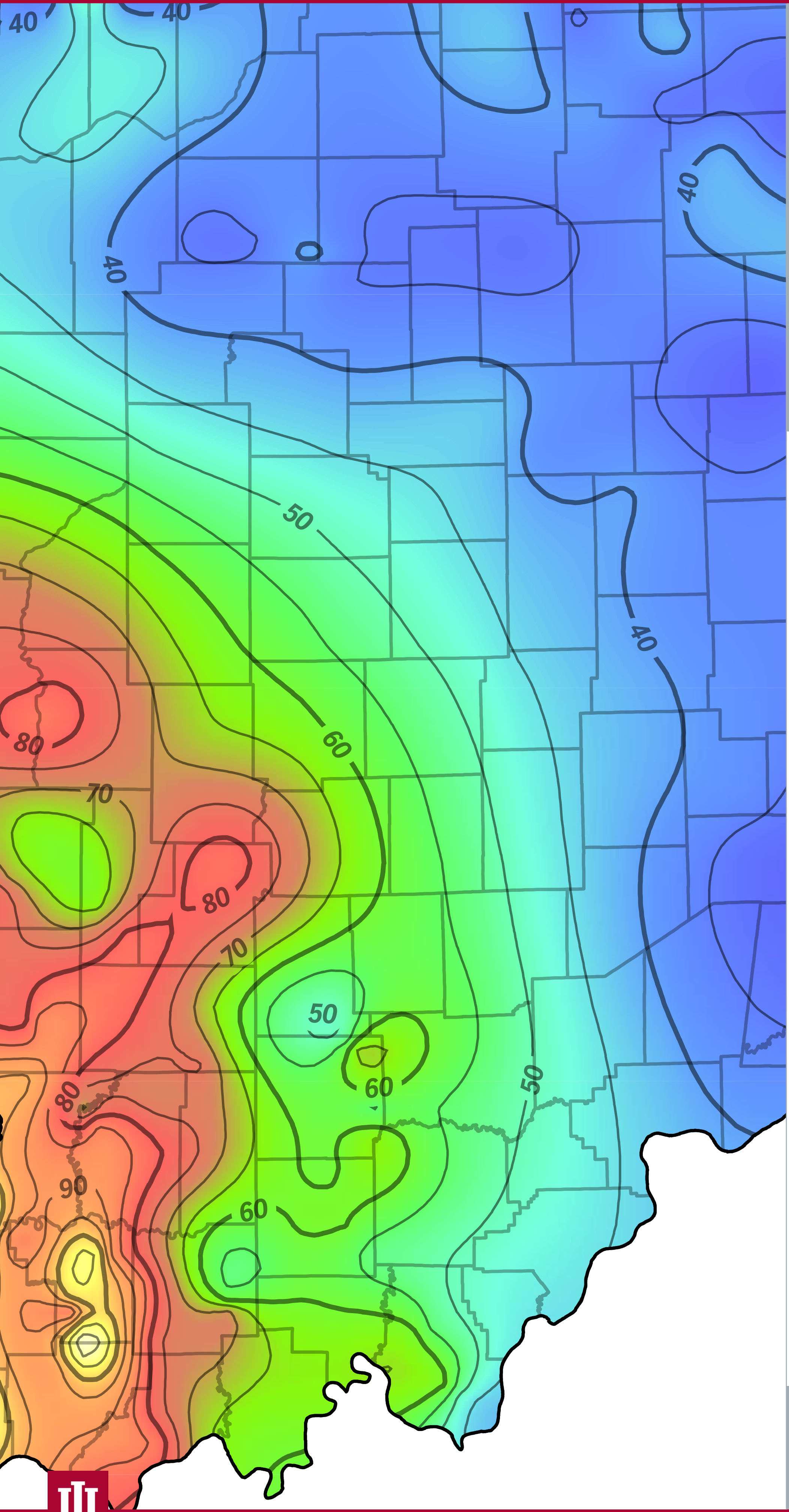

INDIANA HIGH-TEMPERATURE GEOTHERMAL WATER ASSESSMENT

2026

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ON THE COVER:
A gradient map of temperatures at the surface of Precambrian Basement rocks across Indiana is shown. For full figure and legend, see page 13. | Michael Daniel, IGWS

Indiana High-temperature Geothermal Assessment

(executive summary bullet points)

Introduction

Tapping high-temperature geothermal energy for power generation in the western United States has been a pursuit of industry and government entities for decades. Exploration for high-temperature geothermal energy resources in Indiana has not been a priority because subsurface temperatures are lower than the threshold required for power generation (> 150 °C, 300 °F). Although a few temperature anomalies have been reported in subsurface sedimentary rocks in Indiana, they do not reach the required temperatures for power generation, and their origins remain poorly understood due to limited information from the deep subsurface; additional testing would be required to verify their existence and characterize them.

Key findings

- It is estimated that sufficient temperatures needed for power generation in Indiana (> 150 °C, 300 °F) might exist at 7.5 km (23,000 ft) or greater below the surface. Those drilling depths have not been attempted in Indiana, and drilling conditions could be extreme depending on the types of rocks and temperatures encountered.
- Direct use of geothermal energy using heat exchange in the shallow subsurface at depths of hundreds of feet has been a growing industry in Indiana. This type of geothermal energy is widespread, efficient, renewable, and can help alleviate stress on the power grid.

Challenges

- An insufficient number of deep wells hampers the calculation of accurate geothermal gradients, thereby limiting the development of maps showing geothermal temperatures at depth.
- Areas with persistent higher geothermal gradients that may be related to subsurface fluid flow along faults and fracture systems have little data and are poorly understood.
- Seismic, gravity, and magnetic surveys are needed to better address the basement subsurface geology of the state.

Next steps for Indiana

With high and medium temperatures unavailable at economical depths, Indiana should focus its efforts on shallow, low-temperature geothermal systems for heating and cooling.

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Indiana High-temperature Geothermal Assessment

1. INTRODUCTION

Geothermal systems use the temperature of the Earth's subsurface to heat and cool buildings and to generate electricity. Geothermal systems are divided into low-temperature systems commonly used for heating, ventilation, and air conditioning (HVAC) (exceeding 100 °C, 212 °F) and high-temperature systems (exceeding 150 °C, 300 °F) that can produce hot water or steam. This report focuses on the potential for high-temperature geothermal resources in Indiana. Specifically, we examine the possibility of underground reservoirs for generating electricity.

2. TYPES OF HIGH-TEMPERATURE GEOTHERMAL SYSTEMS

High-temperature geothermal systems are hydrothermal reservoirs that contain extremely hot fluids. Most systems harness water within the 150 to 200 °C (300 to 390 °F) range, although some systems operate supercritically, utilizing vapor above 350 °C (660 °F). Rocks deep underground or over magma provide the heat; therefore, most high-temperature geothermal systems are associated with volcanic areas and rift zones, often at tectonic plate boundaries. Hydrothermal systems are the most common type, with naturally occurring hot water. Enhanced (engineered) geothermal systems (EGS) also exist, in which hot, dry rock is fractured and injected with water to create an artificial hydrothermal reservoir.

Several authors have used temperature ranges to classify geothermal resources (fig. 1). Work done by Sanyal (2005) is the most detailed, as it describes the temperature ranges with the fluid phase in the subsurface and wellhead, along with the applicable power conversion technology. Below 100 °C, the boiling point of water at atmospheric pressure, geothermal systems can be used for non-electricity

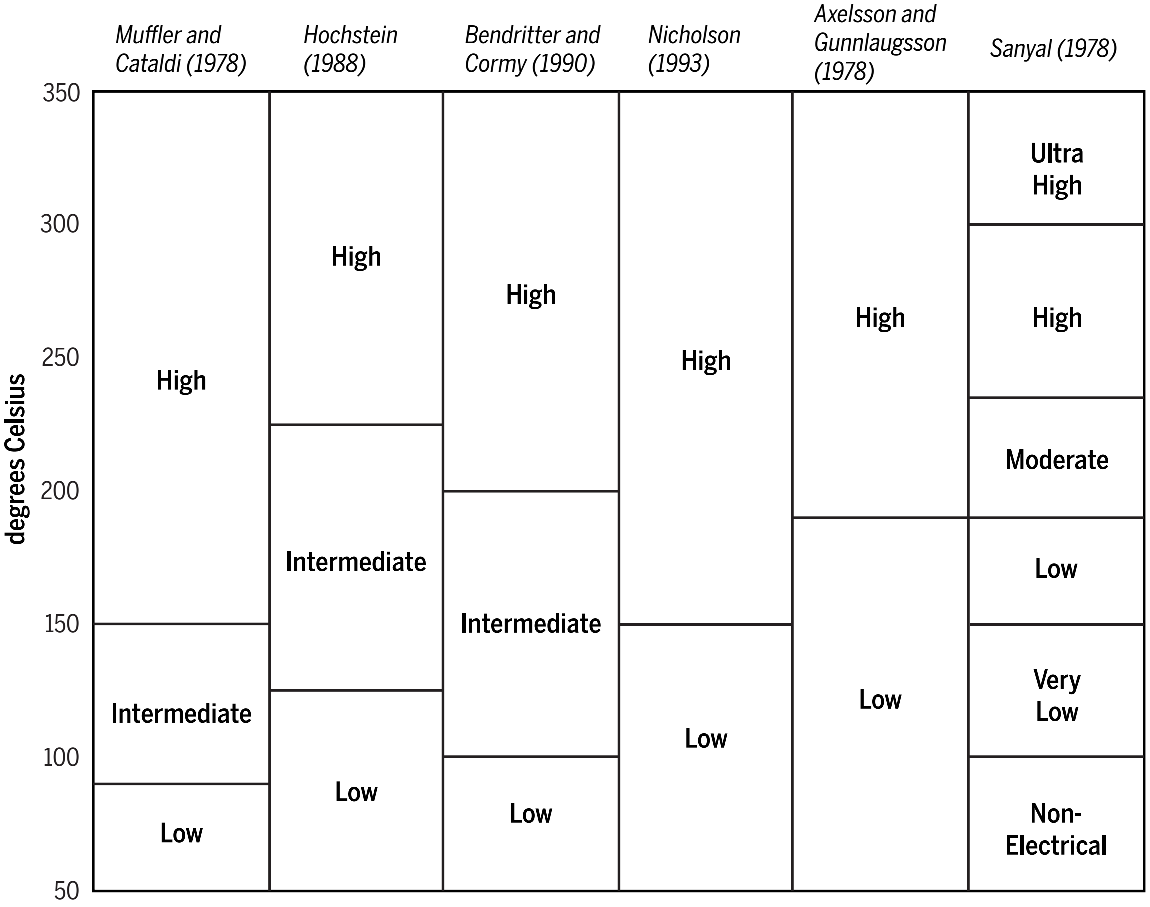


Figure 1. Chart illustrating examples of geothermal resource classifications by temperature. The temperature scale is degrees Celsius (Williams and others, 2011).

generation, including heating and cooling systems. Above 100 °C, and especially above 150 °C, higher power generation is associated with higher temperatures. Projects have been developed in the United States to target the temperature range below 150 °C, many funded by the Department of Energy's (DOE) Geothermal Technologies Program. These projects did successfully generate power at temperatures below 150 °C using a variety of technologies, although some faced technical, marketing, and economic challenges (Sanyal, 2005; Williams, and others, 2016).

3. GEOLOGICAL FRAMEWORK

3.1 Structural features

The subsurface structure of Indiana is dominated by the north-to-south-oriented Cincinnati Arch and the northwest-to-southeast-oriented Kankakee Arch (fig. 2). Consequently, by joining these two arches, Indiana is structurally a northwest-plunging anticline, separating the Illinois Basin to the southwest from the northern Michigan Basin and eastern Appalachian Basin. Stratigraphic units are thin and nearly horizontal across the

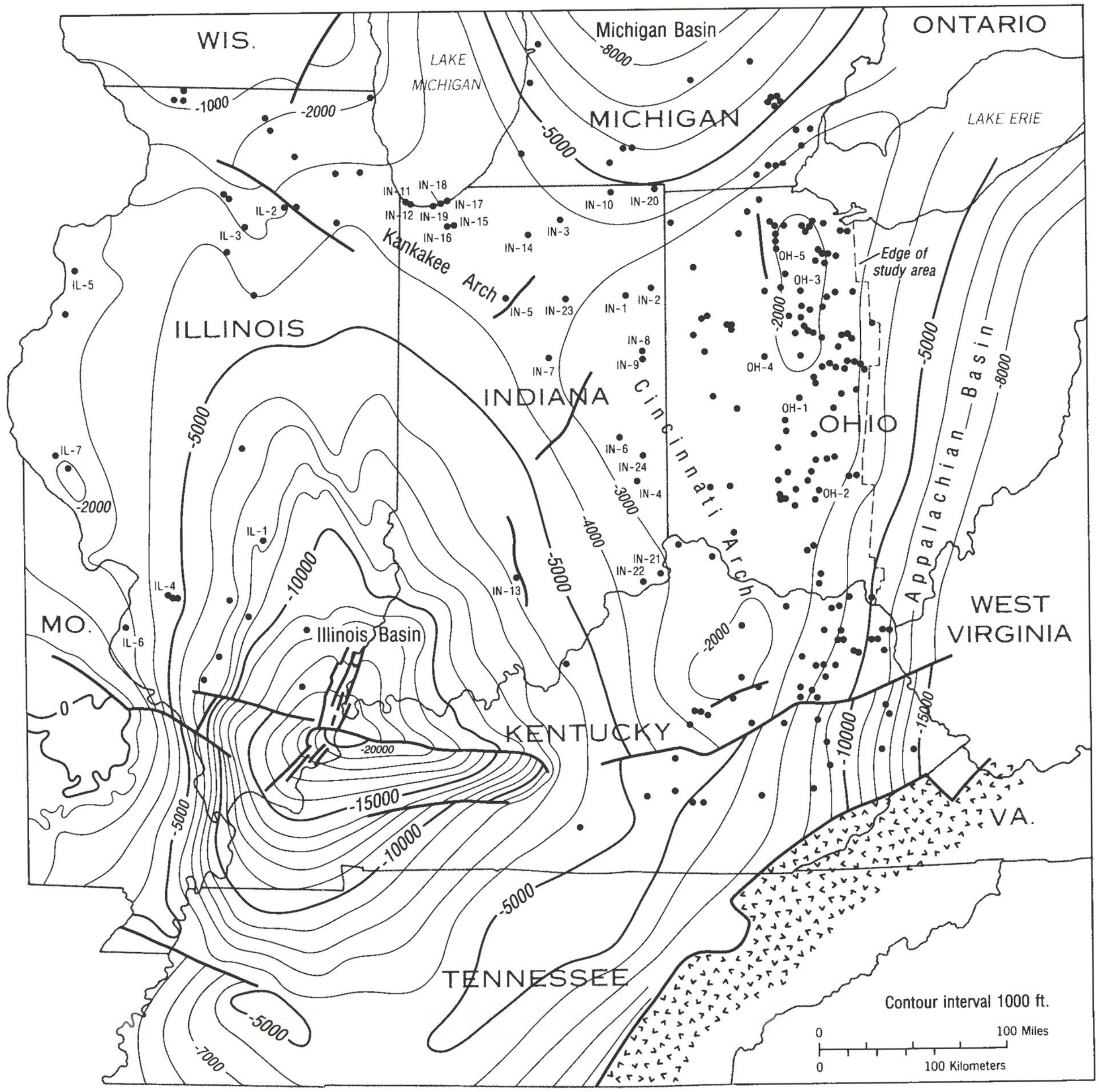


Figure 2. Map of the Midwest centered on Indiana showing major structural features, named basins, and boreholes that intersect Precambrian rocks (Rudman and Rupp, 1993).

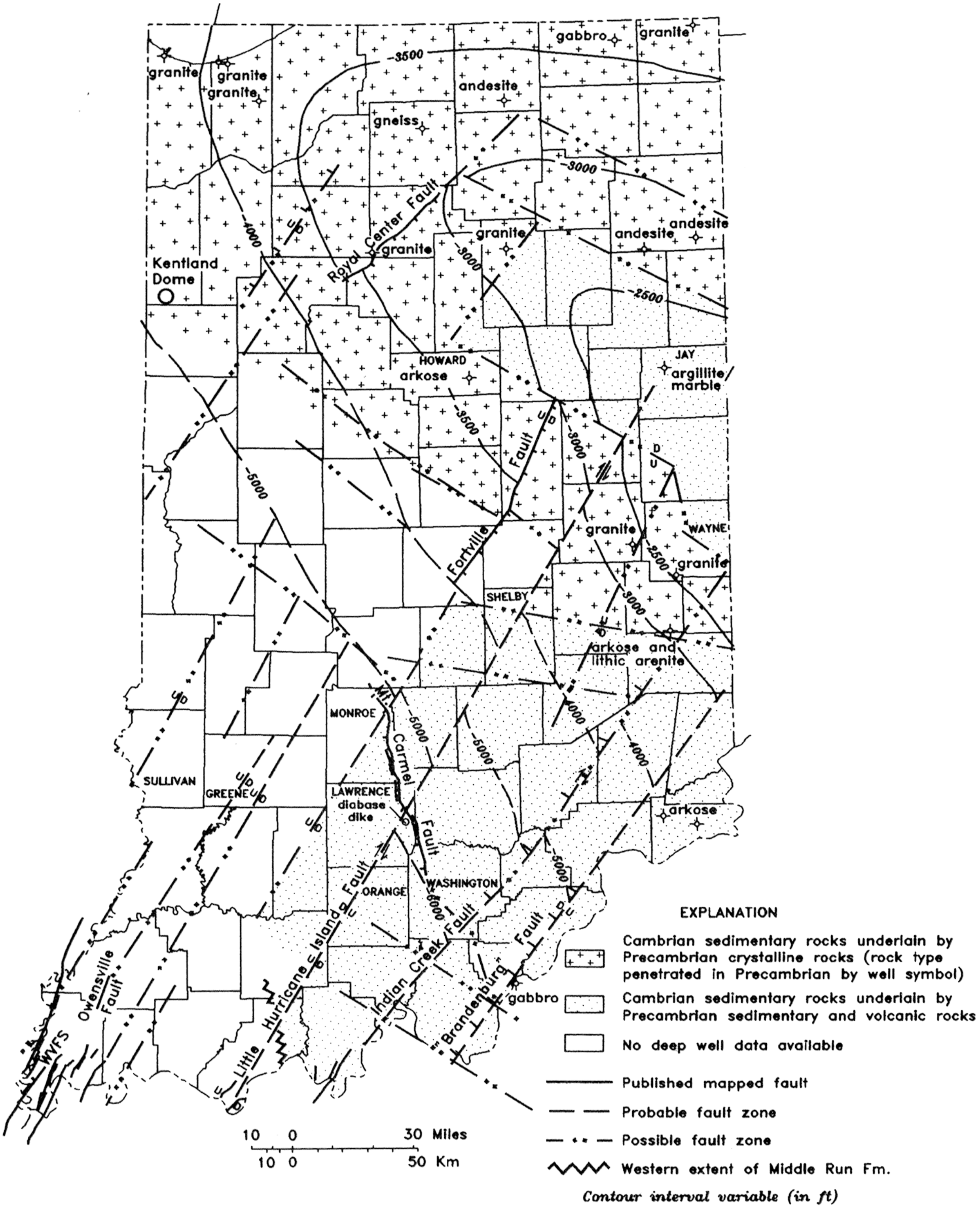


Figure 3. Geological map showing structure and rock types below the Mount Simon Sandstone and known, probable, and possible faults and fault zones (Furer, 1996).

arches, dipping and thickening into the surrounding basins. Of the three basins, the Illinois Basin occupies the majority of the state.

Several prominent faults are present throughout the state, with the largest concentration in southwestern Indiana, part of the Wabash Valley Fault System, and along the Ohio River (fig. 2). Minor folds and faults are also found throughout the state. Furer (1996) has, however, suggested that a series of steeply dipping, basement-seated, northeast-southwest-trending faults and northwest-southeast-trending faults cross the state (fig. 3). The northeast-southwest-trending faults are believed to be an extension of the Wabash Valley Fault System. Compression and extension along these faults influenced the distribution and thickness of lower Paleozoic rocks.

Furer (1969) notes two temperature anomalies used to position a possible and probable fault zone; one is a shallow thermal well in Shelby County reported by Blatchley (1903), and the other is the occurrence of dark-colored conodonts in Putnam County based on 62 localities in a 700 sq km (270 sq mi) area (Harris and others, 1989). Teng and others (2020) studied cuttings from a well in the darkened conodont area and reported thermally mature organic matter that they attribute to hydrothermal fluids that circulated through the New Albany Shale and the Maquoketa Shale. Harris and others (1989) suggested that hydrothermal fluids of at least 200ºC were present in the system, although the data are somewhat inconsistent.

The closest known hydrothermal system to Indiana is in the Illinois-Kentucky Fluorspar District where at the end of the Pennsylvanian and during the early Permian (about 260 million years ago), Paleozoic strata were arched into a northwest-trending elongated dome by a rising body of magma generated at depth. Extensional fractures contain igneous dikes exposed at the surface of southeastern Illinois and western Kentucky. In this area, evidence of hypothermal fluid deposits found along bedding planes at the top of the Mississippian Ste. Genevieve Formation and subsequent fractures and faults indicate the presence of high-temperature water movement in the vicinity of the dome (Frankie and Jacobson, 2001).

3.2 Stratigraphy

3.2.1 Basement rocks

The maximum thickness of the Paleozoic sedimentary sequence in Indiana occurs in the southwestern part of the state, in the deepest part of the Illinois Basin (fig. 2), and is estimated to exceed 3.7 km (12,000 ft). Beneath these sedimentary rocks, most of Indiana is underlain by igneous rocks referred to as “the basement.” These rocks belong to the Eastern Granite-Rhyolite Province and are composed predominantly of felsic rocks such as rhyolites and granites (Lidiak, 1996).

Knowledge of the basement rocks is limited; they are not exposed at the surface, and fewer than 30 wells in Indiana have penetrated the basement. Most of the wells that have drilled to the basement are near or along the arches where the basement is shallow, typically less than 1,400 m (4,600 ft) (Rudman and Rupp, 1993). More borings, drilled throughout the state, and core samples are needed to properly characterize this rock.

3.2.2 Paleozoic rocks

The thickness of the Paleozoic rocks ranges from approximately 1.0 to 3.7 km (3,000 to 12,000 ft). Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician rocks are exposed at the bedrock surface in various areas of the state, wrapping around the Cincinnati/Kankakee Arch (fig. 4). Consequently, the oldest rocks at the bedrock surface are Ordovician in the southeastern part of the state. Stratigraphic units become younger to the west-southwest into the Illinois Basin and north into the Michigan Basin. Older strata, such as the Cambrian, are only present in the subsurface. The Paleozoic rocks of Indiana are dominated by alternating sequences of siliciclastic and carbonate rocks (fig. 5), and their surface distribution has been influenced by proximity to the arch, arch uplift and subsidence through time, and sea-level fluctuations, leading to either nondeposition or erosion. This distribution of sedimentary rocks dictates the distribution of energy, mineral, and water resources across the state.

4. LITERATURE REVIEW

Few studies specifically addressing subsurface temperatures in Indiana have been published, although Indiana has routinely been included in national assessments. The first mention of above-normal temperatures in water-bearing rocks and sediments was by Blatchley (1903). He reported six “thermal” wells with temperatures above 21 °C (70 °F). During the 1960s and 1970s, the American Association of Petroleum Geologists (AAPG) conducted a geothermal survey of North America using temperature data from oil, gas, and water wells (Kehle and others, 1970). This work led to a nationwide compilation by DeFord and others (1976), later reworked by Blackwell and Richards (2004a, b). Blackwell and others (2011) produced a third nationwide geothermal map. The Geothermal Energy Research, Development and Demonstration Act of 1974 directed the U.S. Geological Survey to evaluate and assess the nation’s geothermal resources. Their three reports addressed both high- and low-temperature geothermal. As part of the American Recovery and Reinvestment Act of 2009, the Department of Energy initially funded the National Geothermal Data System. This system collected subsurface temperature

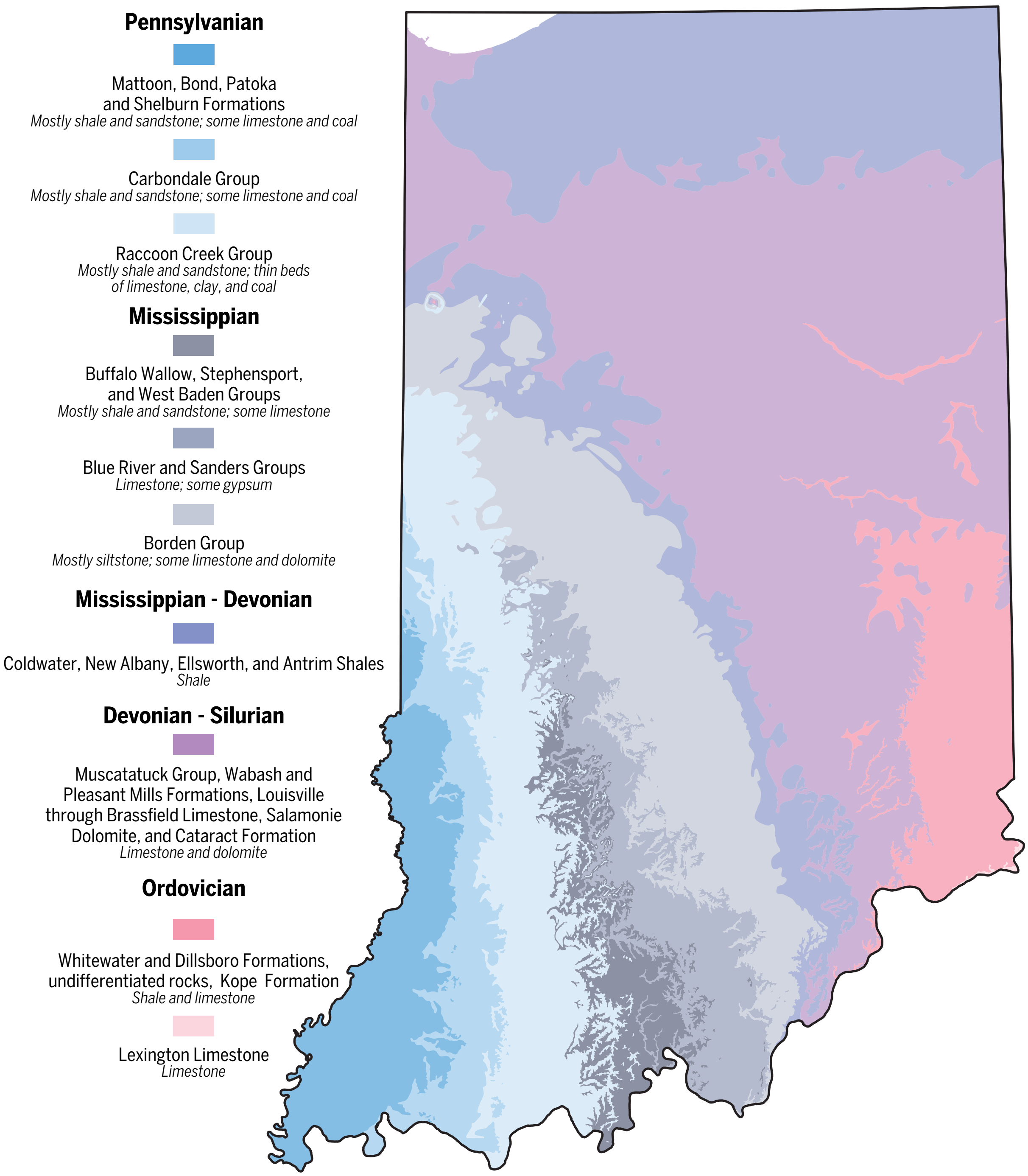
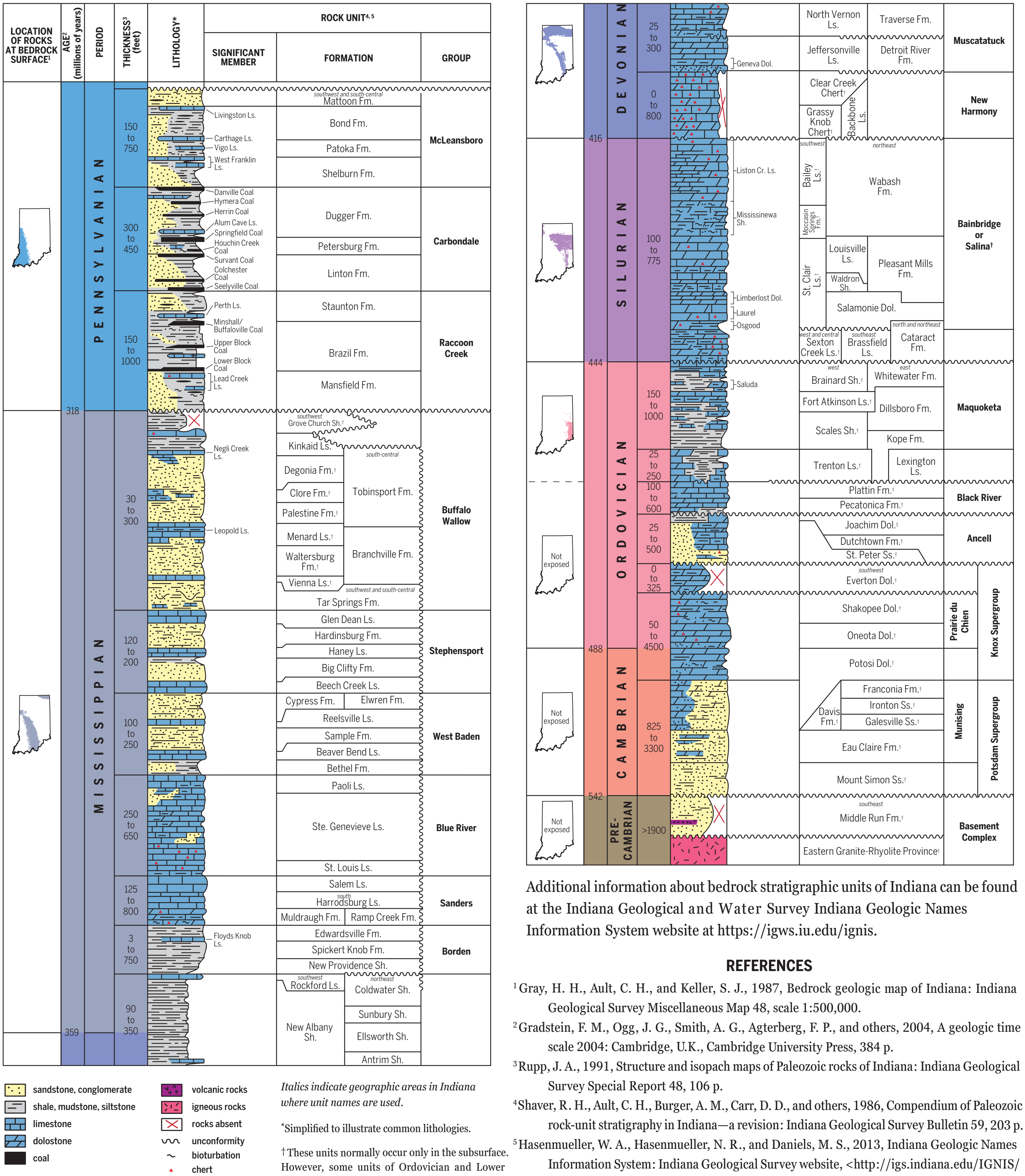


Figure 4. Bedrock geological map of Indiana shown on a digital elevation model of the bedrock topography. Modified from Gray, Ault, and Keller (1987).



Italics indicate geographic areas in Indiana where unit names are used.

*Simplified to illustrate common lithologies.

†These units normally occur only in the subsurface. However, some units of Ordovician and Lower Silurian age are exposed at the Kentland impact structure in northwestern Indiana.

Figure 5. Generalized stratigraphic column of lithologic units in Indiana (modified from Thompson and others, 2015).

Additional information about bedrock stratigraphic units of Indiana can be found at the Indiana Geological and Water Survey Indiana Geologic Names Information System website at https://igws.iu.edu/ignis.

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data from state geological surveys across the nation. The Indiana Geological and Water Survey participated in this program, with data used in the Blackwell and others (2011) map.

Temperature gradient maps for Indiana and surrounding states have been published using various techniques and data types, all of which are hampered by limited data at deeper depths. Vaught (1980) examined heat-flow values, noting that Indiana compared favorably with East Coast values but that additional data were needed. Foust and others (2003) used and added to the AAPG data set to produce 18 geothermal gradient maps of Indiana, evaluating contouring software and potential errors in the data. Also using the AAPG data set but expanding their analysis to the Illinois Basin, Proffitt and others (2013) examined depth-based gradients and concluded that advective heat transport was an important process at depth less than 305 m (1,000 ft), with conduction likely occurring at greater depths. They reported a higher mean geothermal gradient for

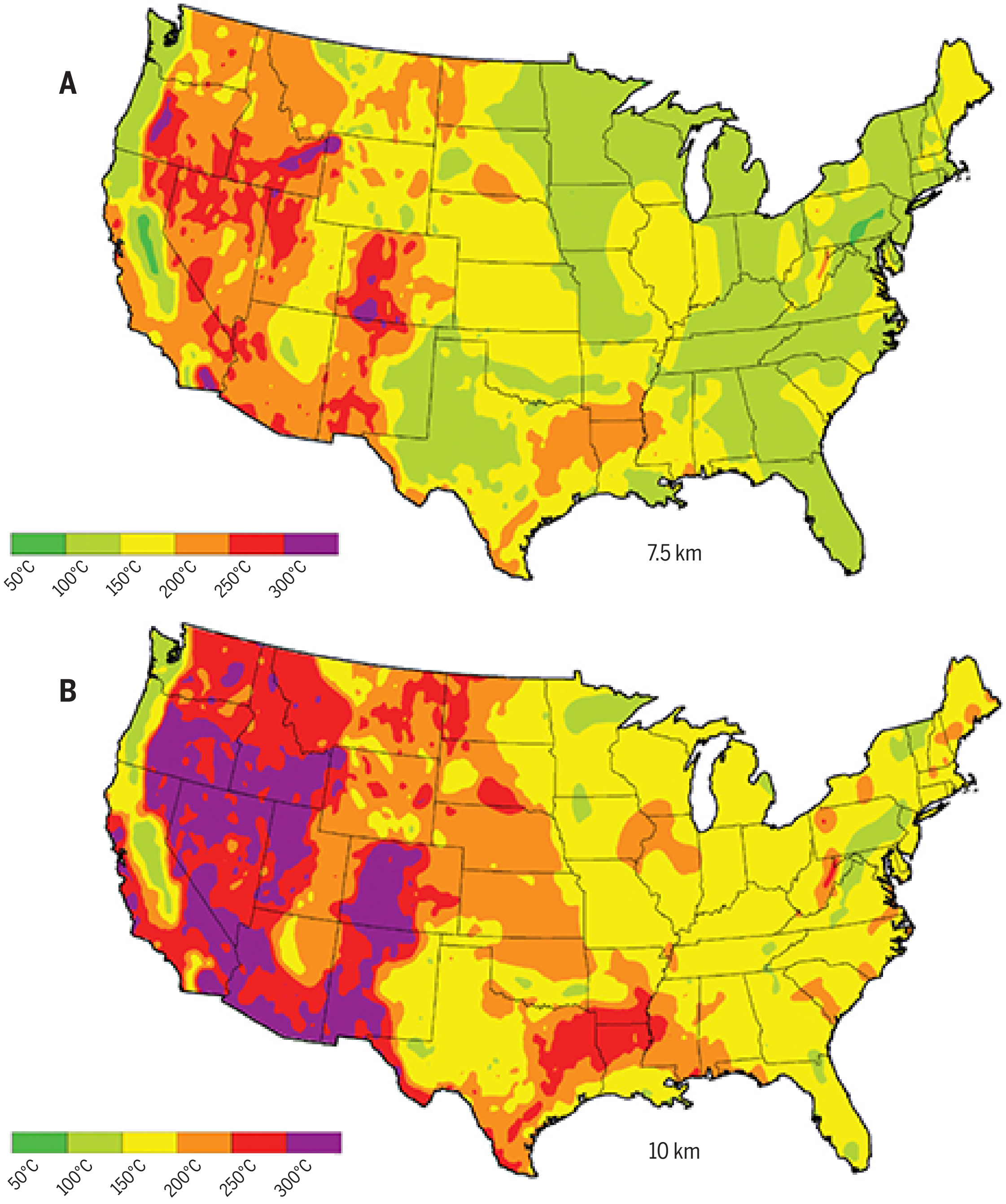

Figure 6. Maps showing average temperatures at depths of 7.5 km (23,000 ft) (A) and 10 km (32,800 ft) (B) (MIT, 2006).

the Illinois Basin of 2.27 °C/100 m (1.56 °F/100 ft) and stressed that combining geothermal gradients calculated from shallow and deep wells can lead to incorrect assumptions when three-dimensional data are projected onto a two-dimensional map. In one of the most recent studies, Crowell and Gosnold (2014) concluded that temperatures suitable for electricity production do not occur in the Illinois or Michigan Basins.

The Massachusetts Institute of Technology (MIT) (2006), using the geothermal gradient map of Blackwell and others (2004a, b), produced a series of average temperature maps at various depths. Their analysis shows that temperatures of 150 °C or higher in Indiana occur at depths of 7.5 km (23,000 ft) or greater (fig. 6). At these depths, only enhanced (engineered) geothermal systems are possible.

5. LITHOLOGIC CONDUCTIVITY AND TEMPERATURE GRADIENT

Lithologic conductivity refers to a rock's ability to conduct electrical or thermal energy. The thermal conductivity of rocks can vary widely from 1 to 6 W/m·K (Watts per meter-Kelvin) (Table 1) and is affected by several factors, including mineralogy, porosity, density, moisture content, and temperature and pressure (Robertson, 1988). Rocks with higher mineral content, lower porosity, and greater density tend to have higher thermal conductivity.

The majority of Indiana rocks, which are sedimentary, have thermal conductivity values at the lower end of the average range. Thermal conductivities can be used to develop a model to estimate the subsurface temperature gradient; however, this is difficult due to variations in lithology, thickness, and other uncertainties. Instead, a subsurface temperature model was created using available well data in the IGWS's Geological Database Management System (GDMS, formerly the Petroleum Database Management System [PDMS]) to calculate temperature gradients and estimate the depth to the basement rock.

To generate a representative subsurface temperature map from well data, several steps were required. Only wells with a total depth (TD) exceeding 610 m (2,000 ft) were included in the calculation of the temperature gradients because the shallow subsurface is subject to temperature variations due to groundwater transport. Additionally, a correction, the Harrison equation (Harrison and others, 1982), must be applied to the recorded bottom-hole temperature (BHT) for wells that have a TD between 914 m and 3 km (3,000 and 10,000 ft) (Blackwell and Richards, 2004c). This correction is applied to estimate the true formation temperature, which is often cooled by the circulating drilling mud. An ambient surface temperature of 13 °C (55 °F), selected based on previous work by Foust and others (2003), was used in the temperature-gradient equation.

Table 1. Thermal conductivity of rocks at 20 °C (70 °F) from Blackwell and Richards (2004a).

Lithology	W/m-k
Water	0.5 9
Marine sediments	0.70–1.00
Shale and siltstone	1.00–1.45
Sand	1.70–2.50
Sandstone	2.50–4.20
Quartzite	4.20–6.30
Lithic sand	1.25–2.10
Limestone	2.50–3.10
Dolostone	3.74–6.30
Evaporites	4.80–6.05
Coal	>0.50
Granite	2.50–3.35
Volcanics	1.25–2.10
Volcanic ash	0.60–1.05

Temperature-gradient calculations are a useful tool, but they must be applied cautiously due to several factors: temperature gradients vary with rock type, conductivities generally increase with depth (which decreases the temperature gradient), projecting linear trends may overestimate temperatures, and shallow wells tend to have anomalously high BHTs (even up to hundreds of meters) due to groundwater movement that alters the geothermal gradient (Vaught, 1980).

The equation and variables used to calculate the temperature gradient were:

d = recorded depth (ft)

D = depth in meters (m)

t = recorded temperature (°F)

T = temperature (°C)

ΔT = change in T

C = Corrected T

ambient surface temperature = 13 °C (55 °F)

Step 1 – convert depth from feet to meters

$d * 0.3048 = D$

Step 2 – convert temperature from degrees in Fahrenheit to Celsius

$(t - 32) / 1.8 = T$

Step 3 – apply the Harrison equation

$$\Delta T = -16.51213476 + (0.01826842109 * D) - 0.000002344936959 * (D)^2$$

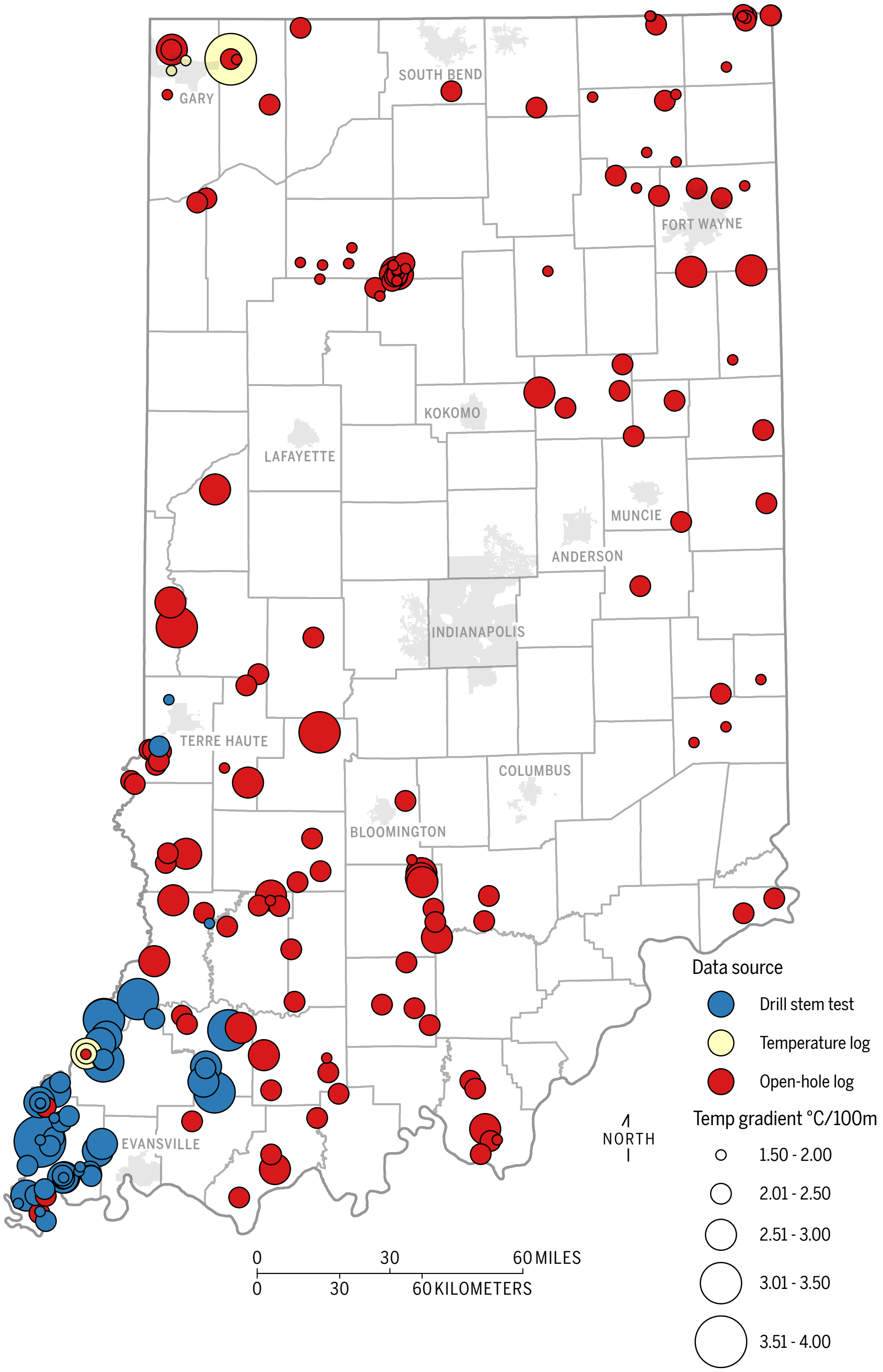

Figure 7. Map showing wells used and temperature gradient at each location used to generate temperature estimations at the surface of the basement rocks.

Step 4 – apply the temperature correction

T + ΔT = C

Step 5 – calculate the temperature gradient

Temp gradient = (C – ambient surface temperature) / D

For the maps created in this report (figs. 7, 9, 10), temperature gradients from 217 wells were used. Data were obtained from three sources: drill stem tests (DSTs), temperature logs, and BHT from open-hole well logs. Each method has advantages and disadvantages.

DSTs are an oil-and-gas exploration procedure that evaluates a formation's potential by measuring the pressure, permeability, temperature, and flow rates. These tests are assumed to have the most reliable temperature

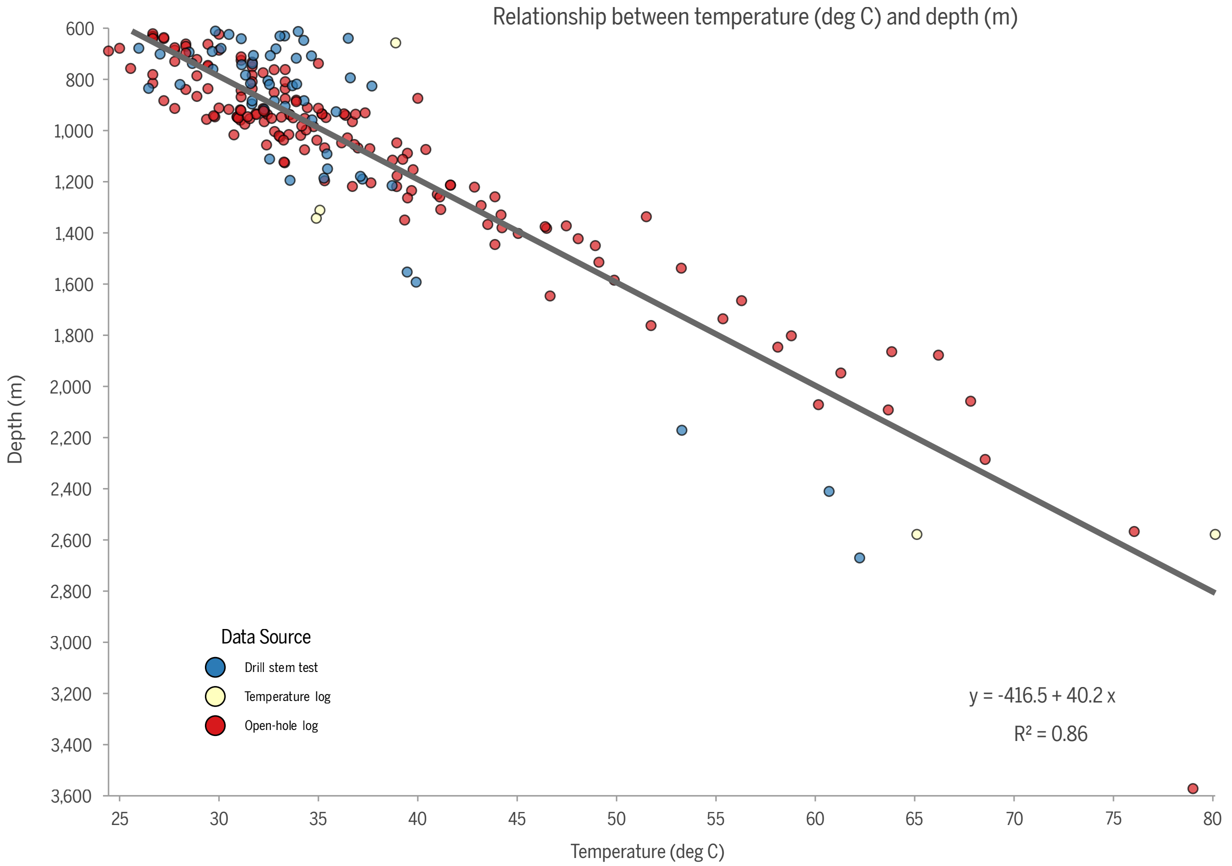

Figure 8. Scatter plot and regression of well depth versus temperature. Colored by data source.

measurement. A temperature log is a wireline tool that is run in an uncased wellbore to measure the temperature of the formations as it is lowered through the well. This method provides a more direct measurement of temperatures but still might be influenced by the circulation of drilling mud and requires a correction in certain depth ranges. An open-hole log records the maximum temperature, typically at the deepest point of an open-hole wireline logging run. This measurement method is the most widely available, but it is often lower than the actual formation temperature due to the cooling effect of the drilling mud, as previously discussed.

Temperature values were recorded from 53 DSTs, five temperature logs, and 159 open-hole logs, which measured values from 24.4 to 98 °C (76 to 208 °F) with an average temperature of 37.2 °C (98.9 °F) (fig. 8). As expected, the data shows a linear trend of increasing temperature with increasing depth, although a linear trend may not always accurately depict true geothermal conditions. Calculated temperature gradients range from 1.64 to 3.97 °C/100 m (0.89 to 2.18 °F/100 ft) with an average of 2.28 °C/100 m (1.26 °F/100 ft). This average value is nearly identical to the value calculated by Proffitt and others (2013).

To estimate the temperature at the base of the Paleozoic sedimentary cover, a depth map was constructed to represent the interface between the sedimentary cover and the igneous basement rocks (fig. 9). The grid of the depth-to-basement map was then multiplied with an interpolated grid of the temperature gradient data points in Kingdom™ (S&P Global, version 2025, build 90). The resulting value provides an estimate for the temperature at the basement rock surface throughout the state. The temperature values range from approximately 35 to 120°C (100 to 248 °F) with the highest temperatures in the southwestern corner of the state where the basement rock is the deepest (fig. 9). The majority of the interface at the basement rock in the state falls between 35 and 80 °C (95 to 175 °F) (fig. 10). These values are insufficient for high-temperature geothermal use.

6. DATA GAPS

Approximately 85,000 wells have been drilled in Indiana since 1936 when the Indiana Department of Natural Resources (DNR) started issuing permits (DNR, 2015). The deepest well drilled was 3.58 km (11,734 ft) in Gibson County, but the average well depth in the state

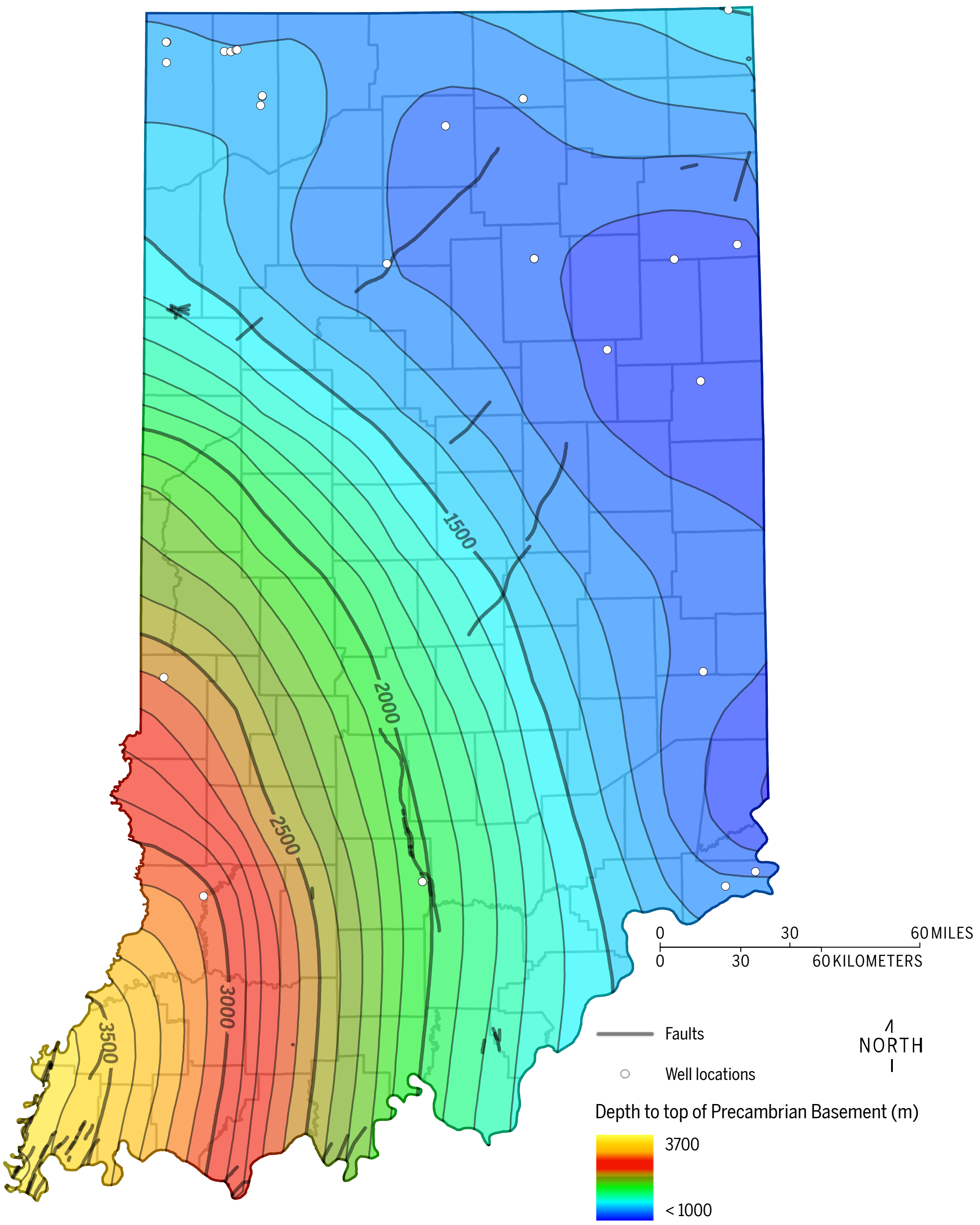

Figure 9. Map showing the depth to the top of the Precambrian Basement, in meters, with structural features and the wells that penetrate the basement.

is less than 460 m (1,500 ft). Even with the number of wells drilled, data remain scarce in both quantity and quality. The lack of deep wells that reach the basement, the absence of new wells with modern logs, the absence of DSTs, lack of geophysical data to map the deep subsurface, and the lack of scanned and digitized data all lead to data gaps that are filled using interpreted geological knowledge of the subsurface. Wells that were previously reported to have abnormally warm groundwater were published almost 80 years before Vaught (1980), and he questioned their validity.

Much remains unknown about Cambrian and Precambrian stratigraphy, especially in the southwestern corner of the state extending into deeper portions of the Illinois Basin. Logs, drill cuttings, and core samples from wells that intersect these stratigraphic units are limited.

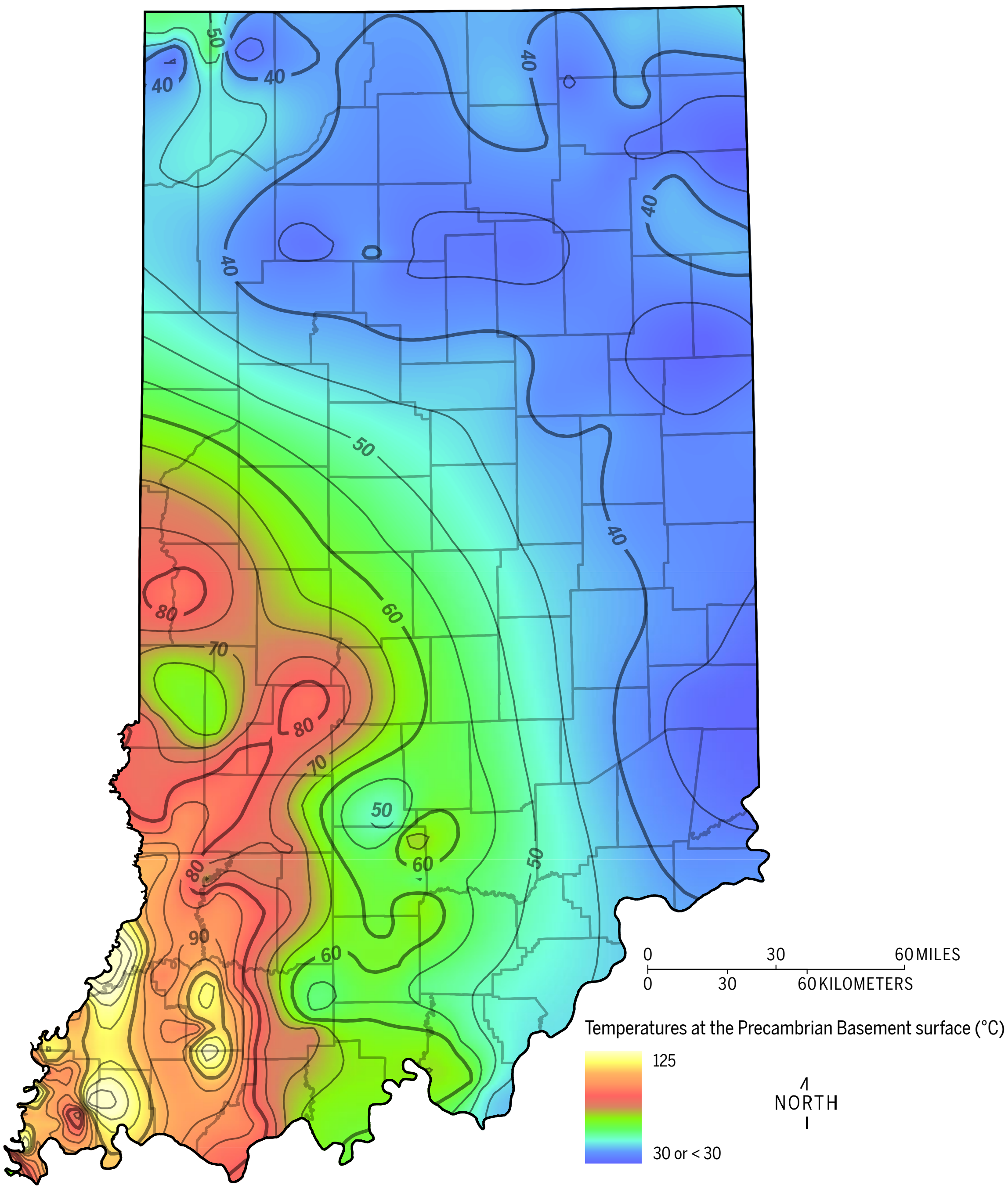

Figure 10. Map showing calculated temperatures at the Precambrian Basement surface in degrees Celsius.

Most wells that penetrate them were drilled in shallower areas concentrated near or along the Cincinnati Arch (Rudman and Rupp, 1993). Recent, deeper well data are derived from carbon sequestration test wells, which were largely funded by the U.S. Department of Energy (DOE). As long as there is no financial incentive for operators to drill new, deeper wells; perform DSTs; cut core; and run open-hole logs, data gaps will likely remain.

A lack of modern geophysical data to image the subsurface also limits understanding of the structural features that may be responsible for temperature anomalies. Faults and fractures can be imaged on geophysical data sets and related to geothermal anomalies; however, that data is lacking for much of Indiana. Regional subsurface imaging data sets, such as seismic, gravity, and magnetic data acquired with modern equipment and processed using advanced techniques, could better characterize the geology of suspected geothermal anomalies.

7. FEASIBILITY/ECONOMIC ASSESSMENT

High-temperature (> 150 °C) geothermal resources are the focus of geothermal power plants in western states, where high-temperature reservoir fluids are closer to the surface. These include accessing high-temperature reservoir fluids via hydrothermal or EGS, where geothermal reservoirs are stimulated to enhance permeability. The Geysers Geothermal Field in northern California accesses subsurface hydrothermal resources and generates 835 megawatts (MW) of power over 116.5 sq km (45 sq mi) (USGS, 2023). Ormat Technologies employed EGS at a geothermal field in Desert Peak, Nev., where an unproductive existing well was stimulated to increase permeability in the geothermal reservoir. This process increased the field's electricity production by 1.7 MW (U.S. DOE, GTO, 2025).

In Indiana, the high-temperature subsurface resources of the western states are absent (fig. 10). Medium temperatures from 90 °C to 150 °C do occur in southwestern Indiana (fig. 10); however, they occur at depths to 3.0 to 3.5 km (9,800 to 11,500 ft) along the basement surface (fig. 9). Many technical and economic challenges associated with EGS would need to be overcome to access these depths and temperatures.

Although implementing high-temperature geothermal has several challenges in Indiana, many homeowners and businesses in the state are using low-temperature geothermal in the shallow subsurface for heating and cooling (< 100 °C). With funding from the DOE (grant DE-FE0032365), the IGWS has been interpreting water well records to map the distribution of these systems within the state. Large-scale low-temperature geothermal projects, such as the one on the Ball State University campus, have had mixed successes. The University of Notre Dame has installed more than 2,400 geothermal wells on campus that can meet approximately half of the university's peak energy demand during the cooling season (Kurtos, 2017; Farrington, 2023).

Additional research into the hydrogeology of the shallow subsurface for low-temperature geothermal development may assist with defining appropriate project placement, designs, and directional array. The IGWS maintains a network of shallow subsurface groundwater monitoring wells (through the Indiana Water Balance Network [IWBN]) and soil thermal conductivity and soil resistivity sensors that actively collect information key to understanding subsurface fluid flow and heat transport in the shallow subsurface. This information can be used to better understand the geothermal potential of different geological units in both the unconsolidated and bedrock systems. Determining heat-transfer efficiency within those units is needed to optimize geothermal energy systems. Measurements of thermal conductivity, specific heat, thermal diffusivity, and density collected at each site will play an important role in informing the design of geothermal systems. Understanding the movement of water which directly enhances heat transfer allows for more efficient design of borehole placement and systems.

Aquifers in the state are poorly understood with respect to their textural composition, mineralogy, thickness, lateral extent, recharge, and water quality. With a more thorough understanding, aquifers could be assessed for their potential for thermal energy storage. Projects that require the transfer of heat from buildings, industrial processes (such as data centers), or electrical generation could use aquifers in the area as a heat source during the off-season or employ Cold Underground Thermal Energy Storage (Cold UTES), depending on the geological framework.

8. SUMMARY AND RECOMMENDATIONS

Unlike states in the western U.S., where the subsurface geology forces high-temperature fluids closer to the ground surface, Indiana's subsurface geology is much less thermally active and does not have the same characteristics. High-temperature geothermal projects are more likely to be developed in those western states than in Indiana. Accessing the temperatures needed to test the feasibility of high-temperature geothermal projects in Indiana has not been achieved to date due to the estimated drilling depths required to access those temperatures (> 7.5 km, > 23,000 ft).

The temperature map generated for this report relies mostly on temperature data from wells that are less than 900 m (3,000 ft) deep, plus a limited number of data points used to characterize the temperature at the interface of the sedimentary cover and the basement, especially in the deepest portions of the state, where temperatures are elevated. Additional wells drilled to the basement and used to characterize temperature gradients would help to reduce the uncertainty in the temperatures at depth. In addition, subsurface imaging techniques, including seismic, gravity, and magnetic surveys, would help characterize areas with persistent higher geothermal gradients that may be related to subsurface fluid flow along faults and fracture systems.

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