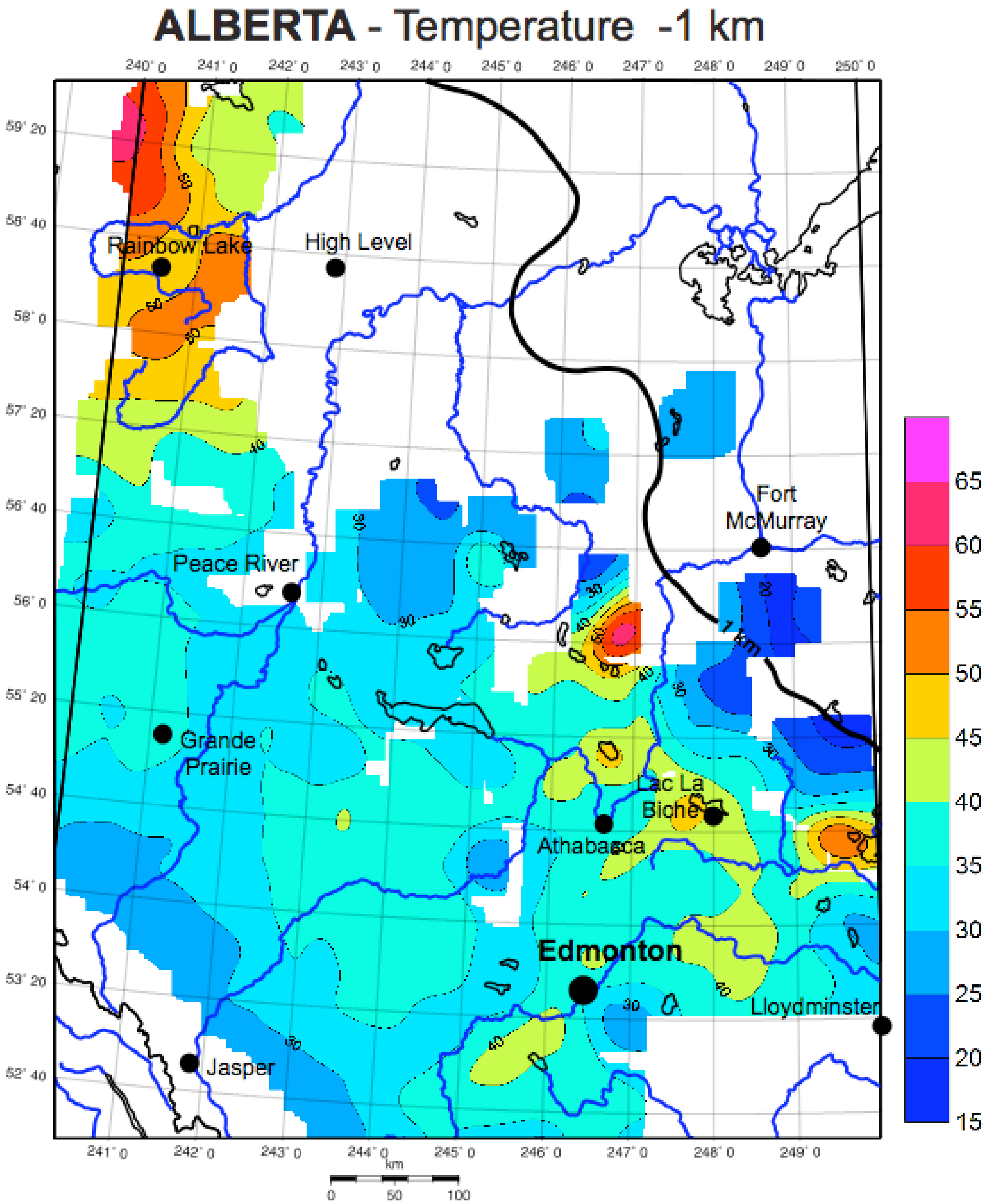

## Figure 8



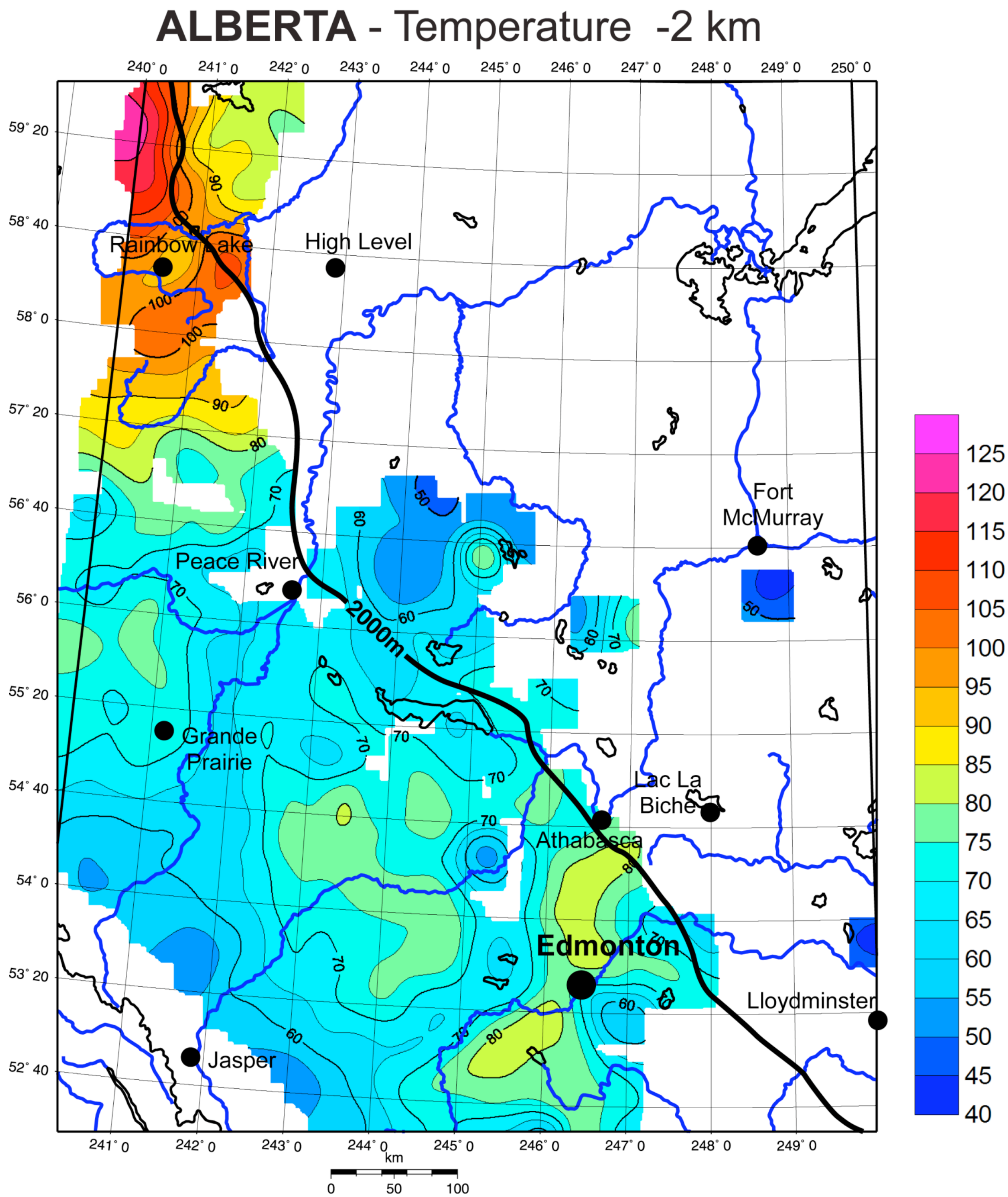
Temperature at depth levels

Maps of temperature at depth levels (Maps 5-9) show temperature patterns for depths 1, 2, 5, 7 and 10 km. These are constructed from the AEUB temperature data, based on heat flow calculations and modeling calculations as described above (equations 1-5). While temperatures at depths 1 km and 2 km are in large part within the western part of the Alberta basinal sediments (eastern parts are below the top of the crystalline basement at these depths), temperatures at 5 km are almost all within crystalline rocks underlying basinal sedimentary succession (except very western deepest part of the basin (>5 km)). Temperatures shown for 7 km and 10 km depth levels are all within crystalline rocks of the granitic crust.

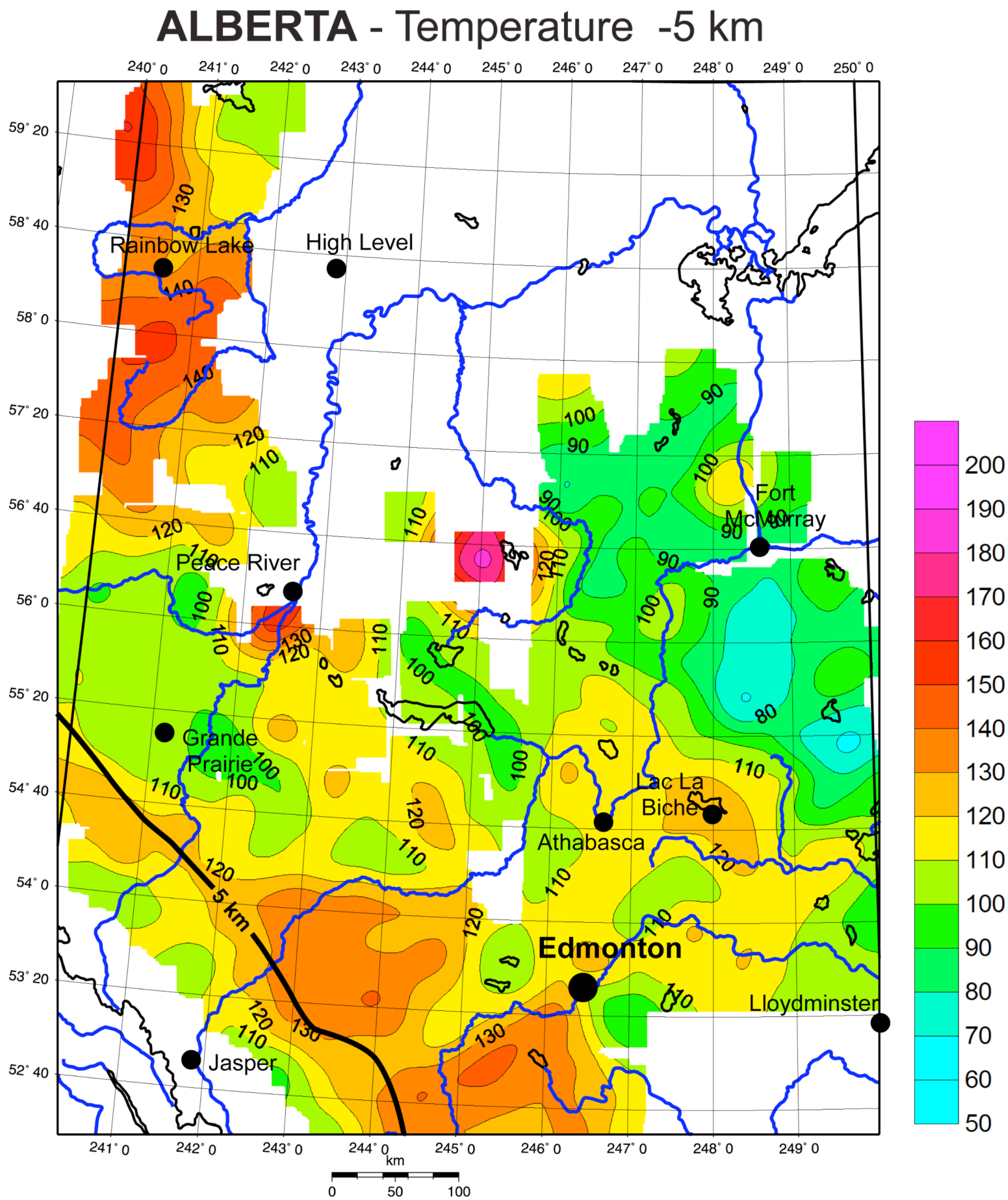
**Map 5**
**Schematic of temperature ($^oC$) 1 km below surface**



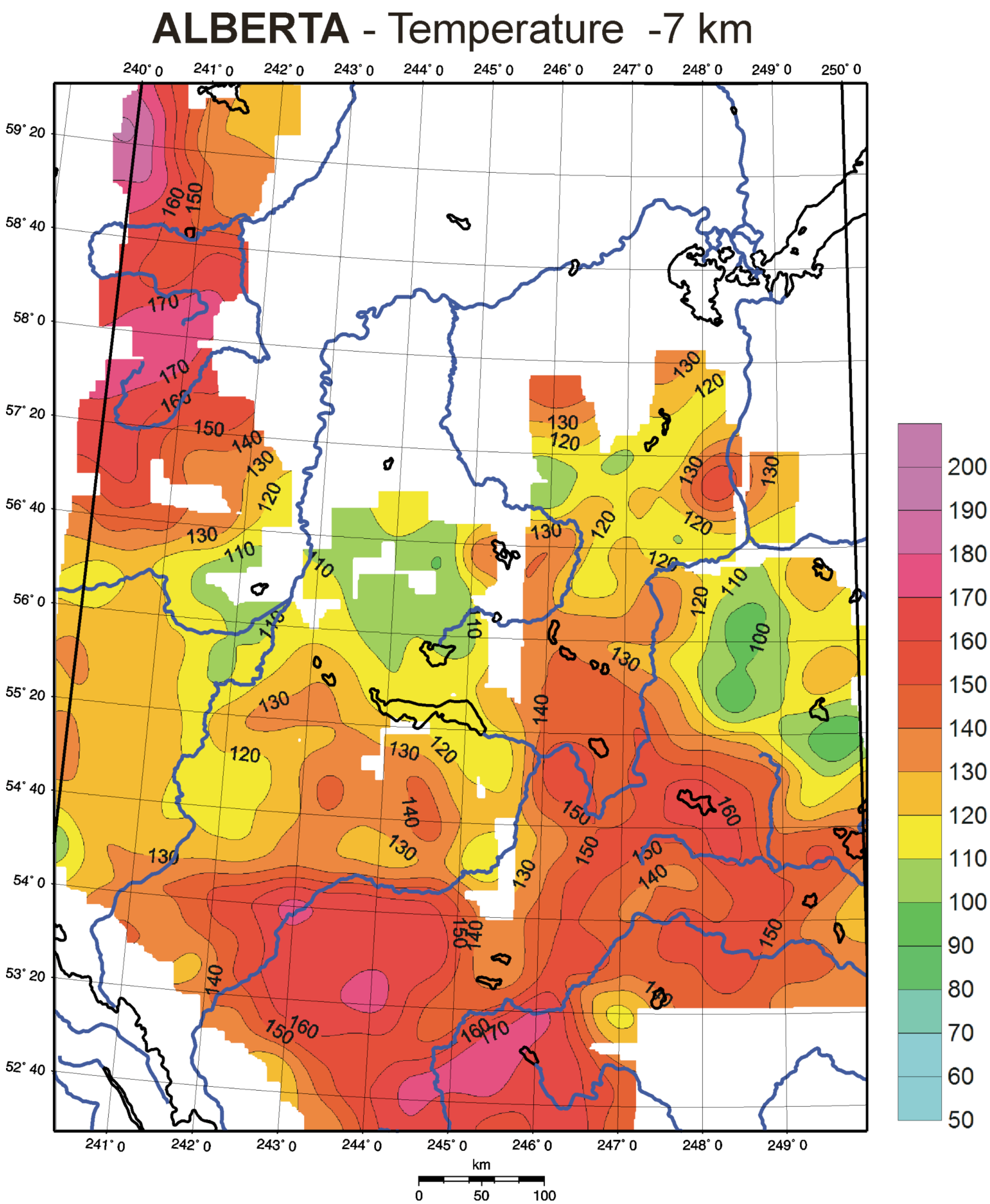
**Map 6**
**Schematic of temperature (°C) 2 km below surface**



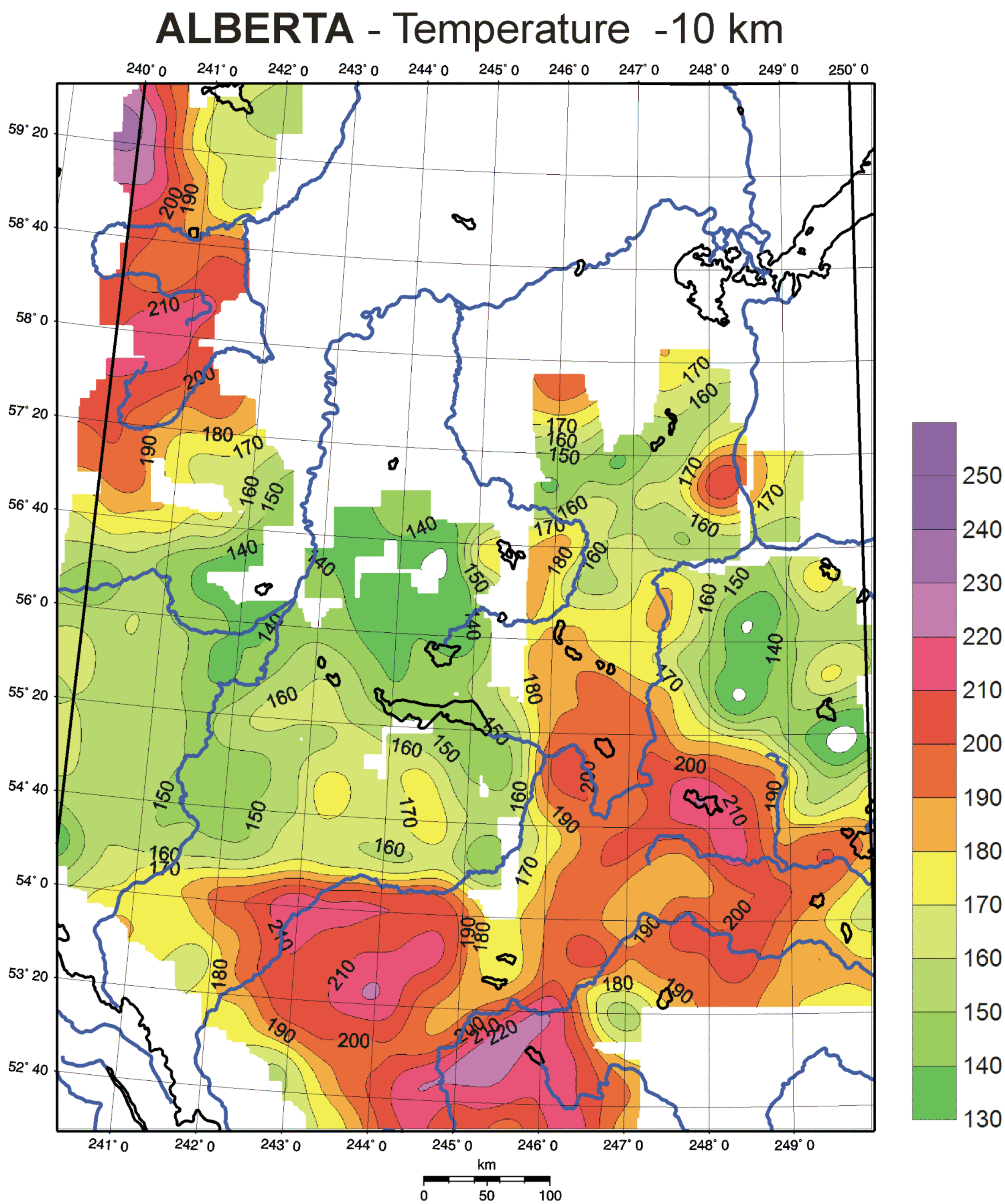
**Map 7**
**Schematic of temperature (°C) 5 km below surface**



**Map 8**
**Schematic of temperature (°C) 7 km below surface**



**Map 9**
**Schematic of temperature (°C) 10km below surface**



The quantity of thermal energy

The magnitude of the thermal energy or heat content of the rock is useful to illustrate potential amount of heat to be removed from the ground. As an example, we can use a 10 km long x 10 km wide x 1.0 km thick slice of rock below the ground surface, with an average temperature of 150 $^oC$.

Reasonable average rock property values are 2,550kg/$m^3$ and 1,000 J/kg°C, for the density (ρ) and heat capacity (*Cp*) of the rock, respectively. If this mass of rock is cooled through a temperature difference of δT $^oC$ (calculated here as a difference between rock temperature 150 $^oC$ down to 50 $^oC$, then the potential heat removed is given by:

THERMAL ENERGY $=\rho^o C_p V \delta T$ (6)

This quantity of thermal energy, which could potentially be released from 100 $km^2$ area of 1km rock slice at depth with temperature 150 $^oC$ can be calculated (Joules) :

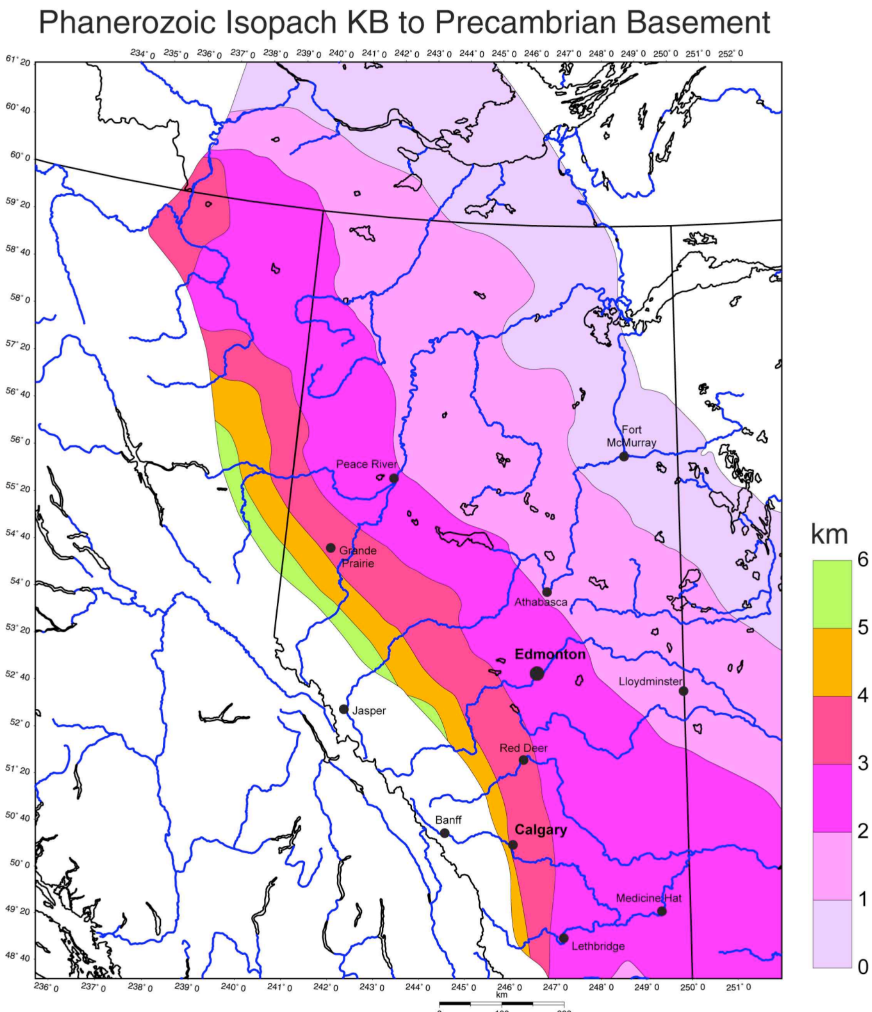
THERMAL ENERGY $_{150C}$ = (2550kg/$m^3$)(1000J/kg $^oC$)(10kmx10kmx1km)(150 $^oC$ - 50 $^oC$) = 25 x1018 J =25 quads

The huge amount of energy from a 1km slice of rock in a 100km $^2$ 'target' area is more than Canada's annual energy consumption. The actual accessible and usable energy resource will be smaller, but still extremely valuable. For future exploration, target areas can be determined from temperature maps and other information (rock parameters etc.). The analysis of the temperature maps shows that we can reach usable temperature zones that average 150 $^oC$ for large areas of the north western Alberta and central eastern Alberta as well as elsewhere from average depth of 7km (Map 7) and smaller areas from 5km depth down to 50 $^oC$ producing large amounts of energy. Temperature of 150 $^oC$ can be reached for the north western part at depths as low as 5km. At a depth of 10km we have large areas of temperatures >200 $^oC$. At 250 $^oC$ the total amount of energy represented by the 200$km^2$ area is greater than 100 quads.

**Implications**

The first highlights of the analysis of the EUB temperature data from well tests show that we have few hot spots in Alberta with heat flow as high as in the basins of the western US. The region of Lac La Biche is one example. Some high values North of Fort MacMurray are suggested by the available data. These, however, are based on data from very shallow wells (few hundred meters) and not always confirmed by also shallow precise temperature logs in Alberta Energy observational wells. The most interesting regions are found in the extreme Northwest region of Alberta, where there is a deep and extensive blanket of sediments with corresponding softer overlying rock to drill through in order to obtain EGS-like temperatures (>150 $^oC$). The lowest heat flow is apparent in the Rocky Mountain foothills. While the basin sediments here are relatively thick, the rate of increase of temperature with depth is low with corresponding low heat gradient. The general trend of the basement formations is shown in Figure 9 below. Since much of the principal heat available for transfer is contained in the basement rock, its surface proximity and the implied sedimentary "blanket" are critical to decisions on well locations and power transfer facilities in the future.

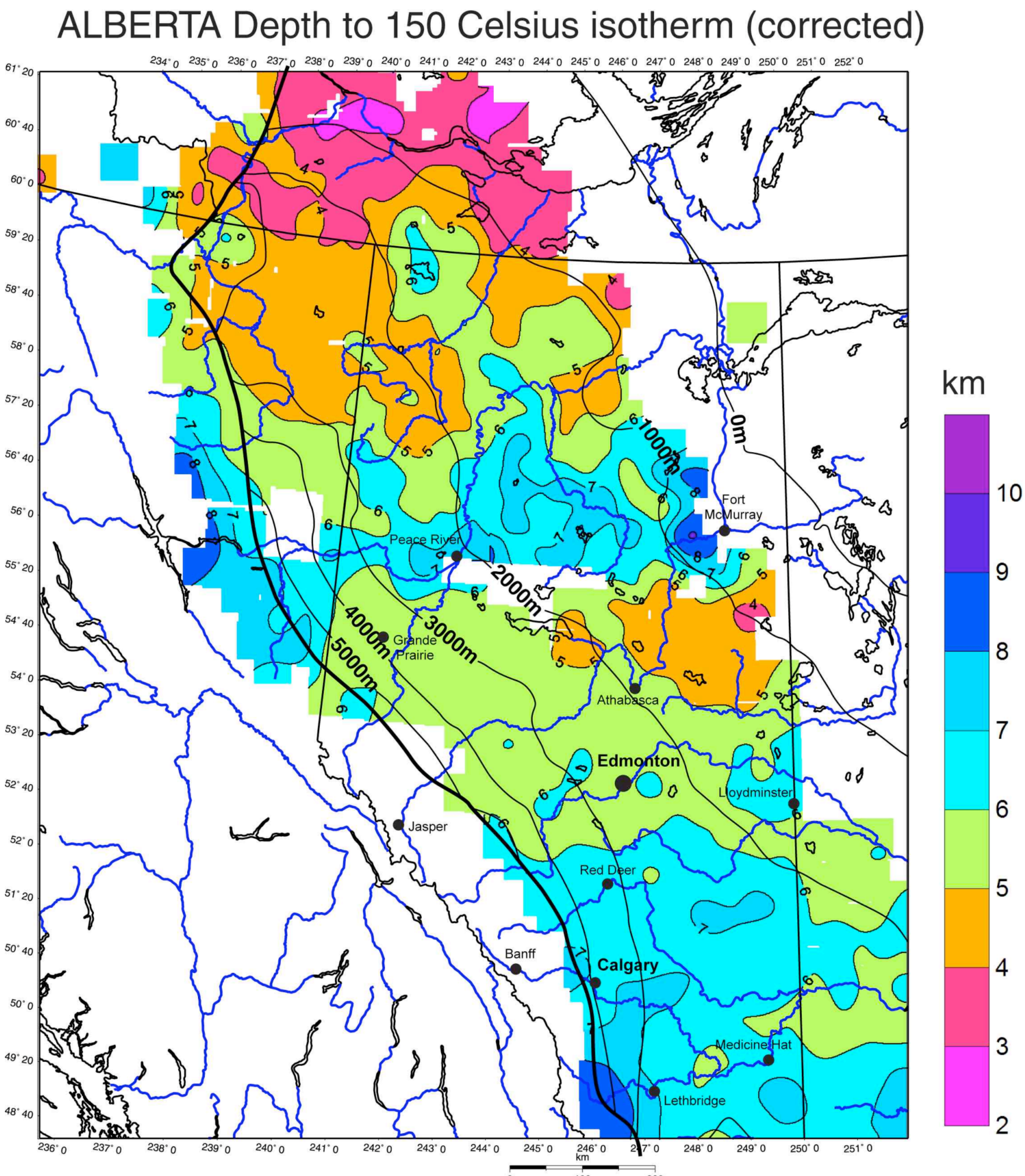
**Figure 9**
**Schematic of Phanerozoic Isopach**
**showing depth to basement**




Source: NRCan, Majorowicz, 2007

When viewed as a pan-Albertan map of depth to reach a minimum of 150 C based on heat flow calculated from the BHT data base of the University of Alberta (data cover all of the province and their distribution is shown in Fig.4), a pattern of resource distribution reveals a slightly larger distributed area than first revealed either by well data or previous geologic reports. The least favorable areas are those of southern Alberta and Peace River Arch where we would need to drill 6-8km to reach 150C. This is apparent in Map 10 shown below.

**Map 10**
**Schematic of depth to 150 °C**



**Conclusions and Recommendations for Further Work**

This preliminary research suggests a more abundant geothermal resource may be present than previously assumed in Alberta if EGS technology is able to be demonstrated, and ultimately used not only for steam heat but electricity generation. This technology will also allow access to more moderate heat zones, making them accessible for heat redistribution (for in-situ operations for instance) and for displacement of some current fuel sources such as natural gas used for steam heat generation.

The mapping exercise used here is preliminary and relies on published data from several sources. It is revealing in several areas, first and foremost in identifying a significant heat resource available within the Province. However, even a cursory examination of the mapping illustrates gaps and areas of potentially inconsistent results. The broad interpretations in some areas underline the need for further assessment and investigation to gain confidence in the extent and depth of the underlying resource. We feel that the next step in data collection should involve a collaborative effort with industry to return to old wells and well logs to extract more accurate and timely data.

In terms of future power generation, the geographic areas we have identified are not convenient or adjacent for use in high-demand power centers such as cities. However, there are power system proposals such as the Northern Lights Transmission line and the Edmonton-West coal power corridor that would provide access to transmission interconnection, capacity and distribution, making this source of power production economic and useful for power dispatch. Our data suggest that wide distribution of useful heat value resources are available at moderate depths which have already been reached in oil and gas drilling operations.

Such synergies will only be seen as desirable when clearer analysis of costs and risk factors are explored. For instance, a new transmission system from the Fort McMurray area will only be attractive to investors when there is excess electric power generated in the region that has a market for delivery. Similarly, the Alberta power market must be capable of absorbing new supplies of base load electric energy to support more remote geothermal development. Nonetheless, power of this type, i.e. baseload, is forecast to be competitive with other existing baseload resources such as pulverized coal or light water nuclear reactors. Developing synergistic relationships with other power system operators such as transmission and distribution, or other large load centers such as oil sands operations, will result in earlier investment and ultimately earlier access to this resource.

Other synergistic opportunities are beginning to be explored and may provide additional incentive to include Geothermal EGS in Alberta's power portfolio. These include combining geothermal drilling and exploration with future carbon capture and sequestration schemes, sharing costs and diminishing the overall cost for either technology in the process. Future geothermal power conversion technologies can be used to dry biomass crops, reducing the cost of this co-power opportunity. In addition, since the life-cycle impacts and costs of geothermal systems are lower than other renewable energy resources, development of this source can provide carbon offsets as well as so-called green credits which can support the creation and liquidity in the coming carbon trading markets.

We believe *prospective* regions should be analyzed in greater detail, in finer grain research in the future. For instance, areas around the North Saskatchewan River may prove to be productive, with estimated heat flow values >80 mW/m. As mentioned previously, combining mid-range EGS heat potential with in-situ operations in the oil sands development areas may provide opportunities for fuel substitution for natural gas.

There are current proposals for new baseload power generation in Alberta that range from new IGCC level coal plants to large nuclear facilities. Geothermal power based on Engineered Geothermal Systems may be able to reduce or substitute for these proposed power sources at competitive prices while providing a side benefit of lower GHG emissions and ultimately tradable credits on carbon markets.

This technology has many possible applications within the Alberta and greater Canadian energy portfolio and should be the subject of a coordinated and multi-faceted on-going research program. This should include enhanced mapping, new well data recording requirements and support for alternative energy resources. Ultimately, developing this resource can provide the model for efficiently and economically diversifying Alberta's energy portfolio, balancing native load and simultaneously providing a dynamic and robust export product.

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