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Texas' geothermal resource base: A raster-integration method for estimating in-place geothermal-energy resources using ArcGIS

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ABSTRACT

The large sedimentary basins of Texas have been and are currently the subject of intensive petroleum exploration and production. The Gulf Coast, East Texas, the Anadarko Basin, and West Texas have all produced significant volumes of both oil and gas. Many of the fields and reservoirs within these basins are now mature or reaching the end of their productive lives and present an opportunity for these deep formations to be transitioned from petroleum production to geothermal-energy production using the existing infrastructure and the legacy of geologic information created by the oil and gas industry.

The Gulf Coast and the Anadarko Basin have previously been analyzed for thermal energy in place, although formations in East and West Texas have not. A problem lies in the fact that previous studies may have overestimated thermal energy by employing a more simplistic method, in which a basin is split into one or more uniform-temperature blocks for which thermal energy in place is calculated. This is overcome in the present study by using ArcGIS to create a maximum extractable depth raster for both maximum well depth and maximum extractable depth in regions of Texas. The thermal energy in place is then derived through integration of the geothermal gradient raster over the block volume defined by the maximum depth raster to estimate thermal energy in place. A reference temperature of 93 °C (200 °F) is used.

The results of this methodology indicate that 1.66E + 23 Joules (2.71E + 13 bbl oil equivalent) reside in place in Texas that is accessible using existing wells. Regionally the Gulf Coast contains 3.20E + 22 Joules (5.24E + 12 bbl oil equivalent), East Texas contains 4.04E + 22 Joules (6.60E + 12 bbl oil equivalent), West Texas contains 1.42E + 22 Joules (2.32E + 12 bbl oil equivalent), and North Texas contains 4.20E + 21 Joules (6.87E + 11 bbl oil equivalent).

1. Introduction

The possibility of wide-scale geothermal power production has been revisited recently because of escalating demand for renewable and domestic energy sources in the United States. This renewed interest is driven by several reinforcing factors, including regulatory pressure to reduce carbon dioxide emissions from fossil-fuel-fired power plants, especially coal plants, and improvements in drilling technology and thermal-to-electrical-energy conversion technologies that make moderate-temperature geothermal resources attractive. Nationally, 50 GW_e or more of coal-fired capacity will probably need to be retired in the next 15–25 years owing to environmental concerns, along with 40 GW_e of existing nuclear capacity (Tester et al., 2006).

Differentiating between the conventional view of geothermal energy and that of geothermal energy developed from deep, permeable, sedimentary formations that contain brines heated by the natural heat flow from Earth's interior is important. The Earth's crust, mantle, and core constantly generate heat. This heat flows outward toward the surface of the Earth 24 h a day, 7 days a week, 365 days a year, and it is sustainable and renewable under any definition currently in use today. Conventional geothermal-energy development has focused on areas such as Iceland, The Geysers, California, and Wairakei, where hot volcanic rock or magma is close enough to the surface to generate large volumes of hot water or steam that can be used directly to power steam turbines that drive electrical generators. Geothermal-energy development also exists in areas such as Dixie Valley, Nevada where fault-controlled, deep-circulation systems produce geothermal fluids (Waibel, 1987).

Conventional geothermal-energy production is geographically limited by locations where circulating groundwater reaches

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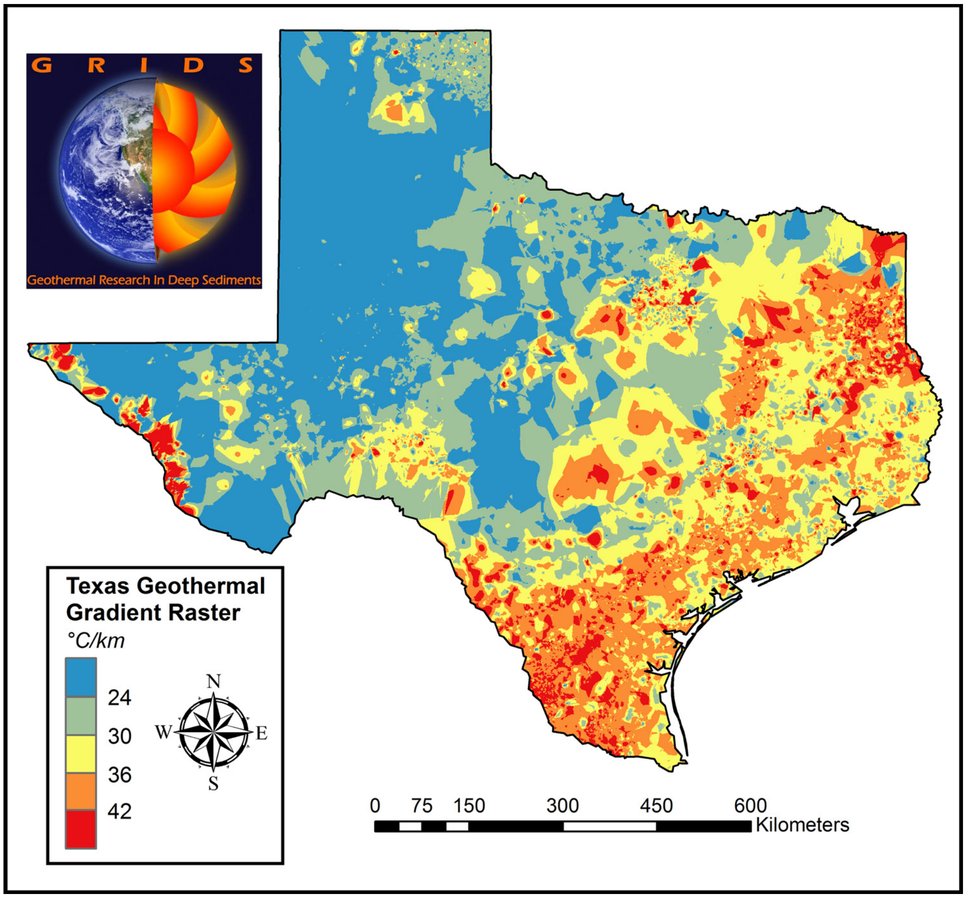

Fig. 1. The geothermal gradient raster of Texas (Zafar and Cutright, 2012).

relatively shallow depths. A viable source of energy, it produces over 10 gigawatts of power in the world-energy market today. Estimates of the geothermal resources and reserves from these conventional resources are site specific and require many geologic investigations to produce a reasonably accurate estimate (Coolbaugh and Shevenell, 2004).

Texas presents a unique, unconventional setting for geothermal-power development owing to the predominance of moderate-temperature, deep sedimentary basins, a preinstalled infrastructure associated with legacy and ongoing oil and gas operations, and existing reservoir knowledge. Subsurface bottom-hole temperatures of more than 240 °C (460 °F) have been reported in Texas. Binary generator power plants are best suited to Texas as many of the temperatures at depth are in the low-medium range. This previously installed infrastructure in the form of transmission lines and drilled wells can greatly reduce the cost of geothermal-power production normally associated with moderate-temperature, deep sedimentary basins (Zafar and Cutright, 2012). In essence, because deep sedimentary, geothermal-power production may be economically feasible in Texas, it can be used as an intermediate test site for future nationwide engineered geothermal systems (EGS) deployment.

The U. S. Geological Survey (Williams et al., 2008) has compiled a review of methods for estimating these geothermal resources, although it focuses predominately on more conventional resources estimates. Evaluating the magnitude of the geothermal resource base is important for early stages of geothermal development. The California Geothermal Energy Collaborative found geothermal resource assessment to be a crucial aspect of improving development of geothermal resources (Brophy et al., 2008). One of the main challenges in this geothermal resource assessment is quantifying the thermal energy of a reservoir (Williams et al., 2008). Traditionally, the thermal energy of a reservoir is evaluated using the volumetric-heat-in-place method put forth by Muffler and Cataldi (1978). This method treats the geothermal reservoir as a block within which a single temperature (derived from triangular probability density) is assumed to be uniformly distributed. The equation used to calculate the stored reservoir thermal energy is:

$$q_r = \rho_c * A * d * \left(t - t_{ref}\right), \quad (1)$$

where q_r is the reservoir thermal energy in joules (J), ρ_c is the volumetric specific heat of rock plus water (2.7 J/cm^3/°C), A is the reservoir area, d is the reservoir thickness, t is the assigned reservoir temperature, and t_{ref} is the ambient and annual mean surface temperature (°C).

Recent studies have used a more complex application of this method. For example, Esposito and Augustine (2011) determined a single temperature gradient for an area or basin of interest then divided the basin volume into 10 °C-interval volumetric blocks. For each block, thermal energy in place was then calculated so that total thermal energy could then be calculated by summing the energy of each block.

Whereas Muffler and Cataldi (1978) provided a simplistic method that was suitable for scenarios with few data points, later studies applied a more rigorous Riemann-sum approach (Esposito and Augustine, 2011; Crowell and Gosnold, 2011). The present study uses GIS raster math to integrate a 3D depth raster over the geothermal gradient to yield more accurate thermal resource estimations. In addition to a base-resource estimate for Texas, further analysis is carried out so that the thermal resource available