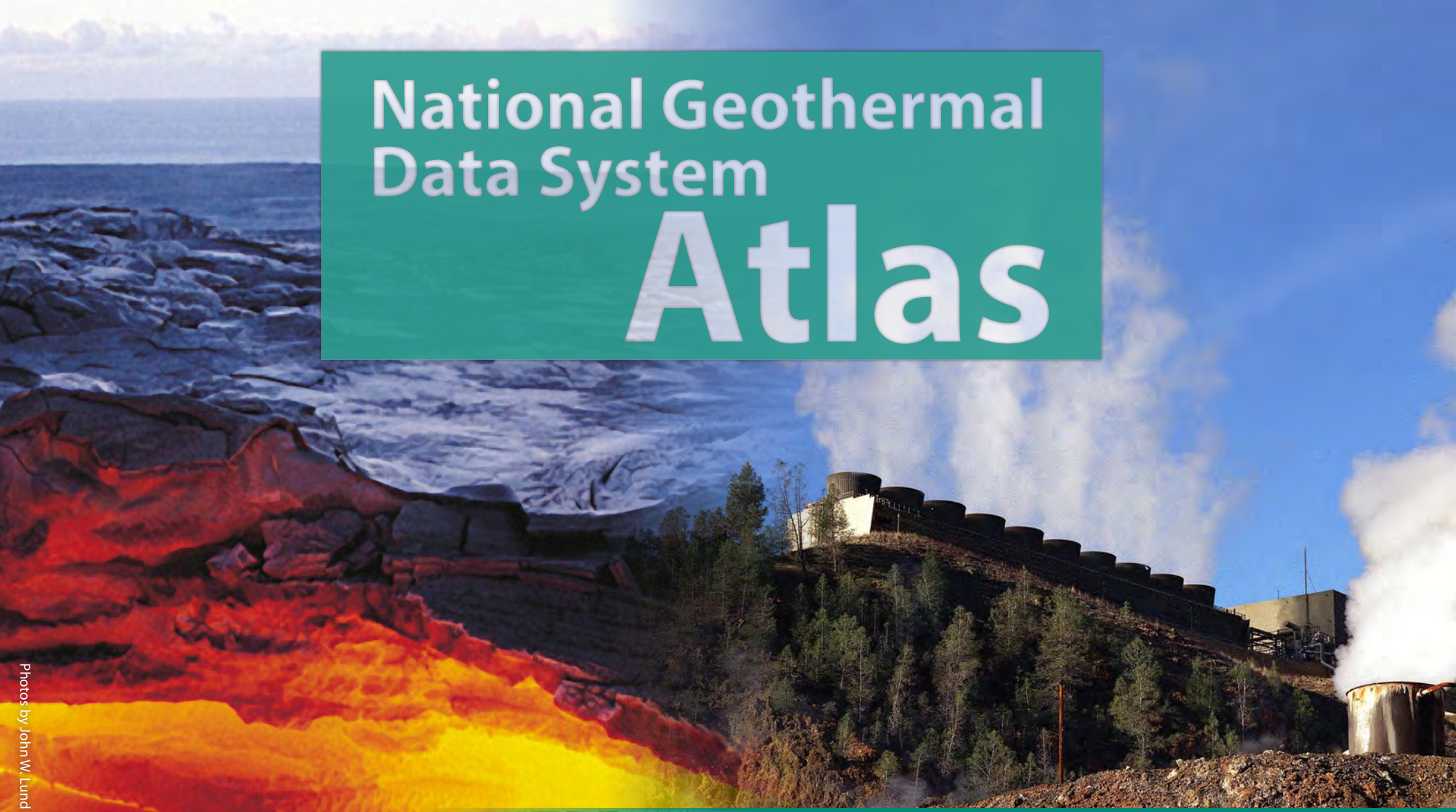
National Geothermal Data System Atlas



NGDS

GeothermalData.org

Photos by John W. Lund , DOE, Robb Williamson/NREL, Robert Blackett

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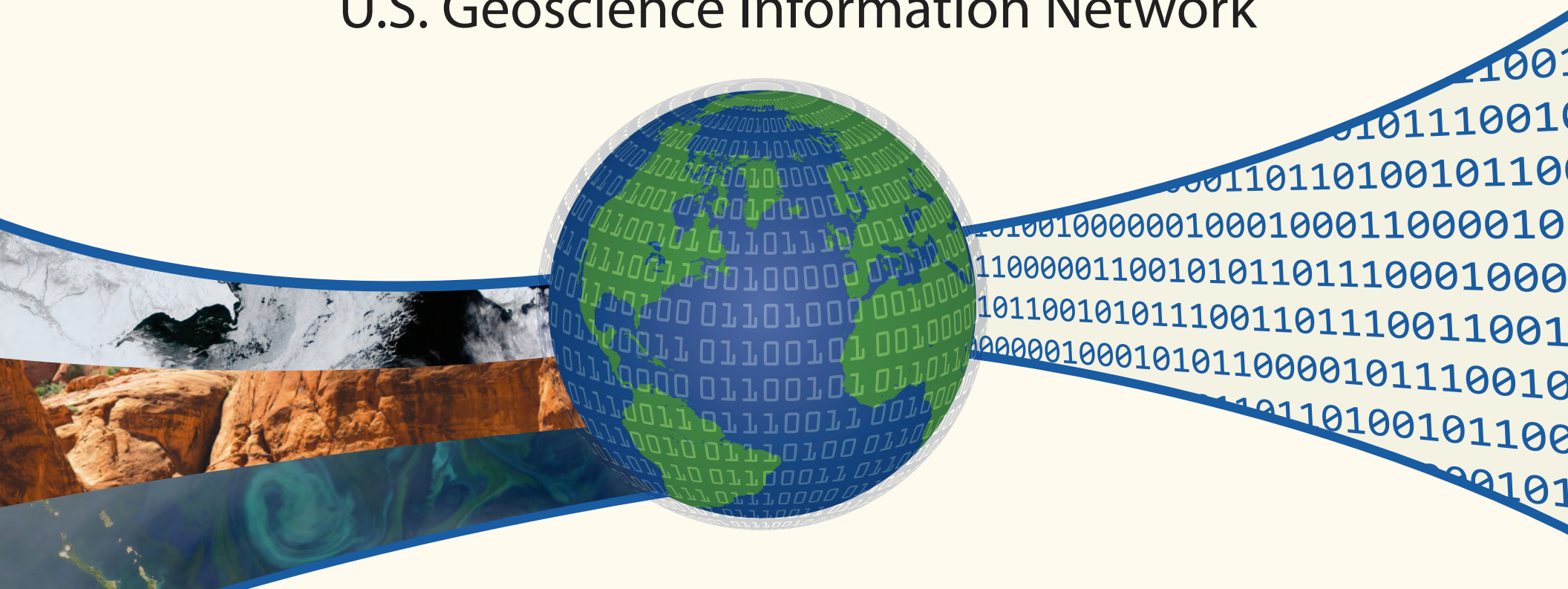
U.S. Geoscience Information Network



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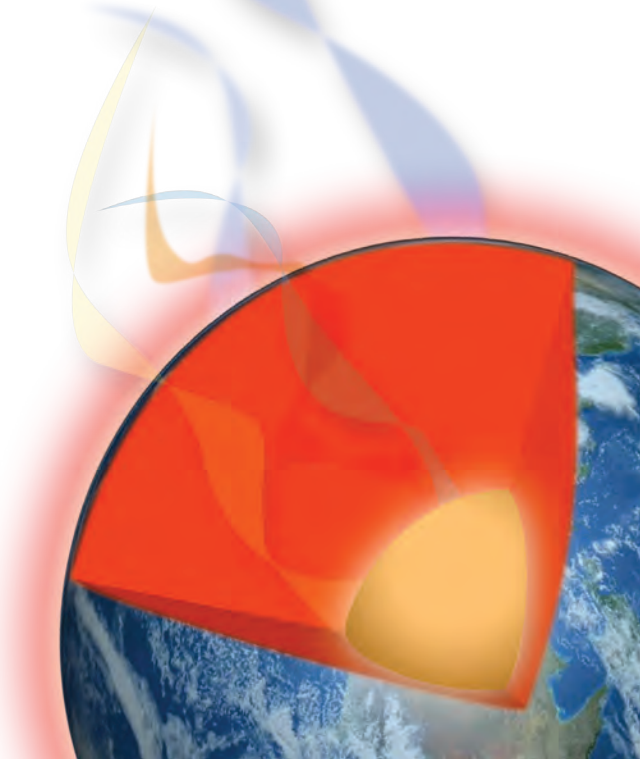


National Geothermal Data System Overview

In May, 2014, U.S. Department of Energy Secretary Ernest Moniz formally launched the National Geothermal Data System (NGDS) at the White House Energy Datapalooza.

The $22 million NGDS project, funded by the U.S. Department of Energy Geothermal Technologies Office, coordinated the nationwide digitization, submission and exposure of geothermal-relevant information.

The NGDS is an online, open-source platform that facilitates the discovery and access of geothermal-related data. The overarching goal is to provide the geothermal energy exploration industry, academia and business with ready access to digital data to break down one of the geothermal energy industry's greatest barriers to development and deployment of this promising clean energy source; the high cost of exploration.

The NGDS was created under two grants. The first was a design and build project administered by Boise State University (more information on the design and build project is available at *http://www.osti.gov/scitech/biblio/1163354*). The second grant coordinated state submissions from more than 50 collaborators, including state geological surveys and sub-awardees, led by the Arizona Geological Survey. The NGDS is now bringing unprecedented volumes of new and legacy data online.

The maps, data products, and information in the State Geothermal Atlas are just a sample of derived data contributed to NGDS under the "State Contributions to the National Geothermal Data System" project. A comprehensive online catalog of state products is available at *geothermaldata.org*.

geothermaldata.org

NGDS

AASG

"One of the most successful [cyberinfrastructure] programs to date is the National Geothermal Data System (NGDS)…"

—Sara E. Pratt, "Earth Magazine" August/September 2013

USGIN Powers NGDS

Access approximately 10 million data records:

- 1.85 million well headers (all wells)
- 520,000 water wells (supply, monitoring, irrigation)
- 666,800 borehole geophysical logs (oil and gas, water, other wells),
- 2 million borehole lithology data records (intervals and intercepts)
- 815,600 digital geologic map features (contacts, units, active faults, volcanic vents, geothermal areas)
- 538,800 borehole temperatures (wells and springs)
- 661,500 well fluid production records
- 387,800 aqueous chemistry records (wells and springs)
- 73,300 drill stem/well test records
- 53,800 geochem records (physical sample, thermal conductivity, and geochemistry)
- 14,000 direct use and heat pump facilities

The records listed above are available as interoperable data that can be seamlessly mapped across all states. Additional data, metadata, and maps are available in structured and unstructured formats (e.g. spreadsheets and scanned images), including:

- 66,600 all other types of data (seismic, gravity, heat flow, hydraulics properties, geothermometry, power plants)
- 59,300 documents, reports, and papers, including 6,300 geological maps
- 3 million data points from Southern Methodist University

GDR Geothermal Data Repository

NREL NATIONAL RENEWABLE ENERGY LABORATORY

USGS science for a changing world

The U.S. Geosciences Information Network (USGIN) is the engine that drives the NGDS.

Developed through the US Department of Energy over five years with American Reinvestment and Recovery Act funding, the NGDS is now managed by the U.S. Geosciences Information Network Foundation, Inc (USGIN).

USGIN

USGIN is a data sharing framework based on conventions and protocols that support a distributed, scalable, digital network specializing in geospatial data. The framework enables the management of interoperable data flawlessly in a number of common formats.

A joint undertaking of the United States Geological Survey and the Association of American State Geologists, USGIN uses the same free, open-source content management system as *Data.gov*, making data fully transparent to researchers and developers. USGIN standards divide data into three tiers: scanned files that are not machine readable (Tier 1), structured data that is machine readable but does not conform to a standard type (Tier 2), and data structured into a standardized schema that allows it to be read in numerous formats and by multiple software programs (Tier 3).

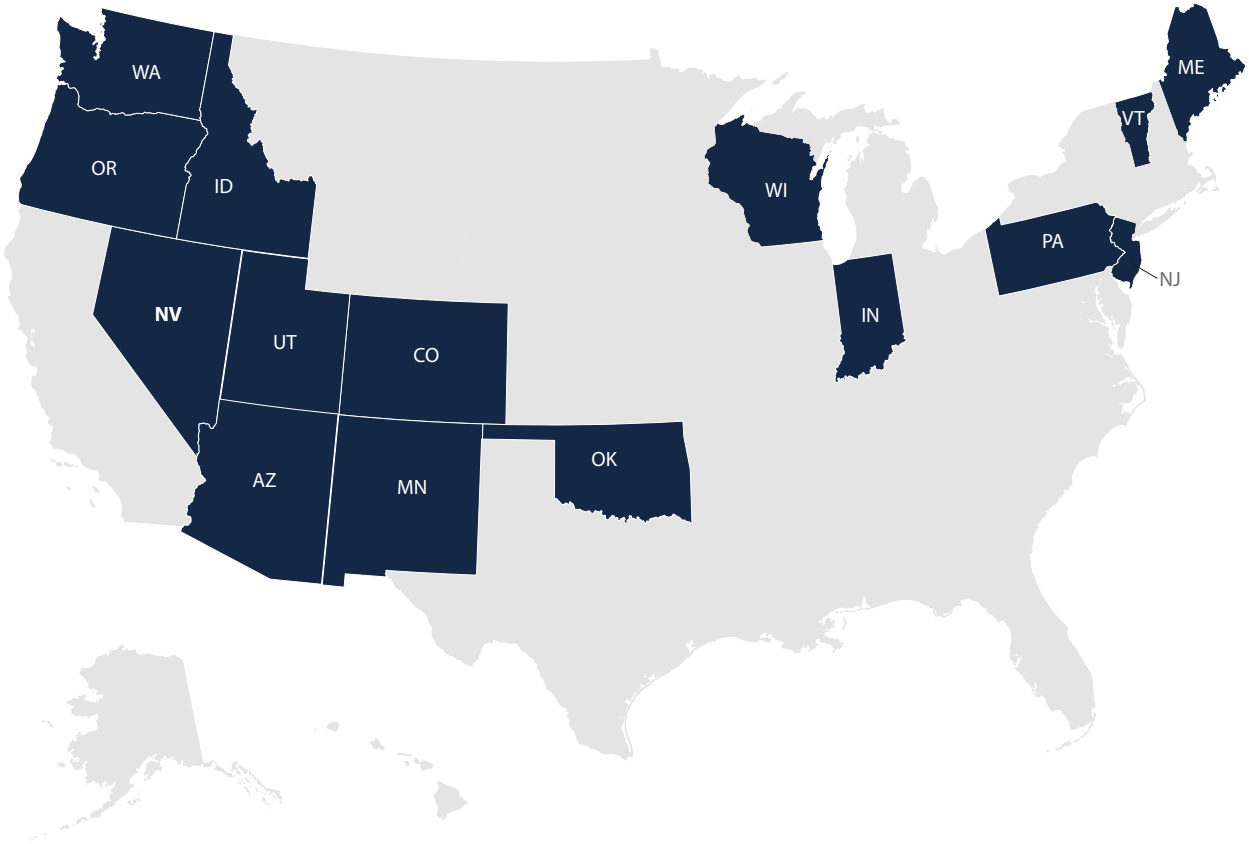
The publicly accessible NGDS data platform draws from millions of newly digitized records, including other DOE geothermal projects, to present information found in the DOE Geothermal Data Repository (GDR) and National Renewable Energy Laboratories (NREL).

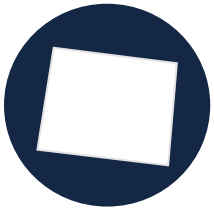
New Geothermal Data Gathered for NGDS

New data gathered in this project, including some from exploration wells, are now available from Arizona, Colorado, Idaho, Indiana, Massachusetts, Maine, New Jersey, New Mexico, Nevada, Oklahoma, Oregon, Pennsylvania, Utah, Vermont, Washington, and West Virginia. Positive results are forthcoming and include the discovery of a new geothermal resource in Utah's Black Rock Desert. Data records for this new exploration are available through the NGDS catalog.
Arizona collected new data as water chemistry from springs and wells, new geologic map data in three locations of known thermal springs.

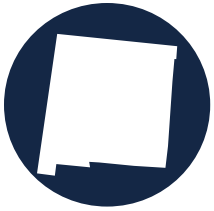
Ongoing Results

The NGDS project provides the data foundation for discovery and development of both large- and moderate-scale energy production and other practical applications, such as direct use and residential/commercial ground source heat pumps. The innovative data management approach adopted by NGDS may well lead to innovations and exploration in other Earth sciences and geospatial fields.





Colorado collected new chemistry data/analyses and obtained new thermal conductivity measurements on existing core.



New Mexico collected new temperature-depth logs from existing wells, new aqueous chemistry samples for analysis, and rock samples for geochronology analysis.

Utah drilled 12 new geothermal exploration wells and obtained well logs, aqueous geochemistry and thermal conductivity data.

Idaho drilled 4 new geothermal exploration wells, obtained lithology logs, thermal conductivity measurements, and heat flow data.

Nevada drilled 2 new geothermal wells and obtained logs, thermal conductivity measurements and aqueous geochemistry data.

Vermont collected new temperature-depth logs and other geophysical logs from a set of existing deep wells without temperature logs. In addition, new rock samples were collected for thermal conductivity measurements.

Massachusetts collected surface rock samples, and measured thermal conductivity and Uranium, Thorium, and Potassium concentrations to calculate radiogenic heat production.

Oklahoma measured thermal conductivity and radiogenic heat production data from existing drill core samples and newly collected surface samples.

Washington collected new aqueous chemistry samples for analyses, completed new temperature-depth logs in existing holes, conducted new geologic mapping related to geothermal activity.

Maine collected new temperature-depth logs from existing deep wells.

Oregon drilled 3 new geothermal exploration wells and obtained logs, aqueous geochemistry and thermal conductivity data.

Wisconsin drilled new wells as part of the primary project (not Supplemental) and obtained well logs and thermal conductivity data.

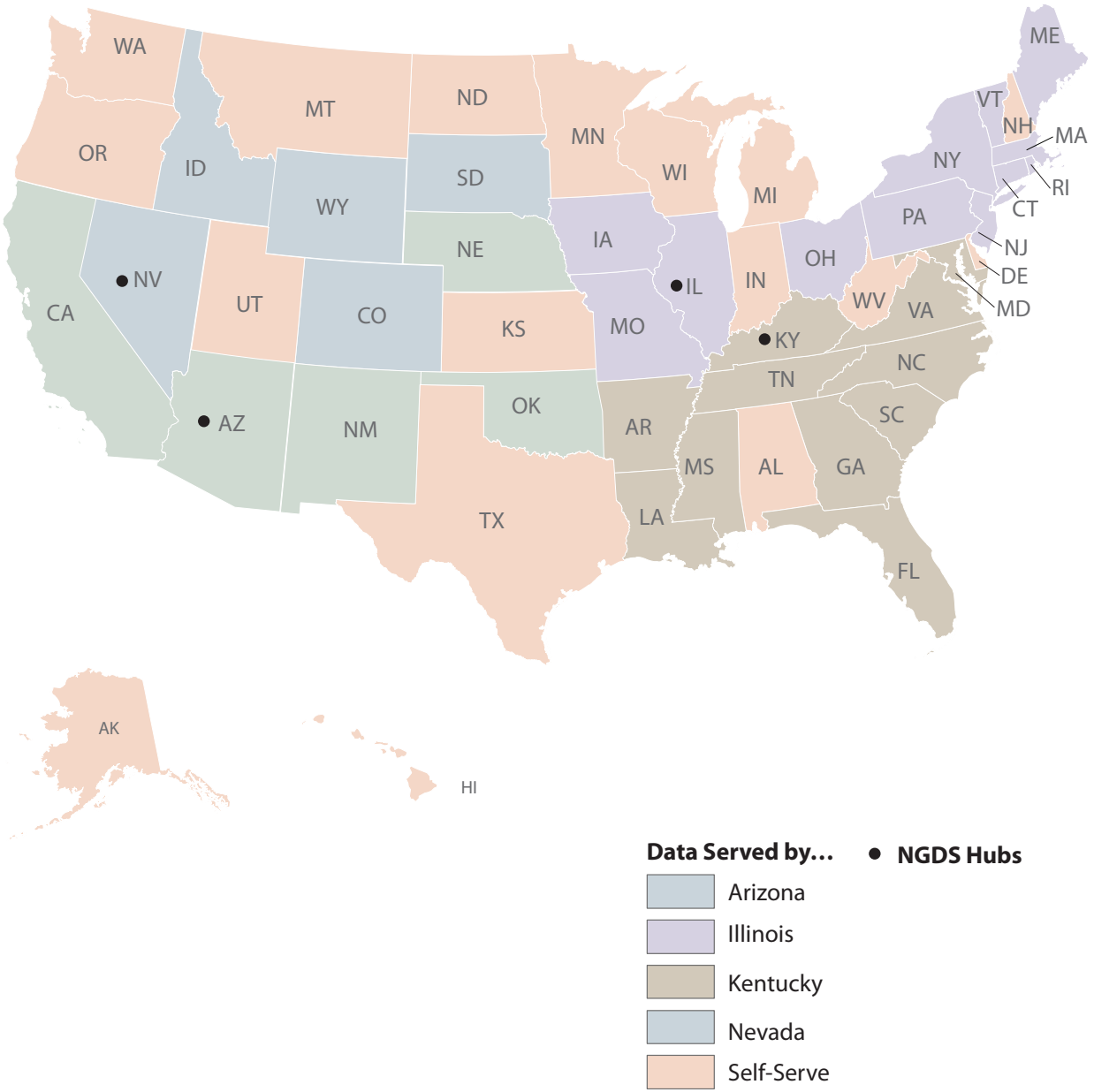
New Jersey collected new temperature-depth logs from existing deep water wells.

Pennsylvania ran well logs in new deep wells drilled by industry in 2014.

West Virginia collected new thermal conductivity measurements from existing core and cuttings samples.

NGDS Serving Data via Distributed Hubs

The NGDS features contributions of geothermal-related data from all 50 U.S. states that is referenced through a central catalog system. Actual data is either independently hosted by states using GeoPortal or GIN-stack software or it is served by a Hub. Currently, four Hubs are responsible for serving data from 34 states. Nevada and Arizona Hubs cover most of the west and westernmost Midwestern states. Illinois and Kentucky Hubs serve data from the Northeast and the Southeast, respectively. States self-hosting their data, known as Nodes, are geographically scattered throughout the country.



About the NGDS Atlas

The chief objective of the NGDS atlas is to inform the reader of the nature, quality and quantity of geothermal-related data available for all 50 U.S. States, free and online through the NGDS catalog.

Currently, over 7.2 million data records are exposed through the NGDS catalog. That number will grow as State Surveys, DOE-funded contributors, industry, and others add fresh data. Potential data contributors and web developers are encouraged to visit our "Data Providers and Web Developers'" webpage to see how to get started (*http://geothermaldata.org/ngds/publish_data*).

Showcasing the breadth and diversity of NGDS holdings—which ranges broadly from PDF documents to Excel data tables, to map services displaying geologic maps, to well log data, to geochemical analyses—is an extraordinary challenge.

NGDS Atlas Data Flower

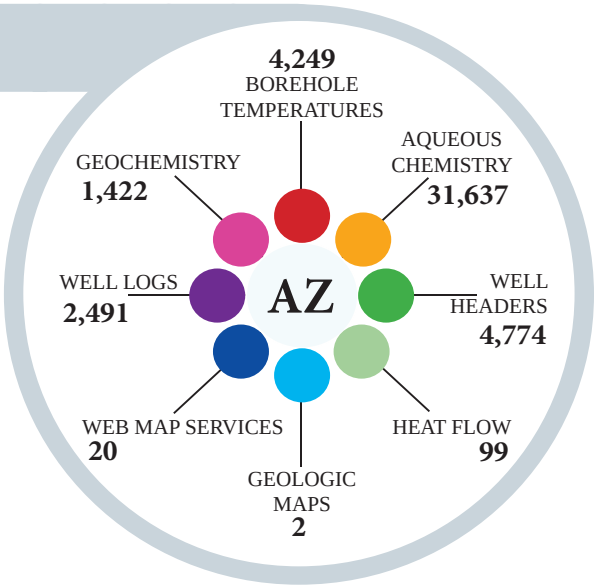
Our solution: to build and display an NGDS Atlas data flower for each state. The data flower displays major data categories and volumes of data available at the NGDS Catalog for each state (*geothermal.org*).

Major Categories

- **Borehole temperatures**—down-hole temperature values
- **Aqueous chemistry**—water chemistry parameters, e.g., pH, alkalinity, conductivity, flow, metals
- **Well headers**—location and elevation of wells, ID
- **Heat flow**—measured or estimated heat flow
- **Geologic maps**—provided by State Surveys
- **Web Map Services**—access to digital maps
- **Well logs**—well report on location and lithology
- **Geochemistry**—major- & trace-element analyses

Graphic Display

We selected graphics to showcase some of the accomplishments that characterize each state's involvement in NGDS. Some states leveraged their participation to build interactive maps and other resources for displaying their data; for others, data compilation has led to the discovery and exploration of previously untapped geothermal resources. The states overwhelmingly report positive outcomes in data management and understanding of subsurface systems as a result of the NGDS project.



The NGDS Atlas data flower shows at a glance the type and volume of data available in NGDS for each state.

The geothermal-geologic data used to construct this map is now available digitally in the NGDS catalog.

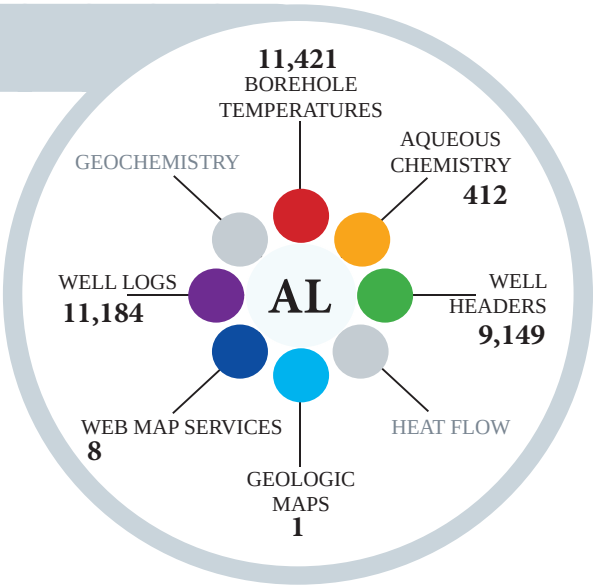
NGDS is powered by USGIN

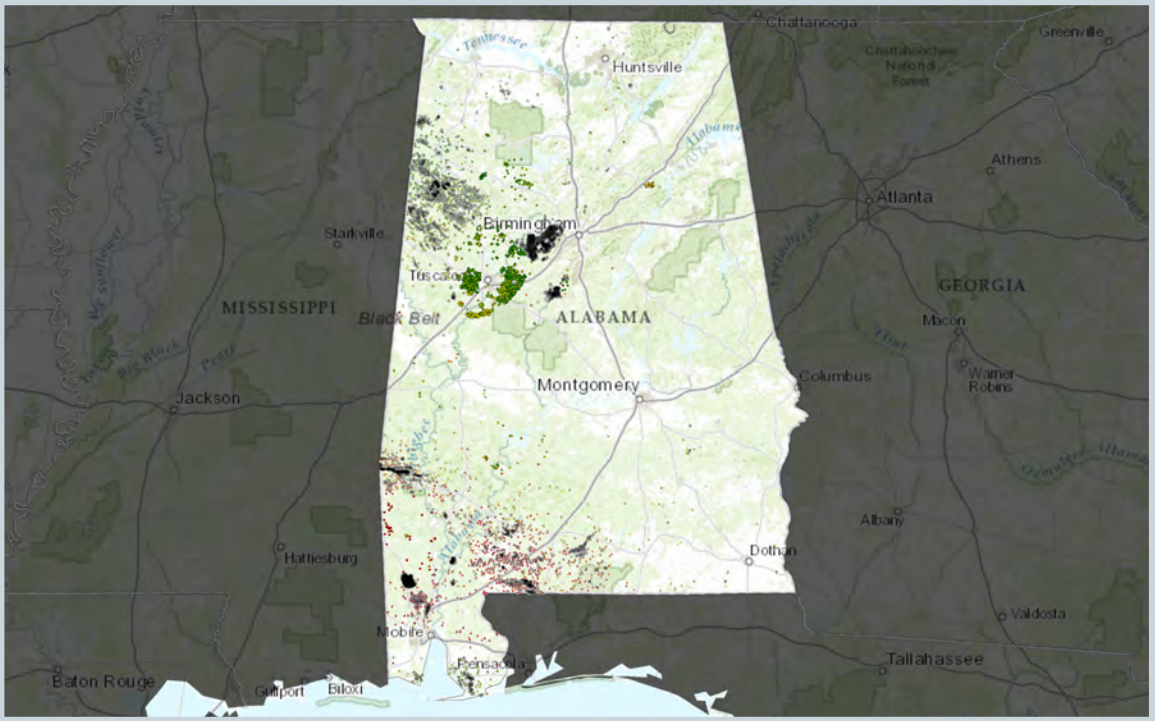
Alabama

Self-hosting NGDS node

In late 2014, Alabama became a self-hosting node for NGDS using the CKAN based software stack called GIN-stack. Alabama is slowly populating their website with available NGDS services. In addition to services for well headers, borehole temperatures, and well logs, anticipated web services will include aqueous chemistry (version 1.10), aqueous well chemistry, borehole lithology intervals, seismic event hypocenters, and well fluid production.

Alabama's ArcGIS map services, including OGB web services portraying their geothermal data submissions, can be located at *http://map.ogb.state.al.us/ogbmaps/rest/services/OGB/map/MapServer*. ■





Graphic representation of Web Map Services conveying borehole temperature measurements and well headers provided by Alabama as part of the National Geothermal Data System, soon to be served through Alabama's independent service.

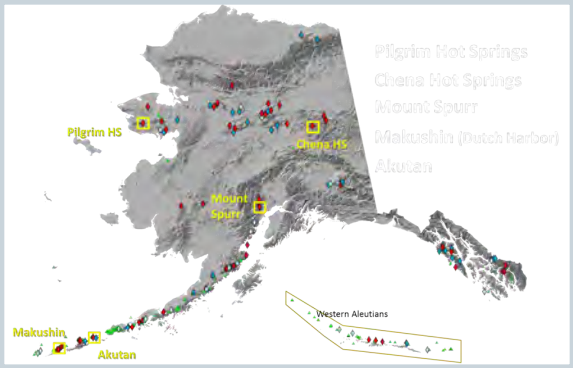
Alaska

Land of Volcanoes

With more than 100 volcanoes and over 50 known hot springs (above 50 degrees C) and 46 warm springs, Alaska is a potential geothermal bonanza. With NGDS support, the Alaska Division of Geological & Geophysical Surveys (DGGS) compiled existing information on exploratory geothermal wells drilled in the 1980s and in 2012 by Alaska Center for Energy and Power.

Data Management & Best Practices

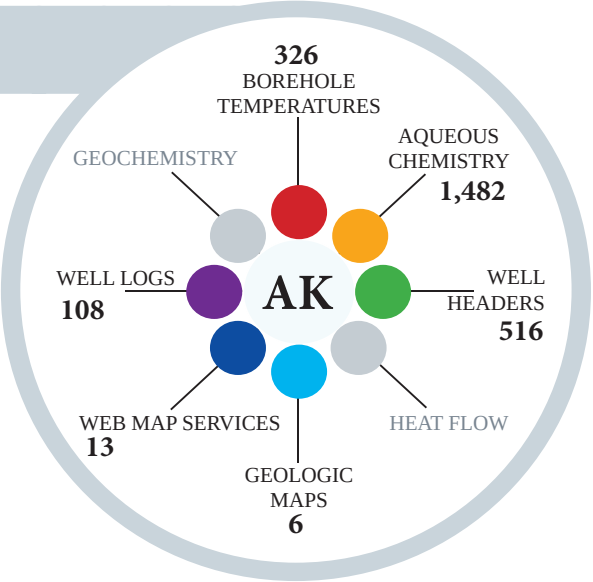
Geothermal-related data are now organized for exposure and easy retrieval—a great improvement over scattered paper records. This structured NGDS data approach breathes new life into legacy data and spotlights existing data gaps, which can drive new exploration projects.

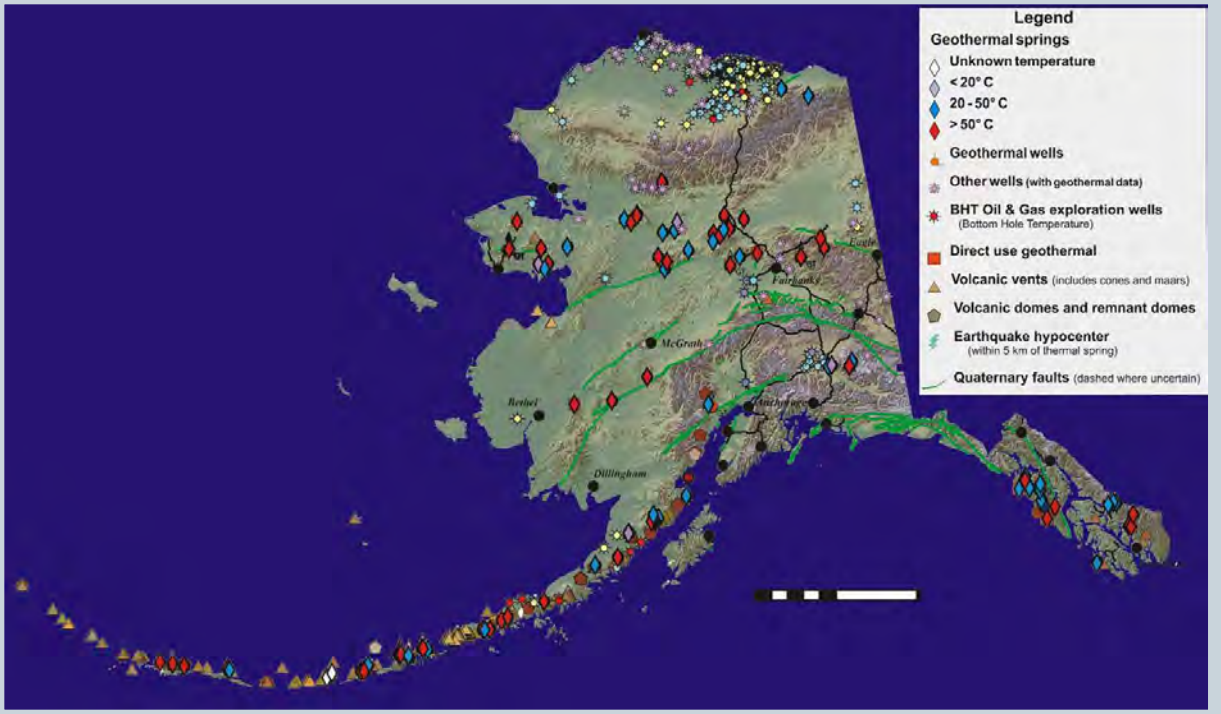


A map of geothermal resources in Alaska; highlighted areas represent recently discovered resources.

As part of their NGDS program, Alaska researchers compiled at-risk legacy and new exploration data for free access at *geothermaldata.org*. The team structured their data to a whopping 30 NGDS-approved schema, creating interoperable Tier 3 data sets that can be read in multiple formats. Tier 3 data is interoperable data, structured and standardized to open in multiple formats and to effortlessly merge with additional data sources in a content model for ease of analysis.

Alaska became a self-serving node of the NGDS using ▸▸





A compilation of digital geothermal data provided by Alaska, including geothermal springs, well data, direct use geothermal sites, and seismic and volcanic features. This is an online, interactive GIS-based, digital map to replace the print-only 1983 analog map.

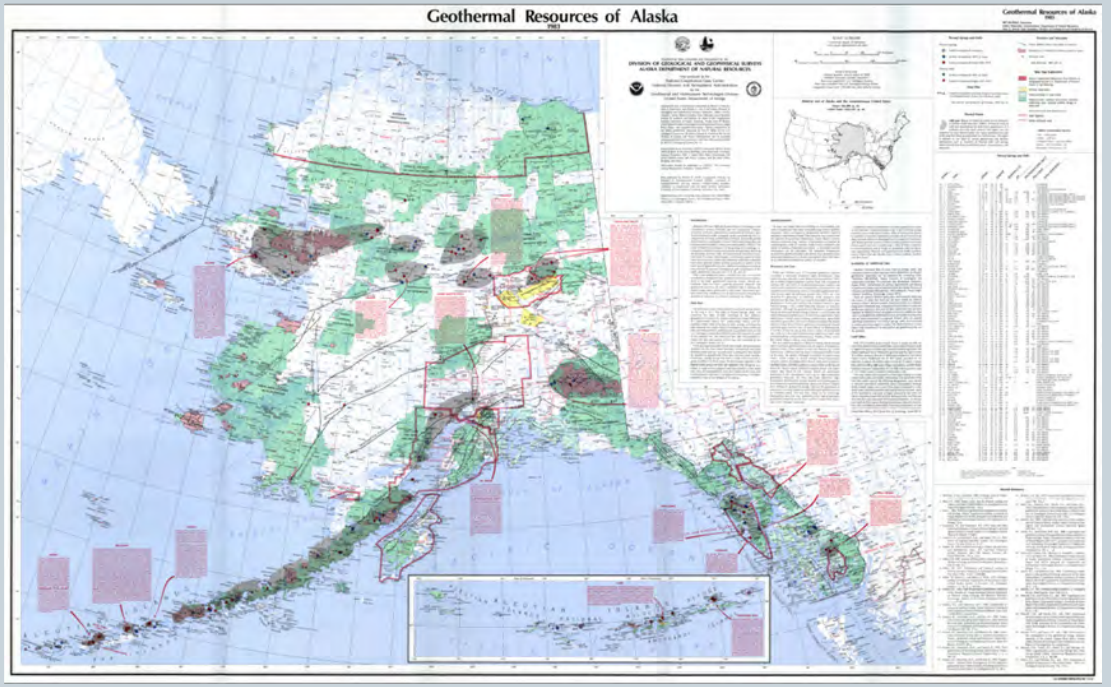
GeoPortal free and open source software in late 2014. The DGGS uses NGDS data to create an online , interactive geothermal map product that will replace paper maps. Look for the Alaska Geothermal Resource Map at *http://www.dggs.alaska.gov/pubs/*.

Geothermal Exploration & New Discoveries

Beginning in 2009, AIDEA-Alaska Energy Authority funded exploration of Hot Springs Valley on Akutan island to evaluate the potential for geothermal development to provide energy to both the City of Akutan and nearby Trident food processing plant.

Newly discovered and currently explored resources include:

- Pilgrim Hot Springs
- Chena Hot Springs
- Mount Spurr
- Makushin (Dutch Harbor)
- Akutan ■



An analog map of geothermal resources in Alaska from 1983; a classic example of legacy data digitized for NGDS.

Arizona

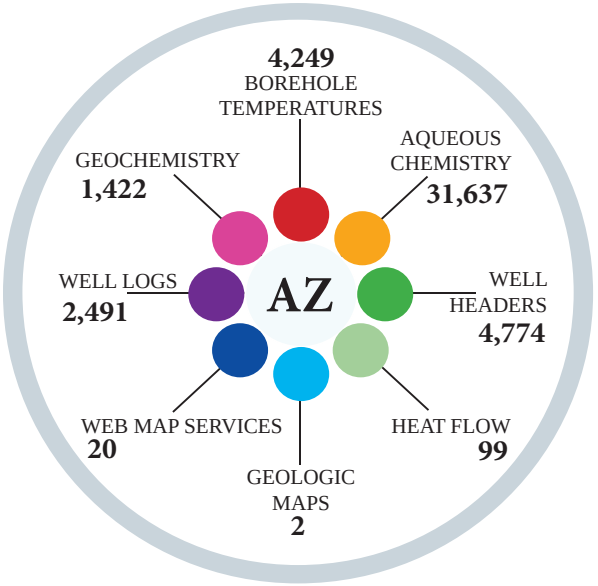
Interoperable Data

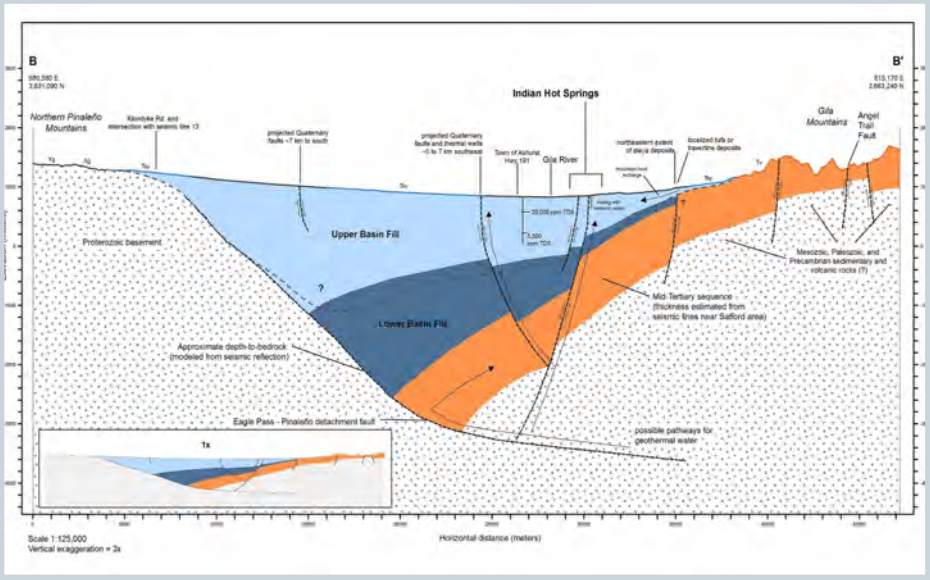
Working with the AASG, team members at the AZGS helped develop the framework for USGIN (US Geoscience Information Network), the collection of standards and protocols that the NGDS project is built upon. Interoperable Arizona data added to the NGDS Catalog includes over 4,000 document metadata for existing and newly scanned documents. Downloadable data is available in interoperable exchange content models or reports and documents. The two submitted geological maps are the geothermal map and the AZGS interactive digital map which covers all the state's geology. This map is available online at *http://data.azgs.az.gov/geologic-map-of-arizona/*.

December 2012 | Verde Hot Spring along the Verde River, southeast of Camp Verde, Arizona. Hot springs throughout Arizona were sampled for isotope and geochemistry analysis, excluding Verde Hot Spring (pictured) which was attempted but inaccessible due to high water flow, to assess the source of thermal groundwater exhibiting unusually high temperature anomalies. The Camp Verde hot springs burble away near the remnants of an old hotel that burnt down in 1962. It was apparently a swank spot in the Jazz Age, but rumors that Al Capone used it as an occasional hideaway are pure fiction.

New Data Collection

The AZGS supplemental 'new data' collection project provided new thermal spring and well aqueous chemistry, rock chemistry, geothermometry data, and temperature data for 17 thermal springs, and geological investigation to determine thermal groundwater sources for three thermally active areas hosting hot springs in southeastern Arizona. A final report detailed Arizona geothermal background, data collection methods and results, and new geologic maps for Aqua Caliente Spring, Hooker Hot Springs, and the Pinaleño Mountains-Safford Basin geothermal area (OFR-14-06 for the *Supplemental Investigation of Thermal Springs throughout Arizona: Geochemical, Isotopic, and Geological Characterization, Arizona Basin and Range Province).*





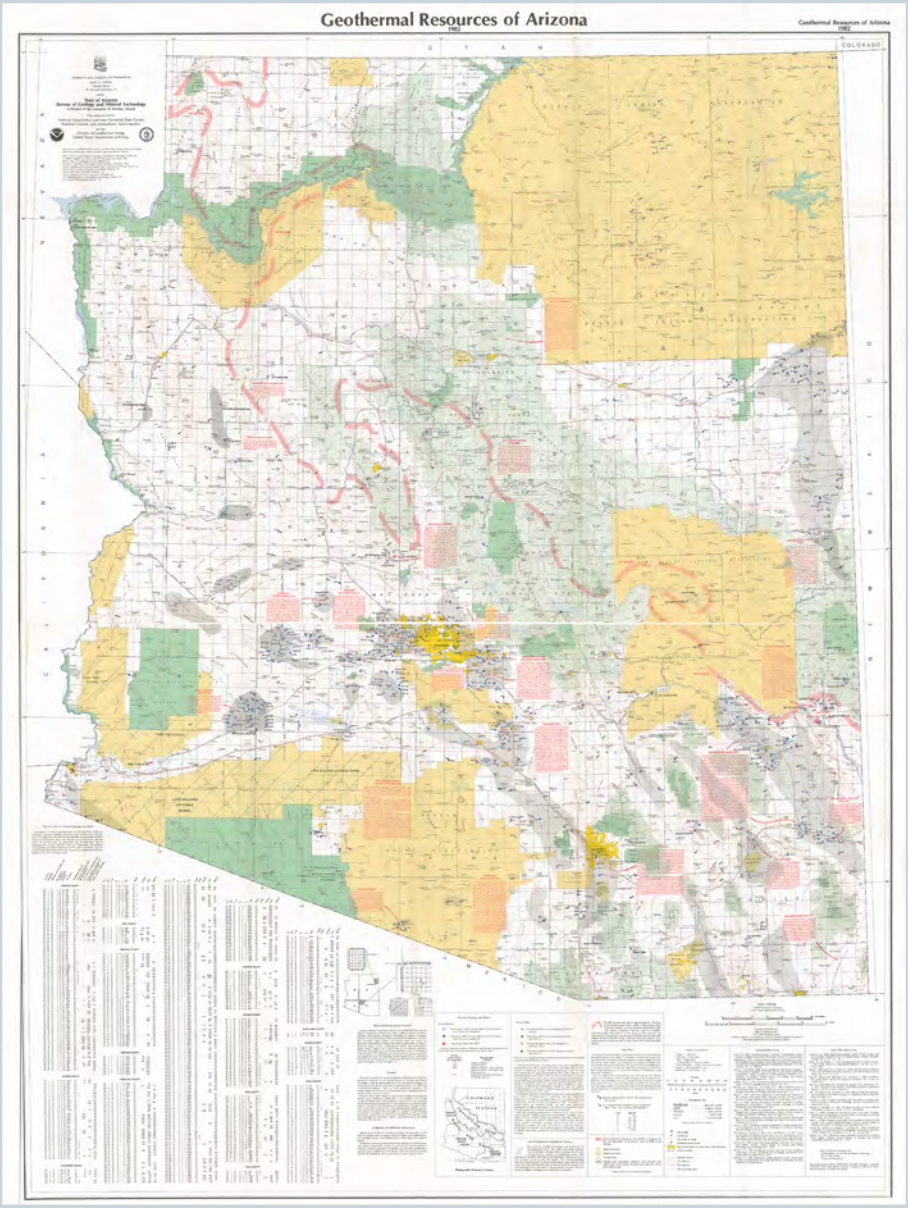
Geologic Cross Section A-A' Across Safford Basin, Cactus Flat to Buena Vista Hot Springs (AZGS 2014) produced for "Investigation of Thermal Springs throughout Arizona: Geochemical, Isotopic, and Geological Characterization, Arizona Basin and Range Province"; authored by Diane S. Love, Brian F. Gootee, Joseph P. Cook, Michael K. Mahan and Jon E. Spencer.

Geothermal Potential

Sedimentary basins in Arizona's Basin and Range Province show potential for high-to-moderate heat flow, moderate to high permeability, especially in fractured and faulted deep basin-fill units, and may be viable targets for large-volume conductive geothermal resources. Temperatures increase with depth below the surface in a near-linear geothermal gradient. Temperatures measured in oil and gas wells greater than 8,000 feet deep may exceed 100 °C. Thermal waters can also materialize at the surface as hot springs with temperatures exceeding 50°C, although most thermal springs temperatures in Arizona range from 20°C to 50°C.

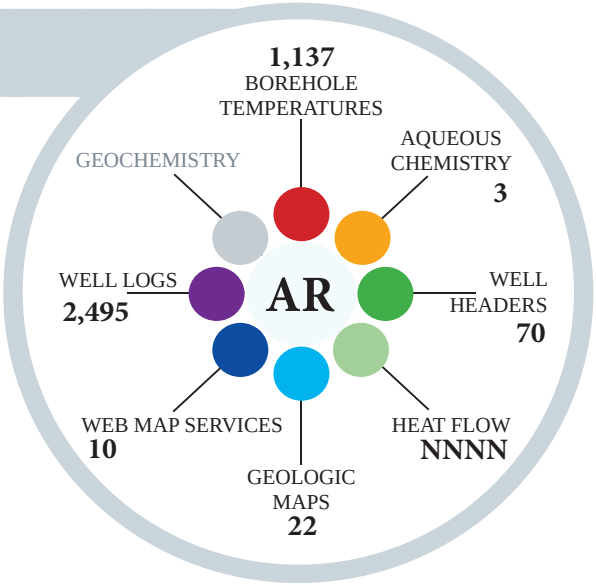
Arid central and southern Arizona supports a large agricultural economic base and several large, rapidly growing metropolitan areas. There is substantial competition between rural agricultural regions and cities over current and future use and control of groundwater, including low-temperature geothermal water sources (Witcher, 1995).

Abundant existing deep water-supply wells and irrigation wells have potential for conversion to private and small commercial geothermal direct-heat uses. Geothermal space heating and district heating are becoming more popular in areas where the resource is co-located with population and feasible for community facilities with large heating/cooling loads, such as schools. Geothermal aquaculture and green-housing are major direct-use applications showing noticeable growth in Arizona. Many geothermal direct-use applications have potential to conserve water while enhancing the value of farm production per acre (Witcher 1995). ■



Map displaying Arizona's geothermal resources (1980). The data comprising this map are now available in the NGDS catalog.

Arkansas



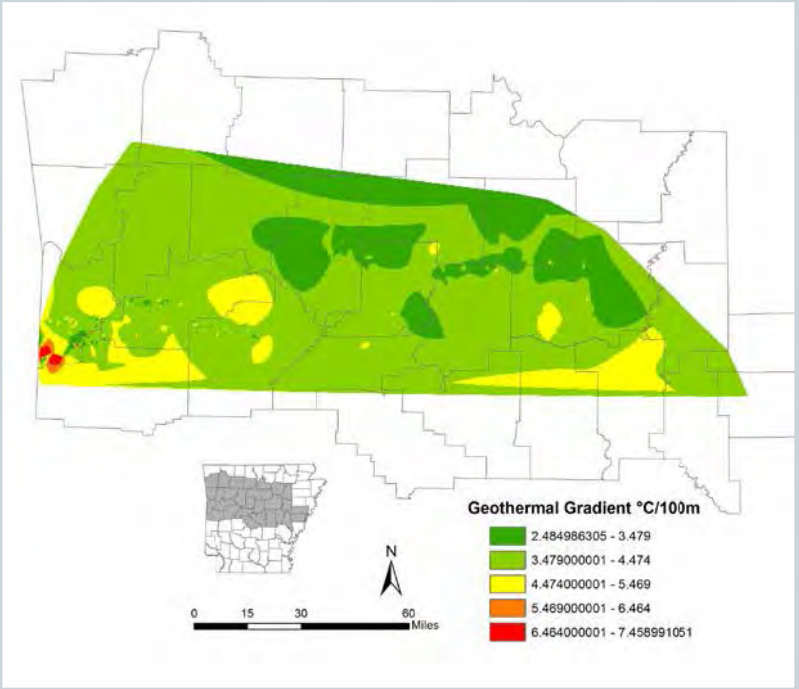
New & Legacy Data

Along with providing reports, maps and cross sections pertaining to basin structure, stratigraphy geothermal gradients, active faults and earthquakes, the Arkansas Geological Survey (AGS) loaded the NGDS project with more than 2,800 digital well logs reporting lithologies and down hole temperatures, as well as bottom-hole temperatures from across the state. Around 120 thermal conductance measurements were performed on core samples from southern Arkansas along with some data provided by the brine industry in southern Arkansas.

Bottom-hole temperatures (BHT) and temperature to depth data from over 1600 well logs from the Arkoma Basin resulted in new geothermal gradient maps. This area of northwestern Arkansas is part of the Fayetteville shale gas play.

Geothermal Potential

Core samples from 18 wells sampling the subsurface Jurassic Smackover Formation in southwest Arkansas were analyzed for thermal conductivity, thermal gradient, and heat flow values by the AGS. Interpretation of the results suggests that areas on northwestern Columbia and northeastern Lafayette Counties exhibit the highest geothermal potential, and further investigations are recommended. ■

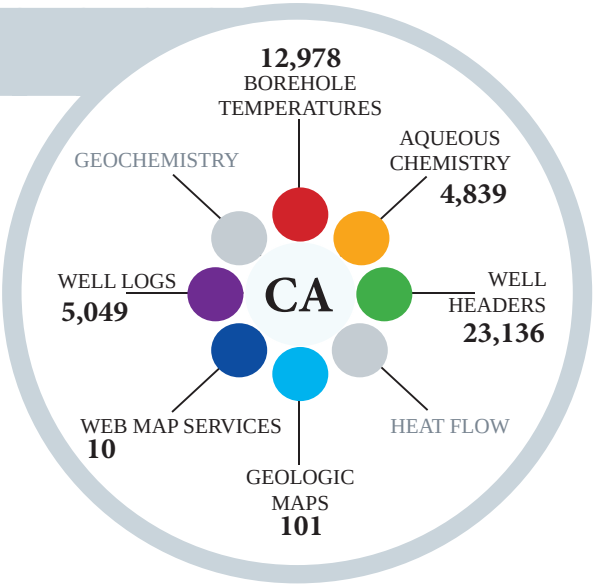


Newly produced geothermal gradient map in degrees Celsius per 100 m for north-central Arkansas.

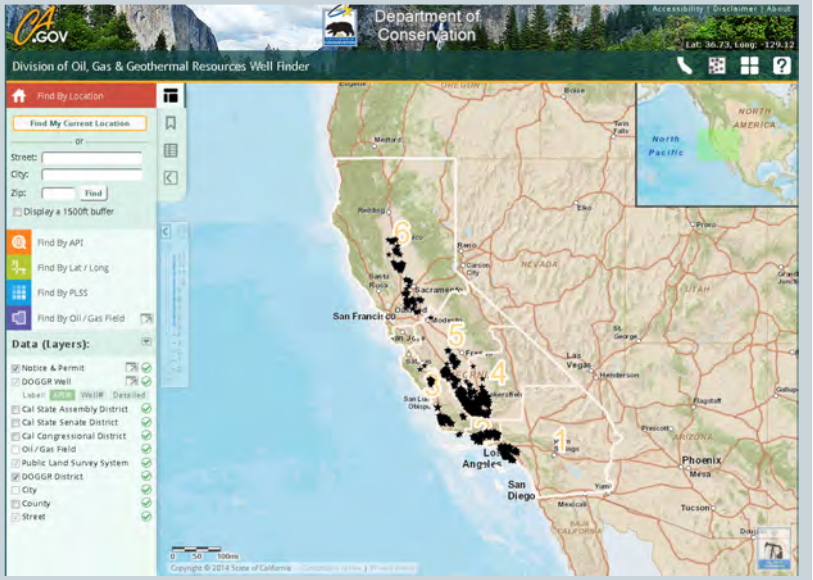
California

New & Legacy Data

California data was compiled by the AZGS with much appreciated cooperation from the California Department of Oil Gas and Geothermal Resources (DOGGR), U.S. Geological Survey (USGS), California Geological Survey, the California Energy Commission, and other entities. For California, 36 deliverable items with 25 Web Map Services were added to the repository, with over 87,000 records for online access. Data was published as an Esri Map Service, web map service, web feature service, and as an Excel workbook for download as appropriate. Metadata for reports and documents were added to the *StateGeothermalData.org* repository and cataloged for the USGIN Catalog.



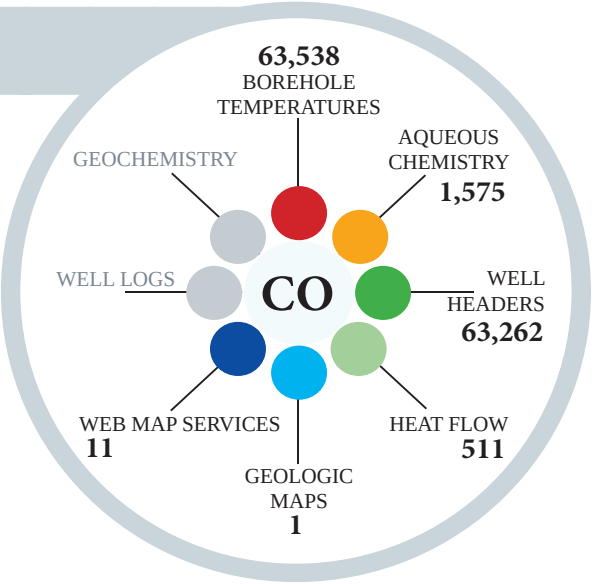
As part of Stanford's participation in NGDS, the Stanford School of Earth Sciences collected and collated about 8,000 technical geothermal papers (including downloadable PDF files), and provided geolocations for those papers specific to particular geothermal fields or sites. Stanford collaborated with the Geothermal Resources Council (GRC) to provide mutual database merges, so that the Stanford collection appears within the GRC database, and vice versa. In addition, they organized and provided some adsorption data (experimental) from rocks of The Geysers geothermal field. ■



Interactive well finder for oil, gas and geothermal wells throughout California.

Published in 2002, these data and more are now digitally available through the NGDS.

Colorado

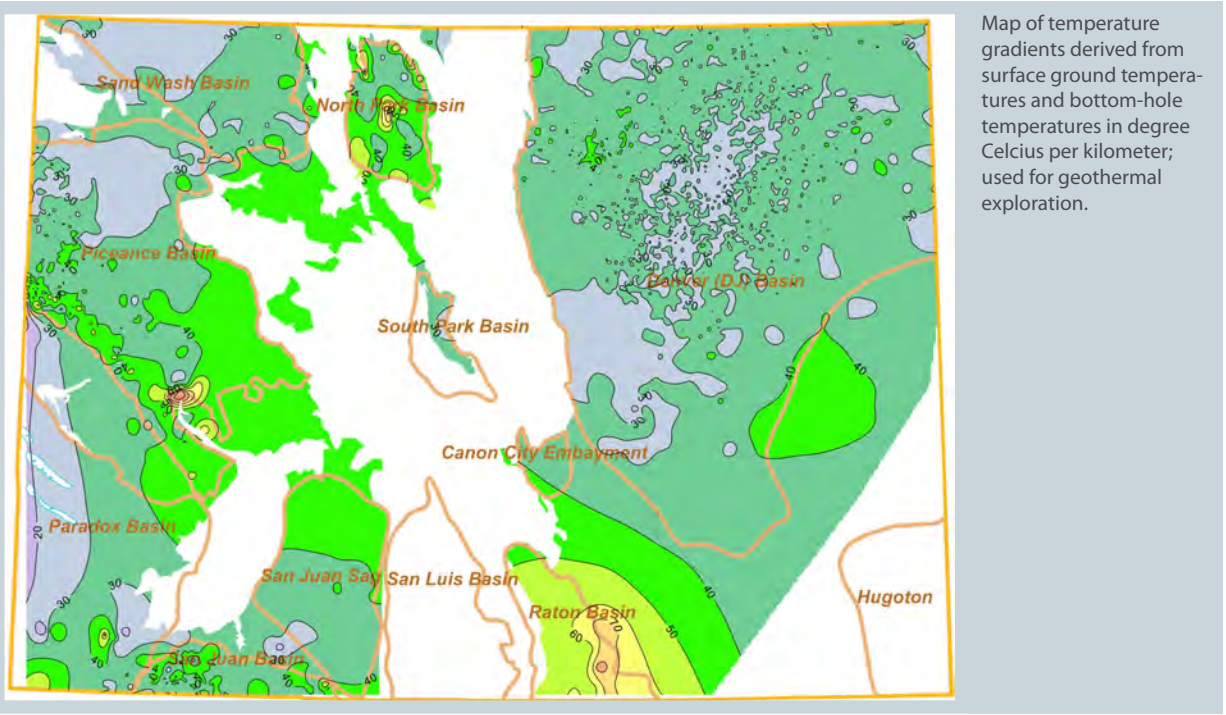


The team at the Colorado Geological Survey focused on digitizing thousands of geothermal-related records to bring legacy data to the NGDS Catalog. The result: better data management practices; out of the box thinking for geothermal assessments; and more industry outreach and involvement in geothermal exploration.

New exploration and assessment maps are proving invaluable in siting locations for electricity production in sedimentary basins, which is considered to be a new horizon. Companies and investors in the energy industry are lining up to break new ground in high yield, renewable, geothermal energy production.

Data Management & Best Practices

The Colorado Geological Survey has been collecting and compiling geothermal-relevant data since the mid-1970s. Most records were preserved as analog data; some data were stored on CD-ROMs. As a result of the NGDS project, however, the analog data has been digitized and converted to machine-readable formats, making them interoperable, searchable, readily cataloged. As new data are collected or legacy data updated, they'll be added to the catalog for public use.



Map of temperature gradients derived from surface ground temperatures and bottom-hole temperatures in degree Celcius per kilometer; used for geothermal exploration.

Industry Benefits

Data of particular importance and of great interest to the energy exploration community have been organized during the NGDS project. For instance, private sector companies are using thermal spring chemistry and geothermometry to help prospect for geothermal resources in Colorado. Bottom-hole temperatures and derived gradients have promoted industry interest in geothermal resources in sedimentary basins, with strong interest from Pioneer Natural Resources and other groups for developing an enhanced geothermal system (EGS) in the Raton Basin. There is additional interest from a major well-logging company to model basin temperatures to better predict optimal temperatures for well-logging, a potentially salable service.

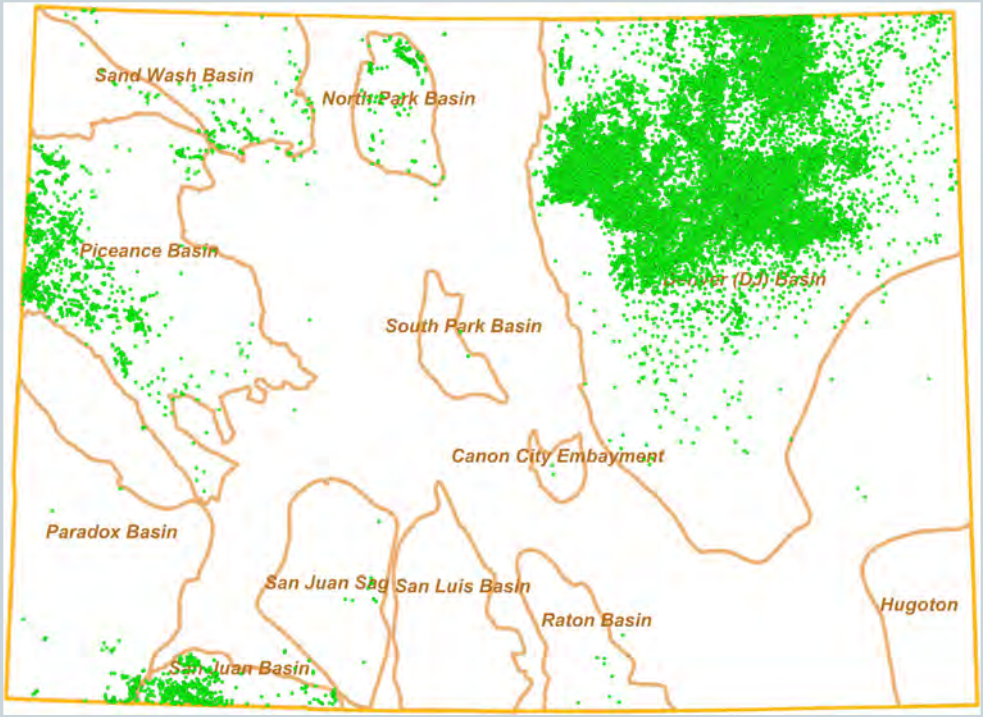
In addition, development groups are using specific temperature depth logs to to target deep geothermal test wells scheduled for drilling in summer 2014.

Geothermal Exploration & New Discoveries

This geothermal gradient map was created using different stratigraphic intervals in which borehole temperatures were selected; gradients were then calculated using ground-surface temperatures, from a model calibrated with climate stations and the BHT/depth data in the stratigraphic interval.

Colorado has potential for some small electricity production from conventional geothermal resource systems. However, these maps reveal much larger potential resources at depth in sedimentary basins that have been previously unexplored at the detail provided by the maps. Exploitation of these resources could bring a new clean, sustainable, renewable energy resource to Colorado, providing revenue and jobs.

These maps are the first maps that account for the effect on the thermal gradients of the low thermal conductivity shales that are widespread in Colorado. Previous maps showed anomalies that were only a function of shallow wells and shallow lithology. These maps may be used with geologic maps and depth sections to reliably estimate temperatures at depth. ■

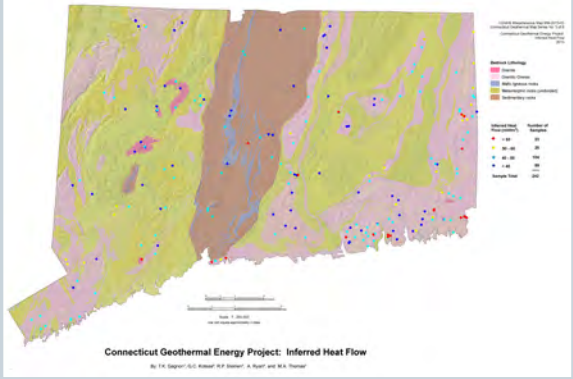


Locations of 26,178 wells used to construct the above temperature gradient map. Data from these wells is available through NGDS.

Connecticut and Massachusetts

Geothermal Assessment

The Connecticut and Massachusetts Geological Surveys collaborated on their contribution to the NGDS project. As a result, Connecticut produced the first statewide geothermal potential assessment. The objective: locate state geothermal resources with an eye towards better design of Enhanced Geothermal Systems (EGS) in bedrock and unconsolidated sediments.



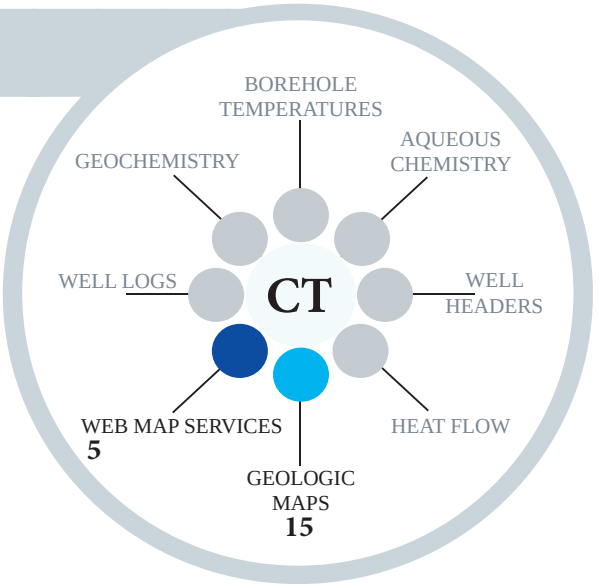
Connecticut inferred heat flow map produced in 2013 from data collected as part of CT's contribution to the NGDS project.

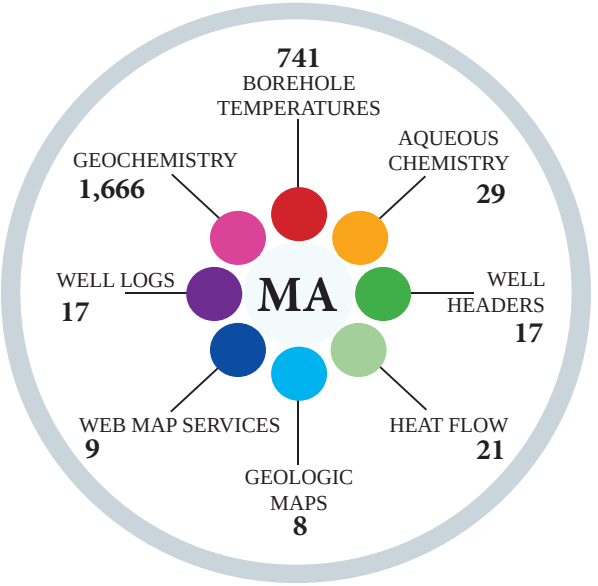
Applied Research

Bedrock units suspected capable of producing radiogenic heat at depth were the primary focus of this study. Other bedrock units were analyzed to provide a regional view of the geothermal potential across the state. A total of 55 bedrock units were targeted and 242 samples collected. Using the surficial and Quaternary maps of Connecticut, 20 unconsolidated sediment units were targeted for the collection of 100 sediment samples.

Rock chemistry, density and thermal conductivity of the bedrock samples were used to calculate heat production, heat flow, and thermal profiles at depth. Thermal conductivity measurements were made and physical profiles of sediment (grain size, sand, silt, clay percent, bulk density, porosity) were created.

A geothermal resource map series has been compiled from these data. Information depicted in the series includes heat production, inferred heat flow, thermal conductivity, and thermal profile maps for bedrock, and a thermal conductivity map for sediments. This map series will guide further work on deep geothermal resources of Connecticut bedrock in the future. All data and map services and products are available through the NGDS. The map series and summary information can also be accessed from the Connecticut Geological Survey webpage: *http://www.ct.gov/deep/cwp/view.asp?a=2701&Q=534290&deepNav_GID=1641.* ■

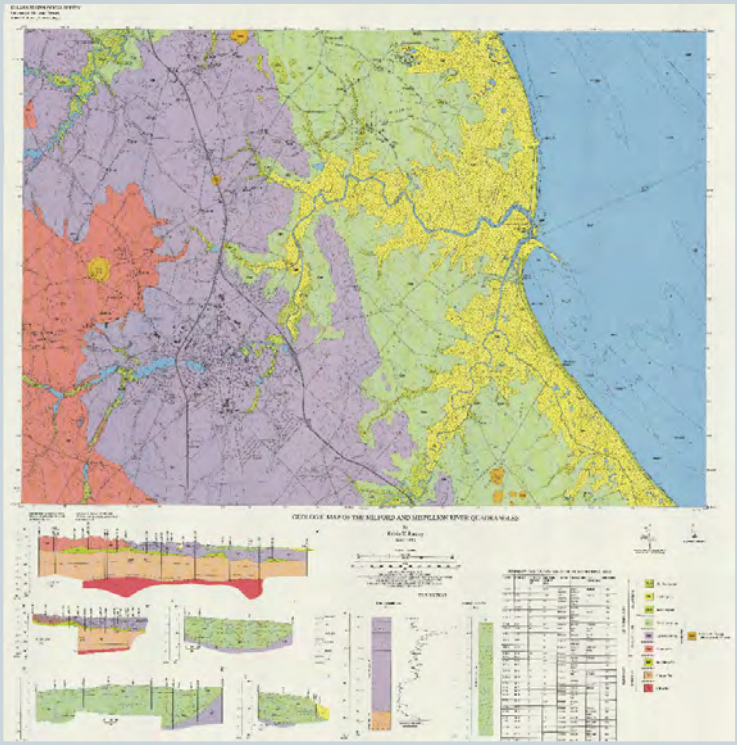




Delaware

A Node at USGIN

Data from the Delaware Geological Survey (DGS) was collected by Virginia Geological Survey. DGS has established a node on the United States Geoscience Information Network (USGIN). The DGS USGIN node exposes geoscience data related to the state of Delaware.

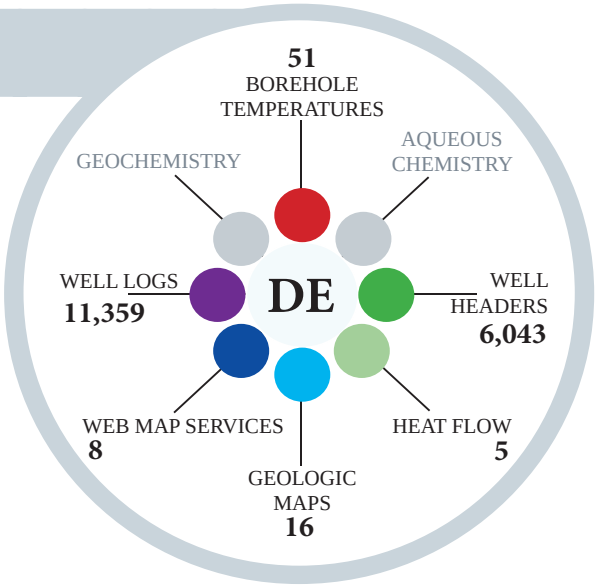


A scanned geologic map of the Milford and Mispillion River Quadrangles. This map represents one of the many products to be digitized for NGDS.

Legacy Data

DGS installed and configured open and interoperable web mapping and metadata services for surface geologic units and contacts within Delaware. These maps were developed at 1:24K and 1:100K scale for the state. All of the data structures match the GeoSciML-Portrayal schema and are distributed as WMS and WFS mapping services. Metadata for all of the data adhere to the USGIN profile standard of the ISO19139 schema, with support of the Catalog Service for the Web (CSW) 2.0.2 service, enabling easy search and retrieval of the metadata records and access to the associated map services. DGS built its IT infrastructure for serving the geoscience data through free and open source software, such as Geoserver (mapping) and GeoNetwork (metadata) applications.

Based on the USGIN node infrastructure, DGS contributed 1:100K scale surface maps to the OneGeology initiative; an international consortium dedicated to exposing and delivering digital geologic map data from around the world. DGS serves map services of data collected for the NGDS. These include datasets of well logs, well headers, thermal conductivity, heatflow and borehole temperatures. Numerous other datasets related to the NGDS are referenced and made available through metadata records. Both OneGeology and NGDS services are hosted through the USGIN node. ■

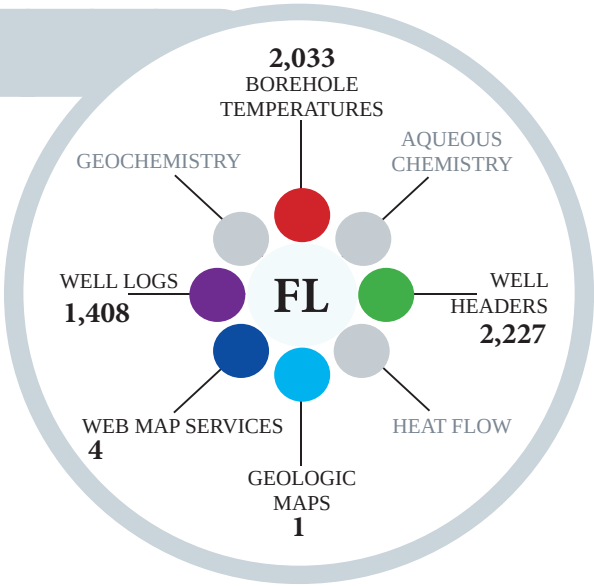


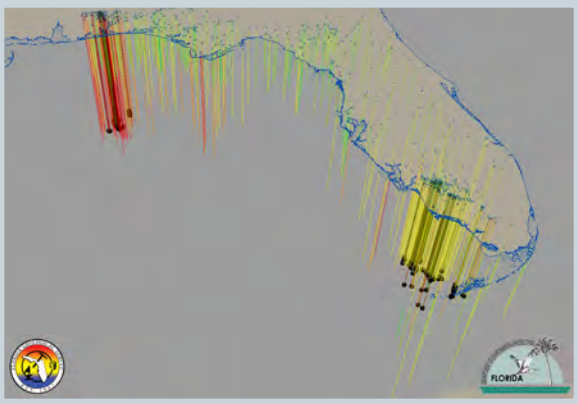
Florida

New & Legacy Data

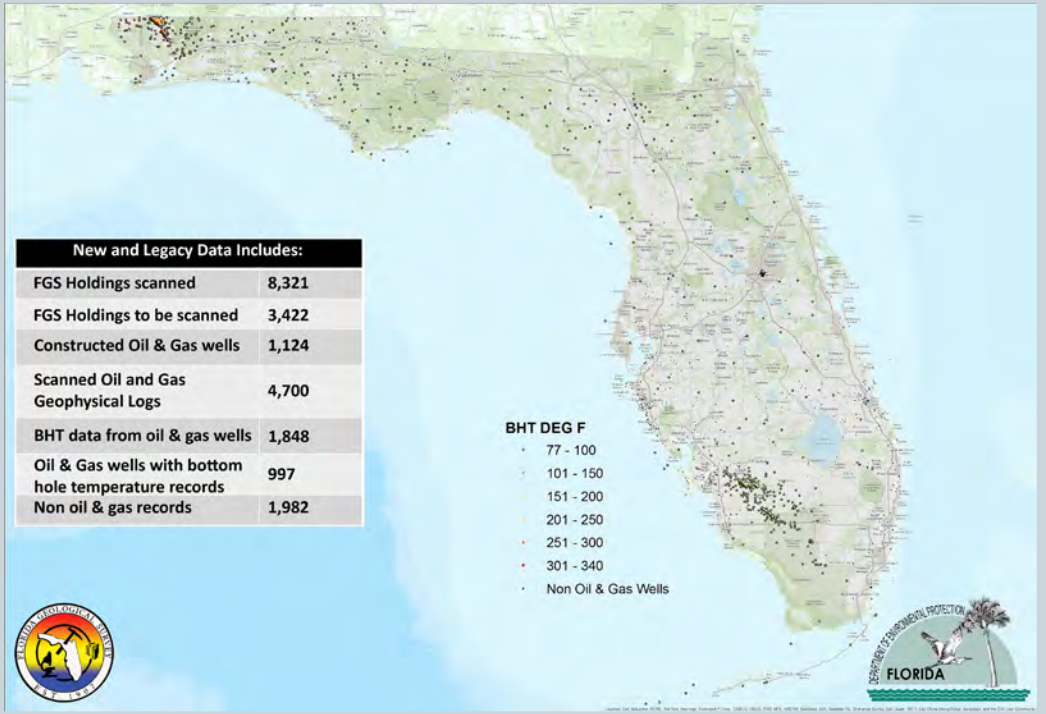
The data collected, digitized and organized through the NGDS has meshed nicely with the Florida Geological Survey's (FGS) efforts to rescue and provide public access to historic and at-risk geological datasets. The FGS scanned more than 4,000 oil and gas geophysical logs, documenting borehole temperatures from oil and gas wells. Supplementary records from other Florida agencies were compiled and the FGS documented nearly 2,000 temperature records from shallow wells throughout the state. The FGS continues to add to its digital collections by organizing and scanning geophysical logs as well as building metadata sheets for that data.

The main usage of geothermal energy in Florida is centered on heating and cooling projects for households and office buildings. An ongoing project in northwest Florida involves a geothermal co-production demonstration unit attached to an oil and gas well. The project produced somewhere between 0.20 and 1.0 MW of energy by skimming the hot water that is co-produced with the oil and gas. ■





A three-dimensional image demonstrating borehole temperature at depth; longer lines represent deeper wells; green lines represent cooler borehole temperature measurements; and warm colors, like yellow and red, represent hotter borehole temperature measurements.



A compilation of digital geothermal data provided by Florida for NGDS, including FGS Holdings, oil and gas wells, well logs and borehole temperature records.

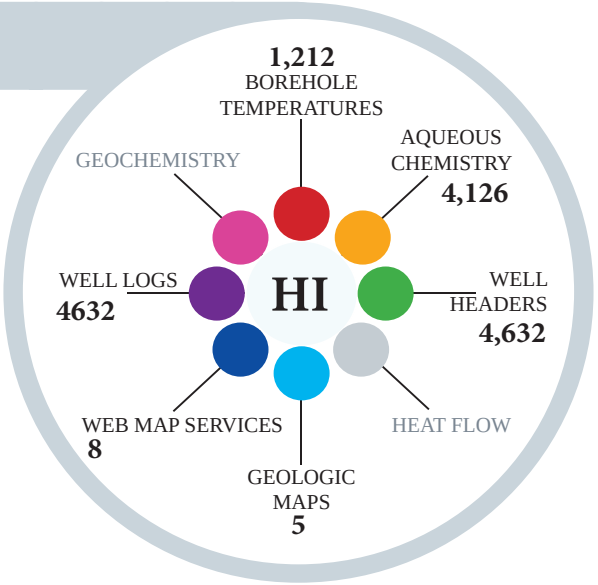
Hawaii

Industry Benefits

The NGDS project, run through University of Hawaii (UH), fostered unprecedented communication between multiple state agencies. Staff of the Department of Land and Natural Resources (DLNR), the Department of Business and Economic Development and Tourism Energy Office, large landholders, and the Department of Hawaiian Home Lands have cooperated with the UH team in compiling data and reports to incorporate into NGDS. Work with these organizations has led to further collaborative efforts and additional funding resources to develop new information on geothermal resources in Hawaii.

This glowing vent developed at the base of the east wall of Halemaumau Crater at the summit of Kilauea Volcano, Hawaii, in March 2008. (CREDIT D. Dzurisin (USGS).

Document sources include the Hawaiian Electric Company, the DLNR, the State Archives, Hawaii Natural Energy Institute, and UH researchers. The acquired documents serve as a reference resource for

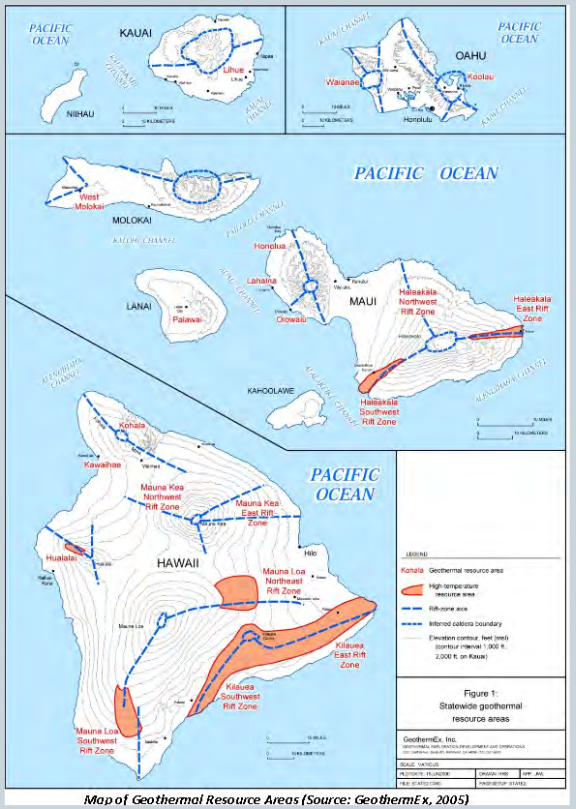


the DLNR-Engineering Division, which is responsible for regulating geothermal drilling in the state. In 2012, a total of nearly 10,000 files were downloaded from this site by ~6000 viewers.

Applied Research

Geothermal resources represent Hawaii's only economically viable source of base-load power. The NGDS project has stimulated cooperation between key players in geothermal development, provided enhanced accessibility to a broad suite of data relevant to geothermal resources, and galvanized new projects on geothermal exploration. The NGDS project is therefore making a critical contribution to Hawaii's transition to a more sustainable energy supply.

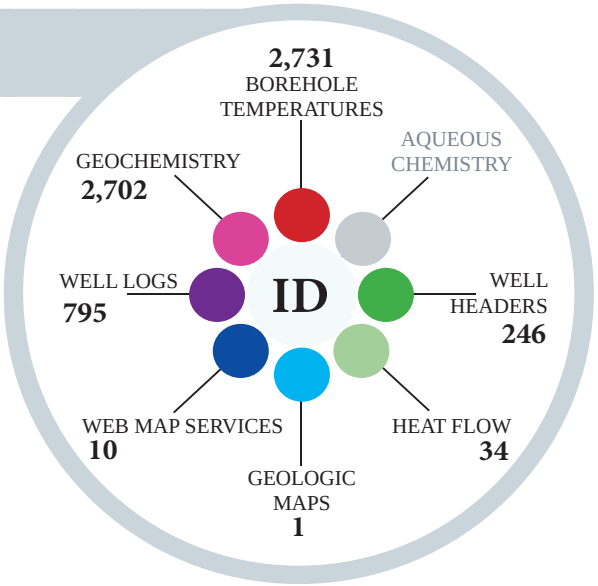
One of the most significant projects that will benefit from the NGDS is a new state-wide assessment of geothermal resources. This work involves magnetotelluric (MT) surveys, covering all the major geologic structures in the state with geothermal resource potential.



Geothermal Resource map shows potential geothermal energy production sites on the Hawaiian Islands.

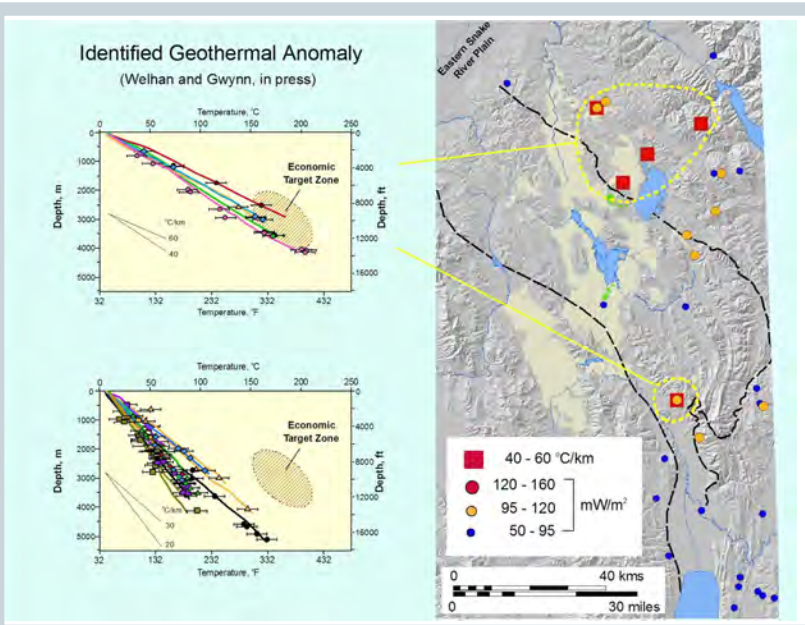
Easy access to the results of prior geothermal work, as well as to the site-specific hydrologic and geologic data contained with the Water Commission files, will tremendously enhance the state's ability to interpret and analyze the MT datasets. NGDS project activities are also enabling the State's Commission on Water Resources Management to transition entirely to an e-document system of water resource oversight and permitting. ■

Idaho



Geothermal Exploration & New Discoveries

Data compiled by the Idaho Geological Survey (IGS) for the NGDS project led to the detection of a previously unrecognized, drillable high-temperature geothermal resource. Idaho's NGDS supplemental heat flow drilling project focused on understanding the high-temperature potential of the Blackfoot volcanic field, one of the largest regions of young, bimodal (basalt-rhyolite) volcanism in the interior U.S. Thought to be a potential geothermal resource in the 1970s and 80s, temperatures from preliminary drilling near the China Hat rhyolite dome were disappointing, and due to advective thermal overprinting by shallow groundwater flow, shallow heat flow drilling was believed to be ineffective. It was only when the agency began to compile NGDS data on deep oil and gas exploration wells that a pattern began to emerge, revealing bottom-hole temperatures consistently higher than expected. Using Looking at the multiple data sets from the NGDS project, IGS re-analyzed data and found four wells with acceptable flow rates and temperatures of 150–200°C at just 2.5 to 4 km deep as The Blackfoot volcanic field may prove to be an economically valuable geothermal resource. IGS credits the NGDS project for facilitating the discovery of these exciting new resources and is compiling additional information for the NGDS project.



Evidence of a hidden, high-temperature magmatic-hosted geothermal resource—a potential location for geothermal development.

IGS recently collaborated with the Utah Geological Survey and Utah's Energy and Geoscience Institute on a Department of Energy proposal to examine the reservoir characteristics of the Blackfoot Volcanic Field and the Black Rock Desert prospect in central Utah (another resource revealed thanks to the NGDS project). The proposal was unsuccessful, but IGS obtained seed funding from NSF's "SedHeat" Research Coordination Network and convened a proposal development workshop to focus research interest on the Idaho prospect. Additional papers and projects are planned, including research and exploratory drilling to gather ▸▸

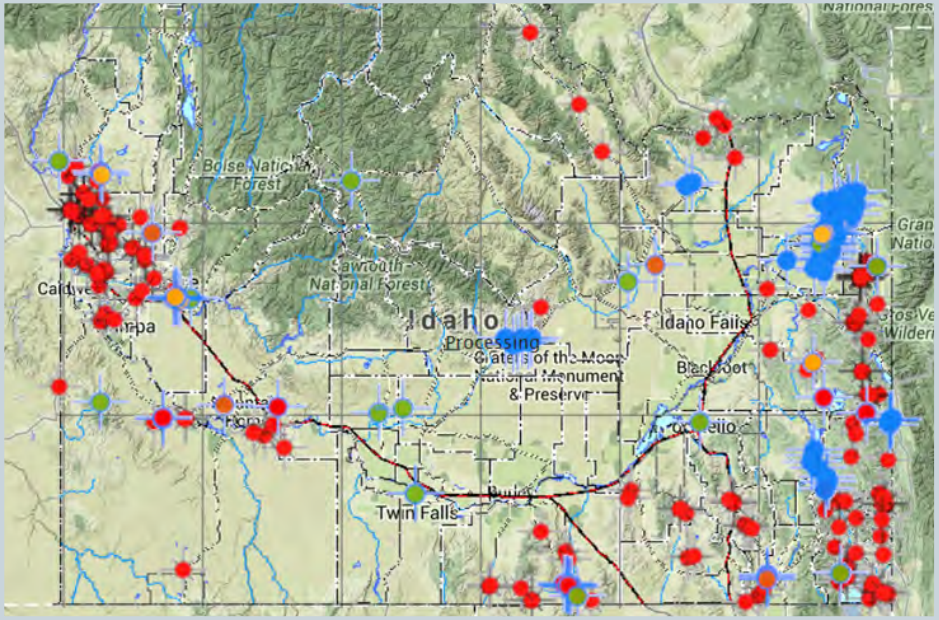
The China Hat rhyolite dome (ca. 2 km across at its base) is the largest of three domes in the central Blackfoot Volcanic Field. Having erupted ca. 58,000 years ago, it represents the most recent phase of volcanism from a magma chamber at 12–14 km depth that is believed to supply the heat encountered in shallow sedimentary reservoir rocks of the Idaho Thrust Belt.

data regarding the suggested presence of large quantities of lithium in some deep wells – possibly another previously unrecognized potential economic resource!

Data Management & Best Practices

In addition to data compiled and exposed via the NGDS, several new features were created for the IGS web site to increase exposure of geothermally relevant data:

- a searchable oil and gas well database and interactive map interface (*http://www.idahogeology.org/services/Oilandgas/*)
- an Idaho interactive map interface to geothermally relevant data, including geology, active faults (Miocene and younger), thermal springs and permitted geothermal wells (*http://www.idahogeology.org/webmap/*)
- fully digital 1:750,000-scale geologic coverage of the state (*http://cloud.insideidaho.org/arcgis/rest/services/IGS/GeologicMapIdaho/MapServer*)
- an Idaho geothermal web page that is currently under development ■



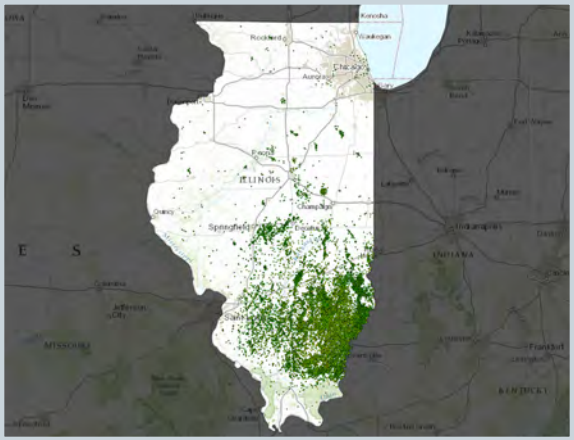
Borehole temperature measurements in the region of Boise National Forest; borehole temperatures can be indicators of geothermal resources.

Illinois

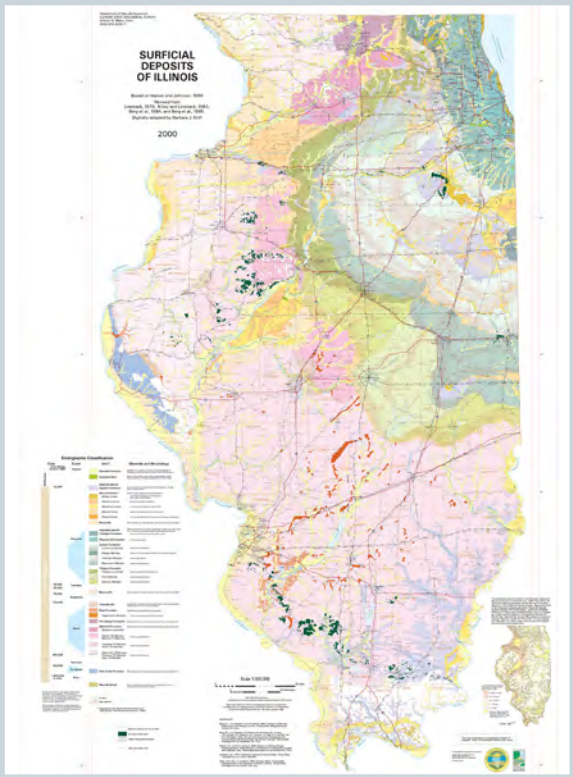
New Technology & Skills

As an NGDS hub hosting data from multiple states, the Illinois State Geological Survey (ISGS) not only compiled data but developed new software. In 2010, ISGS created programing to extract data from their existing state oil and gas database to extract borehole temperature data and drill stem test data to map to the NGDS content models.

In addition, ISGS developed software to data mine information and also manually add DST data to the database in early 2011. These proprietary tools were uploaded to GitHub to create and maintain services for use by other hubs or states that are interested in self-hosting their data.



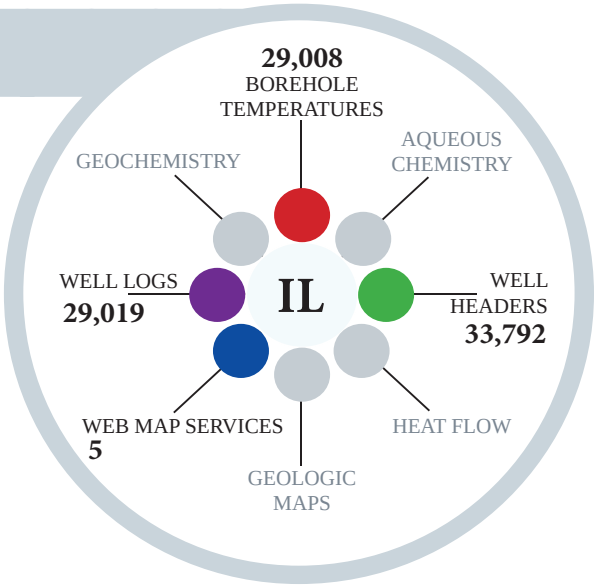
A web map service conveying borehole temperature measurements provided by Illinois is part of their massive data collection efforts for the NGDS project. The ISGS contributed over 29,000 borehole temperature observations.



A 2000 geologic map of surficial deposits in Illinois produced by the Illinois State Geological Survey describes sediments useful for a variety of geospatial analyses.

Data Collection & Standardization

Illinois provided tens of thousands of bottom-hole temperature values and associated data, as well as more than 16,000 drill stem test results. The ISGS contributed digital copies of all temperature logs in the ISGS collection, compiled a bibliography of ISGS geothermal-related publications, scanned oil well folder contents, and researched collections of old geophysical logs donated by industry to find logs lacking in the Survey's collection.



A team of approximately a dozen students identified electronic record information and adding numerous new data fields to files in preparation for their contribution to the NGDS and ensuring Tier 3 interoperability with NGDS schemas and standards. Over 145,000 logs were queried for temperature data to transfer to the borehole temperature Tier 3 template for interoperable web services.

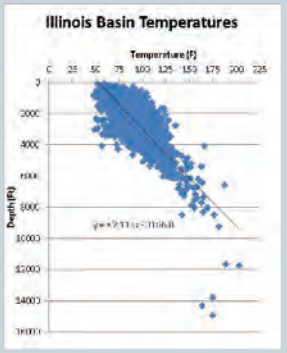
Derivative Products

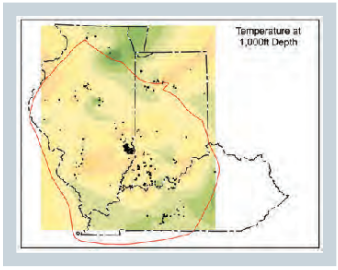
One derivative product of the effort was a joint report by the ISGS, Indiana Geological Survey, and Kentucky Geological Survey titled "Development and Application of a New Geothermal Database for the Illinois Basin," by Tiffany A. Proffitt, Kevin M. Ellett, Charles W. Zuppann (Indiana Geological Survey, Bloomington), Melony Barrett, Bryan Huff, Chris Korose, Alison Lecouris ▸▸

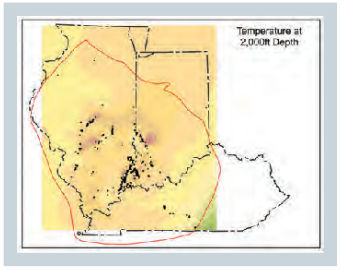
(ISGS), and T. Chase Noakes (Kentucky Geological Survey, Lexington), which was presented at a meeting of the American Association of Petroleum Geologists. Such a comprehensive effort at subsurface temperature data compilation and analysis had not been attempted since the 1970s. ■

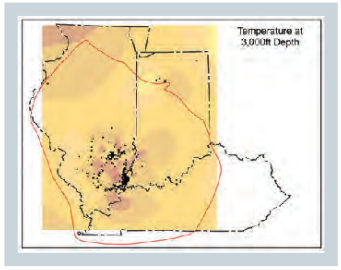
Depth-Based Temperature Slices

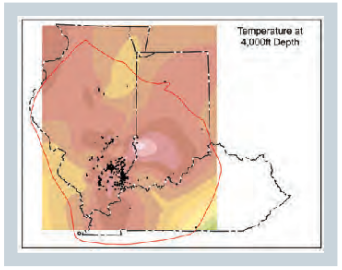
Temperatures and gradients for wells drilled to depths of 1,000 ft, 2,000 ft, 3,000 ft, and 4,000 ft were mapped. In order to ensure a suitable data size, a buffer of up to 75 feet was used for each depth range. Maps confirmed the general trends of increasing temperature, and decreasing gradients with depth. Previous researchers such as Harrison et al. (1982) have found similar results in other regions and further analysis is underway to determine how low thermal conductivity sediments may be enhancing temperature gradients due to a thermal blanket effect. This depth-based analysis also helps to identify regions where advective heat transport may be significant from shallow groundwater flow systems.

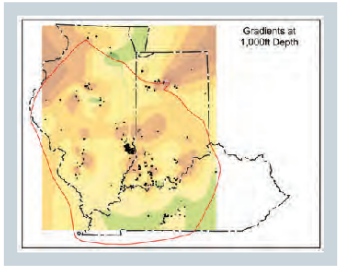


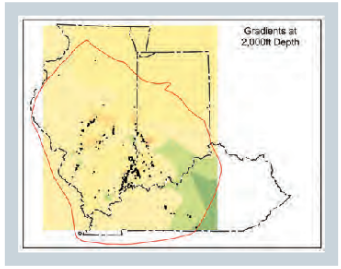


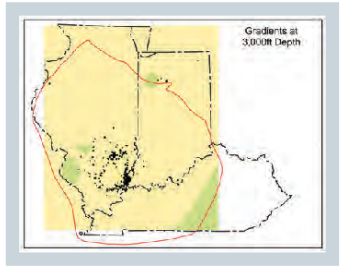


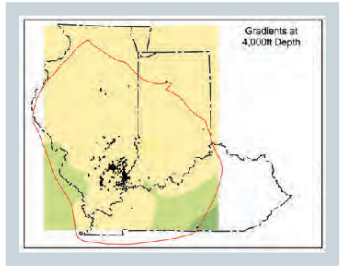


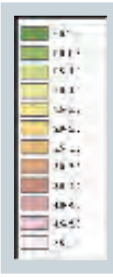




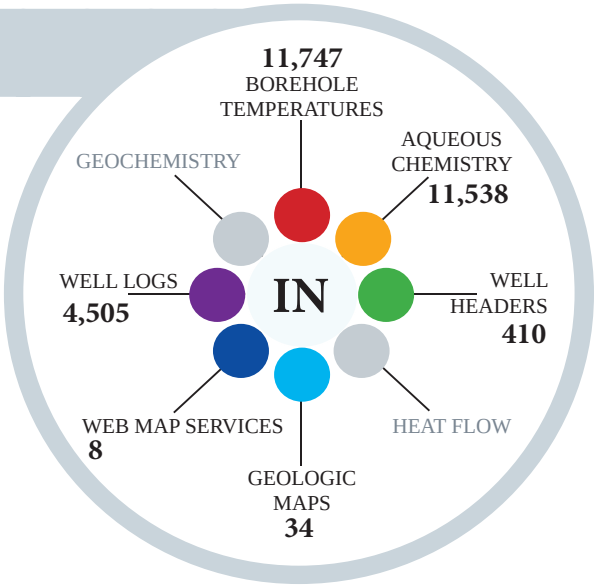








Indiana

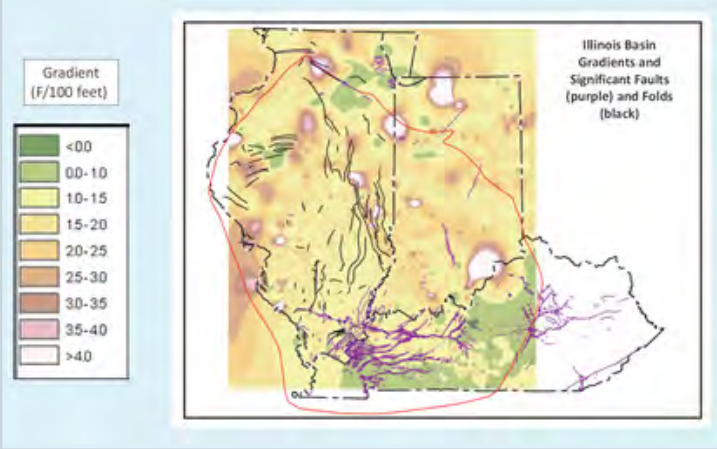


Ground Source Geothermal

Geothermal interest in Indiana pertains largely to ground source heat exchange systems. The NGDS project helped bolster this industry with new maps, standardized data, and better information tracking. In addition, the project excavated new pits and installed new monitoring data for shallow near-surface temperatures and thermal properties.

Data Management & Best Practices

Indiana Geological Survey (IGS) is now a self-serving node of the NGDS, serving data using GeoPortal. The survey reports improved capabilities for serving real-time data from sites throughout Indiana. The project also implemented a standard method for attributing geologic maps in tabular/vector GIS formats for public distribution. Several geologic maps previously not in digital format are now georeferenced or are raster images for viewing in GIS.



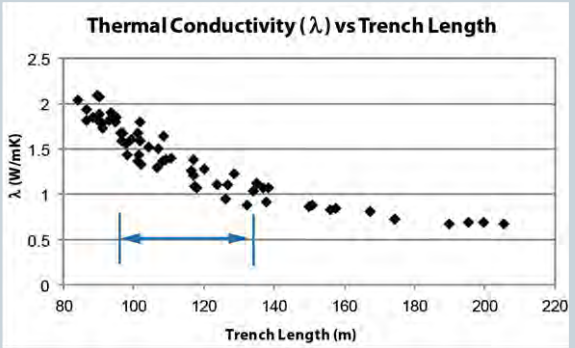
A map of geothermal gradients and significant faults in the Illinois Basin; can be used to facilitate geothermal exploration

Geothermal Discoveries & Exploration

Geothermal gradient analysis for the Illinois Basin region from over 26,000 wells was published in an American Association of Petroleum Geologists (AAPG) search and discovery article. These results are being used to parameterize reservoir temperatures in new modeling studies of carbon capture utilization and storage funded by the DOE.

Industry Benefits

Data from the NGDS project has contributed to two peer reviewed publications: "Controls on ground-coupled heat exchange in glacial sediments" by Shawn Naylor, Kevin M. Ellett, and Andrew R. Gustin (submitted to the journal Renewable Energy); and "Evaluation of regional-scale estimates of shallow thermal conductivity for application in horizontal geothermal heat pump design" by Kevin M. Ellett and Shawn Naylor, an invited paper that will be published in a Geological Society of America Special Paper titled "Geothermal Energy: An Emerging Resource." ■



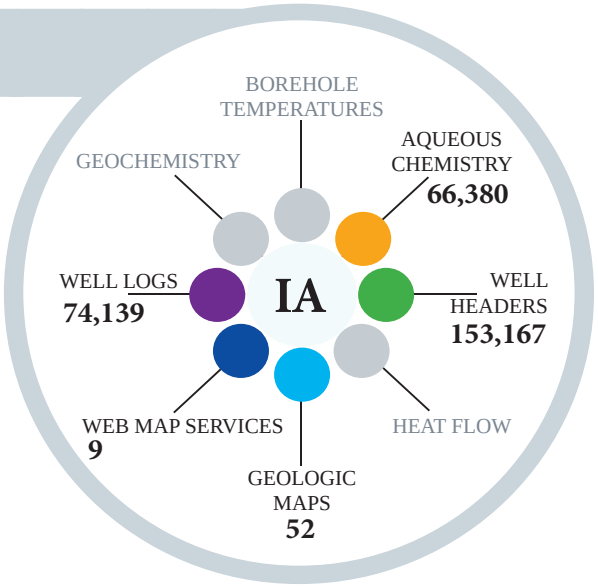
Thermal conductivity of unconsolidated sediments plotted vs. calculated horizontal trench length; this graph demonstrates optimal trench lengths for ground-source heat pumps.

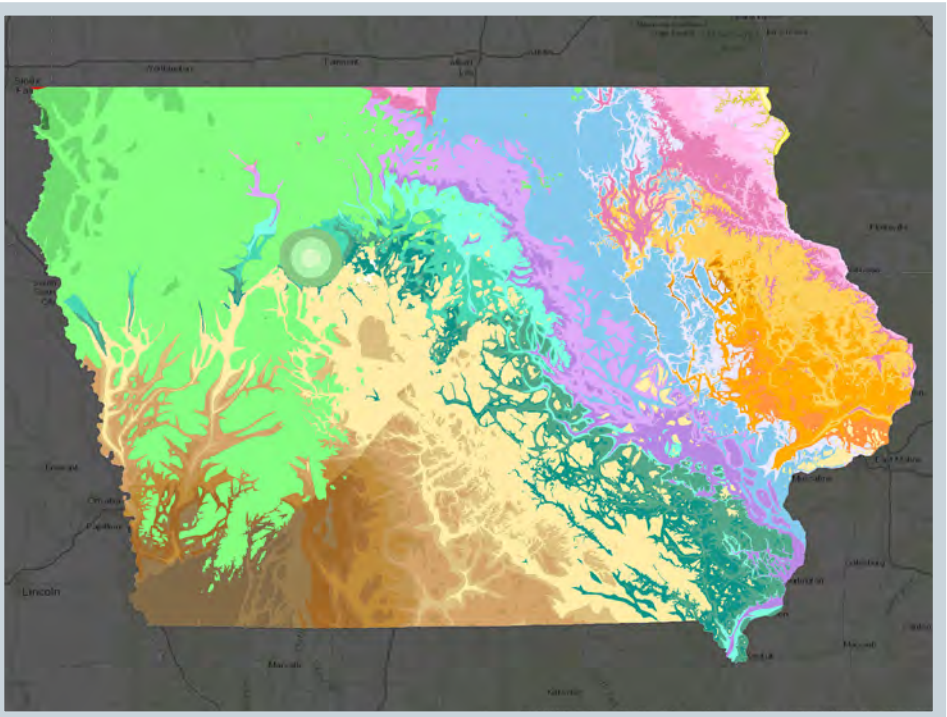
Iowa

Interagency Cooperation

Data collected from the Iowa Department of Natural Resources (IDNR) are deployed in Iowa Suitability Maps through Web Map Services. The suitability map resource is a metadata compilation for 20 map data layers, including vector and raster data, developed to assess site suitability for heat pump development. Information includes karst potential, known wells, contaminant sources, and hydrogeologic properties in the Dubuque County area. The data layers are hosted by the Iowa Geological and Water Survey. Data are stored in Web Mercator projection ESPG:102113 and are available as ESRI ArcGIS Server layers at *http://programs.iowadnr.gov/arcgis/rest/services/Projects/Geothermal/MapServer*. This dataset is delivered as an ESRI file geodatabase. Iowa Hydrolgeologic Map Server provided for 45 various layers including formation thickness, water yield, surface elevation, water levels, sinkholes, underground mines, and aquifers.

The Illinois hub, serving all data the IDNR contributed to the NGDS project, also serves the IA OneGeologyMap with 3 NGDS layers: *http://repository.stategeothermaldata.org/repository/resource/50ec3aefb656b70647f32e38bcf8521a/* ■





Iowa OneGeology map has three layers. Three (3) layers included in the Web Map Service (WMS) at 1:500,000 map scale and are as follows: geologic age, lithology and lithostratigraphy.

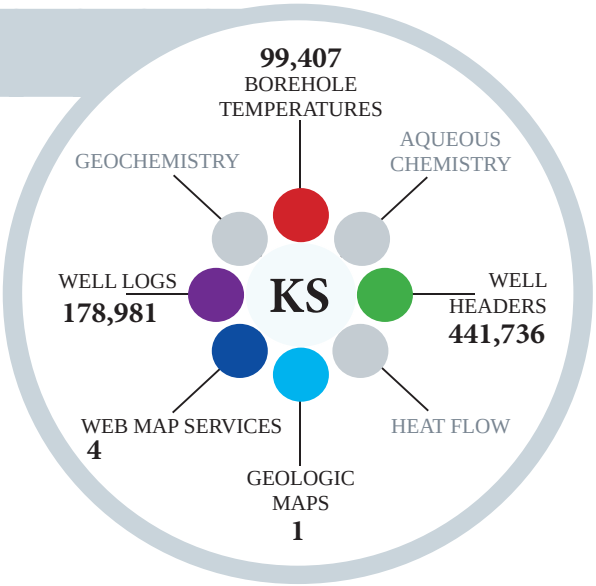
Kansas

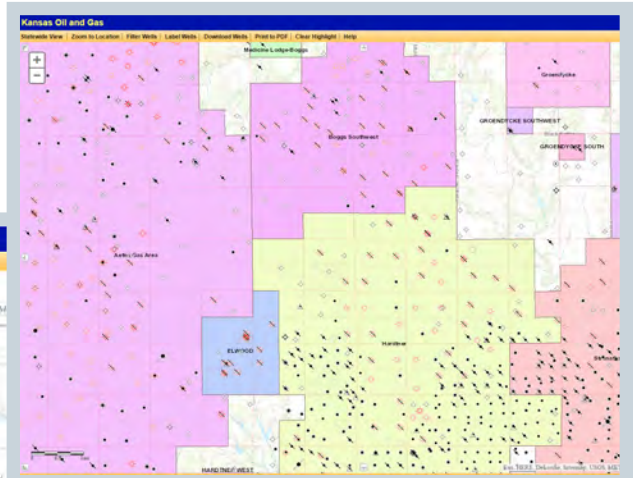
New & Legacy Data

Over the course of the project, the Kansas Geological Survey (KGS) provided NGDS with data for well headers, drill stem tests, borehole temperatures, and well logs. Map Services now available through NGDS include all of these features. Data discovery and processing was performed by KGS to compile Drill Stem Tests from multiple sources, including the Kansas Online Automated Report (KOLAR) system. This data was previously unavailable to the general public.

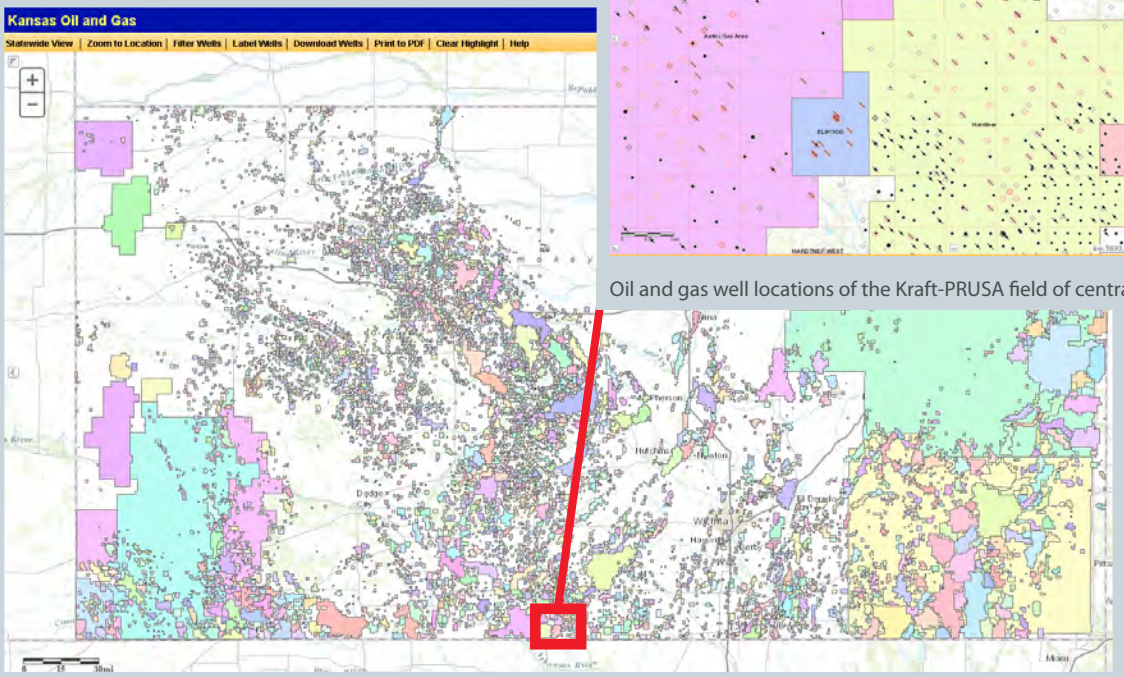
Geologic Maps

The 1:24K Surficial Geology map service was enhanced with 15 additional counties in the first year and 24 counties in the second year. ■



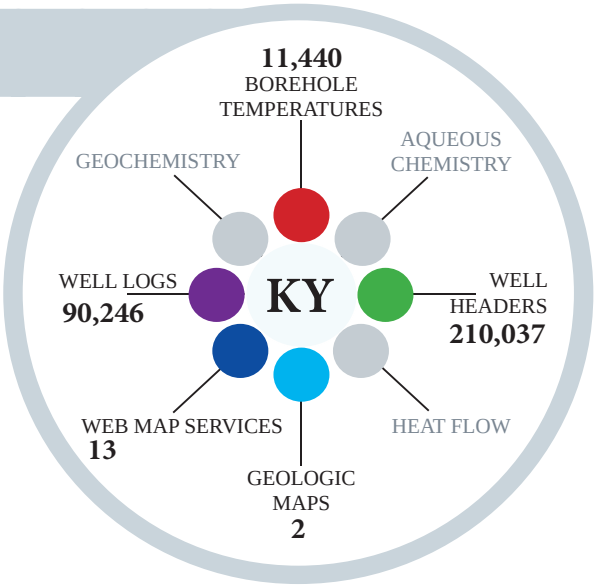


Oil and gas well locations of the Kraft-PRUSA field of central Kansas.



Interactive Kansas oil and gas fields with legend, located online at *http://maps.kgs.ku.edu/oilgas/index.cfm*.

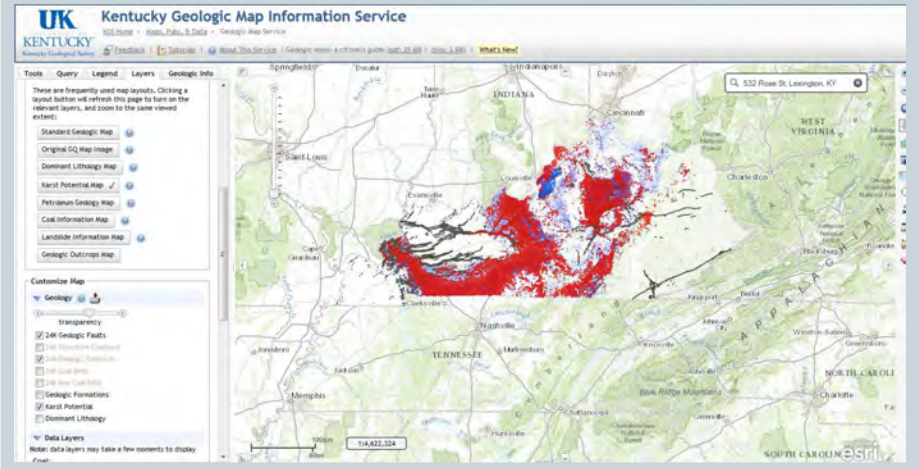
Kentucky



New Data Viewer

The Kentucky Geological Survey (KGS) acts as the Southeastern hub for the NGDS, serving data for ten additional states. The KGS submitted the state's 707 published 1:24,000 geologic quadrangle (GQ) maps in digital format (1996-2006). The 1:500K map data are also made available through an interactive web map application, the "Kentucky Geologic Map Information Service," (*http://kgs.uky.edu/kgsmap/kgsgeoserver/viewer.asp*) to provide interactive and customized geologic maps with links to the related data. These data provide users with detailed earth science information for Kentucky concerning geologic rock units and mapped surface faults. ■

Standard Geologic Map layer of the Kentucky Geologic Map Information Service.



Kentucky Worse – Karst Potential layer of the Kentucky Geologic Map Information Service.

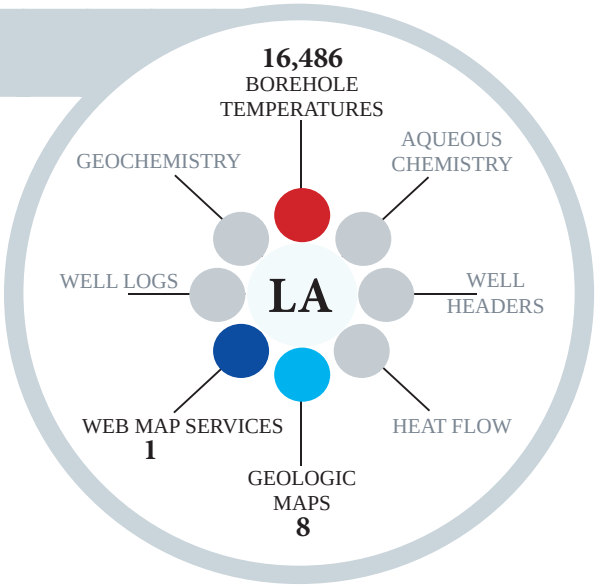
Louisiana

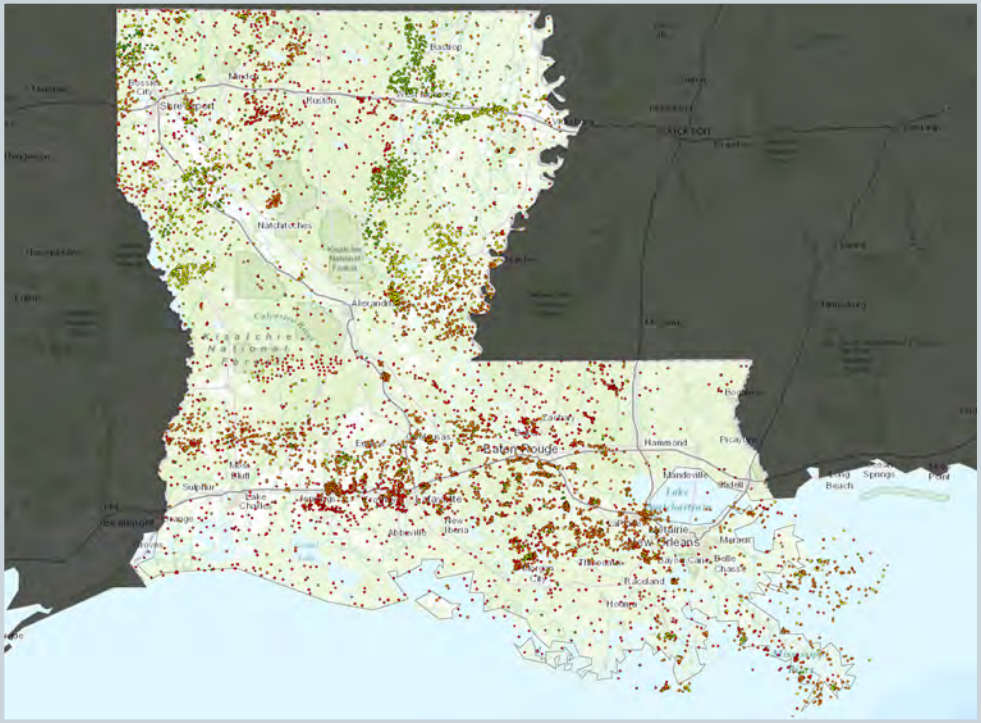
Inter-industry Legacy Data

The Basin Research Energy Section (BRES) is the oil, gas, and coal research section of the Louisiana Geological Survey (LGS), and it performs research into the nature and occurrence of oil, gas, and coal both in Louisiana and around the world. In addition to supplying much of Louisiana's data contribution to the NGDS, BRES disseminates its research and technical information widely, especially to the independent oil and gas producers of Louisiana, thereby enabling more economically efficient exploration and production operations. Services include geology maps, updated aero-mag maps and gravity maps.

Interest in Geothermal Energy

The January 2012 edition of the *AAPG* (American Association of Petroleum Geologists) *Explorer*, which has worldwide circulation, features Chacko John, LGS director, state geologist and research professor, discussing the DOE's research program on geopressured-geothermal resources. The article recognizes LGS's previous work in geothermal energy along the Gulf Coast, including a DOE-funded program from 1975 to 1992 that gathered geological, engineering, environmental and economic information to determine the viability of development of the resource. John said the current interest in alternative energy sources indicates that now may be the appropriate time to pursue geopressured-geothermal resource development. ■



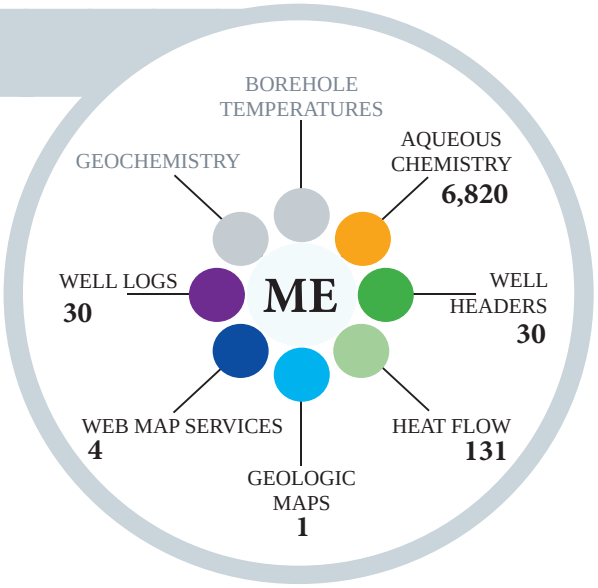


Borehole temperatures collected from BRES available through NGDS displayed on a map of Louisiana though arcMap.

Maine

New & Legacy data

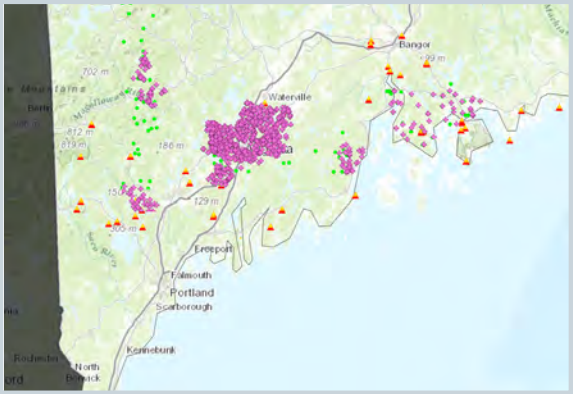
In the first phase of the project, existing unpublished temperature, thermal conductivity, and heatflow data were compiled from various sources, reformatted, and submitted for inclusion in the National Geothermal Data System (NGDS). Existing unpublished groundwater quality data, including near-surface groundwater temperatures, collected from private water wells through various Maine Geological Survey (MGS) projects were also compiled, reformatted, and submitted. A total of nearly 1,500 new records were added to the NGDS in this phase. In the second phase, new temperature profiles for 30 deep bedrock boreholes were collected and formatted for NGDS.



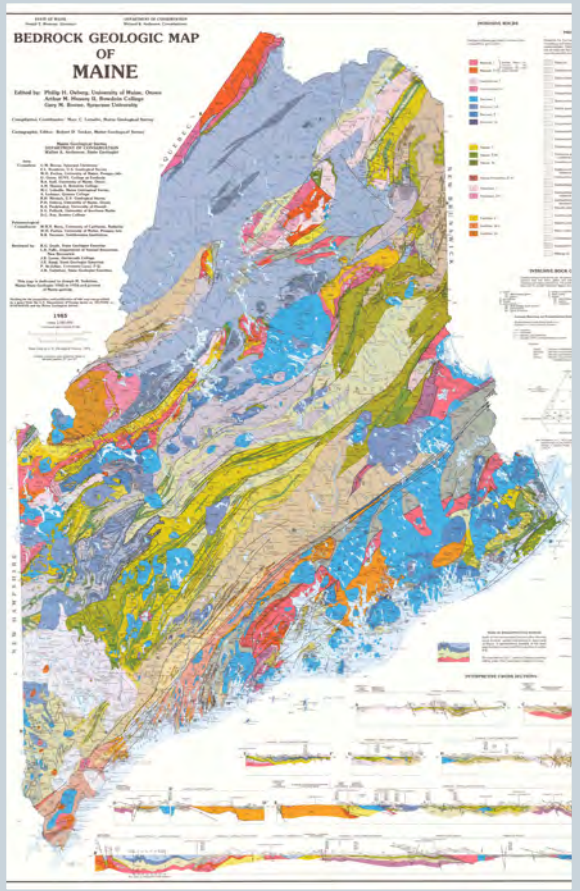
Industry Benefits & Applied Research

The Geothermal Map of North America (Blackwell and Richards, 2004) identifies New England as having among the highest heat-flow values in the eastern United States (60-80 mWm-2). Funded through the NGDS Supplemental proposal process, MGS acquired new geothermal data. New derivative products include the Maine Heat Flow database, and the Maine Aqueous Well Chemistry data map, available in WMS and WFS.

One data set, the Columbia Groundwater Quality database, contains 340 records collected in 2007 from private homeowner water wells. The database is part of a larger study on the occurrence of naturally occurring arsenic in private water wells. ■



Composite map of Maine aqueous chemistry and heat flow data points as they appear in the NGDS Web Map Service.



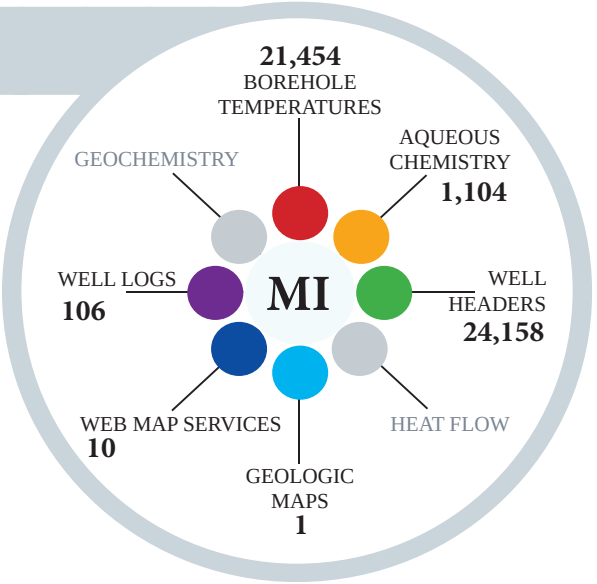
Bedrock geologic map of Maine.

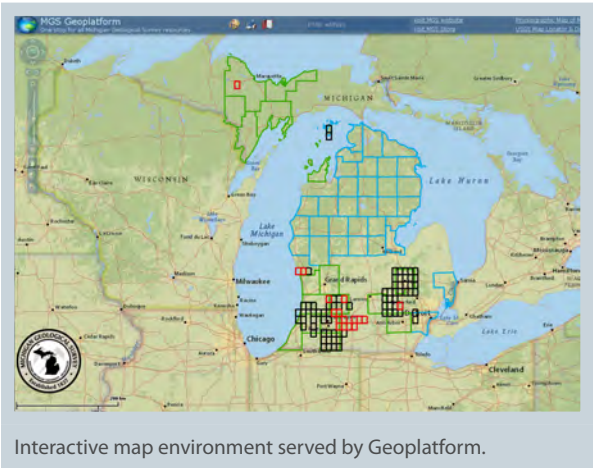
Michigan

New & Legacy Data

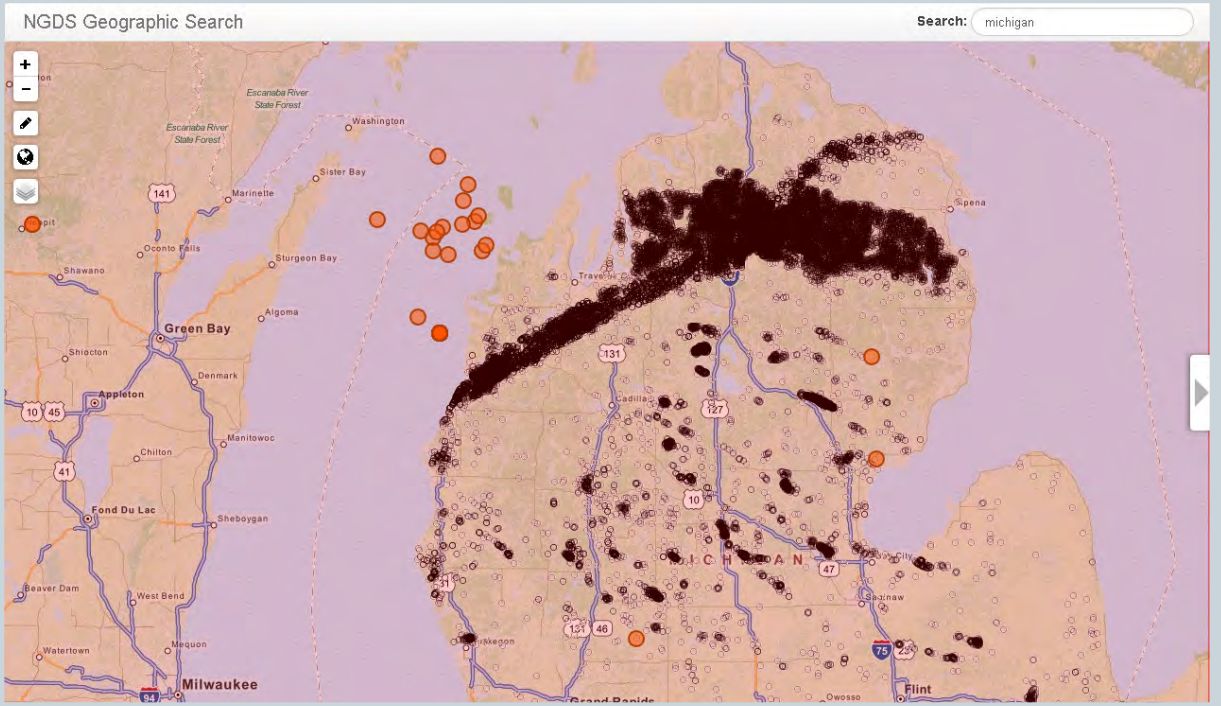
Data collected over two years for the NGDS project in Michigan includes bottom-hole temperature measurements, drill stem tests with temperature and pressure data, and water chemistry measurements with a total of 36 elements or compounds analyzed. In the third year of the project, focus shifted to shallow temperature data, including the characteristics of soils and shallow glacial deposits, thickness of glacial deposits, and depth to water table. More detailed information was gathered on the composition of geological materials, monthly and annual temperatures, and deeper subsurface flow to the surface. Locations of current ground source heat pump installations were also collected.

It is hoped that these measurements will bolster interest in geothermal heat exchange systems in Michigan. ■





Interactive map environment served by Geoplatform.

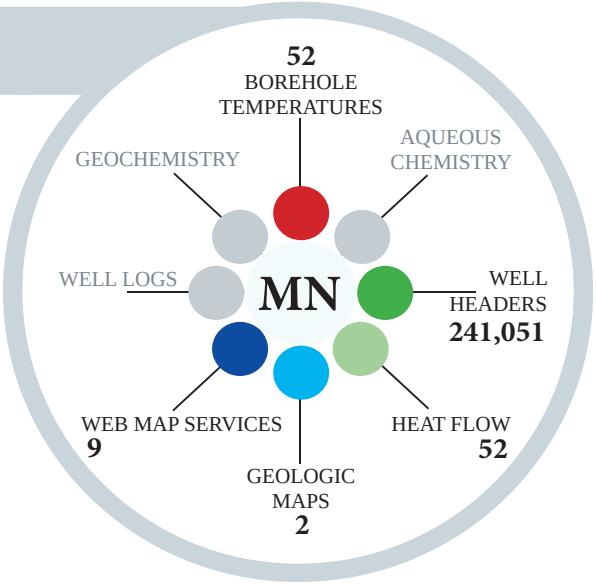


An NGDS well header search of Michigan shows numerous results.

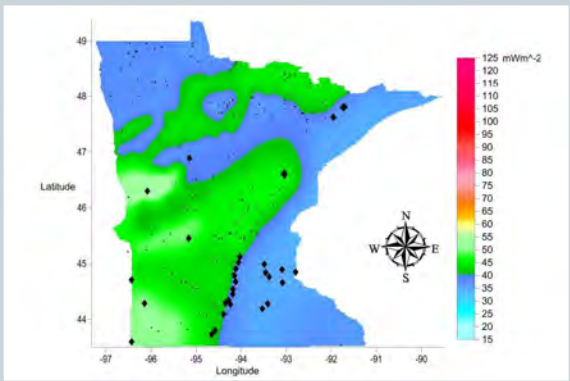
Minnesota

Applied Research

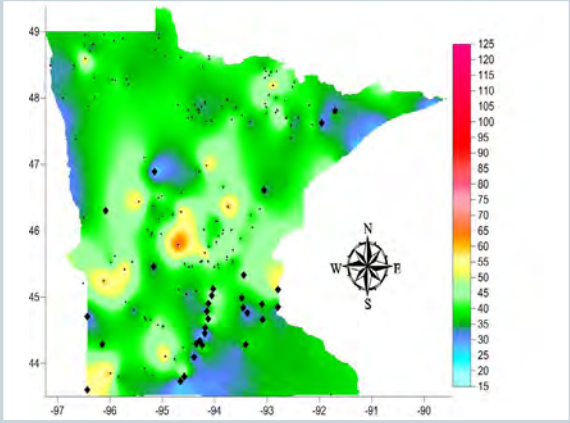
Compiled by the University of North Dakota team in conjunction with data on the Dakotas and Nebraska, Minnesota data has been used in two theses and in the Natural Resources Research Institute Technical Report, "New Heat Flow Map of Minnesota Corrected for the Effects of Climate Change and an Assessment of Enhanced Geothermal System Resources."



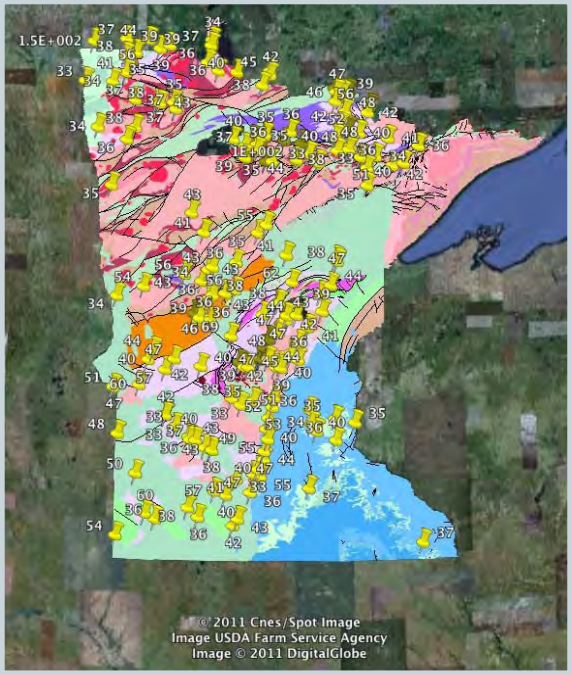
Researchers were able to pull data from the NGDS to show possible climate change/global warming signals. Particularly relevant information is the curvature of temperature against depth plot for 30 boreholes in Minnesota. Some data (from 43.5 N to 49 N latitude, logged in 2010 and 2011) show the combined effects of warming of the ground surface during the past 120 years and since retreat of the Pleistocene ice sheet ~11,000 years ago. ■



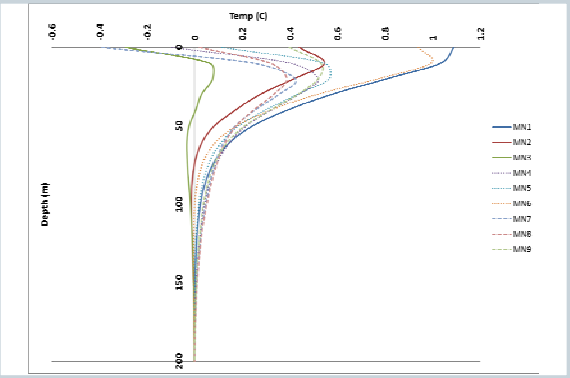
New heat flow map of Minnesota using both traditional heat flow measurements (diamonds) and calculated heat flow measurements (dots) based on the Q-A relationship. The colored vertical scale is heat flow in mW m-2. Horizonal and vertical exes on the map are in degrees latitude and longitude.



Heat flow measurements (diamonds) are systematically lower than the heat flow calculated from radioactivity (dots). This difference gives further evidence that a correction for post-glacial warming needs to be applied. The colored vertical scale is heat flow in an mW m-2 . Horizontal and vertical exes on the map are in degrees latitude and longitude.



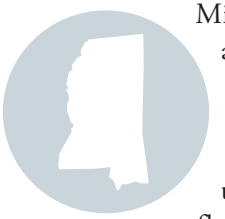
Heat flow locations on the geologic map of Minnesota. These data were used to create the new heat flow map of Minnesota by averaging the heat flow data over the geologic terrain it represented.



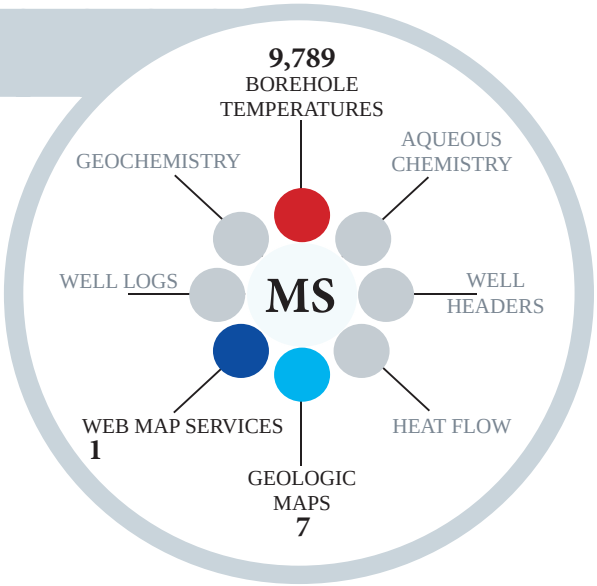
Recent warming perturbations affecting the nine different climate regions in Minnesota. Information captured from "Implications of Post-Glacial Warming for Northern Hemisphere Heat Flow", Gosnold, W. et al., 2011, GRC Transactions, Vol. 35.

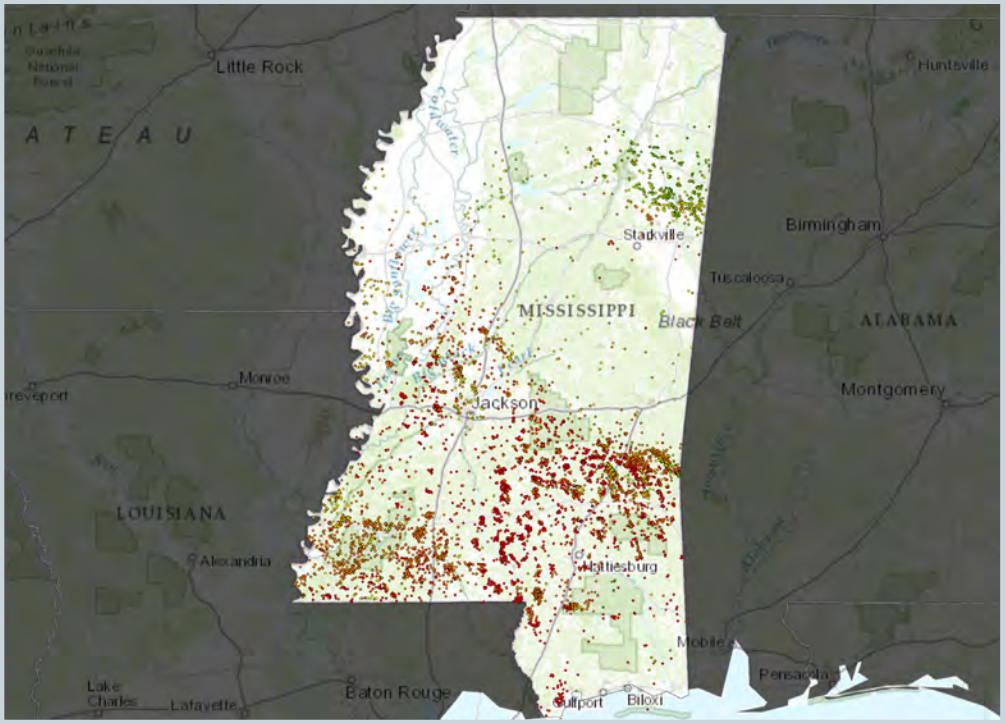
Mississippi

Legacy Data



Mississippi may lack geysers and active volcanoes, but has large volumes of warm salt water coproduced from oil and gas wells. Technology exists to extract useful energy from such warm fluids. Therefore the Mississippi Department of Environmental Quality (MDEQ) is concentrating efforts on collection of data about bottom-hole temperatures from the headers of geophysical logs in old files. The MDEQ delivered metadata for 18 Isotherm maps and documents and submitted production data for oil & gas field pools in machine-readable format. Borehole temperatures can appear as a web feature service in the NGDS catalog. ■





A web map service conveying borehole temperature measurements provided by Mississippi as part of the NGDS.

Missouri

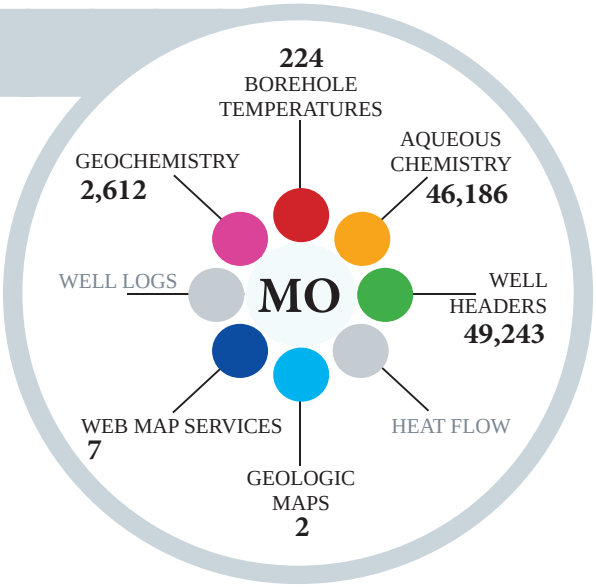
New & Legacy Data

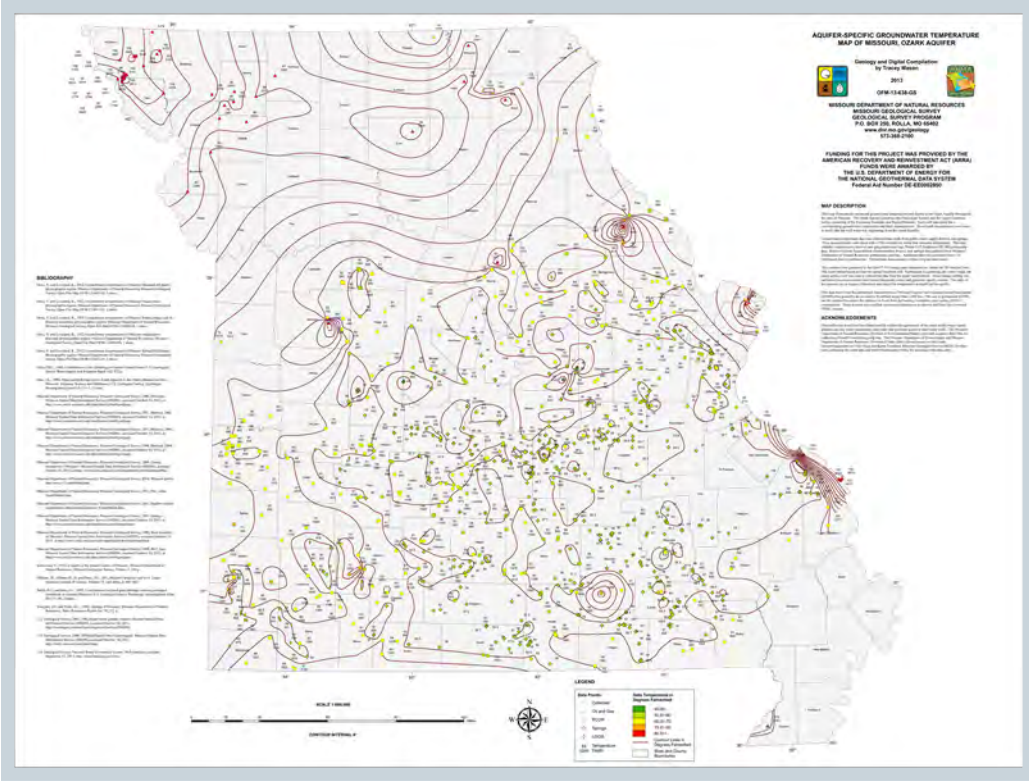
Though the state of Missouri does not have hot springs, fumaroles or any of the high to moderate temperature geothermal features found in some western states, Missourians use heat pumps to take advantage of the moderating influence of the earth to heat their homes in winter and cool them in summer. Data and information found on the NGDS and the Missouri Geological Survey Program website provide valuable assets to aid in development of geothermal resources.

Between May of 2011 to November, 2013, the Missouri Geological Survey produced several datasets and maps, including information on heat pump facilities, borehole temperatures, lithology logs with well headers, aqueous chemistry, rock chemistry and a geodatabase for a 1:500,000 scale map service. The maps include a depth to bedrock map as well as a set of aquifer-specific groundwater temperature maps. Much of the data were collected prior to 2011, but were not readily available.

Data Management

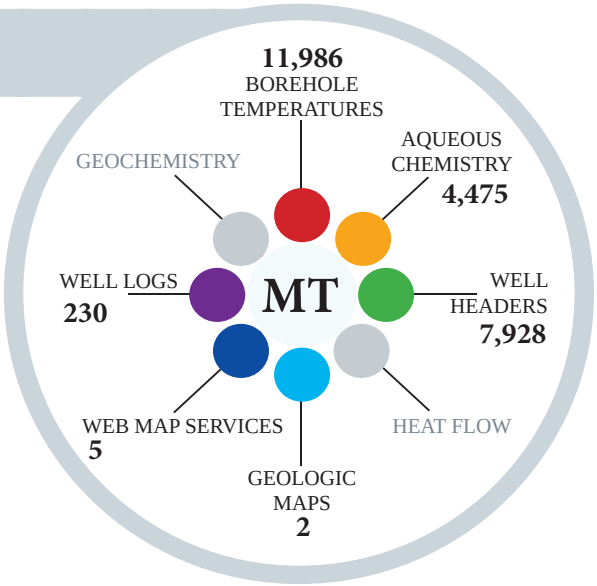
The Missouri Geological Survey developed a web page (*http://dnr.mo.gov/geology/geosrv/geores/geothermal.htm*) devoted to geothermal resources in the state with links to NGDS. This web page also includes information about heat pumps and geothermal usage in Missouri and an interactive geologic map. The Aquifer-Specific Groundwater Temperature Map of Missouri, Ozark Aquifer (right) is one of a series of aquifer-specific temperature maps presenting raw temperature and depth data for Missouri aquifers. ■





This map illustrates groundwater temperatures and depths in the Ozark Aquifer throughout the state of Missouri. Data used to make this map are available through NGDS.

Montana

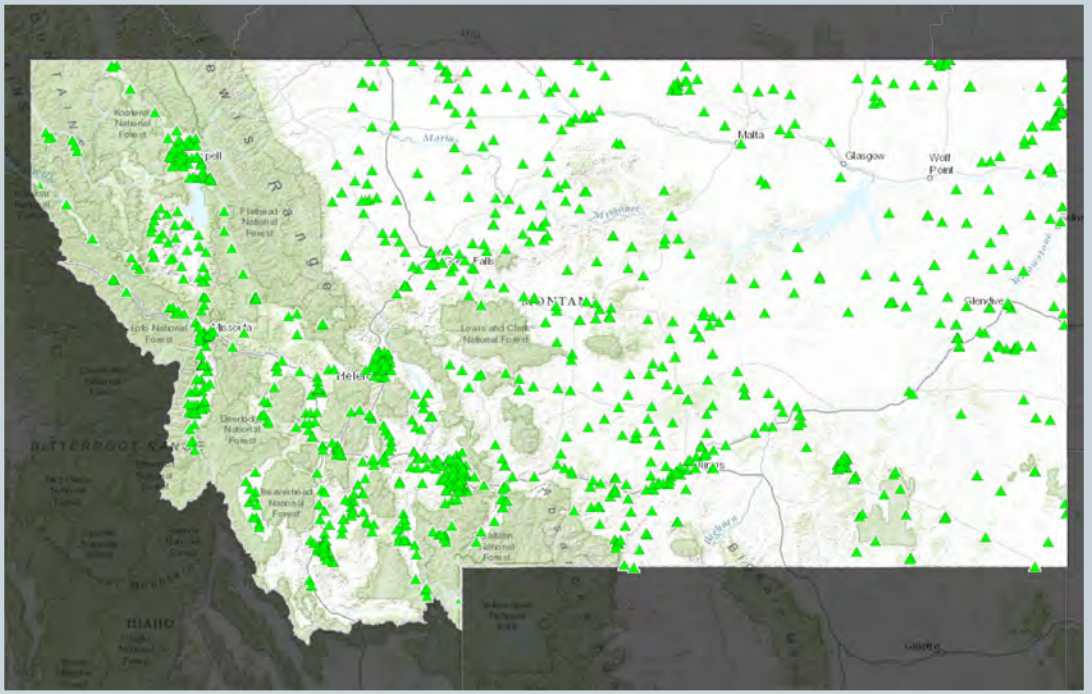


New Data Development Platform

The Montana Bureau of Mines and Geology (MBMG) is migrating their GIS data development processes from an Arc/Info environment to an ArcGIS platform. The MBMG's digital data availability has expanded to include web mapping services, made available through their ArcGIS Server, making spatial data available online. As of November 2013, services include our 1:500,000 geology maps, the Ground Water Iinformation Center database, and the earthquake catalog. Users can access MBMG's ArcGIS web services at *http://www.mbmg.mtech.edu/gis/gis-ArcGISservices.asp*.

New Data Format Standard

MBMG is part of the national effort to standardize the data format for geologic maps and data among state geologic survey agencies. The National Cooperative Geologic Mapping Project (NCGMP) is a USGS-sponsored program to develop standardized data layers for geologic data. The Montana Bureau of Mines & Geology participates in both the STATEMAP and EDMAP portions of the NCGMP. For more information, visit the NCGMP website at: *http://ncgmp.usgs.gov/*. ■

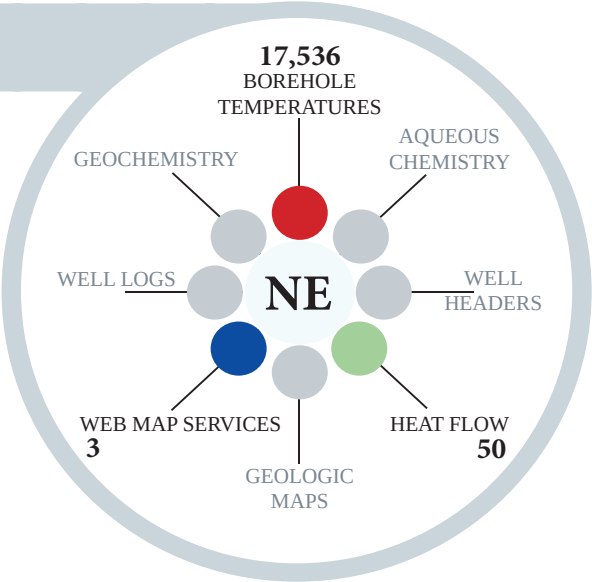


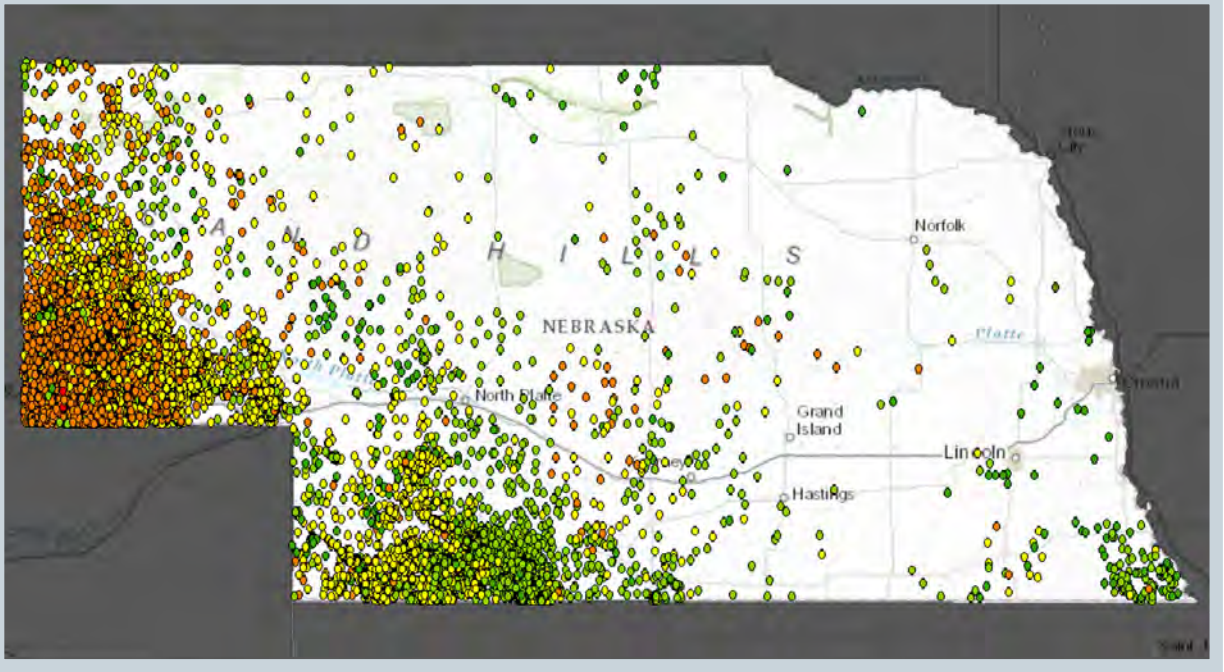
A Web Map Service conveying well construction fields for statewide long-term monitoring network wells provided by Montana's Ground Water Information Center. These wells are used to monitor groundwater, but the data they collect can be used to locate geothermal resources.

Nebraska

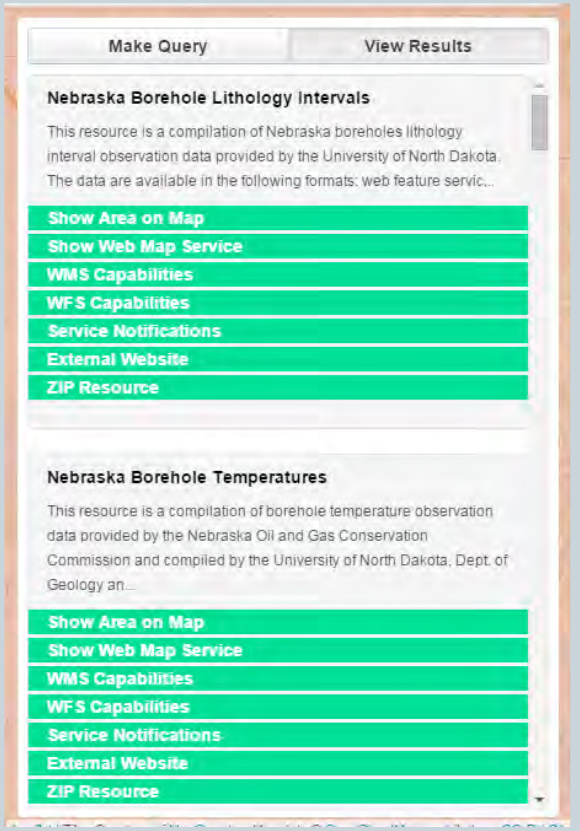
New & Legacy Data

Data for Nebraska was compiled largely by the University of North Dakota. Derivative data from Nebraska fueled one academic thesis, a North Dakota Academy of Science paper on the Chadron Arch heat flow anomaly, and Geothermal Resources Council papers on borehole temperature corrections in 2012 and 2013. ■





Borehole temperature data in the State of Nebraska.

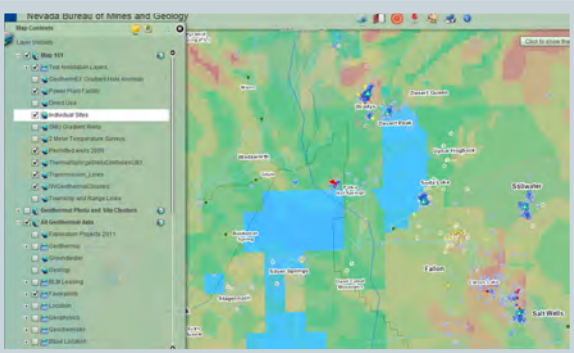


Data on borehole lithography, borehole temperatures, and heat flow are available through Web Map Services on the NGDS interface.

Nevada

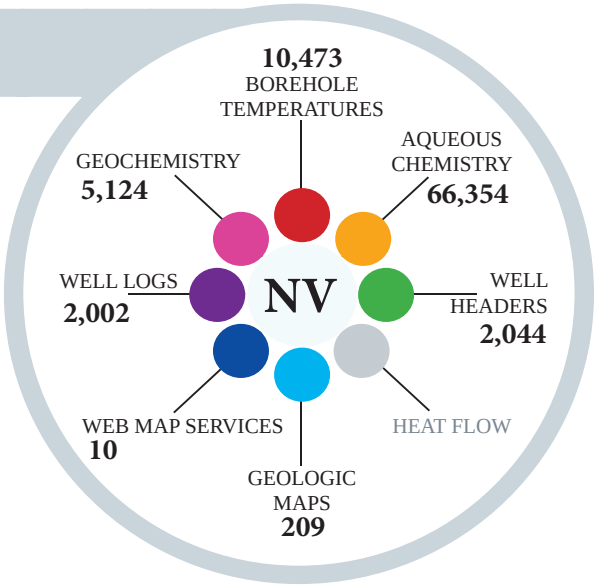
New Map Services

The Nevada team has created an interactive 80 layer mapping tool to help visualize NGDS data, available at *http://gisweb.unr.edu/geothermal/*. Creation of map services has been an important component of the Nevada Bureau of Mines and Geology (NBMG) modernization and adding of new capabilities to geothermal maps. Located here is one single map service where all the geothermal data layers can be accessed, and can be downloaded as a .cvs file.



80 layer mapping tool includes query, search, and extract functions.

The map application will allow the ArcGIS user to directly use any geothermal data layers at NBMG in their own projects after downloading each data set as needed. As databases, are updated, the map application will always reflect the most up-to-date data at NBMG.



Industry Benefits

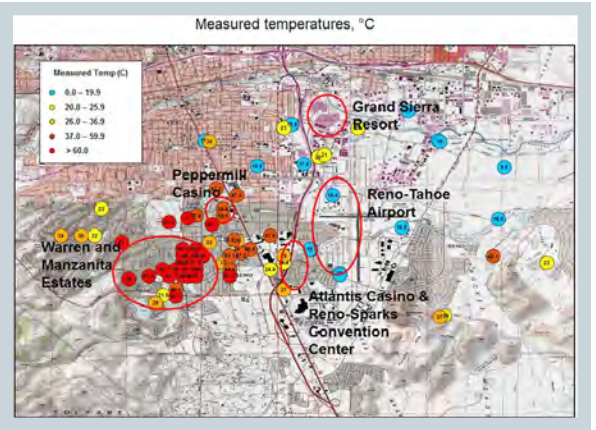
Nevada's NGDS customers include companies conducting exploration:

- ATLAS Geosciences
- Geothermal Development Associates
- Lumos Engineering
- Navy GPO
- Nevada Geothermal
- Ormat
- Zonge Engineering

New Geothermal Exploration

No less than 26 publications are directly related to project activities or use of compiled data from the project.

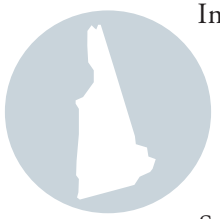
Geothermal site assessments were conducted at twelve sites, including: Baltazor HS, Bradys, Fallon NAS, Fernley area, Grand Sierra Property, Lahontan Valley, McGinnis Hills, Pumpernickel Valley, Black Warrior, Reno VA, Trego HS, and Washoe Tribal Lands. ■



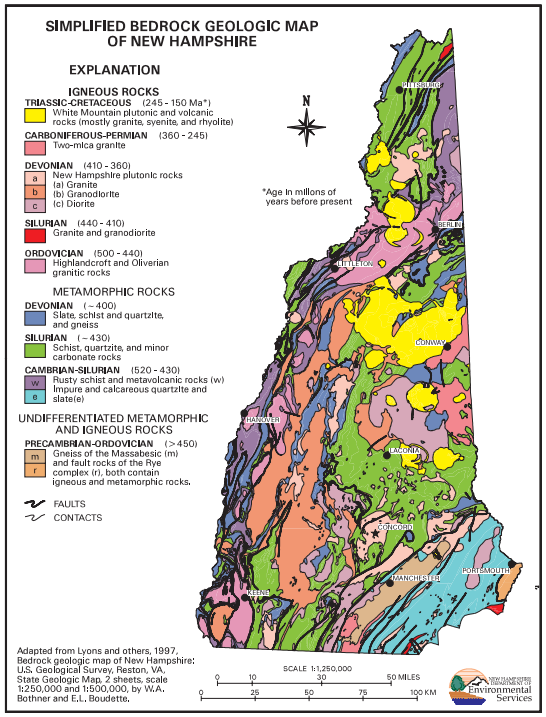
New site assessment of Reno area reveals numerous wells above 60 degrees C.

New Hampshire

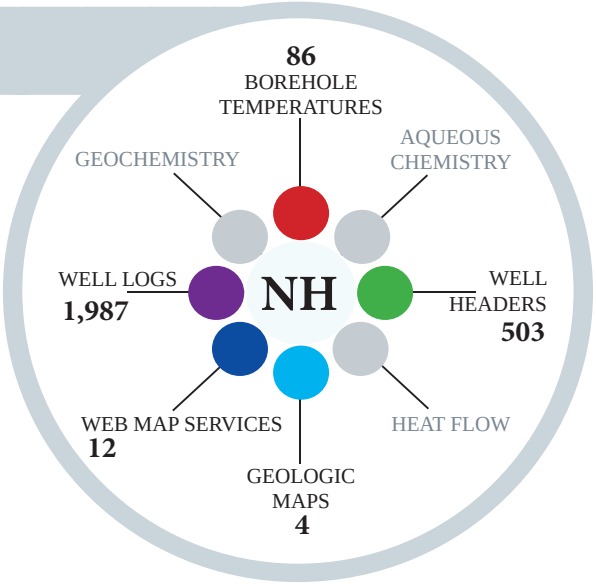
New & Legacy Data



In addition to placing well logs, bedrock sample analyses that include 103 newly collected samples, and temperature and heat flow measurements online, the New Hampshire Geological Survey (NHGS) exposed nine map products, all accessible as web services with fourteen data services.



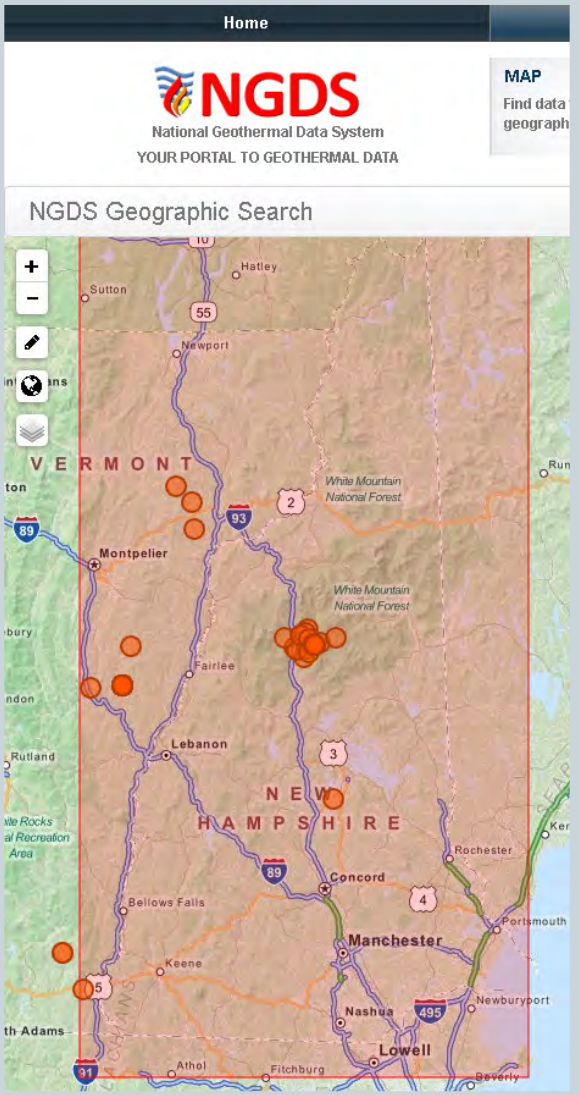
The ESRI shapefiles for this and other geologic maps of NH are at NGDS.



Outcomes & Collaborations

The NGDS project improved understanding of available mapping technologies, especially open source technologies and their applications. New Hampshire is now an independent NGDS node, serving their own data using GeoPortal software.

The work has improved cooperation across state and federal agencies. Two joint publications with the U.S. Geological Survey were released. In addition, the NHGS enjoys a collaborative relationship with the University of New Hampshire Earth Science Department (UNH). The UNH plans to perform an analysis of heat flow for New Hampshire using many of the data sets and is using the bedrock sample collections data service as a teaching tool. ■

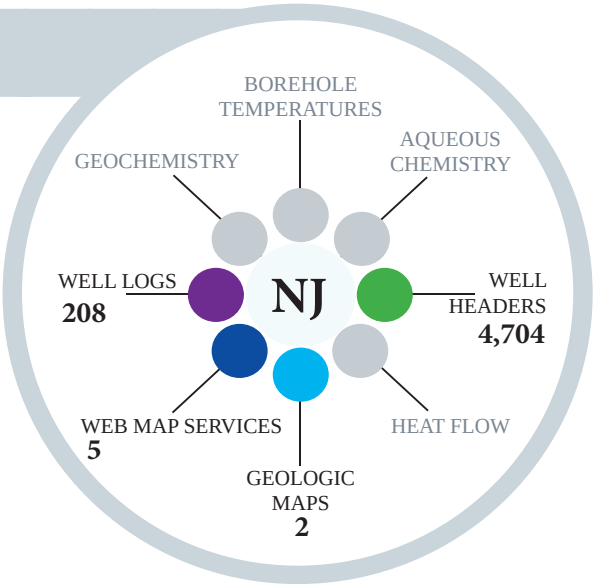


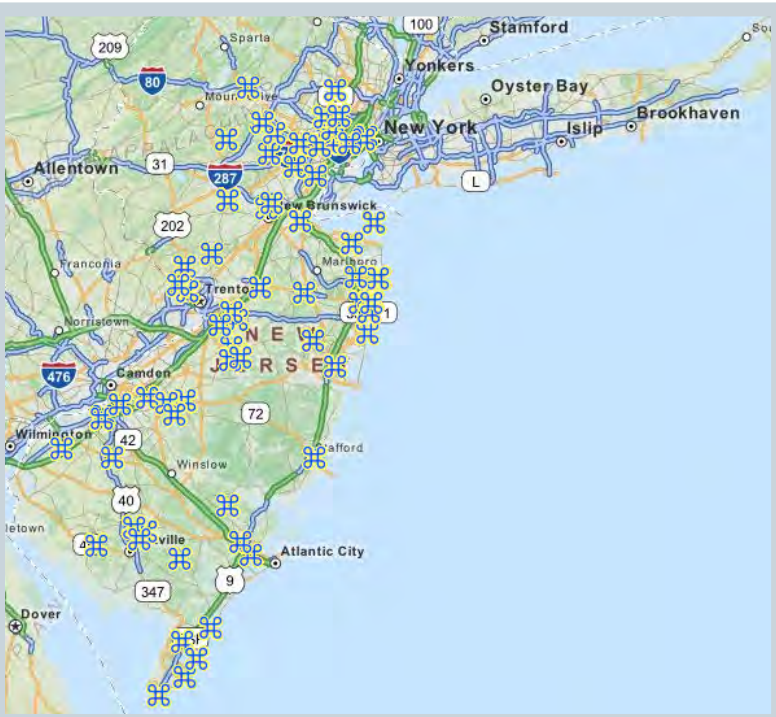
The individual orange circles represent more than 50 data sets loaded into NGDS, including: thermal springs, gravity stations, well logs, well headers, borehole temperatures, thermal conductivity, rock chemistry, depth to bedrock, and more.

New Jersey

Cost Comparison

A state goal of the NGDS project set by the New Jersey Geological and Water Survey (NJGWS) is to provide a cost-benefit comparison of geothermal energy with other energy options for New Jersey homeowners. The NJGWS gathered data on 122 test locations provided by two companies: Alderson Engineering, Inc. and Geothermal Services, Inc., to illustrate how different subsurface material affects the efficiency of geothermal heat exchange systems. Thermal conductivity and diffusivity values were plotted on graphs and physiographic provinces maps. ■



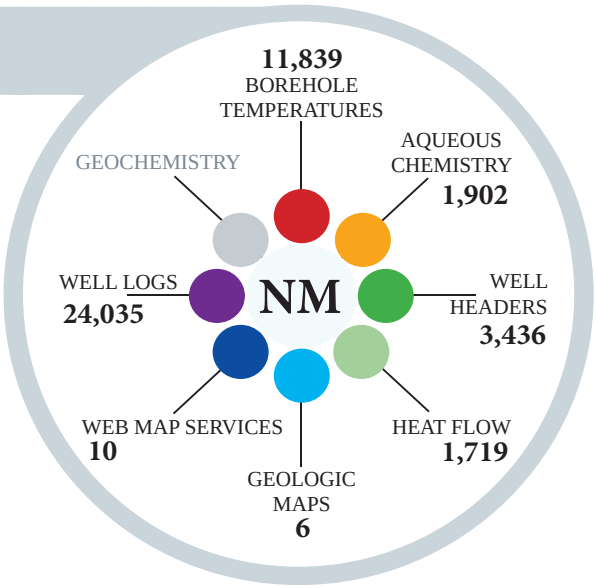


Thermal conductivity map of New Jersey as shown through the NGDS web map service.

New Mexico

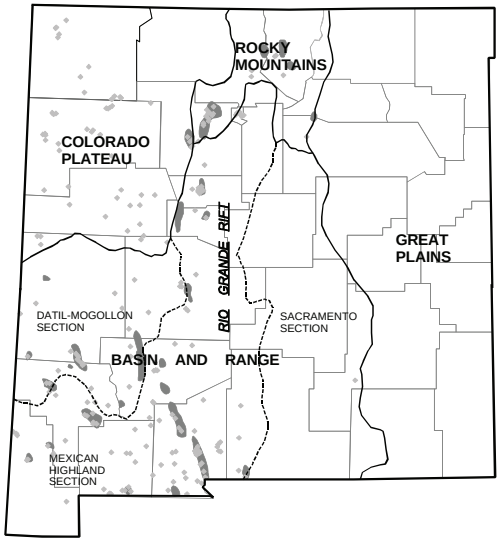
New & Legacy Data

The New Mexico Bureau of Geology and Mineral Resources organized and digitized many of their legacy records as part their NGDS-related work. They report major accomplishments as: 1) the transformation and additions to a petroleum well database, which now includes geothermal data; and, 2) merging project-specific water databases into one master database that can be mined for unexplored resources. The project also made a push toward building and deploying map services.

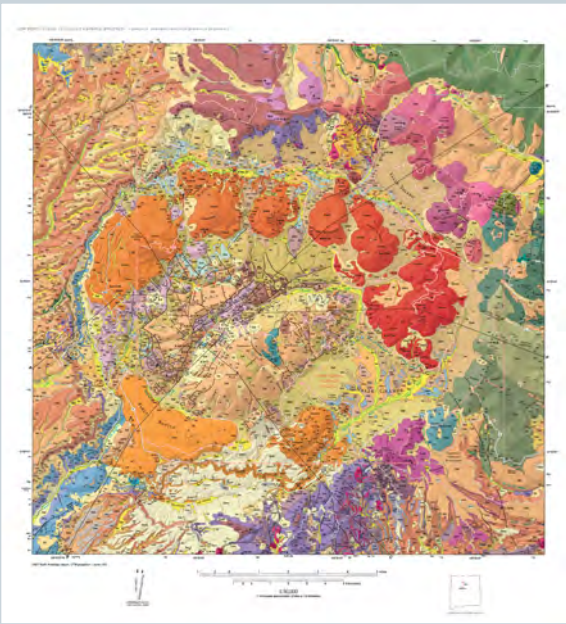


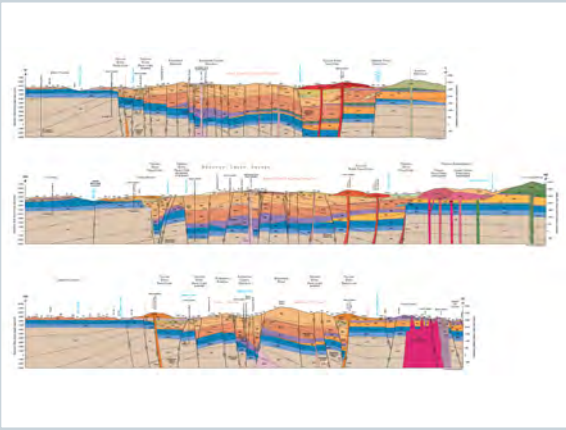
Geothermal Exploration

Rescued data helped reassess information on a geothermal prospect located at the intersection of a Laramide fault system, a caldera margin, and Rio Grande rift faults. Investigations using thermal profiles, water geochemistry, major and trace elements, isotopes and temperature and flow measurements revealed changes from baseline data collected in 1941. ■



Geologic map of the Valles Calera by Fraser Goff and others.



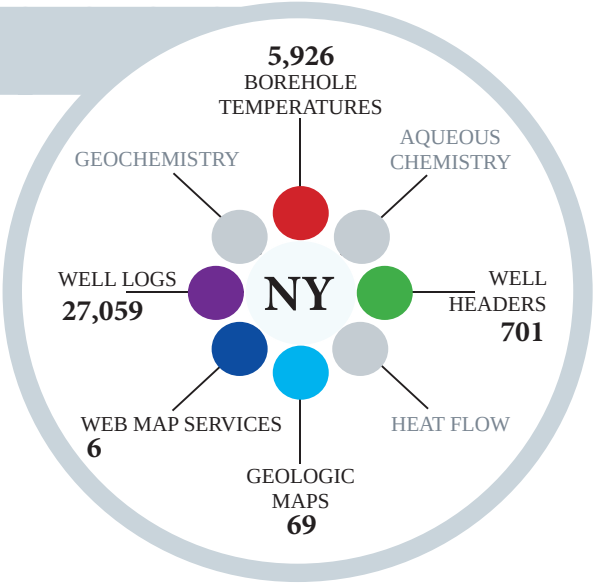


General geothermal resource map by Jim Witcher—available through NGDS.

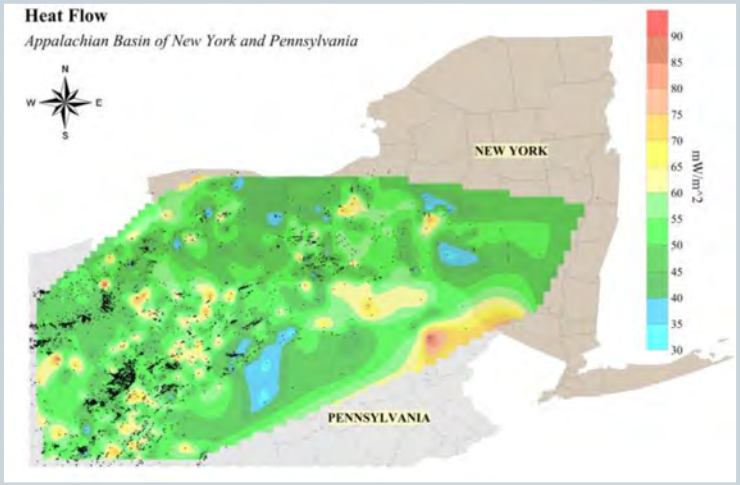
New York

New & Legacy Data

The New York State Geological Survey (NYSGS) chiefly contributed data inventories and collection statistics to the NGDS program. This includes several excel spreadsheets with information regard- ing well logs, drill cuttings, earthquake database, and products such as isopach and structure-contour maps for select sedimentary units. While some of this information was readily available, there were three tasks in particular that required significant time and effort. These three products are anticipated to be especially useful for future geothermal studies.



1) The NYSGS maintains a database known as ESOGIS (Empire State Oil & Gas Information System) which contains records for all of the oil and gas operations in the state. The NYSGS staff digitized over 700 temperature curves from scanned well logs and submitted them to NGDS (also offered through ESOGIS).



Surface heat flow in the Appalachian Basin of New York and Pennsylvania, calculated as the product of thermal gradient and average thermal conductivity for a specified location. Heat flow can be used to facilitate geothermal exploration.

2) Over 5,900 bottom-hole temperatures pulled from 35,000+ well logs were digitized and submitted to the NGDS. Researchers at Cornell University are mining these data as part of their research on geothermal resources in New York and Pennsylvania (Shope et al. 2012, Proceedings from the 37th Workshop on Geothermal Reservoir Engineering).

3) The NYSGS maintains a collection of rock cores collected from 150 wells across the state. These cores are stored in a climate controlled warehouse where they are available for study. Due to limited resources, the inventory of this collection was outdated and lacked crucial pieces of information. In just 6 months, the entire core collection was re-cataloged with a focus on capturing all available data from each core box/container. A copy of the completed core collection catalog was submitted to the NDGS and is expected to help future geothermal research by providing information on the characteristics of reservoir rock, a valuable tool for any scientist attempting to describe a potential geothermal reservoir, not just in New York, but across the entire Appalachian Basin. ■

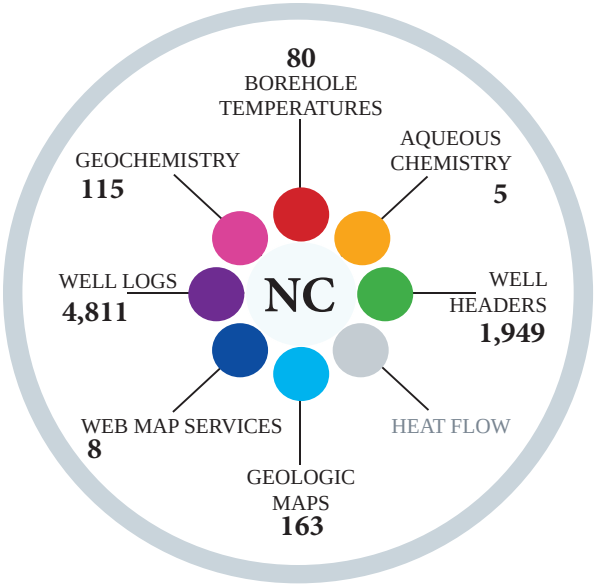
Core of the NYSGS collection; a copy of the core collection catalog was submitted to NGDS to facilitate geothermal research.

North Carolina, Georgia and Maryland

North Carolina

Legacy Data

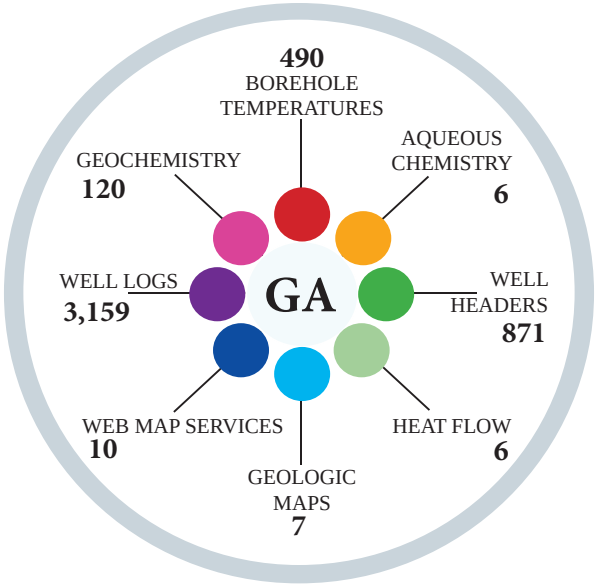
When the North Carolina Geological Survey (NCGS) requested funding under the NGDS, a hiring freeze proved to be an impediment. NCGS funding award was redirected to the Virginia Geological Survey, where their staff made two trips to the NCGS Coastal Plain Office and Core Repository to scan original paper reports, geophysical logs and lithology logs. This project encompassed the largest conversion of paper records to digital files in the NCGS history. While the original paper records have been returned to the Core Repository, digital copies are now available through the NGDS. ■



Georgia

Legacy Data

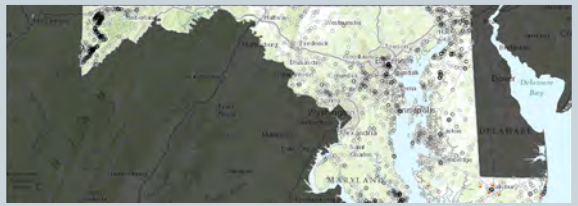
Data from the Department of Natural Resources (GDNR) was collected by Virginia Geological Survey and is served at the Kentucky Hub. Metadata is available for geologic maps, (~250 documents), Georgia geothermal documents and references, and gravity maps. Available services for the state of Georgia include aqueous chemistry (version 1.10), borehole temperatures, gravity stations, heat flow 1.23, rock chemistry, thermal conductivity, thermal springs, well headers, and well logs. ■



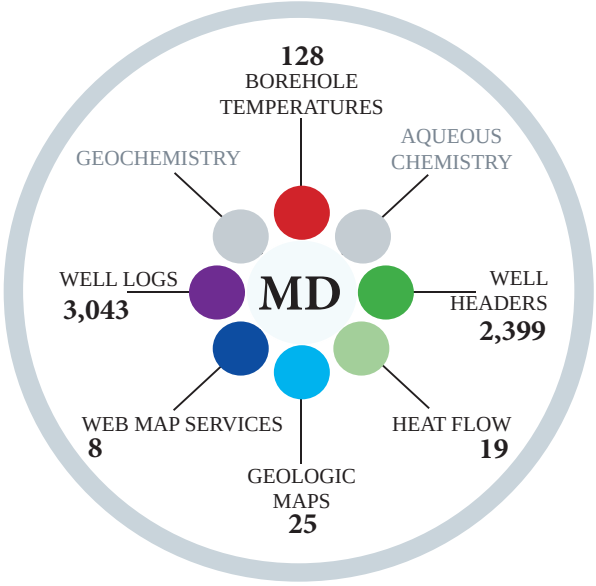
Maryland

Legacy Data

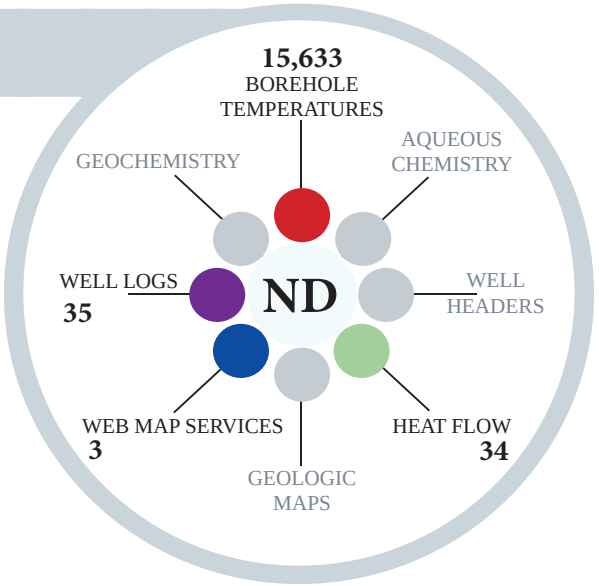
Data from the Maryland Geological Survey (MGS) was collected by the Virginia Geological Survey and is served through the Kentucky Hub. MGS contributed metadata for maps and documents. ■



Maryland's heat flow and well header services are pictured on this composite map.



North Dakota



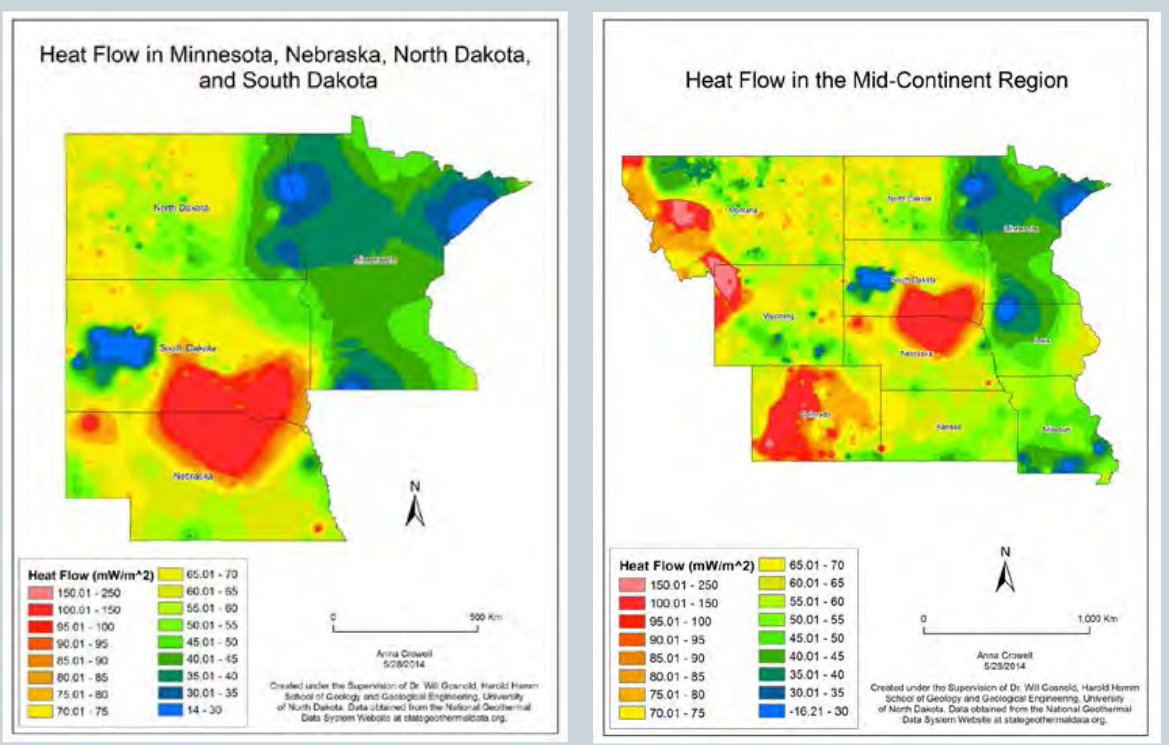
Multiple-State Effort

The University of North Dakota (UND), compiled geothermal-related data for Minnesota, South Dakota, and Nebraska, and forged a successful collaboration with Southern Methodist University (SMU) to aggregate data from both SMU and International Heat Flow Commission (IHFC) databases for the NGDS project. UND used available templates to produce maps on heat flow, thermal conductivity, and radioactive heat production featuring uranium, thorium, and potassium, and to plot temperature against depth measurements. The team at UND also produced a georeferenced NOAA geothermal resource map. This map covers Minnesota, Nebraska, and South Dakota as well.

UND is now independently serving data using the free-and-open-source GeoServer software.

Geothermal Exploration

Data compiled for the project was used in a geothermal analysis of Williston Basin and on at least six thesis projects ranging from geophysical properties of reservoirs to sedimentary enhanced geothermal systems (EGS). Associated research papers explore geothermal resource potential in the northern Midwest. ■



Heat flow in Minnesota, Nebraska, North Dakota, and South Dakota.

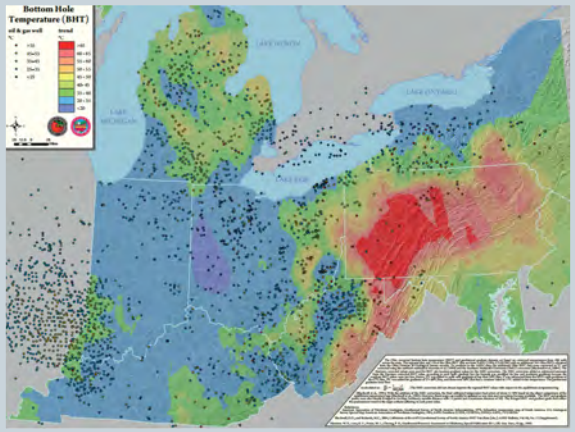
Ohio

Applied Energy Mapping

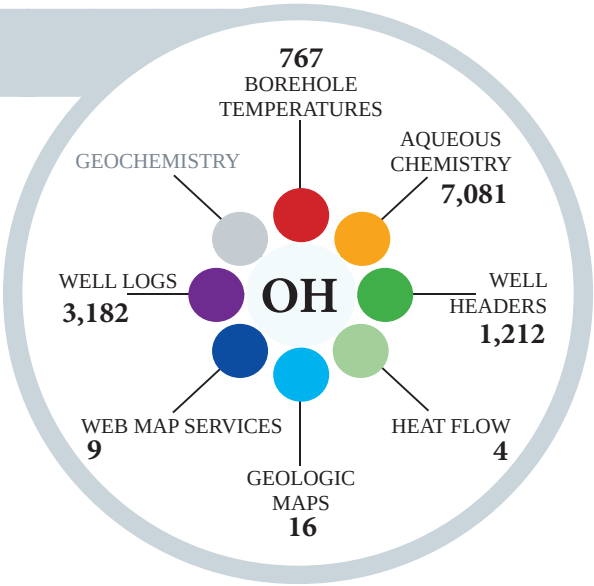
The Ohio Geological Survey (OGS) is currently engaged in a number of projects to appraise Ohio's geologic resources as they apply to developing shale oil and gas, storing CO2, and geothermal potential. This research is being conducted with funding, in part, provided to address specific project objectives for the Ohio Coal Development Office (OCDO), the Midwest Regional Carbon Sequestration Partnership (MRCSP) funded by the DOE, and the NGDS.

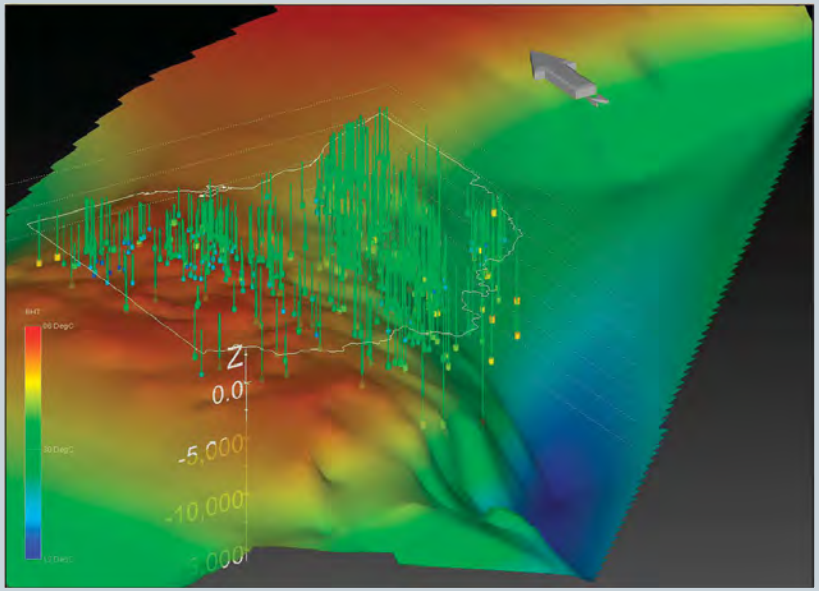
The OGS began research into the state's geothermal resources in July 2010 and is evaluating its very large dataset of bottom-hole temperatures and the American Association of Petroleum Geologists corrected bottom-hole temperature dataset. Specifically, selected bottom-hole temperature data was corrected and used with the AAPG dataset to construct bottom-hole temperature and gradient 3-D plots and maps in order to help evaluate the regional, subsurface geothermal environment.

Maps and information showcased here are from the poster presentation "Applied Energy Mapping " and the paper "Applied Energy Mapping at the Ohio Geological Survey" by the Ohio Department of Natural Resources, Division of Geological Survey. ■



Ohio and surrounding environs with BHT data values and the generalized Krieged BHT surface. The 2,643 data points are from AAPG (1994) and 334 new BHT values for Ohio. The BHT data generally reflect the depth of the well with hotter values found in deeper wells.





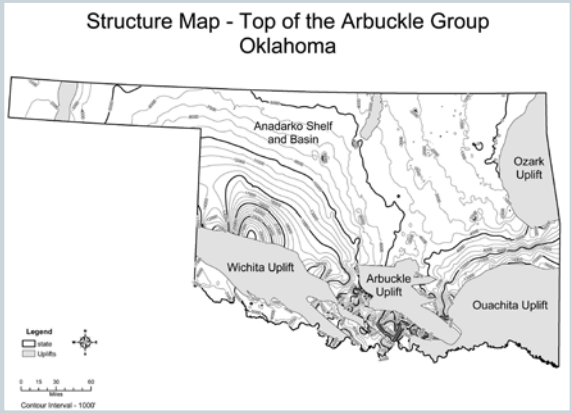
3D perspective of Ohio and surrounding environs Precambrian surface with color-coded barrels that indicate corrected borehole temperature observations. The straws show well locations and observation depths. These data will help to evaluate where geothermal energy, CO2 injection, enhanced recovery, and electricity coproduction may be viable.

Oklahoma

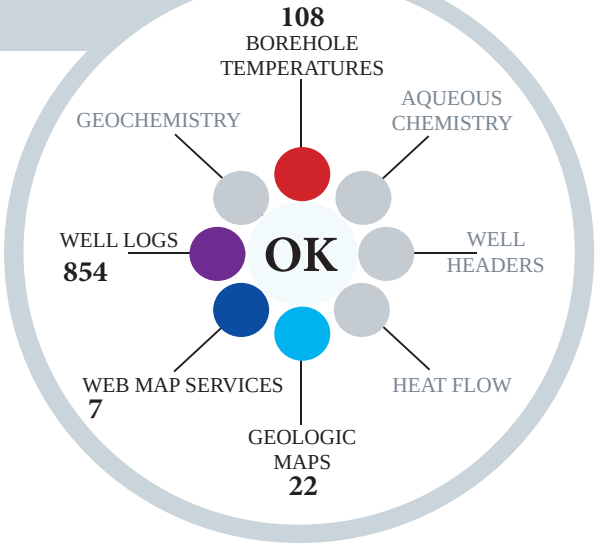
New & Legacy Data

The Oklahoma Geological Survey (OGS) revamped and expanded existing resources through collaboration fostered by the NGDS project. OGS collaborated with agencies and industry to acquire Depth to Bedrock measurements from HIS Energy Group, Natural Resources Information System (NRIS) OGS publications, personal correspondence, and log interpretations.

One accomplishment is correction of errors in the location of active fault lineaments. Recently collected GPS waypoints reveal that the USGS database was inaccurate. OGS integrated new data with the fault trace identified on recently-released, high-resolution aerial photography to produce an updated shape file defining the position and extent of the Meer's Fault in southern OK.



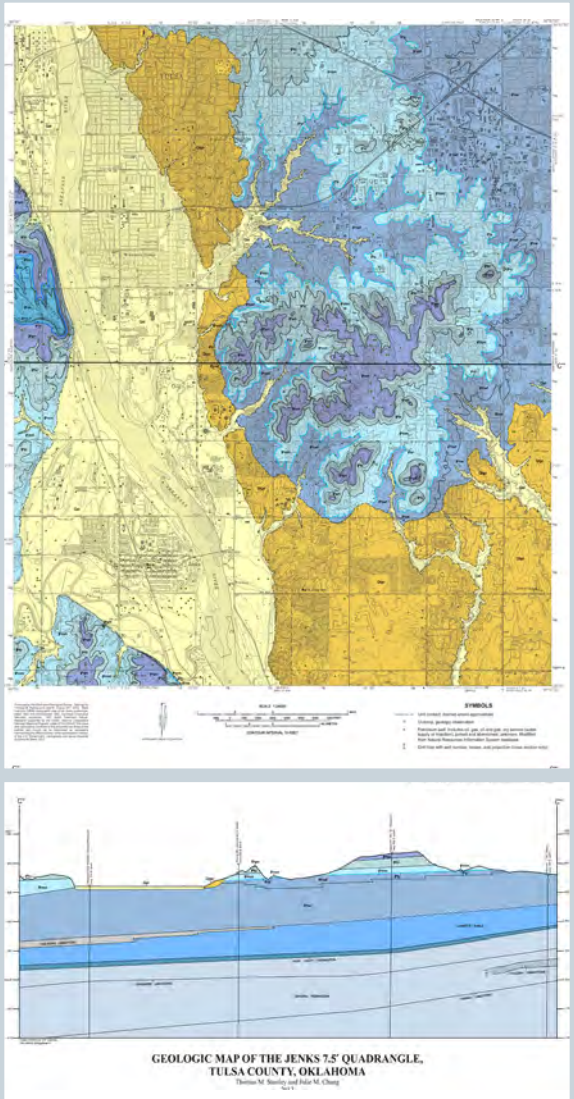
Top of the Arbuckle Group Oklahoma—captured from geographic search of OK geospatial data at NGDS. This resource is a metadata compilation of map images and associated NetCDF data for Oklahoma gravity and magnetic measurements provided by the OGS.



New Map Products

During the course of NGDS work, OGS also produced gravity maps of Oklahoma, including grids and images based on the Total Magnetic Intensity, various residual and upward-continued anomalies, and other effects. OGS uploaded files for a complete Bouguer anomaly map to the NGDS document repository (*www.stategeothermaldata.org*). Additionally, gravity data extracted from a recently located source are in the process of being opened for public access.

Additional data were compiled for Abruckle Group well penetrations, where the OGS merged data from multiple sources to create the most complete data set on the Arbuckle Formation to date. ■



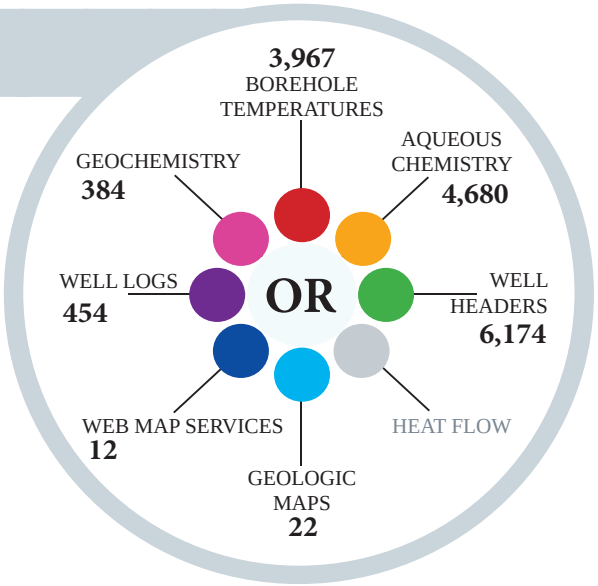
Geologic map of Jenks 7.5 minute quadrangle, Oklahoma.

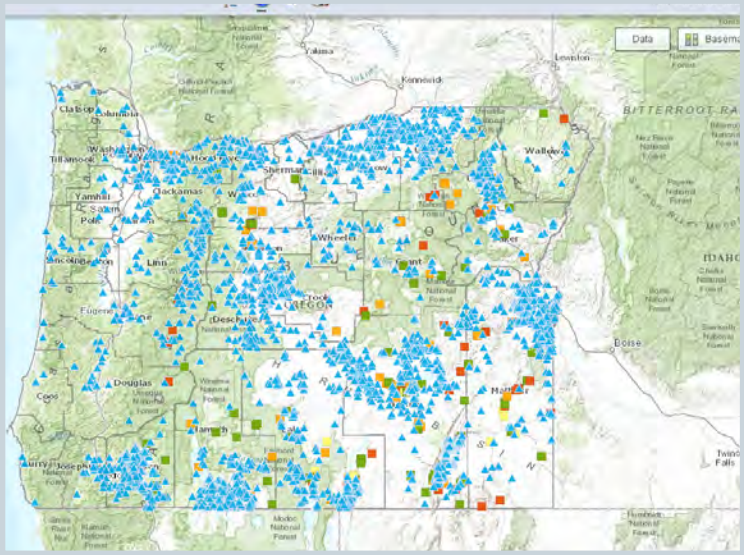
Oregon

Data Management & Best Practices

The Geothermal Information Layer for Oregon (GTILO) is a geospatial database system that stores and manages Oregon's geothermal resource information. The map includes 690 sites representing Oregon's thermal springs, and 4,344 sites representing various types of low-temperature wells in Oregon—domestic/irrigation/other water supply wells.

The Oregon Department of Geology and Mineral Industries (DOGAMI) hosts GTILO. The resource map spotlights areas investigated for geothermal resource potential or which show geothermal potential. (Additional details are available at *http://www.oregongeology.org*).





Interactive geothermal map constructed from the GITLO database.

For each year of the award, DOGAMI digitized its holdings of at-risk, legacy geothermal-relevant data and published this existing digital data by exposing databases to the NGDS. DOGAMI added over 39,700 online records to the NGDS and is currently acting as a distribution node to the system, serving data online and hosting in-house.

New Exploration Data

Supplemental NGDS funds targeted collection of the following:

- A pilot study employing airborne thermal infrared (TIR) and co-acquired lidar
- The drilling of a thermal gradient well at three different locations in Oregon
- Geologic characterization of the quadrangle where each well is located

The experiment using high-resolution, high-accuracy TIR and lidar imagery for geothermal exploration demonstrated that it is possible to collect large swaths of very high quality data and to achieve high spatial accuracy with the thermal imagery by using the lidar data to rectify it.

The AltaRock Co. boom truck and crane during the inspection of the Newberry NWG 55-29 geothermal injection well in 2013.

The combined imagery is extremely effective at locating geologic structures and cold and warm springs, both on land and in water bodies. The data also allow accurate estimation of spring temperature, within the limited testing accomplished.

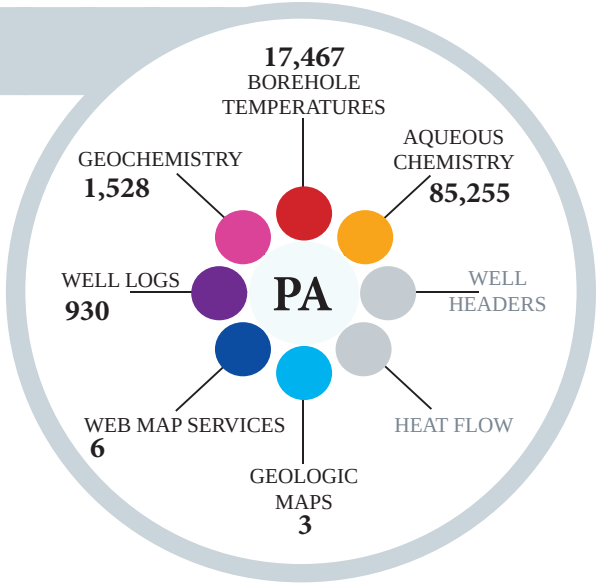
The EGS company AltaRock Co. performed the drilling and testing of new wells. ■

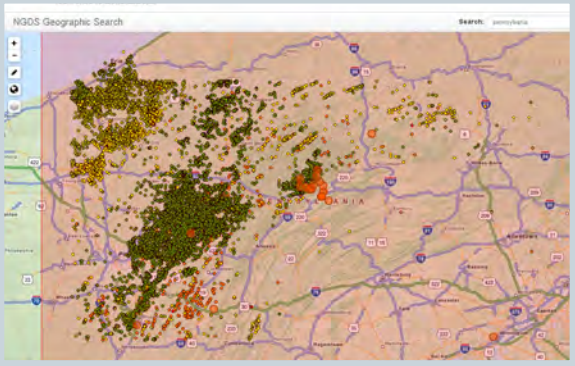
Pennsylvania

Geothermal Exploration

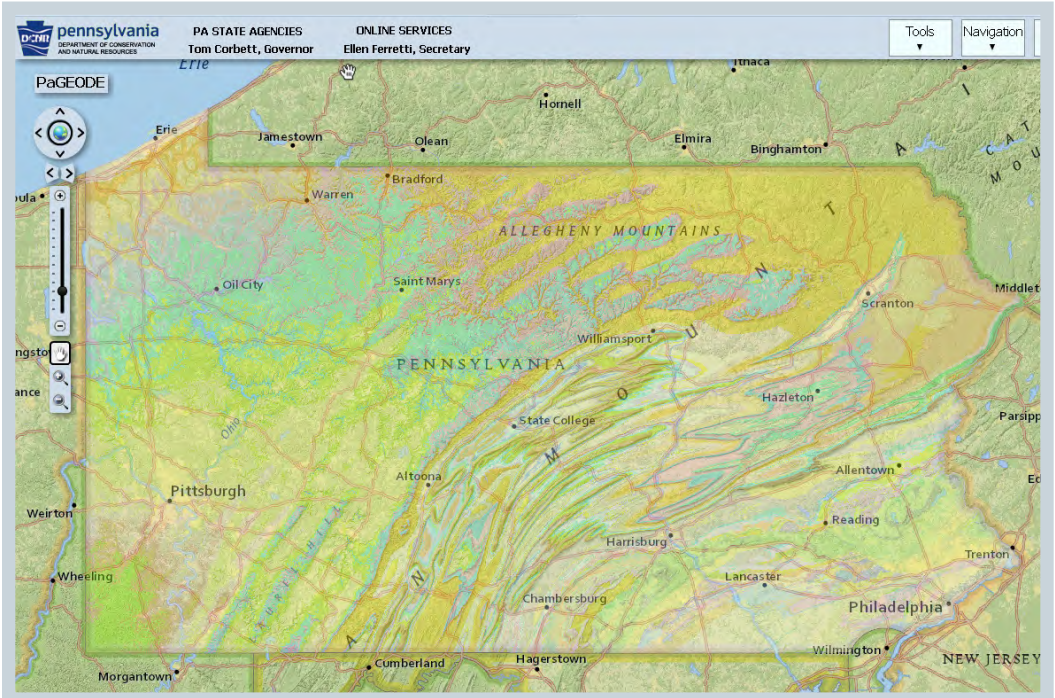
Geologic and geothermal-related data collected, digitized and compiled as part of the NGDS project is now slated for use in identifying areas for more thorough characterization of potential geothermal resources. Bottom-hole temperatures from over 17,000 oil and gas wells, as well as supporting geological, geochemical and geophysical information, are now readily available in one location through NGDS.

Leveraging information gained from work on NGDS, the Pennsylvania Geological Survey is now a supporting partner of Cornell University's "Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin" project, recently funded by the DOE. This preliminary one-year project will assess subsurface data for potential geothermal reserviors in the central Appalachian basin. The Survey will support the project by providing geologic expertise and access to oil and gas well data contained in the PA*IRIS/WIS (Pennsylvania Internet Record Imaging System/ Wells Information System). ■



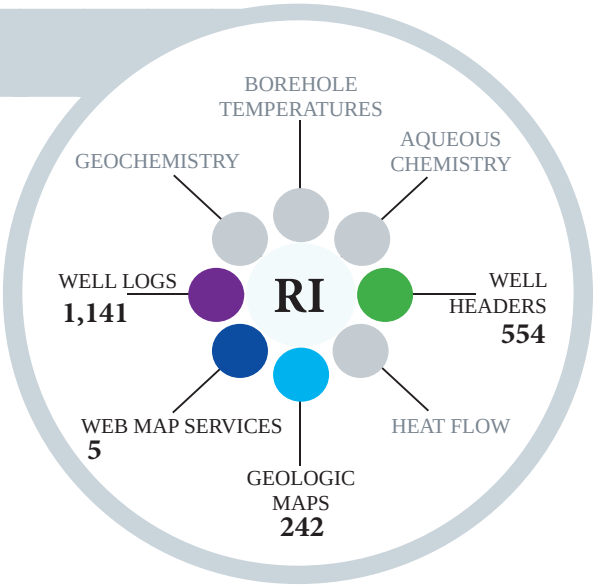


Borehole temperature data for Pennsylvania curated at the NGDS. These data are being used by staff at the Pennsylvania Geological Survey to further assess geothermal potential in that state.



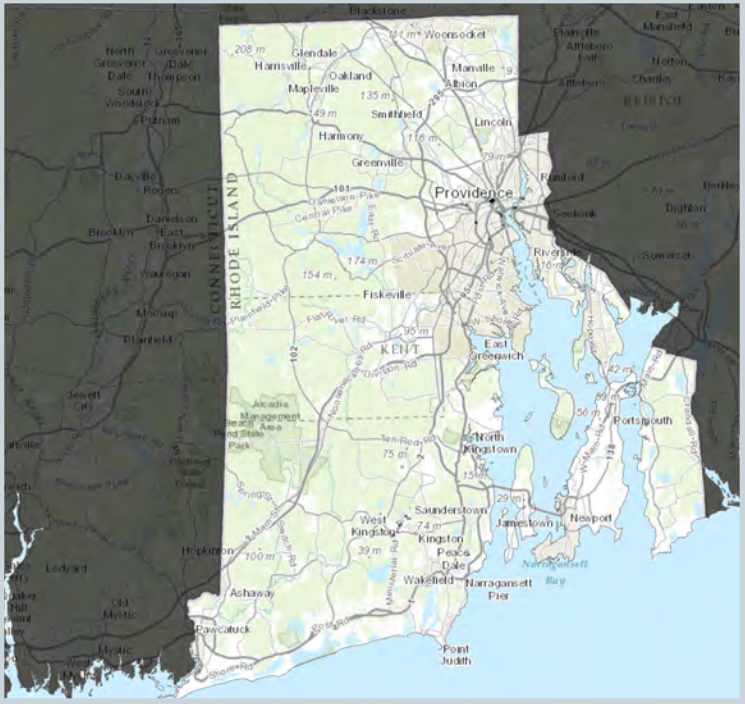
Interactive geologic map of Pennsylvania produced by the Pennsylvania Geological Survey, *http://www.gis.dcnr.state.pa.us/geology/index.html.*

Rhode Island



Legacy Data

The Rhode Island Geological Survey began work on contributions to the NGDS by supervising an undergraduate Energy Fellow funded by URI Energy Center to digitize 400 water well logs, and making digital copies of Rhode Island bedrock and Quaternary (surficial) maps with a drum plotter-scanner. During the project, students were an essential resource in assisting with digitizing and uploading data. In August 2012, RIGS delivered Vector data (polygons) of digitized Quaternary maps that were digitized and re-projected on raster topo images by Co-PI Oakley, along with a total of 8, 1:24,000 scale quadrangles and digital boring logs created using StraterTM software. In 2014, work on rock chemistry was part of undergraduate projects at the University of Rhode Island in partnership with CCRI-Physical Sciences. ■

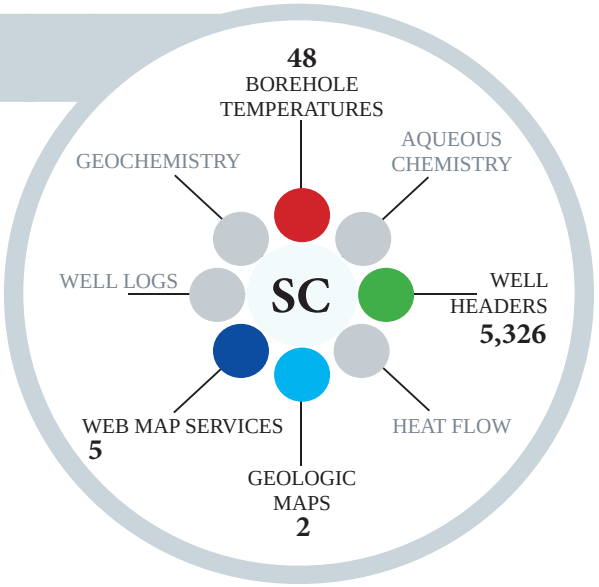


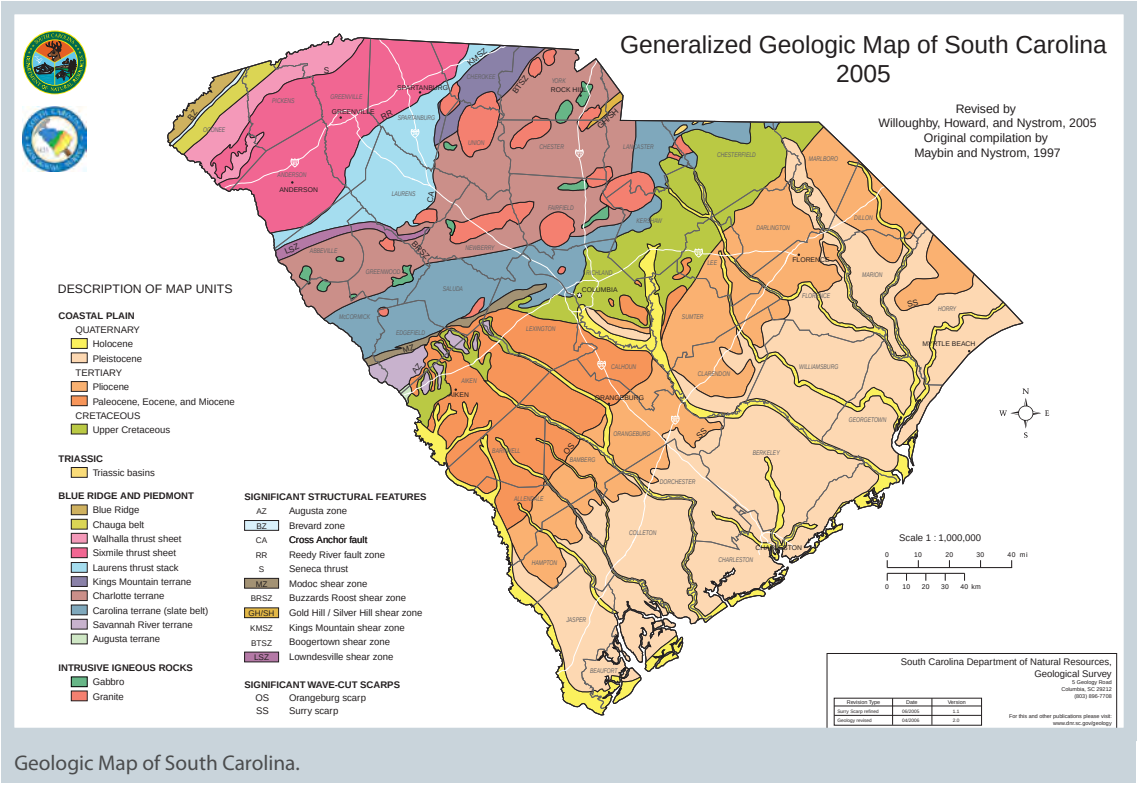
A Web Map Service conveying well headers provided by Rhode Island as part of the National Geothermal Data System.

South Carolina

Legacy Data

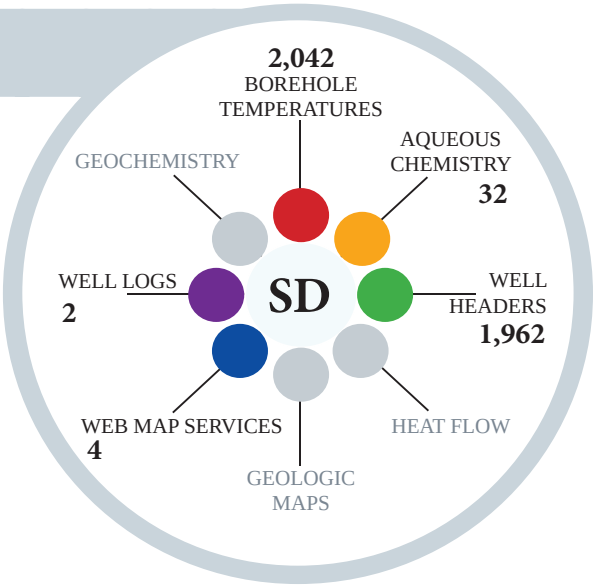
The South Carolina Geological Survey provided a limited amount of data, including metadata for geologic maps, geothermal articles, and maps. Map services are now in place for aeromagnetic and gravity maps (as part of USGS data), limited borehole temperatures, well logs, and 733 records for seismic event hypocenters. ■





Geologic Map of South Carolina.

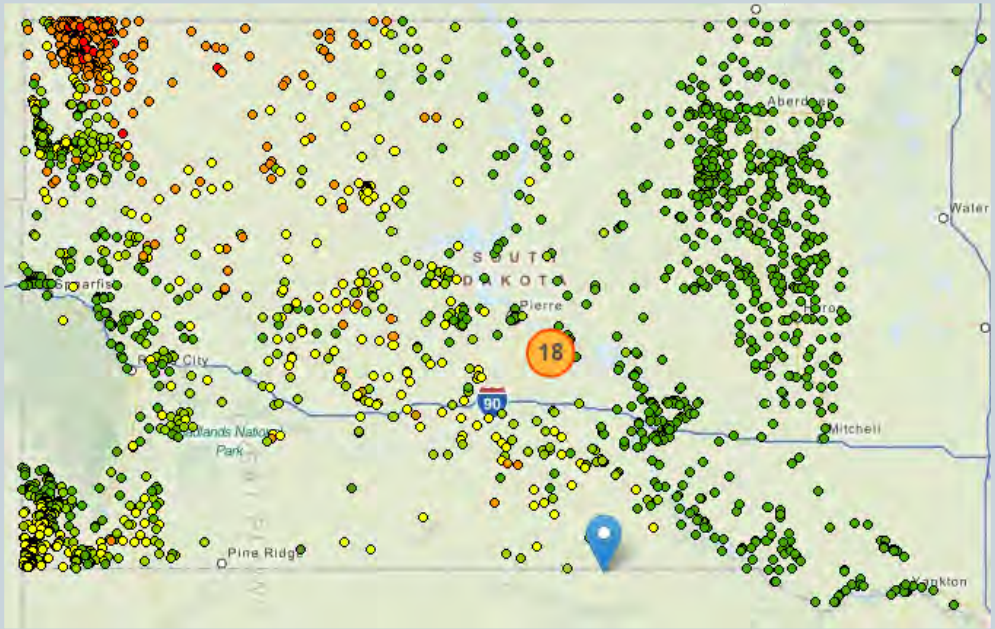
South Dakota



Legacy Data

Geothermal data for South Dakota was compiled by a team at Sinte Gleska University. Major contributions include temperature, flow volumes, and chemical analysis of water for 12 privately owned artesian wells in this area.

Other NGDS-related products include lithological data, logs, and detailed water analysis for two new geothermal water wells near White River, South Dakota, as well as several geological/lithological maps for South Dakota, with special emphasis on the Rosebud Indian Reservation. ■

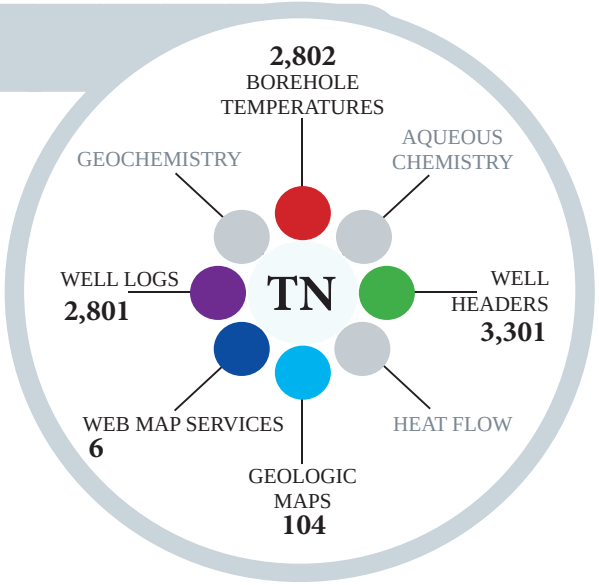


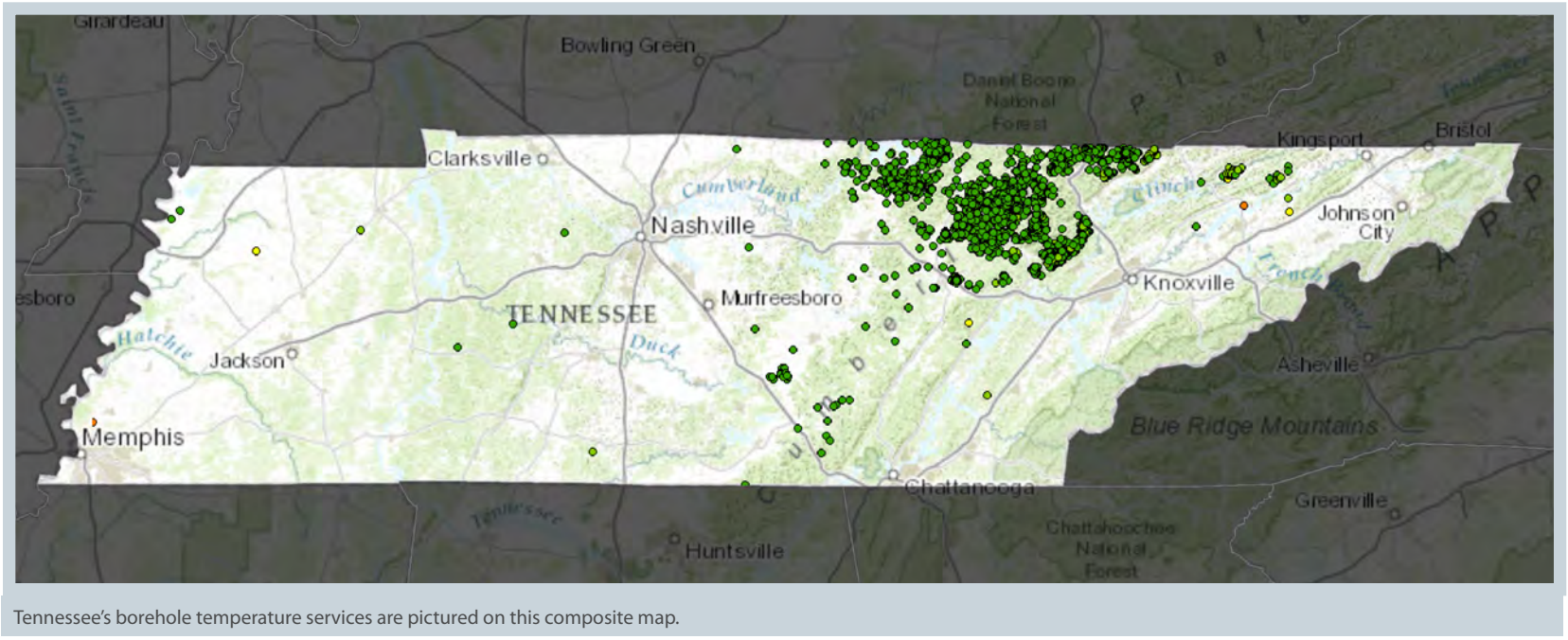
A compilation of borehole temperature observation data for wells in SD, shown as a web map service on the NGDS interface.

Tennessee

Legacy Data

Data from the Tennessee Geological Survey (TGS) is served through the Kentucky Hub. The TGS contributed metadata for maps and documents. They also contributed 21 metadata records for Tennessee heat pump installation and geothermal test reports, 31 records for direct use sites, and 66 conductivity test reports by the Tennessee Valley Authority. ■

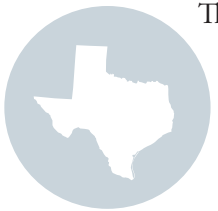




Tennessee's borehole temperature services are pictured on this composite map.

Texas

New & Legacy Data



Though Texas already had an abundance of data in the form of oil and gas logs, the Texas Bureau of Environmental Geology (BEG) team worked to acquire raw data in the form of new well logs, bottom-hole temperatures, reservoir water quality, production information and reservoir characteristics related to the geometry and characteristics of potential geothermal reservoirs found throughout Texas, with special attention to the area west of Interstate 35.

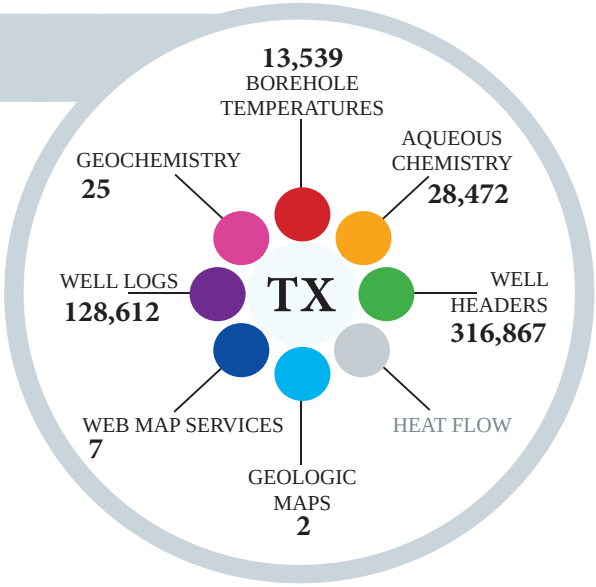
Geothermal Potential

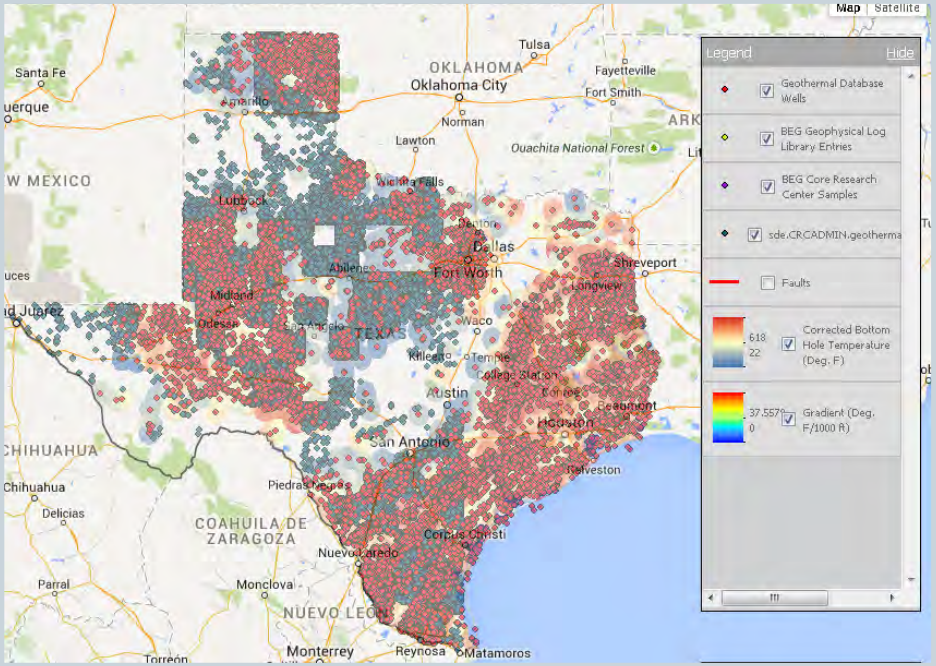
These raw data are being analyzed to provide derivative data products that measure potential productivity of deep reservoirs. A database of these analyzed data is being generated through analysis of railroad commission well production documents and well logs. The team initially completed a detailed analysis for the areas in Crockett and Val Verde Counties as a test example, and then focused on the southwestern Gulf Coast and West Texas regions.

As time and resources permit, the new exploration efforts ongoing in the Anadarko Basin may produce information useful to geothermal energy assessment. If possible, the BEG team will assemble information for the Anadarko Basin area that may be relevant to geothermal production.

Data Management & Best Practices

The BEG developed visualization tools to display the raw data contributed to the NGDS and the analyses via their website; (*http://igor.beg.utexas.edu/geothermalmap/*). They are in the process of building an interactive system to provide insight and motivation for further study, and for development of commercial scale geothermal energy production. ■





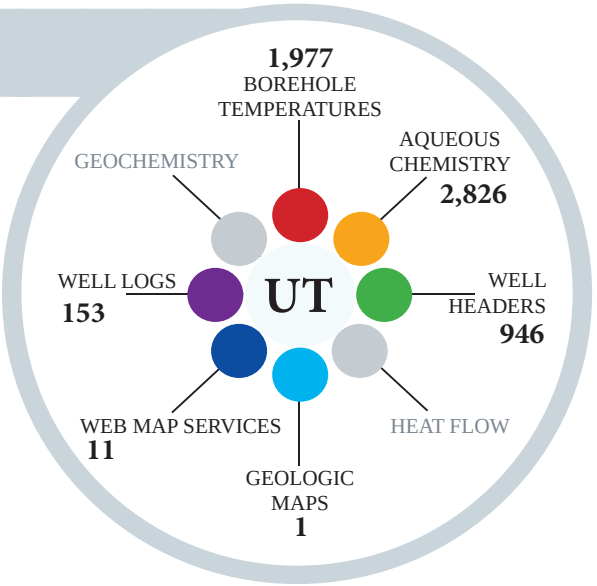
Texas geothermal data available at the NGDS. Includes well, geophysical log library entries, core research samples, faults, geothermal gradient, well log data and more.

Utah

New & Legacy Data

The Utah Geological Survey (UGS), in cooperation with the University of Utah, produced and compiled a large quantity of Utah geothermal data between 2010 and 2013 for inclusion in the NGDS. Published and unpublished legacy data include Quaternary fault and volcanic data, data on individual thermal springs and wells, corrected bottom-hole temperatures and temperature and pressure information from selected oil and gas wells, digital geologic maps of Utah, and geothermal-related bibliographic information.

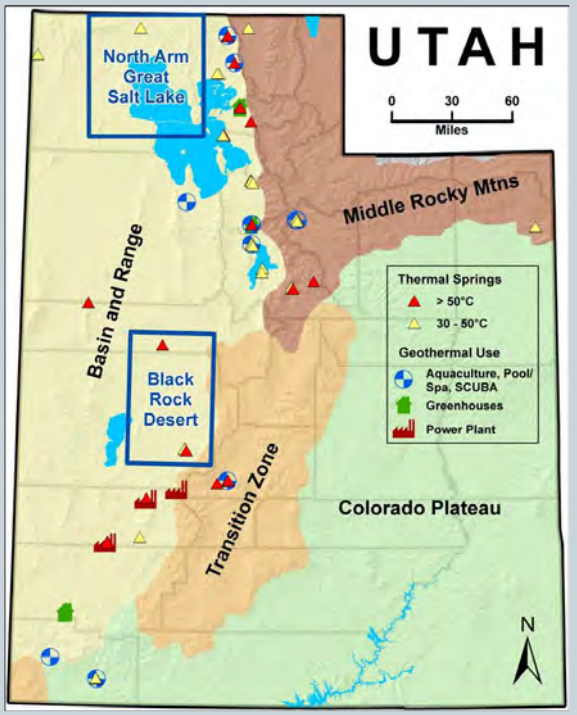
New or supplemental data were collected from studies, mainly in west-central and northwestern Utah, that focused on the Sevier and Black Rock Deserts of Millard and Juab County. These data consist primarily of temperature-depth plots, cutting and core samples, geophysical and lithologic logs, and thermal-conductivity measurements collected from 12 new thermal-gradient boreholes and five deep oil exploration wells. Supplemental temperature-depth data were also collected from 14 previously drilled "wells of opportunity" and new water analyses were obtained from 26 additional well and spring sources. Nine technical papers have been published, and several unpublished reports were written, detailing various aspects of the supplemental data collection work.



A map of thermal springs, wells, Quaternary features, and sediments in northern Utah that can be used to facilitate geothermal exploration and development.

Geothermal Exploration

Though Utah currently has multiple high temperature geothermal power plants, the NGDS effort contributed to the discovery of a major geothermal resource in the Black Rock Desert of west-central Utah where temperatures exceeding 150°C exist over an area of 285 km² at a depth of about 3 km. Temperatures of 200–to230°C at similar depths are present in a centrally-located well and are expected over an area of about 40 km² (Figure 1). Heat flow data were derived from 10 new and 25 previously drilled thermal-gradient boreholes (some not shown in Figure 1) and 12 oil exploration wells. The discovery of a viable geothermal resource has garnered local and national attention since the fall of 2012. ■



A map of thermal springs and direct use geothermal sites in Utah; can be used to facilitate geothermal development.

Vermont

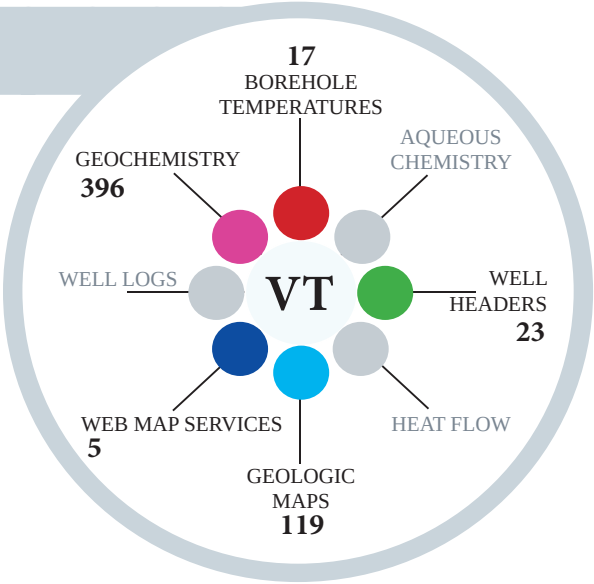
Legacy Data Preservation

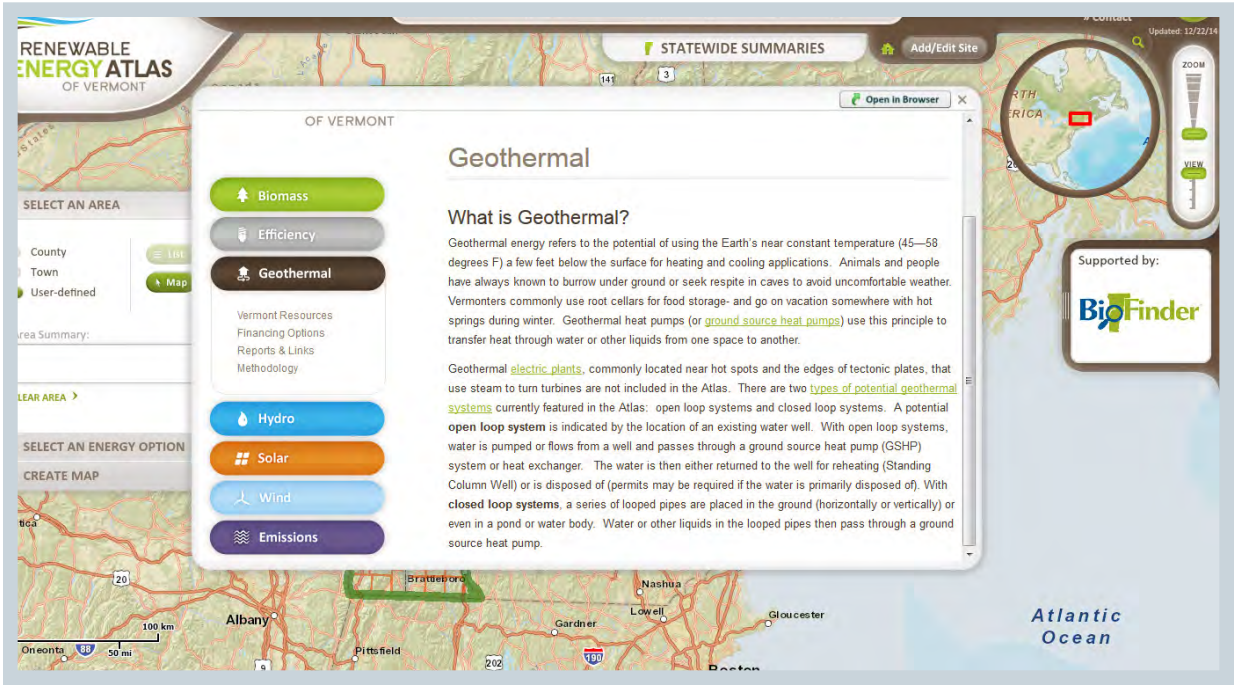
Participation in the NGDS project enabled the Vermont Geological Survey (VGS) to scan, document, and expose its entire library, providing online access to previously unavailable documents including published, draft and open file maps, bound books, field trip guidebooks, volumes with multiple articles, State Geologist Reports and publications of the VGS. Legacy "basement" files including mineral resource documents and maps (i.e. Brandon lignite, mineral springs, peat, phosphate etc), town and county reports, and sand and gravel reports also were brought online.

Hard copies of all these documents had been physically relocated to the office of the scanning contractor in August, 2011 when Tropical Storm Irene hit Vermont. The VGS basement was completely flooded and the bookcases previously containing the archives were substantially affected by flood waters. It is likely that files currently on the affected shelves would have been damaged beyond repair. Instead, the digitization and OCR project is complete and the data are available in computer formats with the paper versions returned and on library shelves. This event clearly illustrates the benefits and necessity of digitizing legacy information.

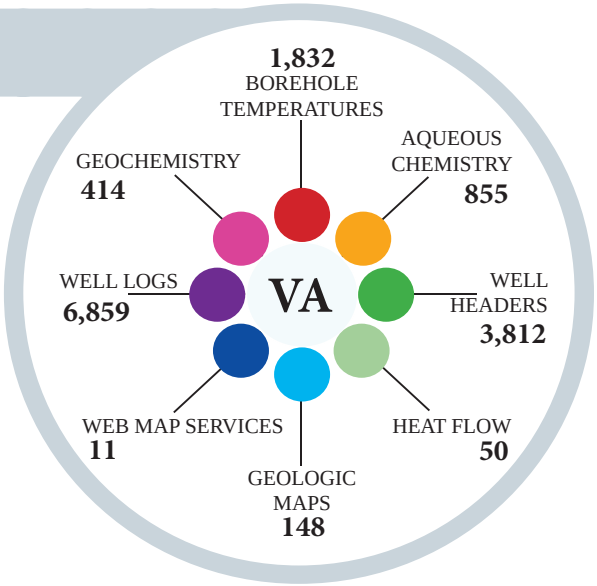
The Renewable Energy Atlas is a project by the Vermont Sustainable Jobs Fund and hosted by Efficiency Vermont, provides information on energy resources in the state at *http://www.vtenergyatlas.com/#*. ■

The Vermont Renewable Energy Resource Map - above and below—helps people locate available renewable energy installations.





Virginia



Inter-agency Cooperation

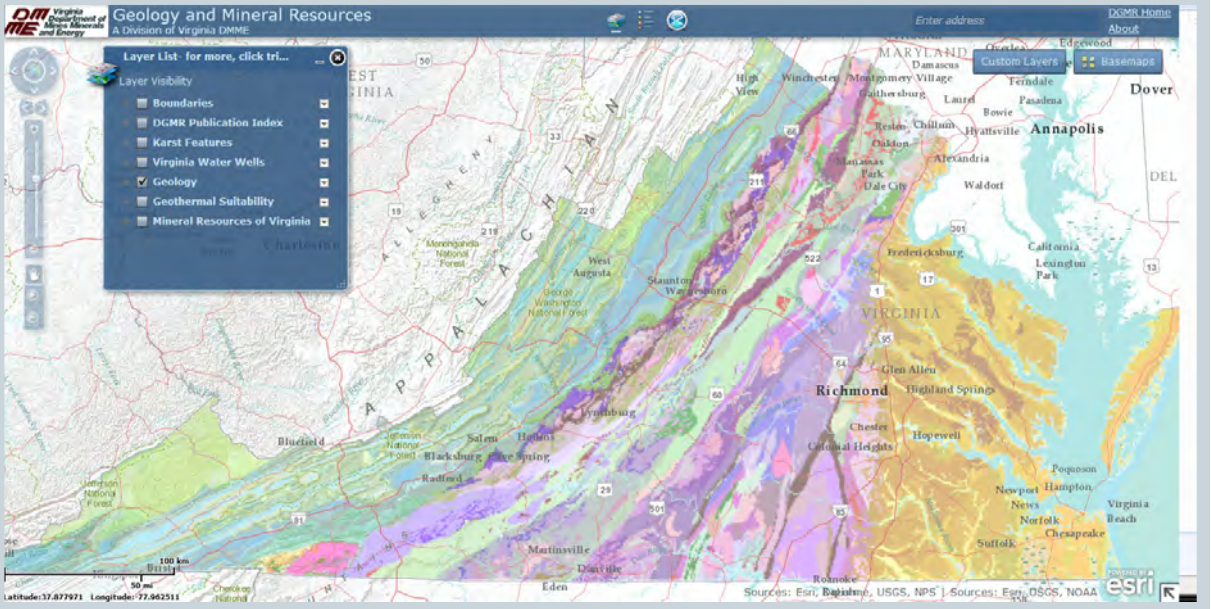
Virginia collected data from Delaware, Maryland, North Carolina, and Georgia, contributing over 50,000 geologic data records from private industry, utility, and state and public agencies to the NGDS project. Numerous collaborators on the NGDS project increased interagency awareness and knowledge.

The Virginia Geological Survey anticipates further collaborative efforts, leading to improved data preservation and efficiency of data collection.

Industry Benefits

The NGDS project resulted in the production of derivative tools that provide a foundation for advancing the eastern geothermal industry. One important product is a comprehensive interactive map located at: *http://dmme.virginia.gov/webmaps/DGMR/*.

This map brings together state data from multiple agencies and geologic maps, allowing users to create custom data profiles. Map features include temperature gradient and heat flow maps using VA Division of Gas and Oil database and VTech Geothermal Program data, heat pump installations, depth to bedrock maps, and more. ■

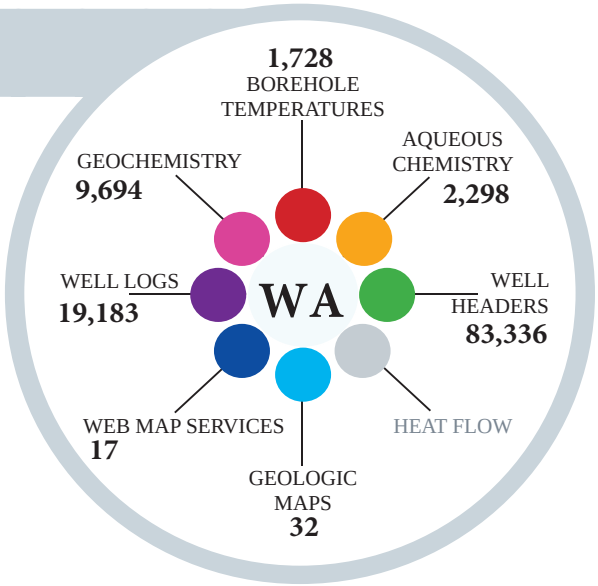


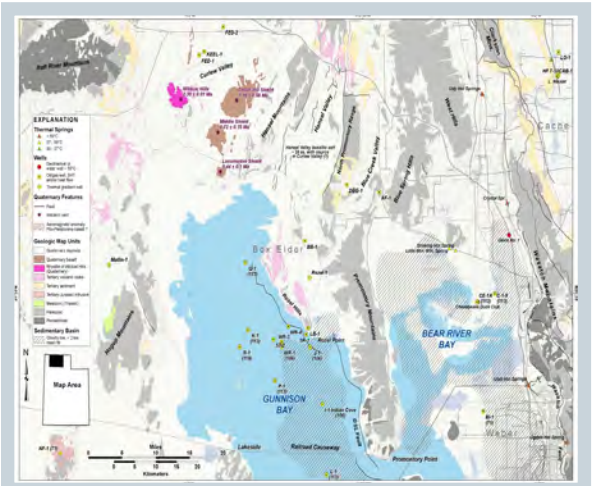
Interactive geologic map of Virginia.

Washington

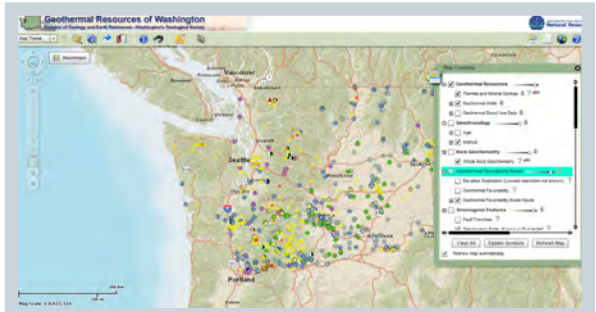
NGDS Stimulates Growth

The Washington Department of Natural Resources (WDNR) reports that the NGDS project was a boon for digital data compilation in Washington State. The datasets created during the project have direct application in geothermal and other geologic disciplines and are highly valued by the geologic community. As a result of this work, WDNR will produce several publications, including digital datasets and open-file reports. Much of the data appears on an interactive map application available at: *https://fortress.wa.gov/dnr/geology/?Theme=geothermal*





Geothermal data available through the NGDS for Washington: thermal springs and more.



Graphic expression of geothermal favorability model for Washington. Applying weighted raster calculations and fuzzy transformations, including weights permeability, heat, elevation, slope, and distance to transmission lines.

Industry Benefits

Private geothermal exploration companies are mining Washington's NGDS data to pinpoint potential resources in their geothermal lease holdings in the state. Maps made from the data yield insight in areas with little previous exploration. Enhanced and rapid data-gathering, coupled with reduced cost and reduced risk, is kicking off new geothermal exploration.

This project has prompted cooperation between the WDNR and the U.S. Army Corps of Engineers in exploring for geothermal resources on the Yakima Firing Center. It has also enabled collaboration with county utilities, as they look to develop renewable resources in their jurisdictions.

Geothermal Exploration

The NGDS is the cornerstone of a government-industry-academia Geothermal Play Fairway Analysis program to evaluate geothermal potential in Washington.

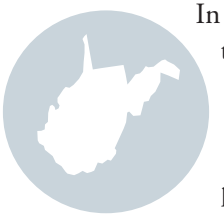
Additionally, thermal and mineral spring chemistry data collected for the NGDS project has been used recently by scientists with the USGS studying noble gas isotopes in the Cascadia Forearc (McCrory and others, 2014). Other USGS scientists used heat flow data and geothermal gradients from NGDS to study heat flow loss in the Columbia Basin. New geologic mapping in the Wind River Valley near the Columbia River recently facilitated the siting of wells that have elevated warm water temperatures and could lead to new geothermal possibilities.

New Data Collection

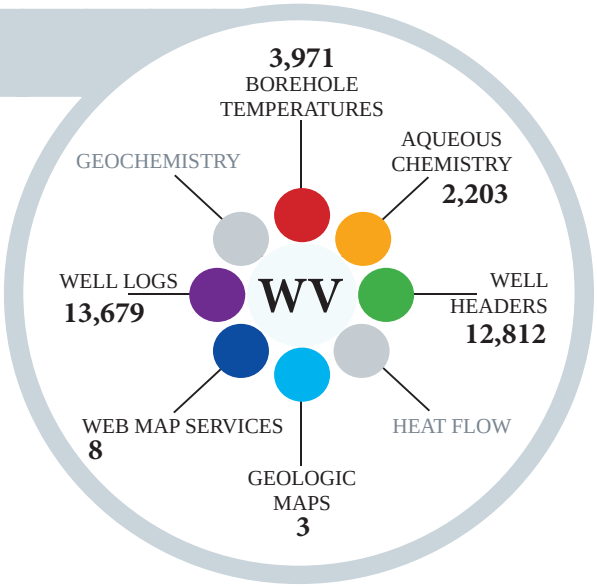
New Data Collection (October 2011 - June 2013) enabled maping of the geology of 61 square miles in the Wind River Valley. New information includes: thermal and mineral spring sampling, temperature-gradient logging, and drill temperature gradient boreholes. ■

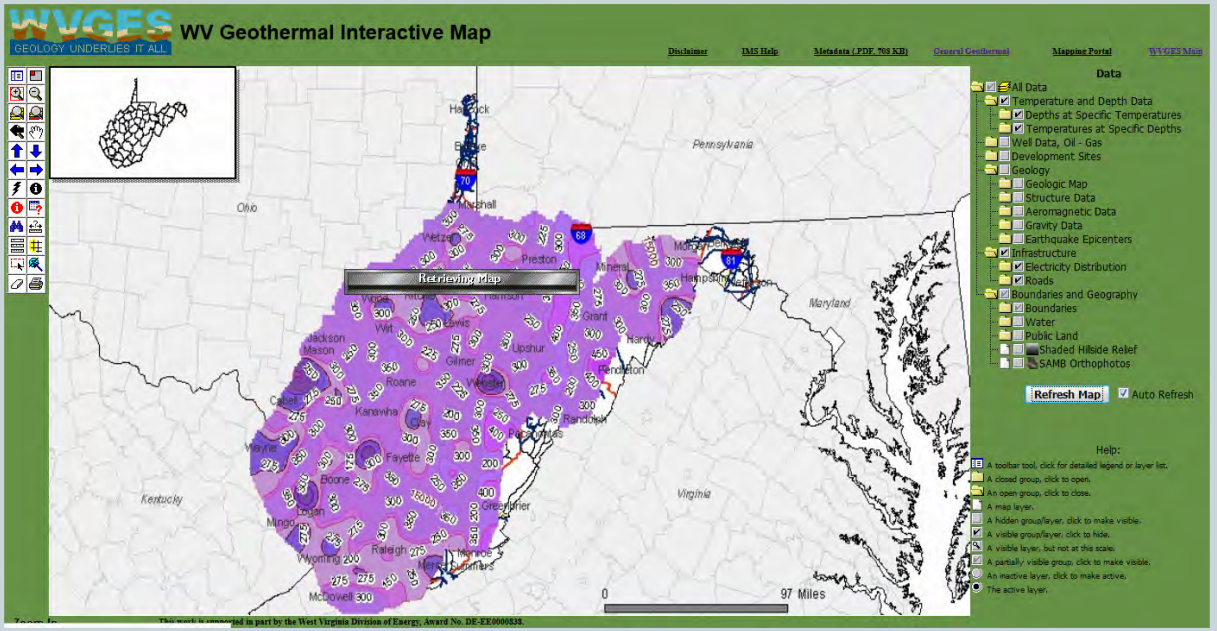
West Virginia

New & Legacy Data



In 2010, it was discovered that the temperature of the earth under West Virginia was much warmer than previously believed, fueling extensive research into a new potential "hot spot" for geothermal energy. Over the course of the NGDS project, West Virginia published seven maps as both Web Map Services and Web Feature Services. Map services now available include a georeferenced basement structure map displaying over 115 individual features (e.g., faults), gravity and magnetic maps, a georeferenced fault map for the state for the Devonian Onondaga Limestone, an earthquake epicenter map, and a geologic map. ■





Temperature data (pictured here) can be viewed in relation to other geological features, infrastructure, development sites, and more.

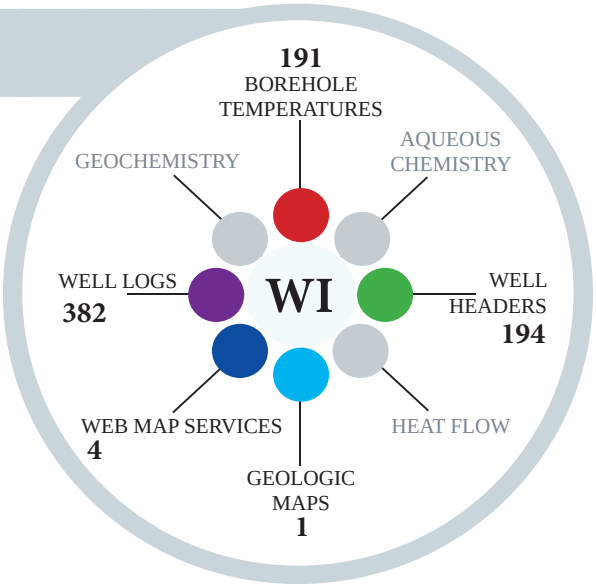
Wisconsin

Applied Research

Wisconsin's participation in the NGDS project culminated in the state's first geothermal energy program, with positive results for funding, installation of energy efficient systems, and additional research. The project digitized existing data, drilled six new boreholes and established a viable state-wide geothermal gradient, and characterized thermal properties of Wisconsin's bedrock.

Staff from the Wisconsin Geological and Natural History Survey (WGNHS) teamed up with the Geological Engineering program at the University of Wisconsin-Madison to assess Wisconsin's resources. Working with local engineering firms and geothermal heat pump installers, the group studied geothermal heat pump systems with a focus on applications in Wisconsin.

To date, this state-private industry consortium has received additional grant funds from the National Science Foundation (NSF) and the University of Wisconsin (UW). The total of the grants is more than $700,000, with just over $300,000 in initial funding from the NGDS. UW is now home to an NSF Research Experience for Undergraduates that focuses on alternative energies; each year an average of twelve students engage in research on wind, solar, geothermal and other alternate energy systems.



New Discoveries

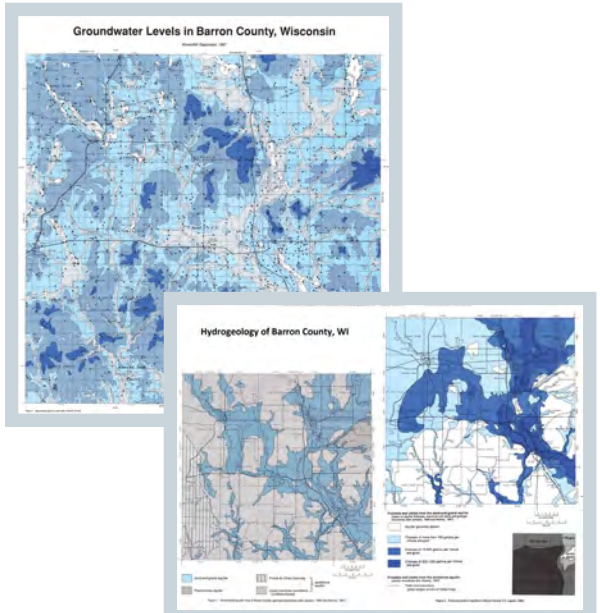
The project enabled seven 1,000-ft deep borings at selected locations in Wisconsin where geothermal temperature profiles were previously unavailable to be drilled and characterized. The project also enabled collection of complete data sets on over 180 existing wells. One of the 1,000-ft borings (Geothermal 7) is being converted to a long term groundwater monitoring well. Another boring (Geothermal 4) will likely be used as part of a ground source geothermal study. A short report on the hydrogeology of Geothermal 5 was used to help locate additional water supply for Fort McCoy, Wisconsin.

The research provided new insights into Wisconsin's hydrogeology, especially in northern Wisconsin where little data was previously available. This data is being used to help regulatory and policy professionals understand flows in the fractured rock, especially with regard to mining issues in Wisconsin and Minnesota.

Data Management & Best Practices

Wisconsin is now an NGDS node, independently serving their data through free-and-open-source GeoPortal software.

The NGDS project improved data management by creating NGNHS procedure for handling geophysical data from collection to serving via the internet. This procedure enabled identification of areas with little or poor geophysical and geologic data where additional effort should be focused and identified specific questions that will direct future research on the state's geothermal properties. ■



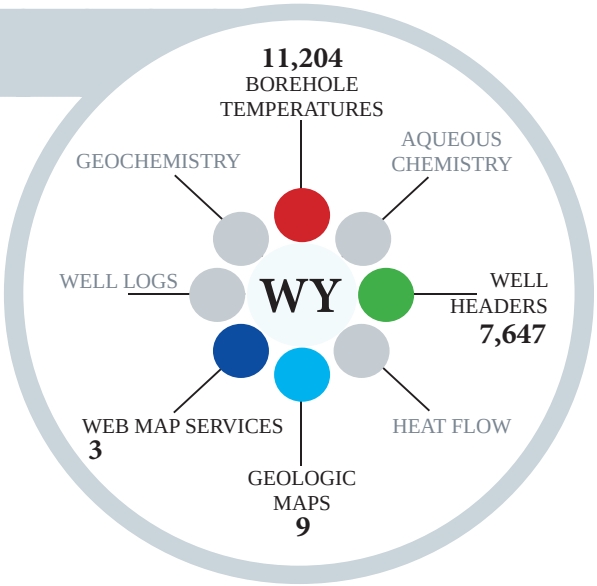
Examples of Wisconsin's maps now available online.

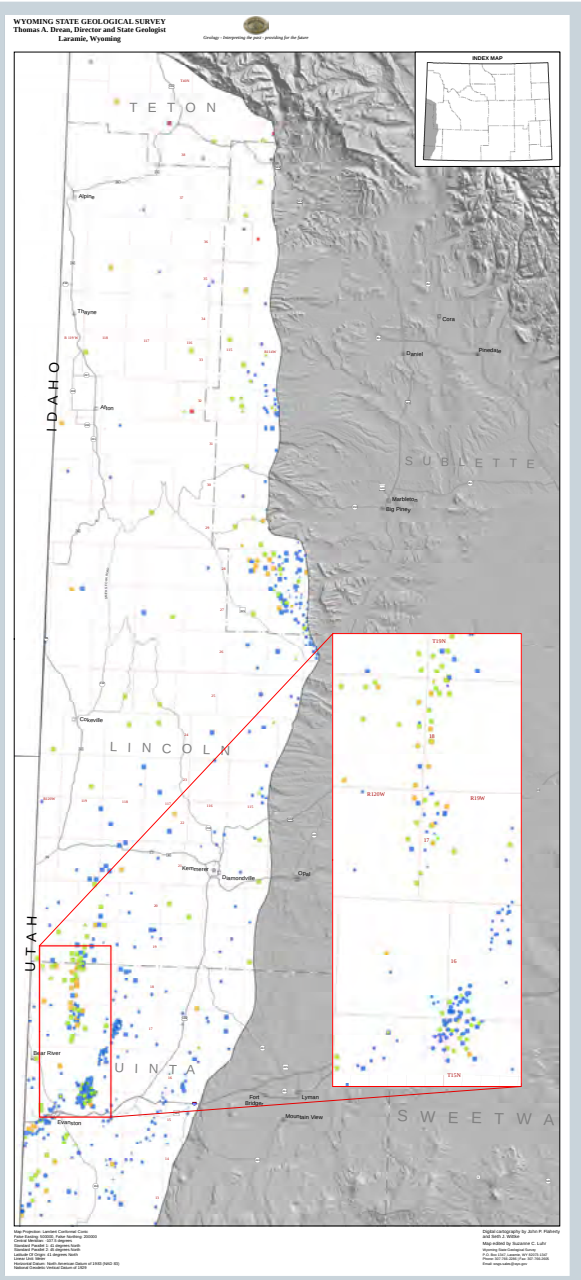
Wyoming

Geothermal Potential

Wyoming is a state with high geothermal potential. Currently, tourism is the primary use of geothermal energy in Wyoming. Geothermal features draw hundreds of thousands of tourists to Wyoming each year, allowing them to enjoy thermal springs in the state, primarily in Yellowstone National Park and Hot Springs State Park (located in Thermopolis). Direct use of geothermal energy is also harnessed as a means to heat buildings, water, and roadways in some areas of the state.

The Wyoming State Geological Survey (WSGS) has a number of publications related to thermal springs and geothermal data in Wyoming. A number of digital reports and maps are available on their website at *http://www.wsgs.wyo.gov/Research/Energy/Geothermal.aspx*. Other Wyoming related geothermal data, including bottomhole temperatures, are available via the NGDS. ■





Map of Reported bottomhole temperatures in the Overthrust Belt, Wyoming.

NGDS Featured in May 2013 *Scientific American*

"Heated to the Core"

"The ultimate goal [of the NGDS] is to capture the full geologic and geophysical profile of geothermal energy reserves across the country."

— ***Scientific American***, "New Geothermal Data System Could Open Up Clean Energy Reserves," by William Ferguson, February 25, 2013