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Geothermal Favourability Map of Alberta following a Global Protocol – Methods and Data Sources

Final Report
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Background

Geothermal energy, despite its potential to provide clean, green, continuous base load power, has remained underdeveloped compared to other renewable energies. High capital costs in the pre-development phase, along with a lack of knowledge in the various geothermal technologies has held back investment opportunities for this vital energy resource. While recent reports from the Federal Government have been key in indicating the geothermal resource potential of Canada, further steps need to be taken to provide technical and geophysical data pertinent to geothermal exploration. The need to standardize how geothermal resources are assessed has been addressed by several international partners in the geothermal industry.

Following Proceedings of the Geothermal Resources Council Annual Meeting in 2010[1], a framework for a Global Protocol to estimate and map the Theoretical Potential and Technical Potential[2] for Enhanced Geothermal Systems was published. This Global Protocol has since been reviewed and endorsed by the International Geothermal Association (IGA), the Executive Committee of the International Energy Agency Geothermal Implementing Agreement (IEA-GIA), and the International Heat Flow Commission (IHFC). The Global Protocol currently provides a globally self-consistent manner for estimating and mapping geothermal potential suitable for development using Enhanced Geothermal Systems, compatible with current geothermal public Reporting Codes. The U.S. and Australia, in cooperation with Google.org, have recently completed maps following the Global Protocol. The U.S. maps are publically available for interactive display on the Google website (www.google.org/egs).

[1] Beardsmore et al., 2010
[2] as defined by Rybach, 2010

Introduction

Following the guidelines set forth by the Global Protocol and the Canadian Geothermal Code for Public Reporting, CanGEA has facilitated the development of a Geothermal Favourability Map of Alberta with the goal of providing a 'transparent' and 'competent' picture of Alberta's geothermal resource potential in a global energy market. Presented to the public in a universal mapping platform format and centralized national geothermal database, the project deliverables provide a means to share, collaborate or update data necessary for making informed commercial decisions around geothermal development. The Geothermal Favourability Map of Alberta and associated database are essential tools for mitigating investment risks associated with geothermal development.

A partial Canadian Geothermal Database (CGD) and an Alberta Geothermal Favourability map have already been developed. The Canadian adaption of the Global Protocol for Estimating and Mapping Geothermal Potential is a public document after a detailed review by 'Qualified' individuals from Australia's Protocol development team, along with authors of the Canadian Geothermal Code for Public Reporting (Toohey *et al.,* 2010). Anticipating any future changes and/or advancements in geothermal technology, the Canadian version of the Global Protocol will serve as a 'living document' and will remain open to continuous review.

The Geothermal Favourability Map of Alberta sets the benchmark for a potential new and renewable energy industry in Alberta. This project, and the opportunity of a geothermal industry in Alberta, offers numerous benefits and advantages. For one, as production of geothermal energy continues to grow around the world, so will the need to estimate and map geothermal resources in a globally consistent manner. By adopting these practices in the pre-development phase, Alberta sets itself up to a high-level industry standard that is compatible with current and future development. Additionally, geothermal developments will not only increase the international movement of skilled personnel to Alberta but also provide opportunities for technology transfer from the already present population of personnel skilled in well drilling, mining and resource exploration. Collaboration and in-kind support from multiple parties involved in this project has already lead to new training opportunities in geothermal resource assessment and data quality control.

As the final maps and geothermal database produced by this project are shared publically via a web portal and Google Earth platform, virtually anyone has the opportunity to learn about Alberta's geothermal potential. Data gaps will also be identified across Canada, encouraging multiple industries to contribute, update and share new and existing data to the national database. By promoting collaboration, it is anticipated that the project will lead to other geothermal mapping and resource estimate projects for the remainder of Canada.

Project Deliverables

Project funding for completion of the Favourability Map and the establishment of a partial Canadian geothermal database was secured by CanGEA from Suncor Energy, Alberta Innovates Energy and Environment Solutions, Borealis GeoPower and the Pembina Institute. While CanGEA provided oversight on the project, the technical work was completed partly by CanGEA and partly by members of the geothermal community in Alberta, Canada. In addition to this, the international geothermal community reviewed the project in its drafting stage.

Deliverable	Description
1	A publically accessible web portal of the Canadian Geothermal Database, including data generated from the Geothermal Favourability Map of Alberta
2	Geothermal Favourability Map of Alberta in KML format displaying heat flow, estimated crustal temperature at different depths, and favourability rating for geothermal potential
3	Collated tables and charts in KML format of geothermal potential (theoretical and technical) for different geological regions across Alberta, depths, temperature ranges and recoverability factors
4	Information and data sufficient to ensure that the above Deliverables comply with the Reporting Code
5	Summary report describing the methods and data sources for completion of all maps and tables, suitable for public release (this document).

1.0 Canadian National Geothermal Database and Favourability Map Portal

The Canadian National Geothermal Database and Favourability Map Portal (CNGD) stores critical geothermal site attribute information. It is similar in scope and intent to the U.S. National Geothermal Data System ('NGDS'; www.geothermaldata.org). The CNGD strives to store such data as:

- temperature at depth, thermal conductivity, heat flow, well logs, bottom hole temperatures (BHT), drill stem test (DST), permafrost data, seismicity/microseismicity, porosity/permeability data, water chemistry, geophysical surveys, etc.

It is relevant to all types of geothermal energy potential, such as:

- direct-use, hydrothermal, hot sedimentary aquifer, geopressured, Enhanced Geothermal Systems (EGS), geothermal fluids co-produced with oil and/or gas and minerals (mining), etc.

The Alberta Favourability Map and Database itself stores the following data:

- temperature at depth, thermal conductivity, heat flow, well logs, bottom hole temperatures (BHT), drill stem test (DST), porosity/permeability data, and water chemistry data

Data stored in the Database includes historical data and geothermal resource assessment data compiled by universities, research organizations, and private and publically funded geothermal exploration projects. As well as regions with geographically proximal data, the Database will also allow interpolation or extrapolation of trends to assess regions of Canada that lack the required local data for assessing geothermal potential. The Database will be made available to the public and will serve as a geothermal exploration tool for making informed business decisions, and as a means for mitigating investment risks. The Database will be initially established and hosted by CanGEA until a more suitable long-term host is identified.

1.1 Data Organization, Formatting, and Verification

A web portal will provide public access to the CNGD. Data are organized based on specific criteria such as location and temperature (i.e. low temperature for direct use, moderate/high temperature for electricity generation etc.). The web portal is user-friendly and flexible, allowing data to also be retrieved for specific geological, geophysical, environmental and/or other purposes related to assessing and identifying geothermal potential.

Data are stored in standard data measurement units (SI units) and documented to ensure quality and validation. This requires that datasets be accompanied by Metadata describing the source of data, methods used in collection of the data, and descriptions of how data quality was controlled.
Verification of the data is completed throughout the various phases of a mapping project. Following the guidelines of the Global Protocol and Reporting Code, data sets are analyzed and assigned confidence levels. Provided that the rest of Canada is mapped similarly to Alberta, all datasets will include a classification system of key site criteria using an overall favourability index. The confidence levels and favourability index assigned to each dataset will provide a useful method for validating and assessing investment risks for geothermal development across Canada.

1.2 Data Sources and Description

The data underpinning the Geothermal Favourability Map of Alberta were obtained from both private and public sources. Data types varied between raw data in text and excel file format to shape files for import into Geographic Information Systems. A description of all data sets is provided below, and sources are given in Appendix A.

1.3 Base map data

AltaLIS is responsible for the distribution of several digital mapping datasets to the private sector, including 'Base Features' maintained by the Government of Alberta. Base Features is made up of several topographic themes that cover Alberta, and is a seamless Geographic Information Systems (GIS) spatial database product to which other natural resource and land management information can be related.

GeoAdministrative boundaries are land areas with explicitly defined boundaries, established by legislation or by an agency to manage or administer land use. The following GeoAdministrative layers and associated metadata reproduced below are maintained within the Base Feature dataset. For further information please visit http://www.altalis.com/prod_base_bound.html.

1.3.1 Ecological Reserves

Areas to preserve and protect natural heritage in an undisturbed state for scientific research and education are Ecological Reserves. Areas contain representative, rare and fragile landscapes, plants, animals and geological features. The primary intent of an Ecological Reserve is the strict preservation of natural ecosystems, habitats and features, and associated biodiversity. They serve as outdoor laboratories and classrooms for scientific studies related to the natural environment. Public access to ecological reserves is by foot only; public roads and other facilities do not normally exist and will not be developed. Most ecological reserves are open to the public for low-impact activities such as photography and wildlife viewing.

1.3.2 Exploration Restricted Areas

Exploration Restricted Areas were developed from reported flowing holes as per the Exploration Regulation (AR 214/98). Primarily used for planning, processing and approval of Geophysical applications.

As per Section 6 of the Exploration Regulations 214/98, identified areas of Alberta have prohibitions and restrictions on the conduct of geophysical exploration. As restricted areas have increased in number since the inception of the Exploration Regulation, these areas of Alberta are now delineated, described and posted on http://www.srd.gov.ab.ca/land/restr_areas/

1.3.3 Land-use Framework Regional Plan Boundary

The Land-use Framework Planning Regions dataset is comprised of all the polygons that represent the land-use planning regions in Alberta, after consultation with stakeholders and the public. The framework sets the direction for natural resource and land-use planning under which Alberta will better balance economic and social considerations with environmental factors. The Land-use Framework Planning Regions dataset provides users with GIS-ready polygonal representation of all the planning areas in the province of Alberta, and is suitable for indexing or analysis purposes. The Land-use Framework Planning Regions represent the seven land-use regions that the Government of Alberta will develop regional plans for each to manage growth, to ensure a future with plentiful opportunities and a healthy environment. The naming of the province's planning regions is based on major watersheds. The regional plans developed will integrate provincial policies at the regional level, set out regional land-use objectives and provide the context for land-use decision-making within each region, and reflect the uniqueness and priorities of the region. Municipalities and provincial government departments will be required to comply with each regional plan. (Reference: Land-use Secretariat Division Oct. 21, 2008).

1.3.4 National Parks

This layer contains polygons representing the location of National Parks in the Province of Alberta. It is an area set aside for recreation, under the jurisdiction of the Federal Government (Parks Canada). They are lands dedicated to the people of Canada for their benefit, education and enjoyment. Lands are maintained and made use of so as to leave them unimpaired for the enjoyment of future generations. This boundary is reconciled with ATS V4.1

1.3.5 Provincial Boundary

Compiled by Spatial Data Warehouse Ltd. (SDW), on behalf of the Government of Alberta, the ATS v4.1 Alberta Provincial Boundary polygon layer contains the polygon that represents the location of the boundaries of the Province of Alberta. This version of the Province of Alberta boundaries should be considered definitive for Government of Alberta use, and supersedes all previous versions.

1.3.6 Provincial Parks

Parks that preserve natural heritage; they support outdoor recreation, heritage tourism and natural heritage appreciation activities that depend upon and are compatible with environmental protection where natural, historical, and cultural landscapes and features are protected under Provincial Parks Act. Provincial parks protect both natural and cultural landscapes and features. They are distinguished from Wild land parks by their greater range of outdoor recreation facilities, the extent of road access, and the interpretive and educational programs and facilities that are available to visitors. Outdoor recreation activities that promote appreciation of a park's natural heritage and cultural features are encouraged. Provincial parks offer a variety of outdoor recreation opportunities and support facilities. Interpretive and educational programs that enhance visitor understanding and appreciation of, and respect for, Alberta's natural heritage (without damaging natural values) are offered in some provincial parks; these programs serve visitors of diverse interests, ages, physical capabilities and outdoor skills. Automobile access is typically provided to staging areas and support facilities.

1.3.7 National Topographic Grid

The National Topographic Grid (NTS) is a standard geographic numbering system that identifies topographic map coverage for all of Canada. The nation is divided into primary quadrangles of 4° of latitude and 8° of longitude. Each of these quadrangles is further broken down into 16 letter blocks (A–P) of 1° of latitude and 2° of longitude. Each individual grid cell therefore varies in size with an average area of 8.1 x 10^8 m^2 (28 x 30km). The 1:50000 (50K) grid divides these letter blocks into 16 more maps (numbered 1–16), which provided the surface grid framework for estimating the geothermal potential of Alberta.

1.4 Transmission Grid

The Alberta Electric System Operator (AESO) provided a transmission system map. GIS layers were then created and georeferenced using ArcMap 10.1. The map is provided as a reference only and the AESO is not responsible for any decisions (financial or otherwise) that are made based on the data contained within the map.

For further information on the transmission grid of Alberta, please visit the AESO web page at http://www.aeso.ca/

1.5 Bottom Hole Temperature Data

The Alberta Geological Survey (AGS) and Borealis GeoPower contributed a large collection of borehole temperature data. A smaller collation of temperature data (about 10 wells) was also extracted from the Geothermal Data Compilation.

The bottom hole temperature database provided by AGS included just over 308,000 records containing, but not limited to, drilling stop dates/times, circulation stop dates/times, temperature measurement dates/times, depths and temperatures transcribed from microfiche of well log headers of oil and gas wells drilled between 1937 and 2000 in Alberta. Borealis GeoPower provided an additional 284,000 well log records. These records were originally extracted from Geoscout, a leading oil and gas data management tool providing public well and land data across Canada. Where multiple temperature readings for one well were identified, the mean value was used. Datasets include recorded bottom hole temperatures

(BHTs), as well as recorded temperatures from wire line tools. Borealis GeoPower filtered discrepancies from the data before providing them to CanGEA.

1.6 Surface Temperature

The 'Second Generation of Homogenized Temperature' datasets from Environment Canada were prepared to provide a spatial and temporal representation of the climate trends in Canada. Non-climatic shifts were identified in the annual means of the daily maximum and minimum temperatures using a technique based on regression models. Datasets were provided for 338 locations across the country. Observations from nearby stations were sometimes combined to create long time series. Data series were extended to cover as much as possible the period 1895-2008.

Vincent et al. (2012) described the Second Generation of Homogenized Temperature dataset in detail. For more information, please contact Lucie Vincent at Lucie.Vincent@ec.gc.ca

1.7 Thermal Properties

Default values of thermal conductivity, heat production rate, density and heat capacity of sediments and basement rocks were accepted as recommended by the Global Protocol.

2.0 Alberta Geothermal Favourability Map

All maps were created using Geographic Information Systems software (ArcMap 10.1) and projected to the North American Datum 1983 (NAD83) coordinate system. All shallow systems, deep systems, heat flow, conductivity, geothermal gradients, depth to basement, surface temperature and favourability maps were interpolated up to a 30km radius using inverse distance weighting methods where local variation was determined from neighbouring data points. Theoretical and Technical potential was estimated for each individual grid cell and no interpolation methods were used. Regions with no known data points were not included in the analysis but are represented in the maps with "hash" marks. This helped to identify regions of Alberta with clearly defined data gaps where future research is recommend.

2.1 Assumptions

All calculations closely followed the Global Protocol published in the Proceedings of the Geothermal Resources Council Annual Meeting 2010[3].

Most of the Lower Proterozoic sedimentary or volcanic rocks underlying the Western Canada Sedimentary Basin have lost permeability by being metamorphosed to high grade. Therefore, heat is assumed to be transported only by conduction. Although transport of heat with fluids moving along fractures and fault zones is possible, no evidence of such cases has been identified within the current dataset.

The heat flow in the sedimentary column is assumed to be vertical and uniform if there are no significant proximal lateral variations in the thermal conductivity of the rocks (as is assumed to be the case within the Western Canada Sedimentary Basin), if the rate and volume of groundwater flow is negligible (an assumption still the object of debate), and if heat generation with the sediment is negligible (see below). Given these assumptions, the vertical temperature profile and variation of the geothermal gradient are determined by the heat flow at the base of the sedimentary column and by the thermal conductivity of the rocks.

2.2 Methods

2.2.1 Temperature Profile

The first step in following the Global Protocol was to estimate and model the temperature profile, heat flow and available heat of the Earth's crust down to a 6 km depth.

[3] Beardsmore et al., 2010

a. Build a Geographic Information Systems (GIS) database and grid Alberta into NTS grid cells with rock property and geological attributes.

   This divided Alberta into 801 effective surface cells, with each cell representing a column from the surface to a depth of 6,000 m in 1,000 m intervals.

b. Create a sediment thickness (depth to basement map) from well-basement intersections, seismic interpretations, potential field inversions, etc.

   Data for a depth to basement map was obtained from the Western Canadian Sedimentary Basin Atlas. The data were supplementary to chapter 30 of the Atlas (Geothermal), under the "Depth to Precambrian" subsection.

c. Populate sediment thermal properties: thermal conductivity (K_S) and heat generation of sediment (A_S).

   Default properties given in the Global Protocol were used for these values. K_S = 2.50 W/mK, A_S = 1.00 $\mu W/m^3$.

d. Populate basement thermal properties: thermal conductivity (K_B) and heat generation of basement rocks (A_B).

   Default properties given in the Global Protocol were used for these values. K_B = 3.45 W/mK, A_S = 2.65 $\mu W/m^3$. For each 3D grid block crossing the sediment–basement contact, these values were calculated as the volume-weighted average of values for sediment and basement components.

e. Create surface temperature map using mean average annual surface air temperature

   Provided by Environment Canada, as listed in Appendix A.

f. Create surface heat flow map.

   For grid cells in which borehole temperature data were available, the surface heat flow was calculated from the product of the average thermal gradient to the deepest temperature data and the thermal conductivity of the sediment, minus half the heat generated within the sediment. This was possible for 700 of the 801 cells. Surface heat flow for the remaining cells was interpolated from nearby cells, for the purpose of mapping. Note that Geothermal Potential was only estimated for those grid cells for which a surface heat flow could be estimated.

g. Derive temperature and heat flow at sediment-basement interface for $S < 4,000$ m and $S > 4,000$ m, where S is the depth to the sediment-basement interface.

The methods and equations as given in the Global Protocol were employed to complete this step.

h. Derive T at depth X, down to 10,000 m depth, where X is the midpoint between 1,000 m intervals.

   The methods and equations as given in the Global Protocol were employed to complete this step. Note that the Global Protocol recommends calculating temperature to 10,000 m for Theoretical Potential and 6,500 m for Technical Potential. The Geothermal Favourability Map of Alberta, however, presents both of these to 6,000 m to reflect current realistic (economic) drilling capabilities in Alberta.

2.2.2 Theoretical Potential

The next step was to estimate the Theoretical Potential of geothermal power in the crust down to a depth of 6,000 m. As noted above, this is a departure from the Global Protocol, which recommends estimating Theoretical Potential to 10,000 m.

a. Derive average temperature for each 1,000 m depth interval. Approximate by calculating temperature at mid-point of each interval.

   The methods and equations as given in the Global Protocol were employed to complete this step.

b. Assign density (ρ) and specific heat capacity (C_p) of interval.

   The methods and equations as given in the Global Protocol were employed to complete this step.

c. Derive volume of each grid cell (V_c). Volume varies slightly with latitude.

   The surface area and hence the volume of each 3D grid cell varies slightly with latitude

d. Calculate available heat for each depth interval in each cell (H).

   The methods and equations as given in the Global Protocol were employed to complete this step.

e. Derive theoretical potential power (P).

   The methods and equations as given in the Global Protocol were employed to complete this step.

2.2.3 Technical Potential

The final step was to estimate the Technical Potential of geothermal power in the crust down to a depth of 6,000 m. As noted above, this is a departure from the Global Protocol, which recommends estimating Technical Potential to 6,500 m.

Technical Potential is defined by the Global Protocol as "Theoretical Potential that can be extracted after consideration of currently 'insurmountable' technical limitations". Technical Potential provides a more realistic estimate of geothermal power potential using current technology, and considering access restrictions.

For the Technical Potential estimate, it was assumed that all grid blocks containing primary data are accessible for geothermal production (Rav = 1), as availability of down hole temperature measurements demonstrates that the location has previously been accessed for exploration. The Technical Potential was estimated for low, medium and high recoverability factor (R) for the rock of 0.05, 0.14 and 0.20, respectively. Note that the 'low' value is a departure from the Global Protocol, which recommends a minimum R = 0.02.

Note that while First Nations and National/Provincial parks are protected, given the potential for geothermal to provide clean energy to northern and remote communities and reduce greenhouse gas emissions, these lands are recognized but not excluded from the assessment. Some National parks and protected areas already have geothermal and other renewable developments and/or climate change policies within their jurisdictions.

2.2.4 Favourability

Although not required by the Global Protocol, this mapping project also defines a 'geothermal favourability rating' based on geothermal gradients and ambient temperatures. This rating, described in the table below, provides a geothermal assessment based on temperature requirements of current technology, and is consistent with geothermal favourability mapping projects completed by Northwest Territories Environment and Natural Resources.

Rating	Geothermal Gradient (°C/Km)	Favourability
Low	< 30	below global average; low likelihood of development
Low-Medium	> 31-40	temperatures at about 2- 2.5 km depth may be high enough to operate an Organic Rankine Cycle (Binary) power plant
Medium	> 40-50	temperatures at about 2 km depth would likely be high enough to operate an Organic Rankine Cycle (Binary) power plant
Medium-High	> 50-55	temperatures at about 2 km depth would likely be high enough for efficient operation of an Organic Rankine Cycle (Binary) power plant at temperatures over 100 °C
High	> 55	temperatures at a depth of 2-3km may be high enough to produce steam for a conventional geothermal power plant

Source: Northwest Territories Environment and Natural Resources (2010)

2.2.5 KML formatting

The Global Protocol recommends that results be presented using common visualization and data architecture in accordance with previous geothermal potential maps, such as that produced for the United States in 2011 (www.google.org/egs).

a. The Geothermal Favourability map of Alberta was created using GIS software. All files contained in the geodatabase have been converted to KML format for visualization in Google Earth and presented in a format equivalent to that of the USA geothermal potential maps.
b. Layers include the following:
    - Estimated temperature at depth for Power Generation at 1 km intervals from 1,500 m to 5,500 m
    - Estimated temperature at depth for Direct Use purposes at 100 m intervals to 500 m
    - Estimated depth to 20°C, 80°C and 120°C
    - Grid blocks of Alberta showing Theoretical Potential to 6 km
    - Grid blocks of Alberta showing Technical Potential to 6 km
    - Geothermal favourability rating
    - Level of confidence as either an Inferred or Indicated Resource
    - Land use including excluded zones, transmission lines/grid access and other major topographic/geological features
c. Layers will be available on the established CNGD (Canadian National Geothermal Database) web portal (http://www.cangea.ca/cngd/) as a single KML file. The public will be able to download and view this file using the publicly available Google Earth program.

3.0 Collated tables and charts of geothermal potential

The value of Theoretical Potential depends on available geophysical data, while the derived Technical Potential is based on the current state of heat recovery and power conversion technology. As all of these will change over time, assumptions such as available heat, depth limits, recovery factor and net thermal efficiency will adjust, changing Theoretical and Technical estimates. Following the Global Protocol, we assumed that conduction is the dominant heat transfer mechanism and that thermal conductivity of sediment deeper than 4,000 m is the same as the basement. Under these conditions and in an effort to remain consistent with the Global Protocol, the tasks described below were completed. Where local data were not available, estimations and calculations relied on the algorithms and global means provided by the Global Protocol.

The tables and charts of estimates of geothermal potential and the data that underpin them are stored in GIS databases available through the CNGD web portal, a user-friendly interface for convenient access by all interested parties. These tables and charts include the following:

a. Temperature at depth data
b. Theoretical Potential estimates
c. Technical Potential estimates
d. Confidence data (in accordance with the Canadian Geothermal Public Reporting Code)
e. Favourability ratings

4.0 Compliance with the Global Protocol and Reporting Code

This report and the data and calculations underpinning the Geothermal Favourability Map of Alberta result were peer-reviewed and endorsed by Dr. Graeme Beardsmore of Hot Dry Rocks Pty Ltd (Australia) as a "Competent Person", and by Dr. Daniel Yang of Borealis GeoPower (Canada) as a "Qualified Person" under the Reporting Code. The Global Protocol respects the Reporting Code's underlying principles of 'transparency', 'materiality', and 'competence', and this project honours those principles by providing public access to all the underlying data, metadata, charts and tables used in the assessment of favourability of Alberta's geothermal resources.

4.1 Canadian Geothermal Reporting Code

The Alberta Favourability Map includes estimates of geothermal potential that could be categorized according to the terminology of the Australian and Canadian Geothermal Codes for Public Reporting.

The "Canadian Geothermal Code for Public Reporting" is designed to provide a level of consistency and transparency for the reporting of "Exploration Results", "Geothermal Resources" and "Geothermal Reserves". The primary data underpinning the Alberta Geothermal Favourability map are borehole temperatures, recorded within actual penetrations of the sediment. The estimates of potential can therefore be classified as Resources rather than Exploration Results. "Indicated Resources" is used to classify estimates based directly on actual measured temperature data within a 3D grid cell, while "Inferred Resources" is used for estimates based on values extrapolated from actual bottom hole temperature measurements. None of the geothermal potential reported in the Alberta Favourability Map can be classified as "Measured Resources" because fluid flow capacity has not currently been determined from any real data. Further analysis of individual well data would be required to determine if there could be an increase in confidence level to Measured Resources for any of the results.

Classification of Reserves requires economic assumptions unique to specific companies and projects, and is inappropriate at the scale of the Alberta Favourability Map.

5.0 Summary

This text report is to accompany the public release of the Alberta Favourability Map. It includes:

- Description of the process used in the generation of all maps and tables
- Data sources (these are available through the web portal for the CNGD)
- Details of any alterations/exceptions to the Global Protocol and Reporting Code

Project team

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Glossary

Enhanced Geothermal Systems (EGS)- a production well extracting hot fluid from the ground and passing it through a power conversion plant (electricity and/or heat) before re-injecting the cooled fluid back underground where it is reheated by the rock in a continuous cycle through an artificially enhanced underground heat exchanger.

Geographic Information Systems (GIS)- an organized collection of computer hardware, software, and geographic data designed to efficiently capture, store, manage, analyze, manipulate and display all forms of geographically referenced information.

Indicated Geothermal Resource- is that part of a Geothermal Resource which has been demonstrated to exist through direct measurements that indicate temperature and dimensions so that recoverable thermal energy (MWth-years) can be estimated with a reasonable level of confidence

Inferred Geothermal Resource- is that part of a Geothermal Resource for which recoverable thermal energy (MWth-years) can be estimated only with a low level of confidence

Theoretical Potential- an estimate of "the physically usable energy supply over a certain time span in a given region. It is defined solely by the physical limits of use and thus marks the upper limit of the theoretically realizable energy supply contribution" (Rybach, 2010).

Technical Potential- the fraction of the Theoretical Potential that can be used under the existing technical restrictions…structural and ecologic restrictions as well as legal and regulatory allowances" (Rybach, 2010).

Symbols

ρ density
A_B heat generation of basement rocks (W/m^3)
A_S heat generation of sediment (W/m^3)
C_p specific heat capacity (J/kgK)
H total available thermal energy (EJ)
K_S thermal conductivity of sediment (W/mK)
K_B thermal conductivity of basement (W/mK)
P Theoretical Potential
P_T Technical Potential
R recoverability factor
V_c volume of each 5' x 5' x 1,000 m cell (m^3)

References

Beardsmore, G. R., Rybach, L., Blackwell, D. and Baron C. (2011). A protocol for estimating and mapping global EGS potential. Unpublished, May 2011 edition.

Hot Dry Rocks Pty Ltd Geothermal Energy Consultants (2011). Summary of process and data sources used in the development of the EGS Potential maps and tables of Australia. 23 September 2011.

Northwest Territories Environment and Natural Resources (2010). Geothermal Favourability Map- Northwest Territories. Prepared by EBA Engineering Consultants Ltd, April 2010.

MIT (Massachusetts Institute of Technology) (2006). The Future of Geothermal Energy- Impact of enhanced geothermal systems (EGS) on the United States in the 21st century. MIT Press.

Rybach, L. (2010). "The future of geothermal energy" and its challenges. Proceedings World Geothermal Congress. Bali, Indonesia, 25-29 April 2010.

Toohey, B., Deibert, L., Thompson, A., Yang, D. and Hjartarson, A. (2010). The Canadian Geothermal Reporting Code for Public Reporting. Canadian Geothermal Energy Association.

Reference Maps

Australia Temperature at Depth (Hot Dry Rocks; 2011): http://www.hotdryrocks.com

Northwest Territories Geothermal Favourability Map:
http://www.enr.gov.nt.ca/_live/documents/content/Geothermal_Favorability_Report.pdf

U.S. Enhanced Geothermal Systems map (SMU/ Google; 2010): http://www.google.org/egs/

Appendix A

Data	Source	Website	Date Retrieved
AB NTS Grid	AltaLis	http://www.altalis.com/	29-Mar-12
Heat Flow	IHFC	http://www.geophysik.rwth-aachen.de/IHFC/	29-Mar-12
Depth to Basement	Geological Atlas of the WCSB	http://www.ags.gov.ab.ca/publications/wcsb_atlas/atlas.html	29-Mar-12
Heat Generation of Sediment	Geological Atlas of the WCSB	http://www.ags.gov.ab.ca/publications/wcsb_atlas/atlas.html	29-Mar-12
Heat Generation of Basement Rocks	Geological Atlas of the WCSB	http://www.ags.gov.ab.ca/publications/wcsb_atlas/atlas.html	29-Mar-12
Mean Average Annual Surface Air Temp	Environment Canada	http://www.ec.gc.ca/dccha-ahccd/default.asp?lang=En&n=1EEECD01-1	25-Apr-12
Temperature Borehole Data	Geothermal Data Compilation	http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/58d02b6c-deea-5f45-aef5-3c162b46666b.html	29-Mar-12
Temperature Borehole Data	AGS	CanGEA Request	01-Jun-12
Temperature Borehole Data	Borealis GeoPower	CanGEA Request	01-Jun-12
Regional Geology	Geological Atlas of the WCSB	http://www.ags.gov.ab.ca/publications/wcsb_atlas/atlas.html	10-Apr-12
Geothermal Gradient	IHFC and estimated	http://www.geophysik.rwth-aachen.de/IHFC/	10-Apr-12
Hot Springs	Parks Canada	http://www.hotsprings.ca/	10-Apr-12
Seismic Events	Earthquakes Canada	http://www.earthquakescanada.nrcan.gc.ca/index-eng.php	10-Apr-12
AB Boundary	AltaLis	http://www.altalis.com/	29-Mar-12
AB First Nations	AltaLis	http://www.altalis.com/	29-Mar-12
Ecological Reserves	AltaLis	http://www.altalis.com/	29-Mar-12

Exploration Restricted Areas	AltaLis	http://www.altalis.com/	29-Mar-12
LUF Int. Reg. Plan Boundary	AltaLis	http://www.altalis.com/	29-Mar-12
National Parks	AltaLis	http://www.altalis.com/	29-Mar-12
Provincial Parks	AltaLis	http://www.altalis.com/	29-Mar-12