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ONLINE INTERACTIVE ASSESSMENT OF GEOTHERMAL ENERGY POTENTIAL IN THE U.S.

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ABSTRACT

Geothermal-relevant geosciences data from all 50 states (www.stategeothermaldata.org), federal agencies, national labs, and academic centers are being digitized and linked in a distributed online network via the U.S. Department of Energy-funded National Geothermal Data System (NGDS) to foster geothermal energy exploration and development through use of interactive online 'mashups,'data integration, and applications. Emphasis is first to make as much information as possible accessible online, with a long range goal to make data interoperable through standardized services and interchange formats.

An initial set of thirty geoscience data content models is in use or under development to define a standardized interchange format: aqueous chemistry, borehole temperature data, direct use feature, drill stem test, earthquake hypocenter, fault feature, geologic contact feature, geologic unit feature, thermal/hot spring description, metadata, quaternary fault, volcanic vent description, well header feature, borehole lithology log, crustal stress, gravity, heat flow/temperature gradient, permeability, and feature descriptions data like developed geothermal systems, geologic unit geothermal properties, permeability, production data, rock alteration description, rock chemistry, and thermal conductivity. Map services are also being developed for isopach maps, aquifer temperature maps, and several states are working on geothermal resource overview maps. Content models are developed preferentially from existing community use in order to encourage widespread adoption and promulgate minimum metadata quality standards.

Geoscience data and maps from other NGDS participating institutions, or "nodes" (USGS, Southern Methodist University, Boise State University Geothermal Data Coalition) are being supplemented with extensive land management and land use resources from the Western Regional Partnership (15 federal agencies and 5 Western states) to provide access to a comprehensive, holistic set of data critical to geothermal energy development.

As of September 2011, we have over 34,000 records registered in the system catalog, and 234,942 data resources online, along with scores of Web services to deliver integrated data to the desktop for free downloading or online use. The data exchange mechanism is built on the U.S. Geoscience Information Network (USGIN, http://usgin.org and http://lab.usgin.org) protocols and standards developed as a partnership of the Association of American State Geologists (AASG) and U.S. Geological Survey.

INTRODUCTION TO NGDS

One of the basic objectives of the National Geothermal Data System (NGDS) is to make access to data simpler. A major time consuming aspect of bringing disparate datasets together is digital data integration. This process involves matching field or element names in the schema for various data sets, selecting those that contain the information of interest, and then merging content in real time into a single working data set with consistent usage of vocabulary and units of measure in a standardized collection of fields or elements. Data integration may be done by data providers who choose to deliver data in standardized interchange formats, by data consumers who acquire data in heterogeneous formats and schema and figure out how to extract what they need, or data integration may be done by middleware layers that implement transformations between known formats and schema.

Data integration in the current system of scientific information interchange is mostly left to the data

consumer. Until recently, the most common approach has been for an investigator to collect various datasets and manually integrate them into a single database that was used for some analysis; some small part of the data might get published, and the compiled dataset was subsequently committed to oblivion. Centralized data aggregation schemes have also been developed and deployed, but rarely outlive project funding or are not maintained and rapidly grow stale due to out-of-date data or use of retired technology. A tremendous amount of effort has been made towards developing systems to promote the management of data such that they may be reused without having to repeat the same integration and cleanup processes over and over.

In contrast, portals and applications for NGDS allow data users to seamlessly discover, access, and explore datasets relevant to geothermal exploration. This paper identifies and tributes the U.S. Geoscience Information Network – the data exchange framework in use for NGDS – and specifies currently available data sets for providing an interactive assessment of various geothermal systems across the United States.

The U.S. Geoscience Information Network

The U.S. Geoscience Information Network (USGIN) is a collaboration between the U.S. Geological Survey (USGS) and the Association of American State Geologists (AASG) to facilitate discovery and access to geoscience information housed in state and federal geological surveys; however the approach can and has been adopted for other relevant data (Allison, et al, 2008; Allison, et al, 2011). The USGIN framework is distributed, interoperable, uses open source standards and common protocols, respects and acknowledges data ownership, fosters communities of practice to grow, and develops new web services and clients. Traditional data-sharing networks are centralized, expensive to maintain, and often require proprietary software. USGIN addresses these issues by means of a distributed network that can be accessed by open access and open-source software available to all (Richard, et al, 2011).

System Technical Design Principals

In order to meet our objective of accessing data simpler, the NGDS must provide online resources to make it easy for users to extract, assess, and synthesize data according to criteria they select. Data will be provided by a community of data providers or data "nodes," many of whom maintain their own data management systems. Current participants in the NGDS include the USGS, Boise State University, Stanford University, Oregon Institute of Technology's GeoHeat Center, University of Utah's Energy and Geoscience Institute, Southern Methodist University, University of Nevada Reno, and the State Geological Surveys and partners (through AASG).

In addition to data maintained by active participants, there are also numerous kinds of existing "legacy" data in various tables, spreadsheets and databases that need to be made accessible through the system, as well as many documents that are or could be in digital form and accessible through the system. Some of these legacy data are "orphaned" in that the original producer of the data is no longer involved, and there is no acting steward of the data.

Resources (e.g. data, metadata, catalogs, services, tools) are made accessible through the system by creating metadata conforming to a shared content model and inserting them into the catalog system. The metadata provide information describing resources that can be indexed for discovery by search engines, information about provenance and quality of the resource so users can evaluate the resource for their application, and information describing how to access the resource. The access instructions should be in a format that can be utilized by software clients to automate the access process and minimize the amount of user interaction required to bring the resource to their desktop.

Users should be able to search all resources in the system through a single search client. Any search client that implements the system catalog service profile should be able to conduct searches against any system catalog that also implements the profile. This means that there can be multiple portals and client applications for accessing system resources; it requires that a single client can search different catalogs in the system without the user having to reconfigure the software. Providing quality information to evaluate system resources requires criteria that can be used to filter data and categorize them according to established and user-defined quality levels. These quality filters will vary depending on the type of data and their targeted use.

Structured data are provided through NGDS services that have published protocol and documented interchange formats. The idea is that multiple data providers can present the same kind of information in the same way, and a client that implements an NGDS service can access that service from any server in the system that offers that service and get data that integrates with minimum operator intervention.

Data queries and web services

A NGDS catalog component implements one or more protocols for searching a metadata store and returning metadata. At least one of the implemented protocols

and interchange formats used for delivering metadata must conform to an NGDS specification. Initial catalog testing and prototypes are using the Open Geospatial Consortium Catalog (OGC) Service for the Web (CSW); other open protocols may also prove to be useful. The CSW was selected for initial development work because it operates in the same framework as the other OGC services for data delivery (Web Map Services and Web Feature Services), is designed for geospatial data, and has a variety of free, open-source software projects developing clients and servers for the protocol, as well as a variety of commercial products (including ESRI ArcGIS) that are implementing the protocol.

The CSW service allows search queries by core queryable elements (e.g. term) or by area bounding box. NGDS Catalog instances may be implemented with various software and hardware configurations on any node in the system. To be an NGDS compatible/compliant catalog, the only requirement is to implement an NGDS catalog service profile, and provide metadata in at least one output format schema and profile that conforms to an NGDS metadata interchange specification. Documents on complying with these schemas and profiles are available at http://lab.usgin.org.

The OGC has produced several different web services that are relevant to geographic information systems (GIS), USGIN, and therefore NGDS. The two types of web services which are most often used to display map data include Web Feature Service (WFS) and Web Map Service (WMS).

Web Feature Services serve data from shapefiles as vector-based features that may be queried for associated attributes (and therefore compared with other data published as web feature services). For example, if data from a shapefile containing information about rivers were published as a WFS, clients attempting to access this service would receive a map in which individual rivers could be queried for any attributes associated with them (such as average flow rate, average depth, etc.). Web Feature Services may also be queried against secondary or tertiary services. For example, a dataset featuring known borehole temperature profiles may be queried against a land ownership layer and/or proximity to transmission lines layer. Owing to the large amount of data associated with WFS, these services tend to require fast internet connections.

Web Map Services display data from a shapefile as a static raster image, regardless of whether or not the source shapefile contains features that may be queried for attributes. For example, if a coverage containing a geologic map of Arizona were published as a WMS, clients attempting to access this coverage would receive a raster image suitable for viewing, printing, displaying, or general visual analysis. Note that certain attributes queries are sometimes possible with a WMS; for example, specific borehole information such as bottom hole temperature and depth can be viewed. Generally WMS are reserved for initial observations whereas WFS are reserved for data layer queries.

AVAILABLE DATA

One of the largest sources for geoscience and geothermal relevant data is the Association of American State Geologists. In 2010, the Arizona Geological Survey, acting on behalf of AASG, signed a cooperative agreement with the U.S. Department of Energy Geothermal Technologies Program to collect, digitize, and present in a distributed online interoperable format, geothermal relevant data housed within the fifty state geological surveys as part of the NGDS (Allison and Richard, 2011). All fifty states are providing data into the NGDS either through contracted services or in-kind services using USGIN interoperability protocols. Four regional information technology and service hubs have been deployed to host content for surveys unable to host their own content and to provide backup services. The hubs include the Illinois Geological Survey in Champaign, IL; the Kentucky Geological Survey in Lexington, KY; the Nevada Bureau of Mines and Geology in Reno, NV; and the Arizona Geological Survey in Tucson, AZ. Each state or hub has provided metadata according to the specifications produced above in the AASG State Geothermal Data catalog service which is interoperable with other NGDS catalog services.

In order to prioritize data for digitization and inclusion in the NGDS, a project Science Advisory Board (SAB) of geothermal experts was established. The SAB is convened at least annually to review individual state progress and provide recommendations to project managers on data collection efforts. Upon reviewing available data approximately thirty geoscience data content types were suggested for inclusion to the NGDS. If at all possible, existing schema and content models are used. During content model development, external review is requested in order to achieve maximum utility. The following data delivery templates are currently available on www.stategeothermaldata.org: Active Fault/Quaternary Fault, Aqueous Chemistry, Borehole Temperature Observation Feature, Direct Use Feature, Drill Stem Test, Earthquake Hypocenter, Fault Feature, Geologic Contact Feature, Geologic Unit Feature, Heat Flow, Lithology Interval

Log Feature, Metadata, Thermal/Hot Spring Feature, Volcanic Vents, Well Header, Well Log Data Compilation. Starting in August 2011, AASG geothermal data templates were posted for review and acceptance for use by other NGDS projects.

Accessing Data

Due to the open standards and protocols in use for the geothermal data system, as well as the decoupling of the data from applications, multiple user interfaces and access portals may be developed. Consider the internet; using standardized protocols users may fairly simply develop web sites. Those web sites are then accessible via a browser such as Internet Explorer, Safari, Chrome, Firefox, etc. While the browsers have certain unique features differentiating themselves from competing browsers they all have one basic function: accessing the internet and the web pages developed using specific standards and protocols. This same concept is in place for the geothermal data system. That is, multiple access portals may be developed with variations of functionality. Currently, data may be accessed directly by accessing the web service, the www.stategeothermaldata.org site (however this is only searchable by state), ESRI's ArcGIS Online, a client application with ESRI's ArcMap, and two USGIN catalog search clients including http://catalog..usgin.org/geoportal or http://catalog.using.org/search. Each of these will be described in detail below.

While functional user interfaces, including certain analysis tools, are in development for the overall NGDS, potential users may still access State Geothermal Data as they become available. User interfaces will simplify the process for accessing data; however, the following steps concerning access to web services will remain applicable. To reiterate, the purpose of the NGDS is to produce a decoupled system – a system removed from one software or portal application – and deploy varying access portals depending on user need and technical skill set and allow third parties to create portals customized to serve their own needs.

State geothermal data web page & tracking map

To track progress of the State Geothermal Data project, the interactive tracking map accessible on the project web site under "Progress" is one of the simpler mechanisms. The Interactive Data Contribution Map allows the user to track progress either by state or by national progress using eight data categories. The eight data categories – temperature & heatflow, water chemistry, recent tectonics, rock chemistry, well logs, map data, metadata & documents, and other – were selected based upon the thirty predetermined content models previously discussed. A user can select one of the categories from the legend (located in the Gulf of Mexico) and see progress in each category across the nation; the darker the state in a particular category, the more data available. Figure 1 provides a screen capture of the status and availability of nationwide

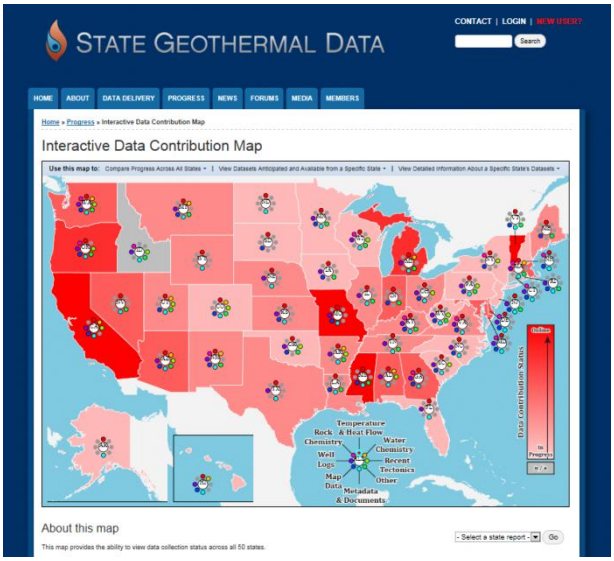

Figure 1: Interactive Data Contribution Map available on www.stategeothermaldata.org for tracking the progress of state's data collection.

Temperature & Heatflow data sets.

Alternatively, users may track the progress by state. Users may identify certain categories within a state, for instance Well Logs, and then select the corresponding circle within the state for additional information. For example, Figure 2 identifies California's progress on Well Log data collection, indicating that their Oil & Gas Borelogs are *in Progress* and DOGGR Thermal Wells dataset is

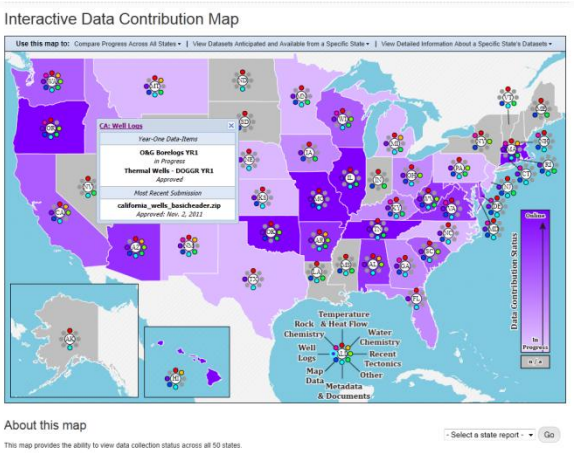

Figure 2: Interactive Data Contribution Map indicating California's progress on Well Logs.

approved (or complete). The popup also permits the user to view the most recently submitted dataset. From the popup associated with a particular dataset, a user may find a more detailed report of that state by clicking on the hyperlinked state name in the popup. Alternatively, a drop down menu for navigating the fifty state's individual progress status is also available and located below the interactive map. Once on the individual state's reporting page, a user can identify the data currently available for download with links to the location of the data or the services available through the XML schema (access to which is described below). Figure 3 demonstrates California's status report page indicating the overall progress of the project.

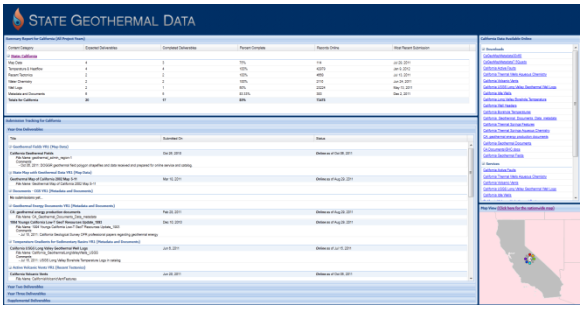

Figure 3: California's progress report. On the right side of the screen are the links to access downloads and services. View the report online at http://services.usgin.org/track/report/CA

Accessing web services through ArcGIS online

In order to provide an alternative access portal and to simplify access to AASG state geothermal data we are providing the services to www.arcgis.com for consumption. Arcgis.com is a freely available GIS software site that allows users to search for keyword specific data sets or by developer. The site also allows users to combine datasets and perform basic queries. This paper will not function as a tutorial to arcgis.com as user guides are available on the site; however, users interested in the AASG data sets can search for geoscience data on the site or can search by user for "USGIN_Initiative." Figure 4 shows Texas borehole temperatures in Arcgis.com with popups enabled showing attributes associated with a specific borehole.

Accessing data through CSW ArcMap Plugin

As part of the decoupled design, Catalog Services for the Web (CSW) may be integrated with existing software applications. To demonstrate this, we have developed an ArcMap add-in application which can access and search CSW catalog services to locate web services that can be added as layers in an

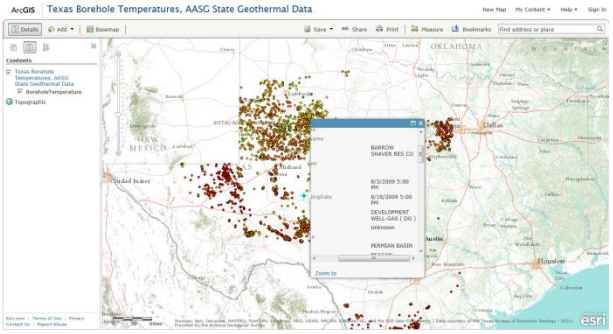

Figure 4: Displaying Texas Borehole Temperature data within ArcGIS.com with popups enabled. The popups allow the users to view specific attributes associated with a data point.

ArcMap (v10) project. The version is specifically configured to search initially the USGIN catalog, the OneGeology catalog, and GeoData.gov.

Once the CSW client is downloaded from http://lab.usgin.org (a link is also available from www.stategeothermaldata.org) and installed into ArcMap, you can search for available services by key words or the extent of the ArcMap View frame. The search results will be displayed in the list box. The application checks for a successful GetCapabilities request to determine if the service connection information in the metadata works and enables the "add to map" function for operational services.

Accessing data through Catalog Search Interfaces

There are currently two access portals for searching for and accessing data, the Geoportal catalog interface and a Beta map based viewer tied into ESRI's ArcMap system developed for integration with the AASG data. These search interfaces are available at http://catalog.usgin.org/geoportal and http://catalog.usgin.org/search, respectively. The Geoportal search permits keyword or browse search capabilities while the map based search portal permits keyword and bounding box search capabilities. Web services can be previewed to ensure compliance with target study area prior to download for analysis. Figure 5 identifies the Beta map based search functionality.

Each of the catalog search portals also allows users to access web services through GetCapabilities or XML schema as well as REST services. Accessing these is described in detail in the following section.

Accessing web services through XML

As the project advances, more user friendly interfaces and applications will become available. However, GetCapabilities, XML, and REST pages will remain

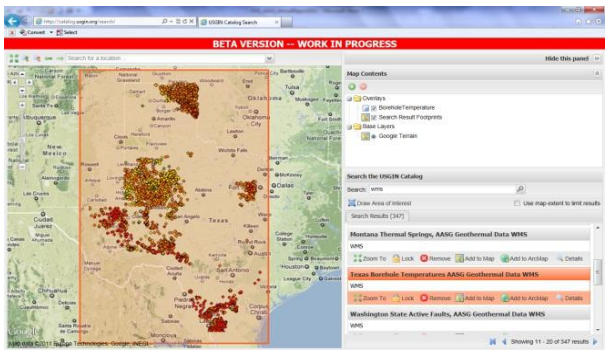

Figure 5: Displaying Texas Borehole Temperature data within the Beta Map Search interface. Users can "save" this search or download the application directly into ArcMap

viable options for accessing data for system developers and back-end users.

The process of connecting to a web service through XML services is actually quite simple. To this point, this paper has discussed accessing the services through ESRI's ArcMap product, but freeware geospatial analysis tools such as ArcExplorer, QuantumGIS, uDIG, GVSIG, and GrassGIS, are all compatible with the XML capabilities. ArcMap has been identified as the core geospatial analysis software by surveyed end users and thus our emphasis on demonstrating ArcMap. XML capabilities documents are one of the simplest forms to integrate in various geospatial visualization softwares.

Either of the catalog search interfaces described above allow the user to access the capabilities XML by clicking on the details button. This opens a separate page in the web browser and displays XML code. With regards to accessing a web service, the contents of the capabilities document (i.e. code) are less important than its URL. Having navigated to the capabilities document, you can select the URL at the top of the web browser and copy it (CTRL+C or right click and copy). Then paste the web service URL into an appropriate URL input text box in the GIS application of your choice. The URL will have to be modified slightly before instructing the GIS application to connect to the service. Specifically you will need to remove everything after "WMSServer?" Each GIS application will have a slightly different procedure for accepting and accessing web service URL's. Most user guides or help functions can instruct you on specifics within the program of your choice.

Accessing the services through REST pages

REST pages are "Representational State Transfer" and are designed to return representations of resources (including maps) over the World Wide Web. A REST page represents a web service and provides various useful information including: links that can be used to view the web service, a description of the web service, the name of the map, a preview of the symbology used in the map legend, a link to any database tables reference by the service, a description of the map itself, copyright information, the spatial reference system used to project the map, whether or not the web service is cached, the extent of the map, units of measure used for the map, document information, interfaces that can be used to access the map, and operations that can be performed on the web service and associated data.

From a REST page it is possible to quickly access the associated web service in ArcMap, ArcGIS Explorer, JavaScript, Google Earth, or ArcGIS.com by simply clicking on the links at the top of the REST page. It should be noted that of the applications readily available for viewing services, only ArcMap has full GIS query and analysis capabilities. However, since NGDS and USGIN support open-source GIS applications, the services can be displayed using the XML capabilities document in a variety of GIS clients.

While the system, including web services and documents, is currently accessible, we must emphasize that upcoming user interfaces and additional client applications will dramatically increase the accessibility, functionality, and overall value of the system.

EXPANDING THE SYSTEM

The data provided by NGDS participants concentrates on geoscience data, including subsurface data, which can be used to help identify the geothermal potential of an area. However, in order to fully develop an area of geothermal potential, the end user must also understand the land use related features of that area. Thus USGIN and the AASG State Geothermal Data project are expanding the network to include nodes such as the Western Regional Partnership which houses over 10,000 land use and land management related data layers.

Western Regional Partnership (WRP) is a consortium led by the Department of Defense consisting of fifteen federal agencies and five western states to share and disseminate land use data primarily for preserving military training facilities in the west. The data made accessible via WRP will help identify geothermal resources with realistic development potential. End users will not be able to avoid detailed permitting and environmental review, though, the

land use datasets will help determine whether a site is economically and environmentally feasible.

CONCLUSION

The NGDS is under simultaneous design, population, and deployment with completion of the initial phases due mid-to-late 2013. At this point, existing geothermal relevant data from the initial network participants will be digitized and accessible via user interfaces and client applications. In addition, a small amount of new data collected under the AASG State Geological Survey's Contributions to the NGDS award and new data collected from the Geothermal Technologies Program funded projects will also be integrated into the system.

The system truly is revolutionary as it provides for data maintenance and ownership with increased accessibility and availability for end users. To demonstrate the functionality of the system, a mashup showing the Nevada well headers within 200 meters of a transmission line was created using GIS visualization software; thus combining geoscience data with land use and geothermal production feasibility data.

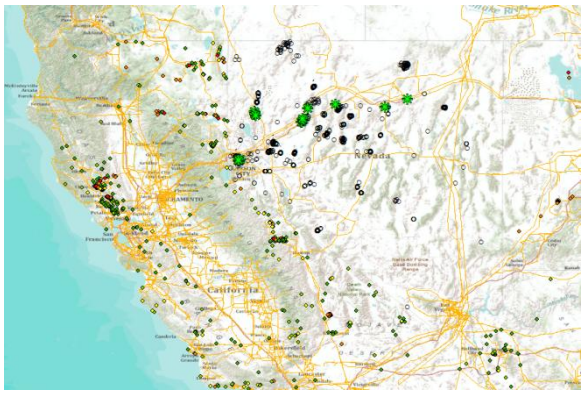

Figure 6: Geographic Information System visualization of data system capabilities.

As more data become available and are accessible via interoperable formats, researchers will be able to more easily discover, access, and integrate new data resulting in more time spent on exploration of the data and of geothermal resources.

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