Low-Temperature Geothermal Energy Characterization by Play Fairway Analysis for the Appalachian Basin of New York, Pennsylvania and West Virginia

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Keywords

Play Fairway Analysis, geothermal direct-use, low temperature, reservoir analysis, BHT, geothermal energy utilization

ABSTRACT

Direct-use of geothermal energy in the Appalachian Basin has the potential to offset a considerable amount of fossil-fuel-supplied heat. Currently, the risks associated with potential projects are broadly unknown. This project aims to assess the risks of developing direct-use geothermal energy in the Appalachian Basin through: 1) organization of data into Play Fairways, 2) quantification of geological, thermal, and utilization characteristics and uncertainty, 3) estimation of region-wide levelized cost of direct-use heat, and 4) identification of additional data collection needs beyond what are currently available. Successful completion of this project will provide a tool to aid decision makers in selecting areas that seem initially favorable to low-temperature geothermal projects. As it is only 6 months into the project, the final analysis of risk factors and resulting maps showing the most favorable areas with low-temperature geothermal resources for direct-use-heat applications in the Appalachian Basin of New York, Pennsylvania, and West Virginia will be presented at the GRC Annual meeting and published as part of this Department of Energy Project DE-EE0006726 Final Report in Fall of 2015.

Introduction

The goal of this project is to develop common risk segment (CRS) maps to illustrate areas of high potential for low-temperature geothermal resources most favorable for direct-use-heat applications in a significant portion of the Appalachian Basin. This analysis is for a subsurface system consisting of several kilometers of Paleozoic sedimentary rocks overlying Grenville basement in New York, Pennsylvania, and

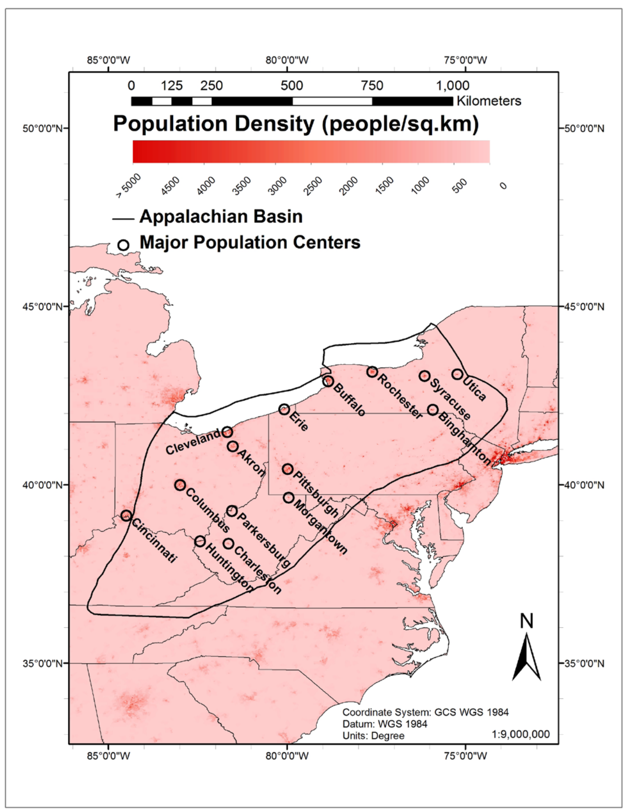

Figure 1. Map of Appalachian Basin displaying major population centers (> 5000 people/sq.km). The project area is a subset of the basin within the states of New York, Pennsylvania, and West Virginia. Given a target of low-temperature direct-use resources, demand locations must coincide with favorable geological and thermal conditions. Population is one factor that underlies the distribution of heating demand.

West Virginia (Figure 1). Major zones of accessible geothermal play area are being identified and evaluated using existing data, based on the co-location of favorable thermal resource, porous sedimentary rocks, end-users, and associated risk factors. The intent is to identify regions with higher likelihood for viable direct-use geothermal projects, coincident with stakeholders in the region who will be able to use the accessible resources. The primary technical objective is to utilize existing data of various types to define Geothermal Play Fairways. A secondary objective is the development of a robust common risk assessment methodology that could be applicable in other sedimentary basins to assess low temperature, direct-use geothermal plays.

The quantitative method of ranking potential geothermal resources and their uncertainty is based on the concept of CRS maps. The data used to define the fairways include information sources from the National Geothermal Data System (NGDS), USGS and State Geological Surveys (PADCNR, WVGES, NYSGS), EarthScope, AAPG COSUNA, Midwest Regional Carbon Sequestration Partnership (MRCSP), and Energy Information Agency (EIA). Examples of data types include petroleum industry well logs, production reports, thermal data, reservoir parameters, and seismic reflection profiles, as well as data from many sources for seismicity, gravity, magnetics, and faults. The data are assessed for spatial and depth distributions and used to develop a set of Risk Factors (RFs) that will be used to determine the plays of the highest potential for successful direct-use geothermal development within the Appalachian Basin. The RFs encompass the geothermal and geological resources, geologic features expected to impede utilization of the resources, proximity of the resources to energy markets, ownership of land, and regulations, such as permitting and environmental constraints on development. Specifically these RFs are: 1) thermal quality, 2) natural reservoir quality, 3) potential for induced seismicity, and 4) potential for utilization of thermal resources.

Representing the RFs spatially as CRS maps provides the ability to rank and visualize the risk factors, paralleling the petroleum industry's Play Fairway ranking categories of low to high risk (e.g., Green/Yellow/Red, Figure 2). The collective Play Fairway ranks will be produced by the merging of the individual risk factor maps by means of a risk matrix. The risk matrix can account for potential preferences of the decision maker and uncertainty in the individual risk factors. There are steps taken within each of the risk factors to assess how the parameters will impact the other risks. For instance, if a particular heat exchange technology functions only above a specific temperature, then the thermal resource may be of zero value below that temperature (a solid red) but has a gradually improving value across higher temperatures (and a gradation in risk "colors" from yellow to green). The final analysis identifies the most promising Geothermal Play Fairways for the region of the Appalachian Basin in NY, PA and WV for direct-use applications.

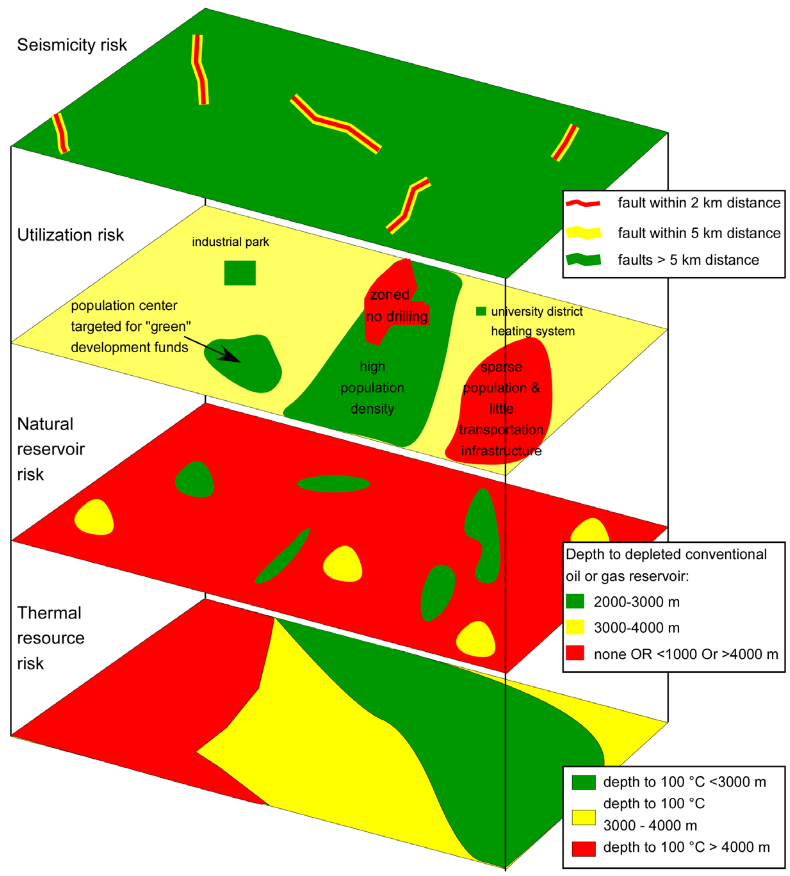

Figure 2. Cartoon illustrating layering of the four primary risk factors associated with mapping the collective risk of geothermal development.

Risk Factors

The following is a description of the data used in developing a map for each risk factor. There are four primary risks studied: thermal resource quality, natural reservoirs, potential for induced seismicity, and surface utilization. Those factors are analyzed individually and in combination to illuminate the overall risk. The project goal is restricted to the states of New York, Pennsylvania and West Virginia, but geological data for a fringe zone (50 km) in the adjacent states is incorporated in several steps in order to avoid distortions of spatial trends due to unnatural edge effects.

Risk Factor 1

The thermal resources are evaluated using oil and gas bottom-hole temperatures (BHTs), equilibrium temperature data (Spicer, 1964), and thermal conductivity estimates. The thermal data for the three states and 50-km-wide strips of neighboring Appalachian Basin states have been merged. For quality control reasons, wells with no record of the depth at which temperature data were collected and wells shallower than 1000 m have been excluded, resulting in approximately 13,800 temperature-at-depth records for the project study area. Temperature measurements shallower than 1000 m are excluded to increase the temperature–depth measurement accuracy. For this project, recently developed BHT correction equations (Whealton, 2015) for New York and Pennsylvania were refined and a new BHT correction equation for West Virginia was devised. Additionally, a computer program was refined to calculate the surface heat flow and temperatures at depths of interest using the corrected BHTs, lithologic thicknesses, thermal conductivities, mantle heat flow, and radiogenic heat generation.

Risk Factor 2

The second risk factor relates to the quality and location of existing natural reservoirs. The purpose of this effort is to use previously acquired data to populate reservoir properties for geologic formations that are potentially favorable for implementing low-temperature geothermal systems. This risk factor builds on the earlier work in the oil and gas industry as well as on assessments for potential carbon sequestration in the Appalachian Basin (Midwest Regional Carbon Sequestration Partnership, 2014). The inclusion of these data sets enhances the team's ability to assess potential reservoirs that are suitable for geothermal development. Data were compiled based on the producing formation and what is known of the reservoir quality, including rock volume, porosity, permeability, reservoir pressure, and depth. Sparse permeability data are extrapolated to reservoirs of similar geology, with considerable added uncertainty. All of these data will be used to understand ranges of achievable flow rates for each of these reservoirs, to better quantify their economic feasibility.

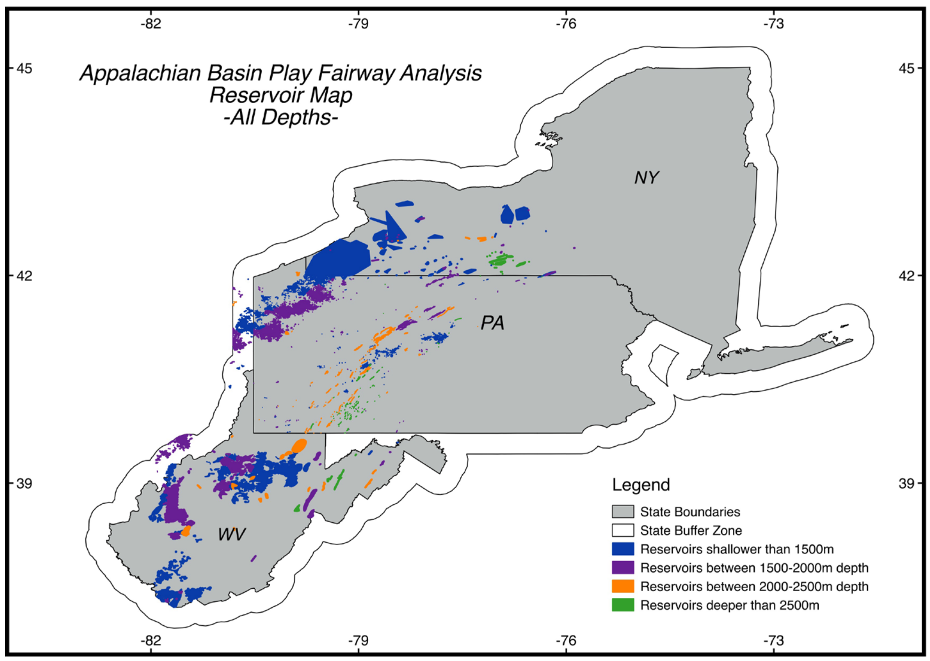

Figure 3. Complete map of potential reservoirs in NY, PA, and WV (with some included from OH). Each color indicates a different depth range. The buffer zone, shown in white, is an equidistant border around our study area to allow for more accurate spatial interpolation in other risk factor maps.

Risk Factor 3

The possibility that a low-temperature direct-use geothermal project induces seismicity is a significant risk for the success of future projects. A necessary step in quantifying seismic risk from pumped geothermal fluids is to locate faults, which commonly act as zones of persistent weakness. The knowledge of the spatial distribution and activity of faults is inconsistent across the Appalachian Basin. A more comprehensive and consistent set of lateral contrasts in rock properties, some of which coincide with fault locations, will be mapped by analysis of potential field data (gravity and magnetics). To accomplish this sub-task, pre-existing gravity and magnetic data are used to form a multi-scale edge representation map, which is part of the CRS map for this risk factor (Horowitz et al., 2015; Horowitz et al., 2000). The potential fields, in combination with data from seismic cross sections, allow for the identification of deep basement faulting and lithologic boundaries. Historic and present earthquake locations are used to aid in identifying potentially active faults in the region. The recent EarthScope Traveling Array data allow location of lower magnitude earthquakes than previously possible. The last source of geophysical information is a small number of seismic reflection profiles that are in the public domain. In combination with published geological maps and cross sections, these sets of geophysical information allow for the initial identification of fault length and orientation to the stress field. A later step will be to analyze the directions of faults whose orientations in the regional stress field make them most susceptible to reactivation if fluid pressure changes.

Risk Factor 4

Risk Factor four relates to the ability to utilize the geothermal heat resource based on the heating demand of population centers and industries. The first step in this analysis is to map out the potential places with intense energy demand in NY, PA, and WV using the population density and climate factors at a census tract level for estimating yearly energy demand. The population density in this study is calculated from the 2010 U.S. Census tract TIGER data, and the climate is estimated using historical average ambient temperature data from 1950 to 2000 (Hijmans et al., 2005). The process of determining utilization builds on the previous work of Reber et al. (2014), which performed an analysis of heating demand in New York State by using GEOPHIRES (Beckers et al., 2013). Using the thermal resource and the reservoir analysis from risk factors one and two, the utilization will incorporate additional parameters such as energy demand, surface temperature, price of conventional heat fuels, and land ownership to select candidate places for technical and economic case studies. The model uses data from our study and other known relationships to determine the levelized cost of heat (LCOH).

Overall Risk

Risk Matrix Analysis is used to analyze the consequences of the four risk factors. The Risk Matrix reveals the overall project risk based on the accumulated and potentially compounded risks. This step involves assigning relative weights to components of the risk layers (Figure 2) and developing appropriate relationships that result in one final map, which will highlight the most promising Play Fairways within the Appalachian Basin in New York, Pennsylvania and West Virginia to develop low-temperature direct-use geothermal projects. Further, more detailed analysis will focus on the six most favorable plays within the region. This methodology should be adaptable to other projects within the greater Appalachian Basin as well as to sedimentary basins in general to assess low temperature, direct-use geothermal plays.

Discussion

This Appalachian Basin regional assessment includes detailed geological, geothermal, and geophysical properties to identify plays with the highest thermal potential in New York, Pennsylvania, and West Virginia. The best plays will be those with the lowest composite risk for developing and utilizing low-temperature direct-use geothermal systems. A more detailed evaluation of the risk factors at a project-scale will be presented for these plays in the final report to the DOE.

Methodologies used in previous thermal resource evaluations in the Appalachian Basin (e.g. Smith et al., 2014; Aguirre, 2014; Blackwell et al., 2011; Frone and Blackwell, 2010) were merged into a uniform numerical approach. In developing this uniform approach, errors in previous thermal modeling studies (Stutz, 2012; Stutz et al., 2012) were identified and corrected.

Previous studies have typically used one empirical BHT correction equation for the region of study (e.g. Harrison Correction) to account for thermal disturbances caused by the drilling process. Recent work by Whealton (2015) shows that separate BHT corrections for the Allegheny Plateau of New York and Pennsylvania, the Rome Trough of Pennsylvania, and West Virginia are statistically justified. We adopted these corrections equations an incorporated them into the geothermal resource assessment for this study. The corrected BHTs are then used, along with lithologic information, in a 1D-steady-state conduction model to calculate the surface heat flow and temperature at depths of interest. Statistical and geostatistical methods are applied to the computed values in order to scan for and remove spatial outliers, interpolate a surface of the predicted mean thermal resources, and analyze the spatial variability in the variations of the thermal resource data by physiographic provinces (Smith et al., 2014). Mapping the spatial variation of the standard error of the predicted mean thermal resource throughout the region provides insight for propagating the uncertainty of spatial thermal resource prediction through the Risk Matrix and the composite risk map.

This study focuses only on the coincidence of naturally favorable reservoir qualities with favorable thermal resources, avoidance of a subset of faults, and promising opportunities for utilization. The potential to produce low-temperature geothermal resources from these rocks using stimulation techniques to enhance reservoir flow is real and might greatly alter the regional risk patterns. However, consideration of stimulation is not within the scope of this project.

Conclusion

This project opens the door to opportunities for geothermal low-temperature direct-use applications in the Appalachian Basin. The ability to narrow the focus to zones where the combined risk is low allows investors and the state and local governments to make better grounded decisions regarding geothermal development.

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