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Low-Temperature Geothermal Geospatial Datasets: An Example from Alaska

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ABSTRACT

This project is a component of a broader effort focused on geothermal heating and cooling (GHC) with the aim of illustrating the numerous benefits of incorporating GHC and geothermal heat exchange (GHX) into community energy planning and national decarbonization strategies. To better assist private sector investment, it is currently necessary to define and assess the potential of low-temperature geothermal resources. For shallow GHC/GHX fields, there is no formal compilation of subsurface characteristics shared among industry practitioners that can improve system design and operations. Alaska is specifically noted in this work, because heretofore, it has not received a similar focus in geothermal potential evaluations as the contiguous United States. The methodology consists of leveraging relevant data to generate a baseline geospatial dataset of low-temperature resources (<150°C) to compare and analyze information accessible to anyone trying to understand the potential of GHC/GHX and small-scale low-temperature geothermal power in Alaska (e.g., energy modelers, communities, planners, and policymakers). Importantly, this project identifies data related to (1) the evaluation of GHC/GHX in the shallow subsurface, and (2) the evaluation of low-temperature geothermal resource availability. Additionally, data is being compiled to assess repurposing of oil and gas wells to contribute co-produced fluids toward the geothermal direct use and heating and cooling resource potential. In this work we identified new data from three different datasets of isolated geothermal systems in Alaska and bottom-hole temperature data from oil and gas wells that can be leveraged for evaluation of low-temperature geothermal resource potential. Based on these compiled datasets, NREL's GeoRePORT Resource Size Assessment Tool (RSAT) was implemented to estimate the low-temperature resource base in Alaska, and its power production and direct use potential. The goal of this project is to facilitate future deployment of GHC/GHX analysis and community-led programs and update the low-temperature geothermal resources assessment of Alaska. A better understanding of shallow potential for GHX will improve design and operations of highly efficient GHC systems. The deployment and impact that can be achieved for low-temperature geothermal resources will contribute to decarbonization goals and facilitate widespread electrification by shaving and shifting grid loads.

1. INTRODUCTION

The U.S. Department of Energy (DOE) Geothermal Technologies Office (GTO) is supporting the Geothermal Heating and Cooling Geospatial Datasets and Analysis project conducted by the National Renewable Energy Laboratory (NREL) as part of a broader effort to demonstrate the multi-faceted value of integrating geothermal power and geothermal heating and cooling (GHC) technologies into national decarbonization plans and community energy plans. Currently, there is a need to better align definitions of low-temperature geothermal resources with modern heating and cooling technologies including geothermal heat pumps (GHP) or geothermal heat exchange (GHX) technologies, standardize technology definitions across industry, establish baseline low-temperature geothermal resource datasets, and evaluate the impact of deploying these technologies to provide the basis for supporting private sector investment. This project seeks to develop an inventory of available datasets that could support the establishment of a baseline low-temperature geothermal resource database for the United States, including the states of Alaska and Hawaii. This baseline database is not intended for geothermal prospecting, but rather to inform future GHC and geothermal power deployment analyses based on regional favorability of low-temperature geothermal resources to support DOE's efforts to move the U.S. toward net-zero carbon emissions.

The low-temperature geothermal resource base in the U.S. has an enormous untapped quantity of thermal energy (GeoVision, 2019). Quantifying the available energy base will be useful to government agencies, industries, and U.S. residents in their mission to reduce CO_2 emissions via low-carbon energy technologies. There are countless applications for low-temperature geothermal resources, including heating and cooling of residential, commercial, and industrial buildings and districts, and for decarbonizing agricultural and industrial sectors via greenhouse heating, process heating, and others. However, access to baseline low-temperature geothermal resource data is limited. By compiling, analyzing, and expanding access to existing datasets, this project will identify baseline datasets of low-temperature (<150°C, defined by DOE) geothermal resources including (1) GHC/GHX geospatial resource-related datasets, (2) low-temperature geothermal datasets, (3) structural geology, permeability, and geophysical datasets, (4) datasets from oil and gas wells, and (5) heat flow and geothermal gradient datasets.

This paper focuses on data compilation for low-temperature resources in Alaska. Unlike the conterminous United States, there is limited data available in the states of Alaska and Hawaii, which has resulted in those states receiving less attention in national-scale studies of geothermal potential. The work by Williams and DeAngelo (2008) identifying the potential for geothermal energy in the western United States is used as a guide in this study to select low-temperature baseline geothermal datasets for Alaska.

2. BACKGROUND

2.1 Past and Current Efforts to Characterize Low-Temperature Geothermal Resources in the U.S.

DOE is currently working with the United States Geological Survey (USGS) to characterize and assess geothermal energy resources in the United States, and to advance the technologies applied to discover, characterize, and utilize those resources (USGS website). The USGS has a long history of investigating the nature and extent of geothermal systems in the United States to produce assessments of accessible resources. The USGS 2008 national geothermal resource assessment (Williams et al., 2008) estimated potential power production capacity from identified and undiscovered conventional geothermal resources and provisionally evaluated the potential from enhanced geothermal systems (EGS). The current and ongoing USGS effort is focused on expanding the scope of the 2008 assessment to lower temperatures and other unconventional geothermal resource types, updating resource assessments for undiscovered conventional and EGS resources, developing improved methodologies for future assessments, and producing comprehensive databases of geothermal information compiled during the assessment work. The effort also includes assessments of “other unconventional resources” (e.g., low temperature and sedimentary basin geothermal resources from thermal aquifers to deep basin brines) as well as the impacts of geothermal development (e.g., induced seismicity, groundwater, and vegetation impacts).

Low-temperature geothermal systems can be divided into convection-dominated (fluid dynamics) and conduction-dominated geothermal plays as is done for moderate- to high-temperature geothermal systems (Moeck, 2014). Several factors and processes must be present to allow convection within a geothermal system, for example high temperature gradient and high permeability (Moeck, 2014). Hence, most low- to moderate-temperature geothermal systems are conduction-dominated rather than convection-dominated plays (Moeck, 2014). Convection-dominated geothermal systems can be divided into magmatic and non-magmatic geothermal systems, and typically, non-magmatic systems tend to host lower-temperature geothermal systems than magmatic plays (Moeck, 2014).

The effort to assess low-temperature geothermal resources began over 40 years ago, when national high-temperature (>150°C; USGS Circulars 726 [White and Williams, 1975] and 790 [Muffler et al., 1979]) and moderate-temperature (90–150°C; William et al., 2008) resource assessments attempted to estimate preliminary low-temperature resources from the scarce information available at the time. USGS carried out the initial comprehensive low-temperature resource evaluation in 1982 (USGS Circular 892—Reed, 1982). Low-temperature geothermal resources have been classified by the USGS as reservoirs <90°C (USGS Circular 892—Reed, 1982). Recent improvements in utilizing low-temperature geothermal fluids for electricity production have broadened development possibilities for low-temperature geothermal resources. Hence, this supply-centered definition of <90°C now encompasses multiple possible end uses for geothermal energy (direct use and power generation).

In light of national decarbonization goals, NREL and DOE are interested in understanding the deployment potential of commercial low-carbon energy technologies such as geothermal. GHC technologies—which include direct use, GHP, or GHX technologies—and hybrid systems are of particular interest due to their ability to achieve decarbonization goals and positively impact the grid by reducing loads (Liu et al., 2022). One major barrier to understanding the potential of GHC technologies is the lack of accessible information for low-temperature geothermal resources.

Thereby, it is important to define GHC. The utilization of geothermal energy underground or naturally arising at the surface of the ground for any purpose other than electricity generation is referred to as geothermal heating and cooling (IGA, 2022). In the geothermal industry community, the usage of the term GHC is frequently referred to as “direct use”; however, experts suggest that heating and cooling is a more appropriated name for this sector (IGA, 2022). GHC applications consist of four major uses: (1) agriculture and food processing; (2) industrial process heat; (3) health, recreation, and tourism; and (4) heating and cooling for buildings (IGA, 2022). Some of the technologies associated with GHC are geothermal heat pumps (GHP) or ground source heat pump (GSHP), geothermal heat exchangers (GHX), direct use of the fluids, district heating and cooling, and combined heat and power.

GHC/GHX technologies take advantage of the ground’s thermal storage properties. For instance, GHP technology uses thermal energy removed from buildings and seasonally stored in the ground during summer cooling operations to keep buildings warm in the winter, thereby reducing rates of electricity consumption. In addition, GHPs cool buildings at higher efficiencies than conventional air conditioners because the temperature of the shallow earth is typically cooler than ambient air in summer (Liu et al., 2019). In general, GHX systems are designed by balancing a building’s heat and cooling demands with the potential heating and cooling capacity of the ground. The load and capacity of a GHX project are directly related to fluctuations in ambient and ground temperatures. Other important parameters to design efficient GHP/GHX systems are soil properties, soil types, thermal conductivity, density, and specific heat (Soltani et al., 2019).

2.2 Low-Temperature Geothermal Resource Data in Alaska

To alleviate the barriers to quantifying the potential of GHC technologies, this paper focuses on data compilation for low-temperature resources in Alaska as the first phase of a national-scale effort. The limited subsurface data available in Alaska poses a major challenge for studies of geothermal potential. However, Alaska’s active volcanism and tectonic setting suggests the presence of geothermal resources (Kolker, 2008). There are over 108 known hot springs in the state of Alaska (Motyka et al., 1983). Most exploratory geothermal work in Alaska occurred from 1970–1985, funded primarily by DOE. During this period, Alaska’s Division of Geological and Geophysical Surveys (ADGGS) catalogued and sampled all known surface expressions of geothermal systems in the state. This work is summarized in the geothermal resources of Alaska 1:2,500,000 scale map (Motyka et al., 1983).

Preliminary exploration studies were conducted in southeast Alaska, western Alaska, and the Aleutian arc during this period. Geothermal drilling occurred at three sites: Makushin, Mt. Adagdak, and Pilgrim Hot Springs. Alaska's Central Alaska Hot Springs Belt (CAHSB) was not part of these preliminary exploration efforts. The CAHSB contains more than 30 known hot springs, some of which are located relatively close to population centers. In 2006, Chena Hot Springs, in the eastern part of the CAHSB and 60 miles northeast of Fairbanks, installed the first geothermal power plant in Alaska. It is the lowest-temperature geothermal resource ever exploited for power generation in the world. This opened many possibilities in utilizing Alaska's low-temperature resources, which were previously eliminated as potential sites for power generation, and a modest effort to characterize these resources was undertaken (Kolker, 2008).

Chena Hot Springs remains the only geothermal power plant in Alaska. It exploits a low-temperature geothermal resource of 73°C to produce 730 kW (Chena Power Company; Boyd et al., 2015), as well as several cascaded direct uses including greenhouse heating, absorption chilling, district heating, and others (Batir et al., 2016, Boyd et al., 2015). It should be noted that Chena Hot Springs has 4°C cooling water from a stream, enabling a temperature differential across the power system that yields an acceptable cycle efficiency (Lund, 2006). Currently, Alaska has 25 to 70 MWe of planned geothermal production, with the 25 MWe Southwest Alaska Regional Geothermal Project in an exploratory drilling and resource confirmation phase. Other notable projects are Mt. Spur, Unalaska, Akutan, and Chena Hot Springs II (GEA, 2014).

Despite efforts to estimate low-temperature resources in the entire United States (e.g., USGS Circular 892—Reed, 1982; Williams et al., 2008), most of the studies only provide limited results for geothermal evaluations in Alaska due to the dearth of available data. There is limited information on conduction-dominated geothermal systems or other unconventional resources in Alaska, and its geothermal resource assessment has solely been focused on convection-dominated resources (Williams et al., 2008; Mullane et al., 2016). One of the most recent studies that contributed to understanding the thermal regime and updating the heat flow map of Alaska is Batir et al. (2016). That study concluded that the Fairbanks area has temperatures of ~150°C for power production at 3 to 4 km depths, and the rest of Alaska has temperatures at least 40°C for low-temperature geothermal applications at depths <2 km. The Aleutian Volcanic Arc is a high heat flow region, where moderate- to high-enthalpy geothermal resources could be located. Finally, the heat flow map of Batir et al. (2016) shows similar heat flow values within the Aleutian arc province and the Cordilleran Thermal Anomaly Zone, which suggest there is a high probability for geothermal systems to exists within central Alaska (see Section 3.5.1; Fig. 5).

3. DATA COMPILATION

The compilation of a baseline database has the goal of advancing the geothermal resource assessment and identifying important gaps in the information available in Alaska that prevent progress in geothermal development. This study includes accessible databases related to geothermal systems in Alaska <150°C. This temperature cutoff is arguably arbitrary, considering the developments in binary power generation that allow lower-temperature geothermal to generate electricity down to temperatures <100°C (e.g., North Dakota in the United States; Neustadt-Glew in Germany), and the ΔT in Alaska is favorable for electricity generation at lower system-inlet temperatures given typically low ambient temperatures for heat rejection (e.g., Lund, 2006).

A variety of geospatial information for Alaska was selected based on broad criteria related to its utility with respect to evaluation of low-temperature geothermal resource potentials, including (1) GHC/GHX geospatial resource-related datasets, (2) low-temperature geothermal datasets, (3) structural geology, permeability, and geophysical datasets, (4) datasets from oil and gas wells, and (5) heat flow and geothermal gradient datasets. Low-temperature baseline data includes resource data from different sources: USGS, ADGGS, NREL, Southern Methodist University (SMU), Association of American State Geologists (AASG), Cornell University, and others; and co-production data from USGS and the Alaska Oil and Gas Conservation Commission. Additionally, we identified geospatial data useful for determining the viability of GHC/GHX, such as ground temperature, ambient temperatures, permafrost areas, thermal diffusivity, and thermal conductivity. Some of the sources of this GHC/GHX data are Oklahoma State University, Oregon State University, University of Alaska Fairbanks, and the National Center for Environmental Information (NCEI), among others (see references).

3.1 Geothermal Heating and Cooling Datasets

This study identified baseline datasets that includes some of the most important information for GHC/GHX systems, including undisturbed ground temperature, ambient mean annual temperature, surficial materials and permafrost, soil type and bulk density properties, and ground thermal conductivity. This section discusses each of these in more detail.

3.1.1 Ground-Temperature Dataset

The ground-temperature database in Alaska was extracted from a worldwide dataset of undisturbed ground temperature on a yearly average basis generated by Xing and Spitler (2017a, b) and Xing et al. (2017). This database is used as a selection parameter for the professional Ground Loop Heat Exchanger design software GHLEPro, created by the School of Mechanical and Aerospace Engineering at Oklahoma State University and distributed by the International Ground Source Heat Pump Association (https://hvac.okstate.edu/glhepro.html). Undisturbed ground temperature is often needed in technical applications, such as analysis of building heating and cooling load calculations and designing ground heat exchangers (Xing et al., 2017).

The undisturbed ground mean annual temperature database of Alaska (Fig. 1) shows a range of temperatures between -3°C and 9°C. Lower ground temperatures are distributed in the northern region of Alaska, while warmer ground temperatures are found in the southeast region near Juneau and Ketchikan area that corresponds to unfrozen regions (see Section 3.1.3; Fig. 2).

3.1.2 Ambient Temperature

Three different databases of ambient mean temperature of Alaska were identified to provide a baseline data for GHC/GHX: (1) The PRISM Climate ambient mean temperature of Alaska database, (2) the U.S. Climate Normals from NCEI, and (3) the North Slope Science Initiative.

The ambient mean temperature of Alaska database was obtained from the PRISM Climate Group at Oregon State University. The PRISM Climate Group utilized the highest-quality spatial climate datasets of the most recent and suitable climatological period from 1981 to 2010 available for Alaska. This database consists of gridded estimates of monthly, yearly, and daily ambient temperature and other parameters (Daly et al., 2018). These grids are available at: https://prism.oregonstate.edu/projects/public/alaska/grids/tmean/. The ambient mean annual temperature database shows minimum temperatures of -22°C in the northern region of Alaska and a maximum mean temperature of 8°C in the southeastern region of Alaska (Fig. 1).

The second database of mean annual air temperature of Alaska is the U.S. Climate Normal datasets from NCEI that are calculated for a uniform 30-year period and consist of annual, seasonal, monthly, daily, and hourly averages and statistics of temperatures and other climate variables from almost 15,000 U.S. weather stations. Data open access is available at the website: https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals and has separate access options for both conventional 30-year (1991–2020) and supplemental 15-year (2006–2020) time periods. However, the dataset of Alaska presented some complications. To resolve the problem, NCEI reran the normals process and replaced the homogenized temperature data with original observations that were quality controlled but not homogenized (Durre and Squires, 2015).

The third database of mean annual air temperature of Alaska was created to develop an Alaska permafrost map (see Section 3.1.3). It is available on the North Slope Science Initiative website (https://catalog.northslopescience.org/dataset/1725). This shapefile database was first developed on February 23, 2016, and it was last updated on July 1, 2021, by the University of Alaska Fairbanks, Institute of Northern Engineering. The mean annual air temperature contains a total of 5,352 measurements that shows minimum temperatures of -12°C in the northern region of Alaska and the highest temperature of 7°C in the southeastern region of Alaska near Ketchikan.

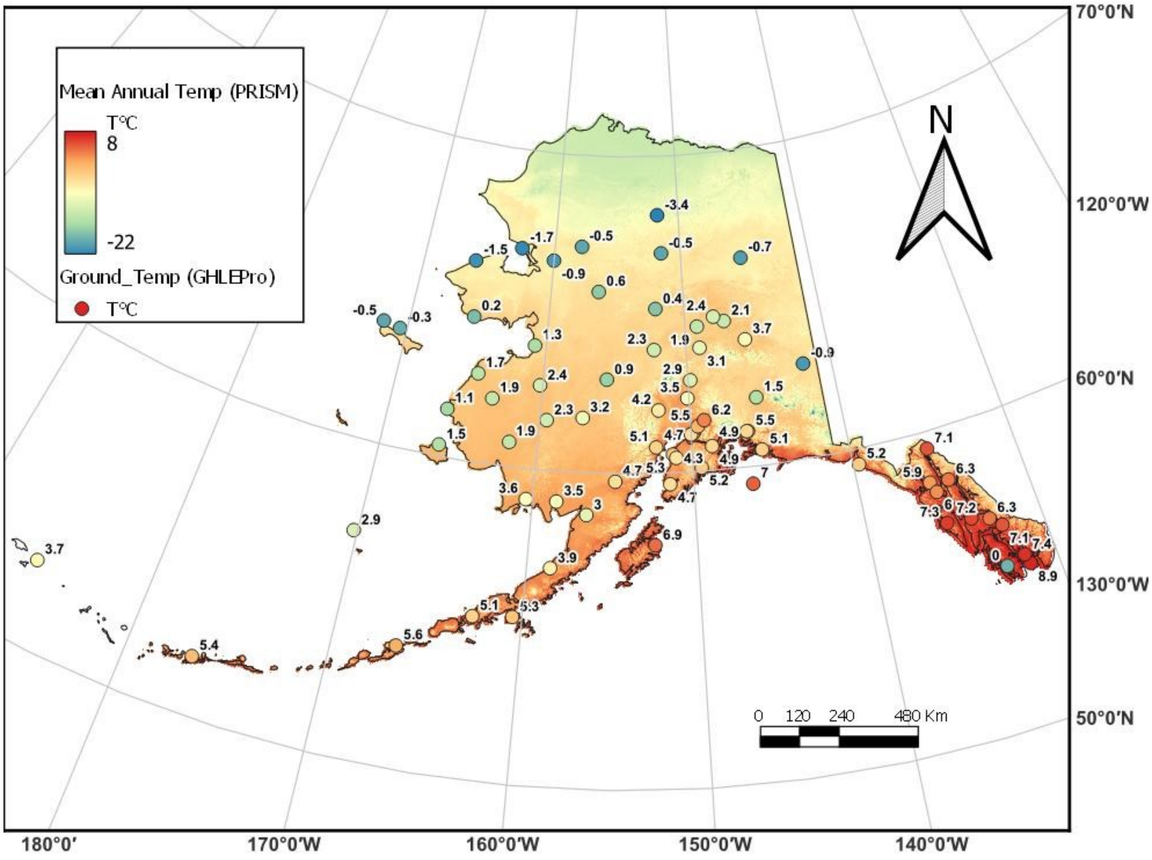

Figure 1: Map of ambient mean annual temperatures of Alaska from PRISM and undisturbed ground-temperature from GHLEPro software.

3.1.3 Surficial Material and Permafrost Areas

The surficial material and permafrost areas database consists of shapefile-type data necessary to create an Alaska permafrost map (Fig. 2), including surficial geology, mean annual air temperature, primary soil texture, permafrost extent, ground ice volume, and primary thermokarst landforms, were all coded into the permafrost shapefile. The North Slope Science Initiative website (https://catalog.northslopescience.org/dataset/1725) hosts this geospatial database.

The relevance of the surficial materials geology and permafrost database of Alaska is due to the importance of knowing the soil type and properties to design efficient GHP/GHX systems. For instance, GHP or GSHP can be utilized to maintain building foundation integrity in permafrost conditions by keeping the ground around them frozen throughout the summer. This specialized application is called ground frost heat pumps (GFHPs). A GFHP can maintain the permafrost by extracting heat from the ground close to building foundations. Additionally, the costs associated with using conventional methods to maintain the structural soundness of foundations in permafrost can be reduced or even eliminated, while the recovered heat can provide up to 20% to 50% of the building's space heating requirements (Minister of Natural Resources Canada, 2001–2005).

The surficial material and permafrost database together with other geothermal relevant data is expected to inform stakeholders, industry, and other developers of important parameters to consider for developing GHX systems in Alaska.

3.1.4 Soil Type and Bulk Density

The density of the ground is another parameter to take into consideration for the design of GHP/GHX, and it is directly related to the type and composition of soil. In this study we identified a global soil physical properties database from World Soil Information ISRIC that comprise bulk density, pH, soil organic carbon content, bulk density, coarse fragments content, sand content, silt content, clay content, cation exchange capacity, total nitrogen, as well as soil organic carbon density and soil organic carbon stock. The content of clay, sand, and silt can also help estimate thermal conductivity values from literature (e.g., Dalla Santa et al., 2020).

The open-access data is available as shapefiles or as grid files, and it can be downloaded as 2 x 2 degrees tiles from: https://soilgrids.org/. SoilGrids$^{\text{TM}}$ is a system for global digital soil mapping that uses machine learning methods to map the spatial distribution of soil properties around the globe. The outputs of this database are global soil property maps at six standard depth intervals at a spatial resolution of 250 meters.

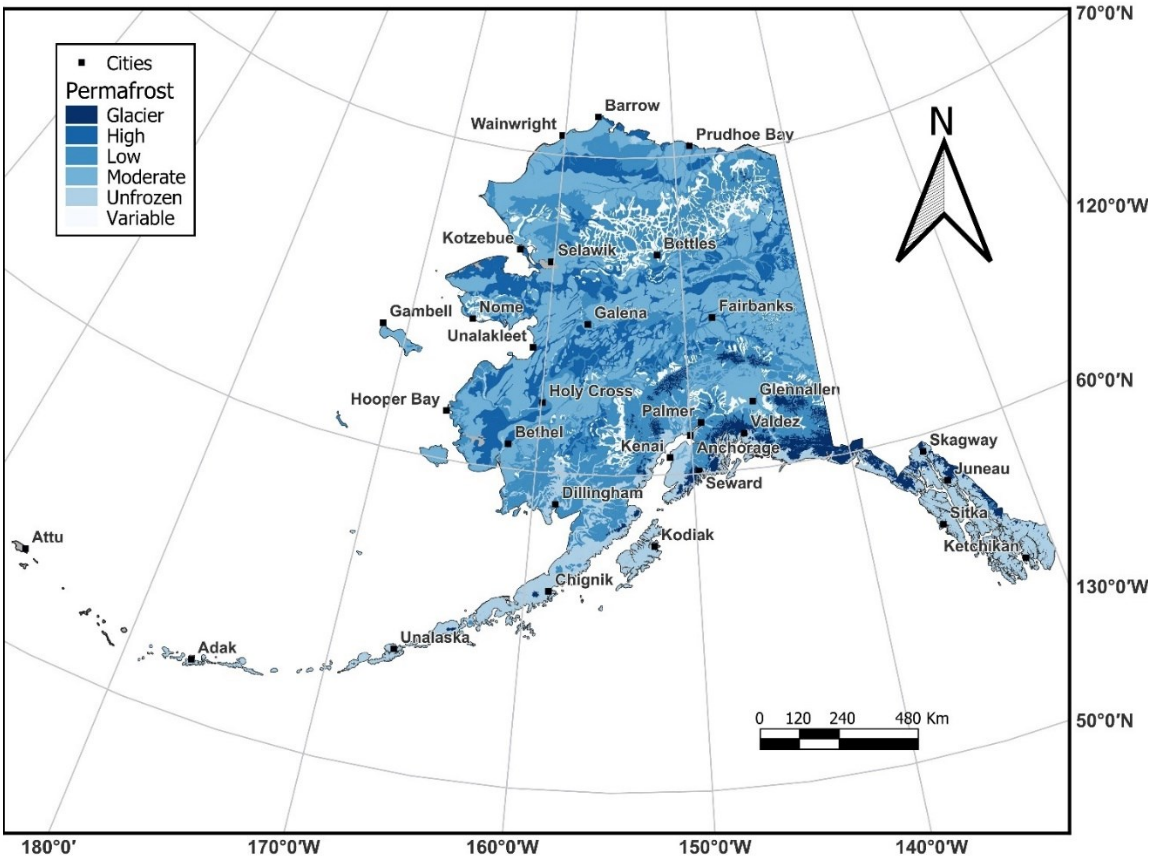

Figure 2: Map of permafrost regions in Alaska.

3.1.5 Ground Thermal Conductivity

The thermal conductivity of the ground is an important parameter for GHP/GHX design and installation. For specific heating and cooling loads, the thermal conductivity has a substantial impact on GHP/GHX size and cost (Liu et al., 2016).

The thermal conductivity (k') of the ground is described by the equation:

$$k' = \frac{Btu}{hr.ft.°F} \tag{1}$$

The thermal conductivity of soils can be determined from laboratory analysis (Mitchell and Kao, 1978); thermal probe (Mitchell and Kao, 1978); classification by soil type (Bose, 1989); and/or in situ tests (Austin, 1998). It is recommended that the thermal conductivity measurement be done on-site because final GHX designs are very sensitive to the actual ground thermal properties (e.g., Dalla Santa et al., 2020). Thermal response tests are required to determine effective soil thermal conductivity field values, including the effects of groundwater flow and natural convection in boreholes (Gehlin, 2002).

There is no specific database of ground thermal conductivity for Alaska. However, GLHEPro (see Section 3.1.1) contains data for several common soil types from which ground properties can be selected that best represent the local conditions. For instance, thermal conductivity and specific heat parameters required for GHLEPro can be estimated using the surface material dataset of Alaska (see Section 3.1.3) or the soil type dataset of Alaska (see Section 3.1.4).

Thermal conductivity data is reported by SMU from rock cores of oil and gas wells in all 50 states (Liu et al., 2016). The thermal conductivity data of Alaska wells was derived from Batir et al. (2016) (Section 3.4.2). Batir et al. (2016) described thermal conductivity values as estimated based on (1) stratigraphic model (Correlation of Stratigraphic Units of North America, COSUNA) and rock types from basin scale cross sections from literature (Mendenhall, 1905; Miller, 1951; Magoon and Claypool, 1981); (2) published thermal conductivity measurements from Gallardo and Blackwell (1999); and (3) measurements from Batir et al. (2013) assigned to a single region based on the majority rock type. These authors estimated an error of thermal conductivity values at ±15% and additional details related to thermal conductivity are available in Batir et al. (2016).

3.2 Low-Temperature Geothermal Datasets

We identified low-temperature geothermal datasets related to convection-dominated magmatic and non-magmatic geothermal plays. The selected low-temperature geothermal datasets correspond to (1) an updated list of all identified isolated hydrothermal systems with surficial and reservoir temperatures (estimated by geothermometers) less than 150°C (e.g., Berry et al., 1980; Motyka et al., 1983); (2) identification of magmatic geothermal systems using volcanic vents and active volcanism datasets that can host low- to high-temperature geothermal systems; and (3) geochemistry data of hydrothermal systems.

3.2.1 Isolated Hydrothermal Systems

In this study we identified three different datasets that identify isolated hydrothermal systems in Alaska:

1. Berry et al. (1980) conducted an early compilation of thermal springs lists for the United States by the National Oceanic and Atmospheric Administration (NOAA). The report is available at https://www.ngdc.noaa.gov/hazard/data/publications/Kgrd-12.pdf. Berry et al. (1980) identified 108 hot springs in Alaska.

2. Motyka et al. (1983) compiled and interpreted hot springs datasets for Alaska (108 hot springs and 3 wells) to inform the first Geothermal Resources of Alaska map by the Department of Natural Resources Geological and Geophysical Survey. This geothermal resource map is available at: https://dggs.alaska.gov/webpubs/dggs/mp/oversized/mp008_sh001.pdf, and a shapefile of the hot springs in Alaska is available to download at https://dggs.alaska.gov/pubs/pubs?reqtype=citation&ID=671.

3. Mullane et al. (2016) compiled datasets from three USGS primary sources: Muffler (1979), Reed et al. (1982), and William et al. (2008). This database is available on the Geothermal Data Repository (GDR): https://gdr.openei.org/submissions/842. Mullane et al. (2016) includes only 80 hot springs for Alaska, and Williams et al. (2008) included only 53 hot springs.

The hot springs in Alaska have surface and reservoir temperatures (estimated by geothermometers) between 13°C and 150°C (Fig. 3; Muffler, 1979; Berry et al., 1980; Reed et al., 1982; Motyka et al., 1983; Williams et al., 2008).

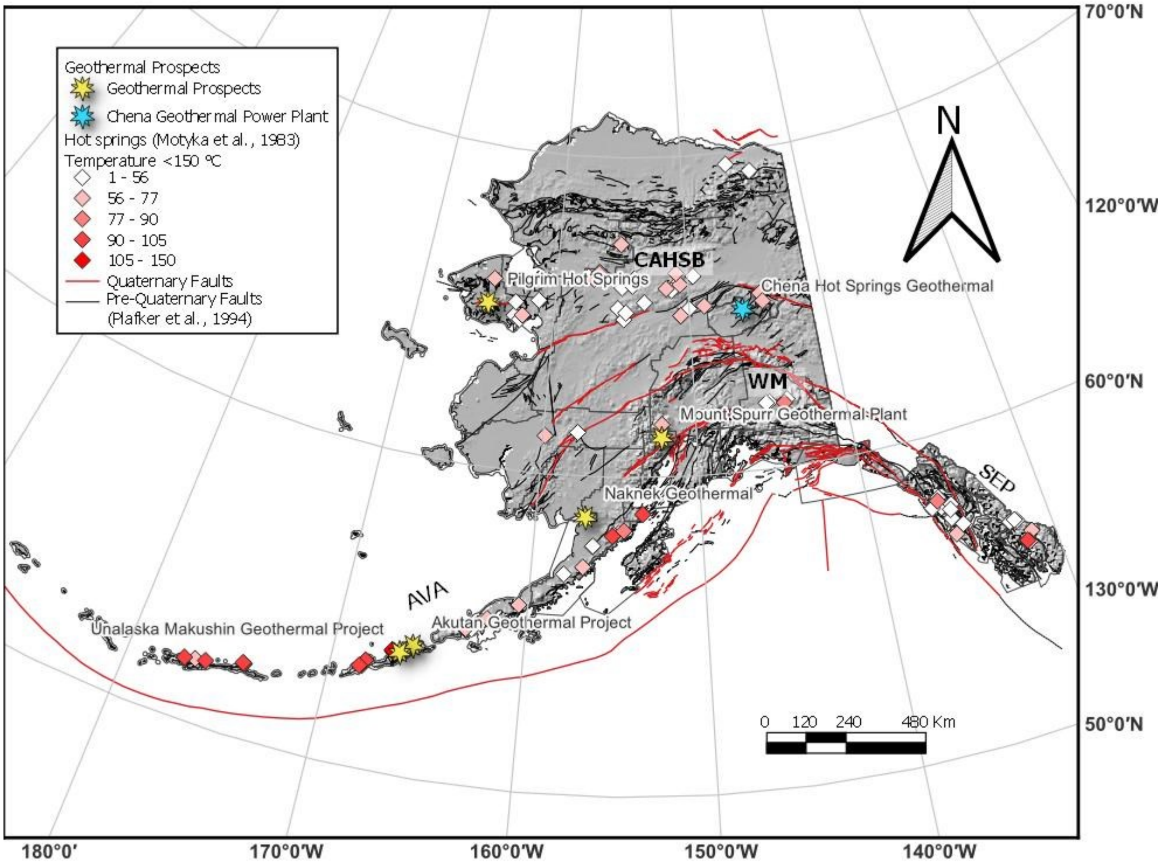

Figure 3: Map of Alaska hot springs (isolated hydrothermal resources) with measured temperatures, Quaternary and Pre-Quaternary faults, and geothermal prospect. CAHSB= Central Alaskan Hot Spring Belt; WM= Wrangell Mountains; SEP= Southeastern Panhandle; AVA= Aleutian Volcanic Arc.

3.2.2 Volcanic Vents and Active Volcanism

Magmatic play systems can be found in Alaska associated with the active volcanism along the Aleutian Volcanic Arc (AVA), and in the Wrangell Mountains (WM) in a convergent tectonic margin (Batir et al., 2016). While other volcanic centers and geothermal systems are in the CAHSB, which is described by Batir et al. (2016) as a partially mantle derived heat flow zone associated with backarc thermal processes (Blackwell et al., 1991; see Fig. 3). In general, Quaternary felsic volcanism is characterized by relatively shallow crustal magma chambers that locally correlate with known geothermal manifestations (e.g., Smith and Shaw, 1975).

This study identified three different datasets of volcanic centers in Alaska:

(1) Motyka et al. (1983) compiled all volcanic vents in Alaska to inform the first Geothermal Resources of Alaska map by the Department of Natural Resources Geological and Geophysical Survey. As noted previously, the geothermal resource map is available at: https://dggs.alaska.gov/webpubs/dggs/mp/oversized/mp008_sh001.pdf, and a shapefile of the volcanic vents is available to download at https://dggs.alaska.gov/pubs/pubs?reqtype=citation&ID=671.

(2) Cameron et al. (2018) created a dataset that lists the historically active volcanoes in Alaska and the year of the last major eruptive event. The dataset was published by the ADGGS, and it is available as ASCII tabular file and shapefile formats at: https://dggs.alaska.gov/pubs/id/30142.

(3) A Global Volcanic database that contains 1,331 volcanoes that erupted during the Holocene period was compiled by the Smithsonian Institution. This database is available in .xml file format and it can be downloaded at the following website: https://volcano.si.edu/volcanolist_holocene.cfm.

3.2.3 Geochemistry Data of Geothermal Systems

We identified only one database of aqueous and gas chemistry as well as water isotope analyses of geothermal systems in the state of Alaska. It was compiled by the ADGGS for the AASG/DOE project, but it is currently being edited. The data will be available in the following formats: web feature service, web map service, ESRI service, and an Excel workbook for download. The workbook contains 12 worksheets, including the individual analyte service layers, information about the template, notes related to revisions of the template, resource provider information, chemistry data, a field list (data mapping view) and a worksheet with vocabularies for use in populating the data worksheet (valid data terms). This information will be available at the website: https://geoportal.dggs.dnr.alaska.gov/portal/apps/webappviewer/index.html?id=28ed3938684448bb8d8fabad2c505e4d.

3.3 Structural Geology, Stress Field, and Geophysics Datasets

In general, non-magmatic geothermal play systems are either fault controlled, or fault leakage controlled (the fluid leaks from structures to permeable strata; Moeck, 2014) and of low to moderate temperature. Understanding structural geology facilitates better interpretation of geophysical data and the selection of favorable settings for drilling (Moeck, 2014). The stress field and reservoir mechanics are crucial elements because the direction of the present stress field affects fluid flow along faults and, ultimately, on the permeability anisotropy in fractured reservoirs (Barton et al., 1995). Dilational or shear dilation faults appear to be the most favorable structures in structurally controlled geothermal systems, and slip-dilation analysis is used to determine the tendency of slip and dilation along faults (e.g., Davalos-Elizondo et al., 2023). Quaternary faults play an important role as pathways and/or storage of geothermal fluids in structurally controlled geothermal systems (e.g., Faulds et al., 2010). A quantitative structural geologic assessment that incorporates 3D structural geological modeling, stress field analysis, and fault stress models are an essential aspect of geothermal field evaluation from exploration drilling to reservoir engineering (Moeck et al., 2009).

The CAHSB is a region of low-temperature geothermal fluids (Kolker, 2008) with a poorly understood tectonic setting due to lack of data. It has been suggested that geothermal activity is related to circulation along backarc faults and radiogenic decay of felsic plutons (Kolker, 2008; Batir et al., 2016). It is necessary to expand the structural geology and geophysical knowledge not only in this region but in other magmatic geothermal systems that also have favorable structures controlling the transport of geothermal fluids to the shallow subsurface and surface.

A variety of datasets were selected to help advance the understanding of structurally controlled geothermal systems in Alaska: (1) Quaternary faults; (2) stress field; (3) seismic data; and (4) geophysical data and models.

3.3.1 Quaternary Faults

In this study we selected a baseline dataset for Quaternary faults (Fig. 3) created by the ADGGS and the Geophysical Institute at the University of Alaska Fairbanks. There is an interactive map that displays locations and relative activity of Alaska's faults and folds. This resource is intended to provide simple and quick means of visualizing structure locations and characteristics that potentially influence geothermal systems. The Quaternary faults dataset is available in a shapefile format. It can be downloaded at the following website: https://dggs.alaska.gov/pubs/id/24956.

3.3.2 Stress Field Data

The orientation and relative magnitudes of tectonic stresses in the state of Alaska can be derived from the World Stress Map Project (WSM; Heidbach et al., 2016). The WSM is a global compilation of crustal stress field magnitudes and directions maintained since 2009 at the Helmholtz Centre Potsdam German Research Centre for Geosciences. The most recent version of this database was released in 2016 and contains 42,870 data records within the upper 40 km of the Earth's crust. The WSM is an open-access public database: https://www.world-stress-map.org/download. It is used in a wide range of Earth science disciplines such as geodynamics, hazard assessment, hydrocarbon, and geothermal exploitations and engineering.

3.3.2 Earthquake Data

Seismic activity is an important tool to identify active faults that may serve as pathways for geothermal fluids. Earthquake catalogues for Alaska are available at the Alaska Earthquake Center website: https://earthquake.alaska.edu/earthquakes.

The most complete seismic database available to download global and national earthquakes information is maintained by the USGS and can be downloaded by a selected geographic region in different formats such as .cvs, .kml, QuakeML, etc. on the following website: https://earthquake.usgs.gov/earthquakes/search/.

3.3.3 Geophysical Data and Models

Magnetic, electromagnetic, and radiometric geophysical data is available at the ADGGS. They provide links to metadata, options for viewing, downloading, and ordering data from the list of airborne geophysical surveys at https://dggs.alaska.gov/pubs/geophysics.

Other geophysical models are available from the National Science Foundation IRIS program. IRIS is an organization made up of more than 125 U.S. universities that operates science facilities for the collection, management, and dissemination of seismological data. We identified three seismic models of Alaska that can be relevant for geothermal exploration:

(1) A 3D shear-wave velocity model of the Alaskan Cordillera from inversion of ambient noise tomography was developed by Ward and Lin (2018). The Alaskan Cordillera's shear wave velocity structure is imaged by using seismic data from earlier ambient noise tomography research. This dataset includes the absolute S-wave velocity structure across Alaska with a depth coverage from 0 to 70 km below sea level, and it can be downloaded at: https://ds.iris.edu/ds/products/emc-alaskaantrfward2018/.

(2) A 3D P- and S-wave velocity model of Alaska from inversion of regional earthquake locations, body-wave data, and surface-wave data was created by Nayak et al. (2020). The dataset includes absolute P- and S- wave velocity structure of Alaska with a depth coverage from 0 to 300 km below earth surface. These data can be downloaded at: https://ds.iris.edu/ds/products/emc-alaska_cvm_akan2020/.

(3) A 3D Tomography Earth Model of shear velocity waves of Alaska via inversion of Rayleigh wave ellipticity was created by Berg et al. (2020). The dataset includes S-wave velocity structure across Alaska, relations of Vp and density to Vs used to constrain Vp and density with a depth coverage from 0 to 144 km below earth surface. These data can be downloaded at: https://ds.iris.edu/ds/products/emc-alaskajointinversion_rfvphhv-1berg2020/.

3.4 Oil and Gas Well Datasets

Drilling and completion expenses can make up 30% to 40% of the entire geothermal project expenditure in a conventional geothermal development, is one of the main challenges of geothermal projects (Leitch et al., 2019). The costs associated with a single-purpose geothermal exploration well are reduced by using existing oil and gas wells to generate geothermal energy. Learning about reservoir and fluid characteristics and other subsurface information when drilling oil and gas wells reduces subsurface uncertainty related to geothermal exploration drilling stages (Watson et al., 2020). Geothermal energy is particularly well suited for use in oilfields because of its base-load generation profile and stable power demands (Wang et al., 2018). Geothermal energy and oil and gas production can work together to provide decarbonization options that generate reliable power and reduces greenhouses emissions (Cespedes et al., 2022). Geothermal can provide electricity to oil and gas operations in remote locations such as Alaska (where connecting to power grids is challenging) and can also be used to generate heat for direct-use applications (Choi et al., 2017).

In this study we identified different useful oil and gas well datasets to update the low-temperature geothermal resources assessment of Alaska and heat flow estimations. These includes: (1) bottom-hole temperatures; (2) thermal conductivity; and (3) water production from oil and gas wells.

3.4.1 Bottom-Hole Temperatures (BHT)

Alaska BHT data (<150°C) and depths of the onshore basins provide information relevant to evaluation of low-temperature geothermal resource potential. Figure 4 shows the distribution of oil and gas wells in Alaska. Note that wells are clustered almost exclusively in the petroleum-rich areas of Alaska's North Slope and Cook Inlet in south-central Alaska. There are a few wells in southwest Alaska (the AK peninsula and the Aleutian Islands) and southeast Alaska, but the dataset is highly skewed toward North Slope and Cook Inlet basins.

The data can be accessed via (1) AASG or (2) the SMU repository. The AASG dataset of the entire U.S. provides BHT recorded from log headers, and includes other information such as well logs, temperature measurements, etc. This dataset was originated for the EGS Site Planning and Analysis project (Augustine, 2013). The dataset can be downloaded from the GDR, where it was cleaned and converted into consistent units across all datasets. The data can be downloaded from https://gdr.openei.org/submissions/252. In this study, we selected only the Alaska BHT data with temperatures <150°C (Fig. 4). This selected dataset contains a total of 311 wells with low temperatures (<150°C) at a variety of depths.

The SMU dataset consists of corrected BHT data from oil and gas wells. We selected data from Alaska (<150°C) with a total of 198 BHT data points. These data are mainly from the work of Batir et al. (2016). The BHTs were corrected with the Harrison Correction (1983) with 10% error associated with BHT points deeper than 600 m (Blackwell et al., 2010; Batir et al., 2016). Additionally, this dataset includes valuable information for evaluation of low-temperature geothermal resource potential in Alaska's onshore basins including temperature gradient from the surface to the BHT depth (°C/km), thermal conductivity, and heat flow values for selected wells (mW/m^2). The BHT datasets can be downloaded from http://geothermal.smu.edu/static/DownloadFilesButtonPage.htm. See Batir et al. (2016) for more information about how these data were processed and compiled.

After analyzing these datasets, we combined both datasets with BHT information to create a database with a total of 509 wells without duplicate data (Fig. 4).

3.4.2 Thermal Conductivity

The thermal conductivity baseline datasets of Alaska were compiled for onshore sedimentary basins in Alaska and include (1) SMU lab measurements and estimates based mainly on the work by Batir et al. (2016); (2) other thermal conductivity values derived from lithological models and correlations from Correlation of Stratigraphic Units of North America (COSUNA; Mendenhall 1905, Miller 1951, Magoon and Claypool 1981); and (3) published data sources (Gallardo and Blackwell, 1999; Batir et al., 2013). Thermal conductivity values derived from stratigraphic models have an expected error of 10%, while thermal conductivity measurements of rock samples have errors below 5% (Gallardo and Blackwell, 1999; Batir et al., 2016). See Batir et al. (2016) for more information about how thermal conductivity was estimated for this dataset. This dataset can be downloaded from https://gdr.openei.org/submissions/252.

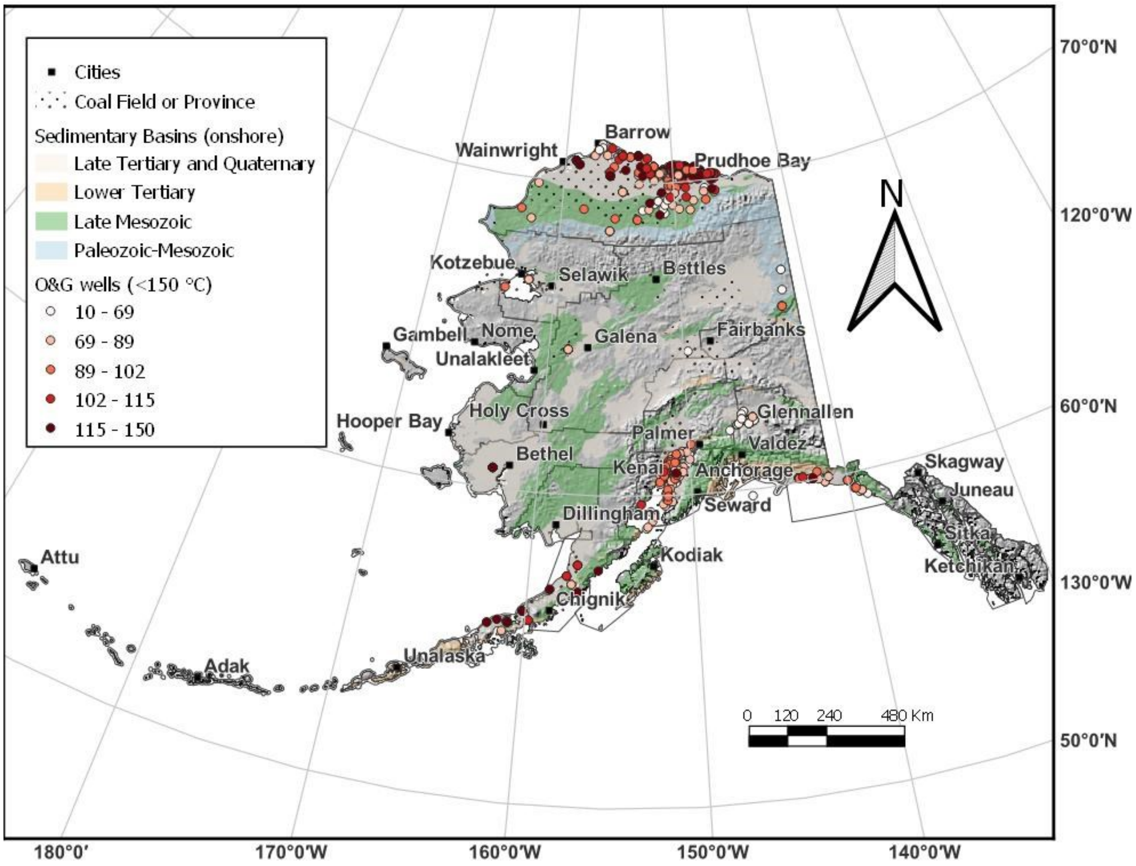

Figure 4: Map of onshore sedimentary basins of Alaska and oil and gas wells showing BHT of <150°C.

3.4.3 Water Production from Oil and Gas Wells

Water production data from oil and gas wells can be used as a proxy for permeability, which is a key factor in resource assessment of natural geothermal reservoirs. Water production data provides information about the natural reservoir quality of rocks (i.e., their ability to maintain sufficient fluid flow rates between injection and production wells to mine heat from reservoir rocks).

The baseline database of water production from oil and gas wells in Alaska identified by this study are: (1) USGS database of aggregated oil and natural gas drilling and production history of the U.S., and (2) AOGCC produced water data.

The USGS dataset provides an overview of the production history of all U.S. wells from 1817 to 2020. The USGS database was built from data compiled by IHS Markit, a commercial database. The production data is aggregated in 2- to 10-square-mile-increments that sum the total production of oil, gas, and water volumes. The dataset is available from https://www.sciencebase.gov/catalog/item/632b67a5d34e900e86c509ce.

The Alaska Oil and Gas Conservation Commission is a public dataset that provides daily updates of oil and gas well history, production, and injection. The datasets consist of water volume production pre-2000 and post-2000 per well. It is available from: https://www.commerce.alaska.gov/web/aogcc/Data.aspx.

3.5 Heat Flow and Curie-Point Depth (CPD) Datasets

Developing geothermal resources on a global scale requires developers to have access to regional information on geothermal potential. Heat flow is an important factor in early geothermal exploration stages that reveals areas where large-scale heat transport is occurring. If a significant portion of heat transport is due to convection through magma or water, high heat flow values are observed, creating a surface manifestation of heat storage in the Earth (Prol-Ledesma and Moran-Zenteno, 2019). Determination of the geothermal potential of each region is highly dependent on the heat discharge values related to the Earth's heat flow. Heat flow maps are extremely useful to identify areas of high geothermal resources potential in a particular region or country (Blackwell et al., 2007; Prol-Ledesma and Moran-Zenteno, 2019).

Heat flow measurements are scarce in Alaska; published heat flow maps of the region include data calculated from BHT in wells (e.g., Blackwell and Richards, 2004; Batir et al., 2013; 2016). Other methods such as Curie-point depth (CPD) have been used to calculate heat flow in other regions of the world when BHT data is scarce (e.g., Tanaka et al., 1999; Li et al., 2017). An estimate of the geothermal gradient can be determined by the difference between 580°C and the average ambient surface temperature divided by the modeled depth to the Curie-point temperature (i.e., CPD is the depth where the temperature is 580°C). The CPD is calculated with spectral analysis of magnetic anomaly data. Magnetic data are available for much of Alaska, allowing for an estimate of geothermal gradient to be determined across the state.

However, CPD methods to estimate heat flow have shown ambiguity in some cases related to factors such as thermal conductivity and heat generation constraints, variations on radioactive heat production, heat transfer from active volcanism or groundwater circulation, etc. (e.g., Okubo et al.,1989; Bouligand et al., 2009).

To calculate heat flow temperature as a function of depth, it is required to estimate a geothermal gradient, and the thermal conductivity that depends on the lithology. The following equation was used to estimate the heat flow:

$$Q = dT/dz * K \qquad (2)$$

where Q is the heat flow (mW/m^2), dT/dz is the geothermal gradient (°C/Km), and K is thermal conductivity (W/m * K).

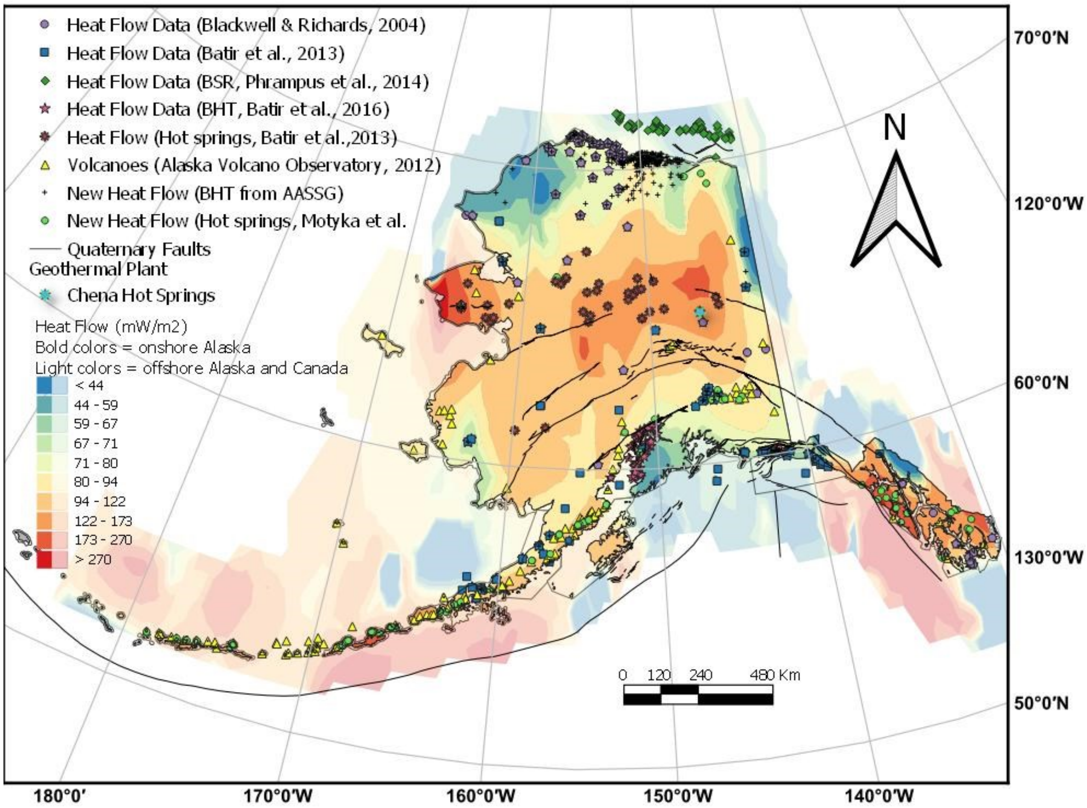

Figure 4: Updated heat flow map of Alaska modified from Batir et al. (2016). New heat flow values from 311 bottom-hole temperature data points by AASG and 72 hot springs by Motyka et al. (1983) were added to this version.

3.5.1 Heat Flow Datasets

The most recent heat flow map from Alaska was updated by Batir et al. (2016). The dataset is available at the SMU repository at https://gdr.openei.org/submissions/252. Batir et al. (2016) used 249 new locations to update the latest version of the heat flow map (Table 1) from Batir et al. (2013) and Blackwell and Richards (2004, HFMAK). They calculated the geothermal gradient from equilibrium temperature logs, previously published gradient values, bottom simulating reflectors from seismic data (Phrampus et al., 2014), and BHT data from oil and gas well logs. Batir et al. (2016) used volcanoes and hot springs to contour areas of scarce data such as the CAHSB region that indirectly indicate above average heat flow, and Quaternary faults were assumed to be geothermal boundaries.

Table 1. Heat flow data for Alaska from Batir et al. (2016).

Data Type	Total Data Points	Standard Error	Reference
Heat Flow Data	61	Variable	Blackwell & Richards (2004)
Heat Flow Data	63	Variable	Batir et al. (2013)
Heat Flow Data from Bottom Simulating Reflectors	63	±27%	Phrampus et al. (2014)
Heat Flow Data (BHT)	172	±30%	Batir et al. (2016)
Hot Springs	36	Variable	Motyka et al. 1983
Volcano	136	Variable	Alaska Volcano Observatory, 2012

In this study we identified a total of 313 new corrected BHT data from AASG (see Section 3.4.1; Fig. 5) that could be used to update geothermal gradients and heat flow of Alaska, as well as 72 hot springs from Motyka et al. (1983) that were not used by Batir et al. (2016) to update the heat flow map. The thermal conductivity could be assigned using the stratigraphic model based on the measurements and estimations of different regions by Batir et al. (2016), as well as the mean annual temperature.

Fig. 5 shows an updated heat flow map using information from Batir et al. (2016) and new BHT data from AASG and hot springs that were not used before, within a total of 952 heat flow data points. There are not great differences between this new map and the heat flow map by Batir et al. (2016). The minor variations could be related to the type of interpolation used in this study. The data show variable heat flow ranging from above 270 mW/m^2 to below 44 mW/m^2. The new hot springs data in the interior of Alaska (CAHSB) support the continuation of high heat flow and high variability in heat flow values. Hight heat areas show similarities to the Batir et al. (2016) map – specifically when looking at the CAHSB, AVA, and Southeastern Panhandle (SEP) regions.

3.5.2 Curie-Point Depth Dataset

A global CPD model was published by Li et al. (2017) using a robust inversion algorithm and magnetic anomaly inversion based on fractal magnetization. The CPD dataset was available after request to the authors of this research. The paper can be downloaded from: https://www.nature.com/articles/srep45129#Sec12.

Fig. 6 shows CPD gradient estimations from Alaska with maximum values of ~74°C/km in the CAHSB, WM, and SEP region and minimum values of ~15°C/km in the north region. High geothermal gradients are shown in regions including the CAHSB, WM, and SEP. The CPD shows some discrepancies, with low geothermal gradients in the AVA region where high geothermal gradient values are expected due to the active volcanism in that region (Batir et al., 2016). Through a crustal-scale estimate, geothermal gradients estimated from CPD show higher geothermal gradients values in the CAHSB and SEP regions similarly to the updated heat flow map (Fig. 5) of Batir et al. (2016).

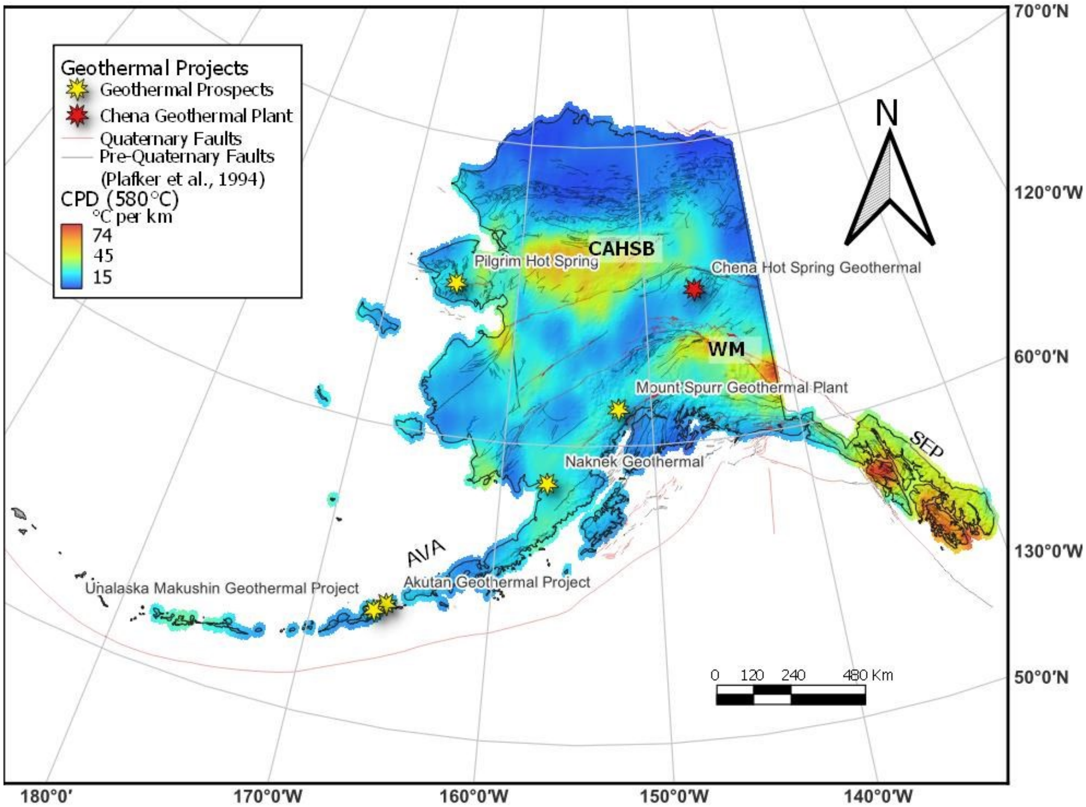

Figure 6: Curie-point depth gradient °C/km in Alaska. CAHSB= Central Alaskan Hot Spring Belt; WM= Wrangell Mountains; SEP= Southeastern Panhandle; AVA= Aleutian Volcanic Arc.

4. LOW-TEMPERATURE GEOTHERMAL RESOURCES IN ALASKA: A PRELIMINARY ESTIMATE FROM THE GEOREPORT RSAT TOOL

In this work we identified new data from three different datasets of isolated geothermal systems in Alaska and BHT data from oil and gas wells that can be leveraged for evaluation of low-temperature geothermal resource potential. A total of 112 isolated hydrothermal systems (<150°C) from different datasets (e.g., Motyka et al., 1983; Mullane et al., 2016; Williams et al., 2008) at depths between 0 to 1 km were used to update isolated geothermal resources of Alaska (Table 1). Williams et al. (2008) reported 53 geothermal systems for moderate- to high-temperature geothermal resource assessment, and Mullane et al. (2016) used 80 isolated systems within Alaska to estimate low-temperature geothermal resource potential. Additionally, a total of 509 BHTs (<150°C) from SMU and AASG with depths of 350 to 5,700 meters were used in this work to estimate low-temperature geothermal energy recovery resources from oil and gas wells in Alaska (Table 2).

To estimate low-temperature resources of isolated hydrothermal systems and contained in oil and gas wells of Alaska, we used the Geothermal Resource Portfolio Optimization Reporting Technique (GeoRePORT) Resouce Size Assessment Tool (RSAT) developed by NREL (Rubin et al., 2022). GeoRePORT is a geothermal resource reporting tool based on the concept that a geothermal system can be defined in terms of the quality of geothermal resource potential and progress of the research of the specific project (Rubin et al., 2021). The RSAT module of the GeoRePORT tool allows users to make early-stage estimates of the size of a geothermal project (in MWe and/or MWth) from user-input resource information. The estimates provided by the RSAT are simplified outcomes using published methods and are not comparable to detailed resource analyses performed by engineering professionals, and not a substitute for detailed numerical reservoir modeling. RSAT implements three commonly used methods: the volumetric heat-in-place method (Williams et al. 2008), the power density method (often used by geothermal companies) (Wilmarth and Stimac 2015), and estimation of the supplied heat from the fluid flow rate (Rafferty 2004). For the purposes of this study, we applied the volumetric method only.

The volumetric method was originally developed by Nathenson (1975), White and William (1975), Muffler and Cataldi (1978), and Muffler et al. (1979), and it has been widely used in geothermal resource assessments (Williams et al., 2008). This simple heat-in-place methodology for estimating geothermal resources potential breaks down the reservoir into volume of rock, heat energy storage in the rock, and how much heat will be extracted over a certain amount of time. The volumetric method used the following calculations:

The accessible resource base or mean thermal energy q_R is the total thermal energy present in the reservoir (William et al., 2004):

$$q_R = pCV\,(T_R - T_{ref}) \tag{3}$$

where pC is the volumetric specific heat of the reservoir rock and porosity (2,680 kJ/m^3/°C), V is the volume of the reservoir, T_R is the characteristic reservoir temperature, and T_{ref} is the mean annual surface temperature (0°C for Alaska; however, in this study we use 1°C to avoid multiply-by-zero errors in calculations).

To determine the amount of energy that could be extracted by power plant or utilized for direct uses, the accessible resource base is multiplied by recovery factors that account for the amount of heat that can be recovered at the wellhead (Sorey et al., 1983; Rubin et al., 2021). Resource determinations based on this resource calculation do not depend on the time scale over which development occurs (Sorey et al., 1983).

$$q_{wh} = R_g * q_R \tag{4}$$

where R_g is a recovery factor of the reservoir (how much of the heat can be recovered to be used at the surface).

The beneficial heat q_{ben} is the thermal energy applicable directly to a specific application not intended for electrical use. The following methodology of Nathenson and Muffler (1975) was used to calculate the beneficial heat for isolated systems >10°C and <150°C in Alaska:

$$q_{ben} = pCV*Rg * 0.6\,(T_R - T_{ref}) \tag{5}$$

where R_g is a recovery factor, pC is the volumetric specific heat of the reservoir rock and porosity (2680 kJ/m3/°C), V is the volume of the reservoir, T_R is the characteristic reservoir temperature. The constant 0.6 is a value obtained from an empirically derived line for effective temperature drop as a function of reservoir temperature for various direct use applications (Reed, 1982).

For estimating the amount of the accessible resource base that can be converted to power, the GeoRePORT tool used the following equation by Pocasangre and Fujimitsu (2018):

$$P = (q_R * R_g * C_e) / (P_f * t * 3.154 * 10^{10}) \tag{6}$$

where P is the size of the power plant in Mwe (megawatts-electric); Ce is the conversion efficiency of the plant being used to capture the energy; P_f is the percentage of time a plant may be used to produce electricity throughout the year, the power factor or capacity factor; and t is the economic lifetime of the plant, and 1 year= 3.154 * 10^{10} seconds (Rubin et al., 2021).

For estimating the amount of accessible resource base that can be utilized as heat in MWt (megawatts-time), the following equation was used by the GeoRePORT (modified from Reed, 1982):

$$H = (q_R * R_g * E_{e)} / (L_f * t * 3.154 * 10^{10}) \tag{7}$$

where H is the resource size in MWt, E_e is the effectiveness of the heat exchange process while moving heat from the geothermal brine to the intended usage; L_f is the load factor or the percentage of the year that heat will be delivered/under demand (Rubin et al., 2021).

In this study most of the isolated reservoir volumes in Alaska have been assumed to be minimum 0.5 km^3 and maximum 3 km^3 (Williams et al., 2008). Previous work has used Rg values of 0.08 and 0.2 (Garg and Combs, 2015). Williams et al. (2008) used a Rg of 0.1 for fractured reservoirs at the Geysers and Coso geothermal fields, whereas a Rg of 0.25 was used by Muffler et al. (1979) in USGS Circular 790. However, 0.25 recovery factor was found to be too high in most cases (Grant, 2014). We used a recovery factor of 0.08, a default value for binary plants used by the GeoRePORT tool (Rubin et al., 2021). GeoRePORT used default values for recovery factor, conversion efficiency, power factor, and plant lifetime based on the type of power plant used and assumptions from published data.

The GeoRePORT tool uses probability calculations to determine a range of possible resource size outcomes. Each of the above equations is subjected to statistical Monte Carlo analysis. To reflect the uncertainty inherent in many input values, each parameter in the equation is given some kind of probability distribution, either chosen by the user or used as a default value (GeoRePORT calculates a default of 1,000 iterations; Rubin et al., 2021).

The results of estimated resources of 112 isolated hydrothermal systems in Alaska, using the GeoRePORT tool, are shown in Table 2, whereas the results of estimated resources from 509 isolated oil and gas wells are shown in Table 3. All electric and direct-use applications are calculated on a basis of 30 years of production. P90 represents a 90% probability chance (high degree of confidence) that actual value will be at least the amount tabulated; other probability percentages are defined similarly. N is the number of identified geothermal systems.

Table 2. Electric power generation potential in megawatts-electric (MWe) and heat potential for direct-use "space heating" in megawatts-time (MWt) from identified low-temperature isolated hydrothermal systems in Alaska.

Low-Temperature Isolated Hydrothermal Resources									
		Power Resources (MWe)				Direct Use "Space Heating" (MWt)			
Region	N	P90	P50	P10	Mean	P90	P50	P10	Mean
Aleutian Island and Peninsula	38	125.35	262.35	546.94	311.54	6236.75	13105.9	27384.16	15575.60
Central Alaska	20	15.3	33.82	74.63	41.25	1284.11	2754.2	5875.56	3304.62
North-Central Alaska	26	75.47	159.45	340.93	191.95	3502.72	7521.42	16076.83	9033.65
South-Central Alaska	11	14.42	31.35	67.05	37.60	856.78	1868.37	3903.25	2209.46
Southeastern Alaska	17	49.36	106.38	224.51	126.75	2359.99	4970.79	10565.34	5965.37
TOTAL	**112**	**279.9**	**593.35**	**1254.06**	**709.10**	**14240.35**	**30220.68**	**63805.14**	**36088.72**

Table 3. Electric power generation potential in megawatts-electric (MWe) and heat potential for direct-use "space heating" in megawatts-time (MWt) from identified low-temperature geothermal energy recovery resources form oil and gas wells of Alaska.

Low-Temperature Geothermal Energy Recovery Resources from Oil and Gas Wells									
		Power Resources (Mwe)				Direct Use "Space Heating" (MWt)			
Region	No.	P90	P50	P10	Mean	P90	P50	P10	Mean
Aleutian East	14	12.74	27.18	56.29	32.07	654.24	1381.72	2889.31	1641.75
Bethel Census Area	7	5.99	12.63	26.57	15.06	310.67	650.68	1382.03	781.13
Kenai Peninsula	59	41.07	88.54	186.05	105.22	2527.75	5335.67	11140.66	6334.69
Lake and Peninsula	17	15.58	32.88	67.87	38.78	764.85	1599.1	3335.85	1899.93
Matanuska-Susitna	12	7.83	17.18	36.13	20.38	498.18	1066.07	2223.83	1262.69
North Slope	293	291.12	620.58	1295.06	735.59	14432.09	30616.61	64033.57	36360.76
Northwest Arctic	6	2.96	6.41	13.3	7.56	214.68	454.87	947.77	539.11
Valdez-Cordova Census Area	71	21.28	50.35	112.31	61.31	2273.76	4810.14	10076.83	5720.24
Yakutat City	15	6.54	14.28	30.87	17.23	513.71	1102.52	2292.19	1302.81
Yukon-Koyukuk Census Area	15	5.6	12.87	28.39	15.62	518.45	1102.16	2311.67	1310.76
TOTAL	**509**	**410.71**	**882.9**	**1852.84**	**1048.816667**	**22708.38**	**48119.54**	**100633.71**	**57153.87667**

5. CONCLUSIONS AND FUTURE WORK

The U.S. Department of Energy Geothermal Technologies Office is supporting the Geothermal Heating and Cooling Geospatial Datasets and Analysis project conducted by the NREL. This is part of a broader effort to demonstrate the multi-faceted value of integrating geothermal power and geothermal heating and cooling/exchange technologies into national decarbonization plans and community energy plans. This paper presents an inventory of available datasets that could support the establishment of a baseline low-temperature geothermal resource geodatabase for Alaska. The compiled baseline datasets can be used to generate favorability maps, develop play fairway analysis methods, and update the low-temperature geothermal resources assessment of Alaska, including enhanced geothermal systems resources. The future work of this project will consist of a refining selection of relevant datasets and identification of important gaps for low-temperature play fairway analyses and developing methodologies for sedimentary basin, radiogenic, and orogenic geothermal play types.

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