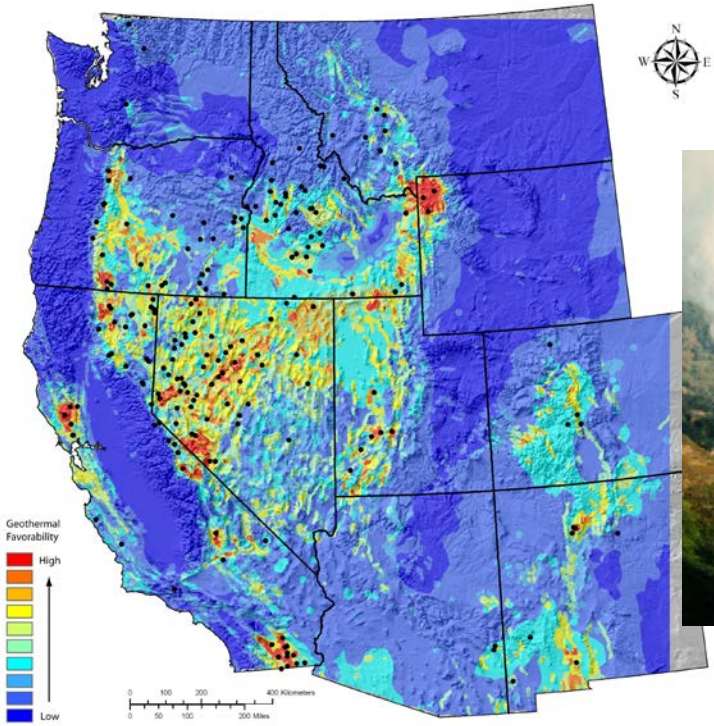


National Geothermal Resource Assessment and Classification

April 24, 2013

Colin F. Williams

US Geological Survey

Data Systems and Analysis (Resource Assessment)

Relevance/Impact of Research

- Overall Summary
  - Major Project Goals
    - Develop new Geothermal Resource Classification standards
    - Expand Resource Assessment scope across all 50 states including low temperature, EGS, sedimentary basins
    - Improve assessment methodologies for EGS and undiscovered resources through targeted field and modeling studies
    - Work with NGDS to provide data and USGS report access
  - Timeline
    - August, 2010 to December, 2013
  - Budget
    - $2,893,000 total from DOE
    - Matched by USGS internal funding $1,500,000 each Fiscal Year
    - By end of March, 2013, DOE funds spent and obligated = $1,635,00

Relevance/Impact of Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- DOE Identified Barriers
  - 3.1.2 Lack of Available and Reliable Resource Information
  - 3.2 Resource Assessment and Data Needs

  Key issue is for the geothermal community to have access to comprehensive, up-to-date, logically organized information on geothermal resources

- Relevant GTO Goals
  - Enhanced Geothermal Systems (EGS)
  - Hydrothermal Resource Confirmation
  - Low Temperature, Co-Produced and Geopressured Demonstration Projects

Relevance/Impact of Research

Significant and Innovative Aspects of Project

- Resource Classification – Define resources from a systemic perspective with inherent thermal, hydrologic, and geologic features that span the full spectrum of resource types and utilization practices. (e.g., Williams et al., 2011)
- Low-Temperature(<90 ºC) Assessment – Application of revised approach to determining temperature, reservoir volume, and potential thermal energy recovery as developed for 2008 assessment of resources (>90 ºC) by Reed and Mariner (2008) and Williams et al. (2008)
- EGS Assessment Methodology – Develop models for EGS thermal energy recovery that accurately anticipate reservoir performance, by applying a quantitative understanding of the relative roles of tectonic stress, depth, lithology/mineralogy, temperature, fluid chemistry, and alteration. Initial work described by Williams (2010, 2011a,b)

Significant and Innovative Aspects of Project

- EGS Assessment Methodology – Improved knowledge of potential EGS resources through characterization of upper crust in regions of significant EGS potential, including mapping subsurface plutons (Ponce et al., 2010) and temperatures in the Great Basin (see supplemental slides)
- Assessing Undiscovered Resources – A critical, but as yet unquantified, factor in the occurrence of hydrothermal systems is the creation and evolution of fracture permeability. Coupled modeling studies are providing the tools to quantify rates of permeability changes with deformation and mineral precipitation/dissolution (Kaven et al., 2011a,b, 2012; Palguta et al., 2011a,b)
- Assessing Undiscovered Resources – Targeted geological and geophysical field studies, generally conducted in conjunction with industry drilling projects, are providing critical data on the nature of hydrothermal systems that can be used to inform modeling efforts described above (see supplemental slides)

1. Conventional Geothermal Resource Characterization and Assessment
   - Conduct geophysical, geological and geochemical surveys for evaluation of identified and undiscovered geothermal resources. (e.g., Pilgrim Springs, Warner Valley, Long Valley/Mono Basin, NE Nevada) ***Key issue – Use targeted field studies to inform assessments***
   - Update the low-temperature (<90 ºC) geothermal resource databases, report on revisions to the low temperature geothermal resource assessment, and produce online databases and summaries of the results. Revisions applied using USGS methodology developed for 2008 assessment of resources >90 ºC. ***Key issue – What are the geothermal resources of the US across entire temperature range?***
   - Utilize coupled thermal-mechanical-chemical-fluid flow models to investigate the evolution of hydrothermal systems and to develop life cycle models for the creation and evolution of these systems that can be utilized in improved resource assessment methodology. ***Key issue – Can numerical models replicate observed characteristics and be used to quantify resource occurrence statistics?***

2. Enhanced Geothermal Systems
   - Develop a provisional comprehensive geothermal resource classification system incorporating EGS and other “unconventional” geothermal resources. Revise and update the classification system based on community feedback and the results of the field and modeling studies. ***Key issue – How best to describe and classify geothermal resources?***
   - Conduct field studies of in situ stress, fault and fracture permeability, geologic structure, seismicity and heat and fluid transport at sites with potential for future EGS development.
   - Develop in situ stress, fracture permeability models and methods for EGS reservoir stimulation utilizing field measurements and observations.
   - Incorporate the results of these investigations into improved methods for assessing potential EGS resources (Williams, 2010, 2011a,b). ***Key issue – Can we improve existing simple approaches to predict EGS resource exploitation by calibrating physical models with new and existing field data?***

3. Geothermal Resources in Sedimentary Basins

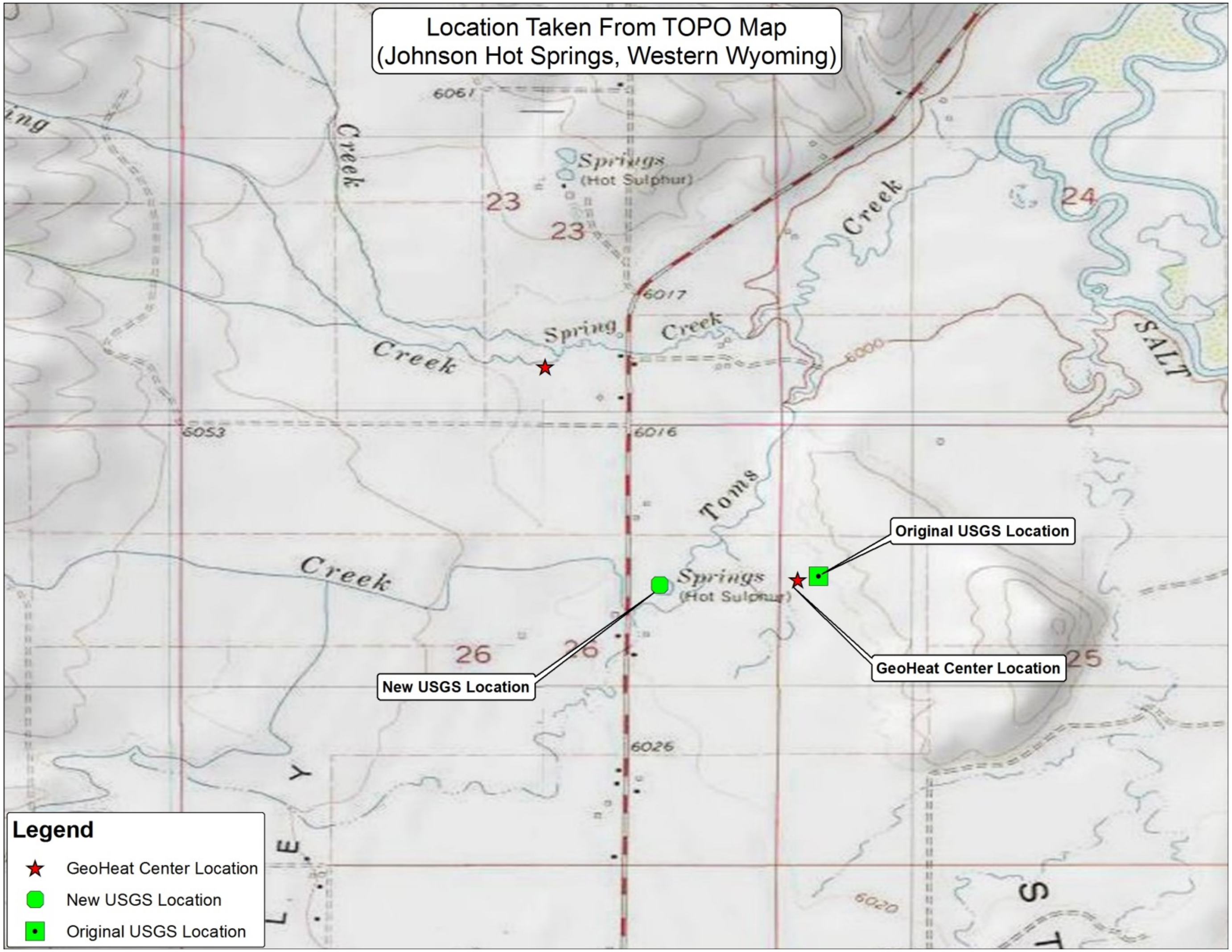
- Compile data on subsurface temperatures, lithologies and reservoir characteristics for sedimentary basins and identify regions of significant geothermal potential.
- Conduct focused studies on the basins with greatest potential to determine the geologic constraints on geothermal development.
- Incorporate the results of these investigations in an expanded resource assessment, publish the results of the assessment and place the supporting data and reports online. ***Key issue – What resource contributions can be expected from diverse geothermal production approaches (e.g., shallow thermal aquifers, petroleum coproduction, geopressured geothermal) in sedimentary basins across the US?***
- Combine results of assessment and classification work conducted in Tasks 1, 2 and 3 with previous assessment results in summary report on the full spectrum of geothermal resources in the United States.

4. USGS Geothermal Data and NGDS Collaboration

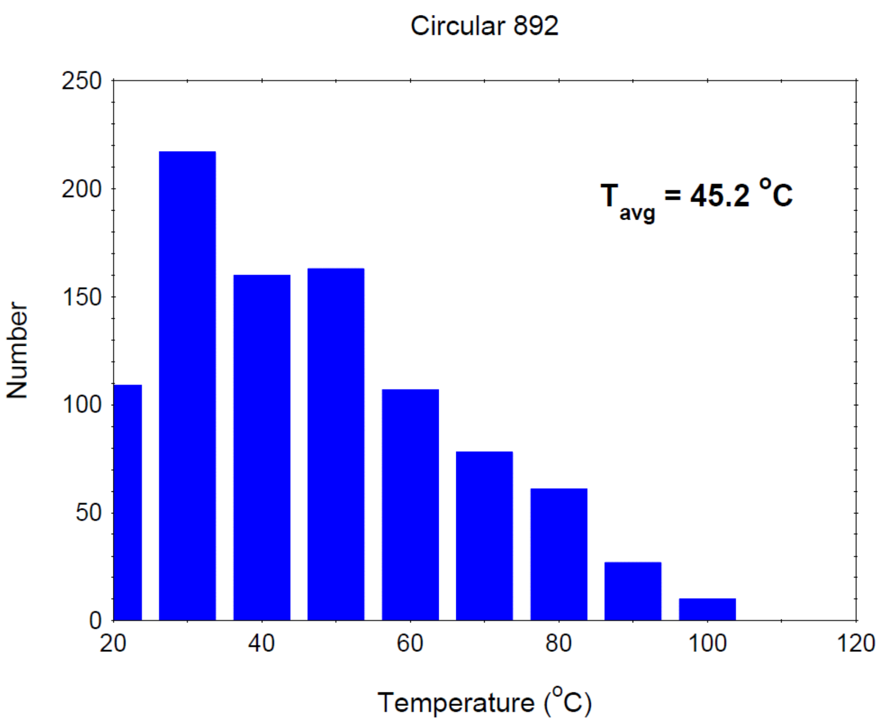
- Complete compilation, review and publication of relevant geothermal databases assembled as part of the national geothermal resource assessment project (e.g., Long Valley thermal data - http://pubs.usgs.gov/ds/523/)
- Work with NGDS staff to identify database requirements, place USGS data in formats compatible with those requirements, and transfer to the National Geothermal Data System.
- Consult with and advise the center staff on the format, structure and accessibility of geothermal databases.
- Continue to provide new data to the center from the results of new and ongoing field projects and industry collaborations.

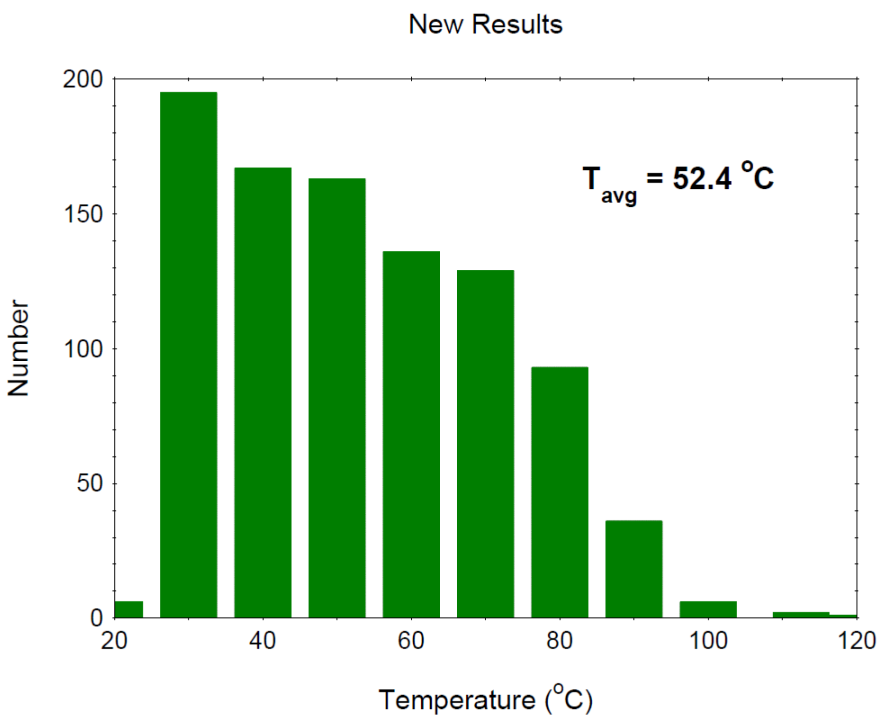
Key issue – Provide effective access to both new and existing USGS data as well as interpretive assessment results.

Low Temperature - Relocating Geothermal Sites



- T < 90C Assessment
  - Geothermometer and in situ temperature revisions to 1982 low-temperature data, with geothermometer approach as specified by Reed and Mariner (2008). Example results –





Thermal Parameters in Low T Assessment

Exergy (or available work) is commonly used for classifying varied resource types and can be calculated easily using public domain software.

$$\text{“Minimum Temp Function”} = T_s + 10^oC + 25z$$

$$Q_r = \rho V(T_r - T_{ref})$$

$$Q_{wh} = \rho CNQP(T_r - T_{ref})$$
$$Q_{wh} = R_g \rho V(T_r - T_{ref})$$

$$Q_{ben} = 0.6\rho C(ka/a_w)QP(T_r\text{-}25^oC)$$

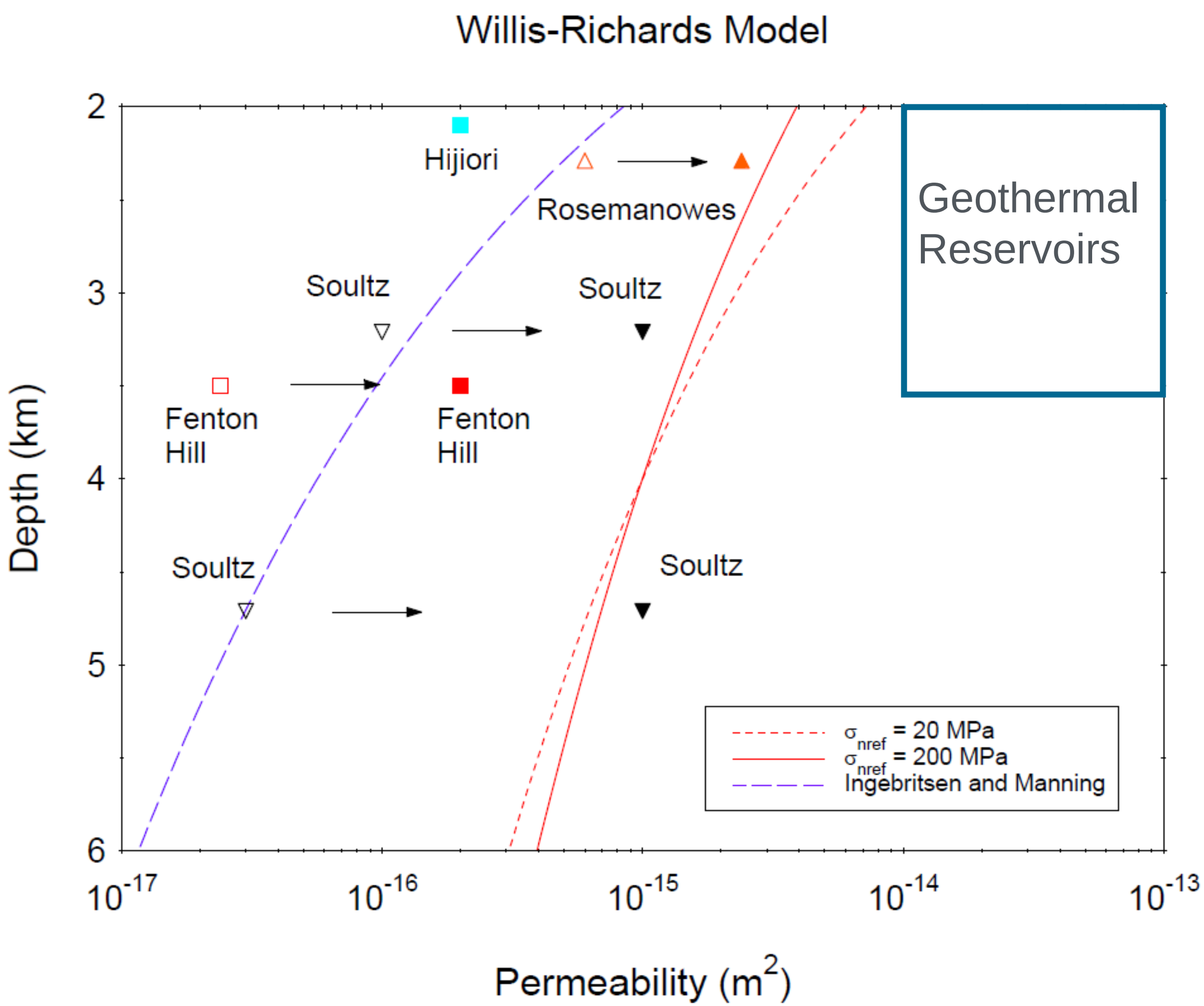
$$E = m_{WH}[h_{WH} - h_0 - T_0(s_{WH} - s_0)]$$

Summary T <90C Assessment Results

- Improved system, chemistry and temperature database
- For entire United States ~ double previous estimates
  - New Beneficial Heat = 42,600 MWt
  - Old Beneficial Heat = 28,900 MWt
  - Old Thermal Energy = 58×10^{18} J
  - New Thermal Energy = 87×10^{18} J
- Overall electric power potential
  - 410 MWe for T< 90C
  - 1640 MWe for 90C < T < 150C

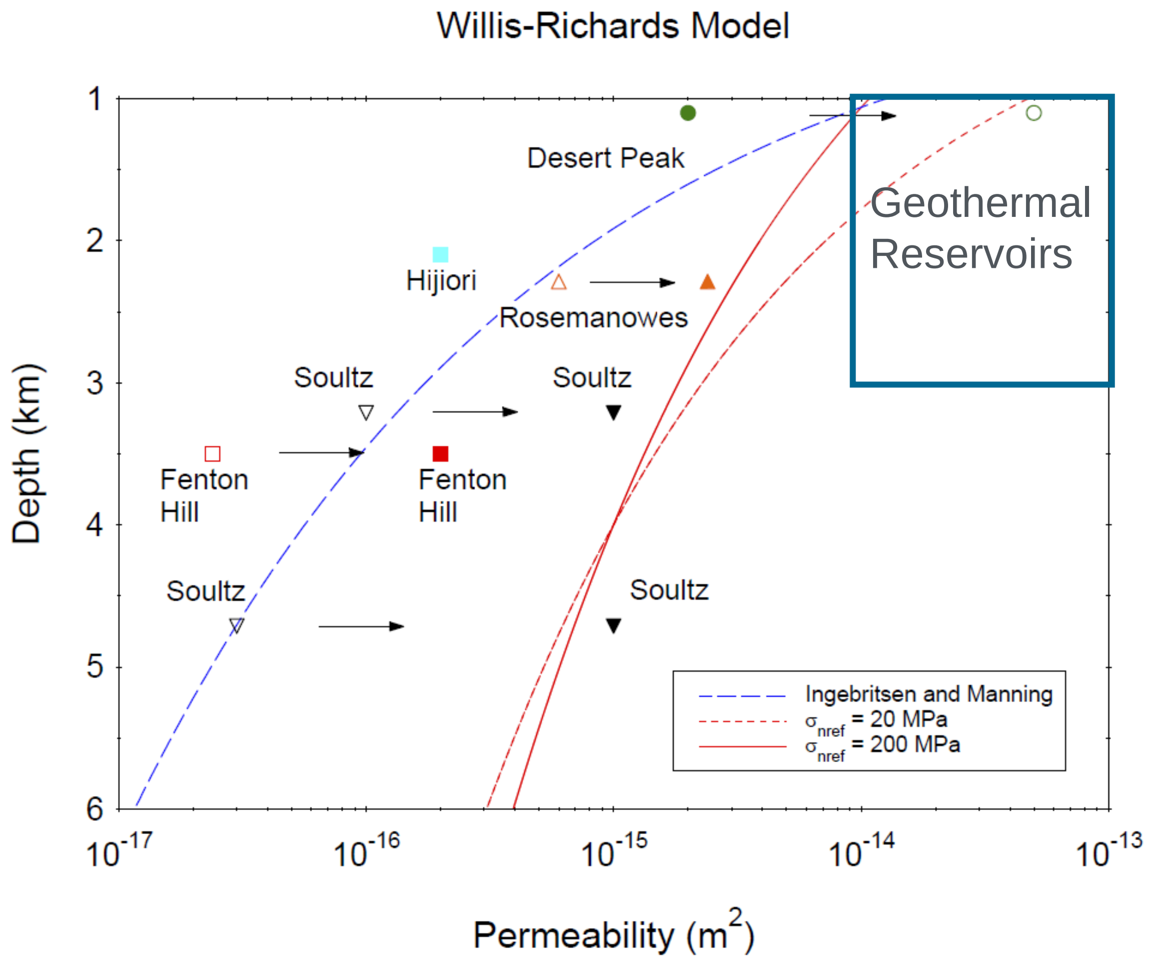
Evaluating EGS Permeability Creation - 2012

Earlier comparison of models with data from EGS experiments indicated that reservoirs created by shear stimulation in crystalline rock are relatively insensitive to stress but that shear stimulation alone may not be consistently capable of achieving permeability equivalent to natural geothermal reservoirs. The 2012 figure shows permeability increase at EGS sites compared with natural geothermal reservoirs and models for variation of permeability with depth for shear fractures (red curves).

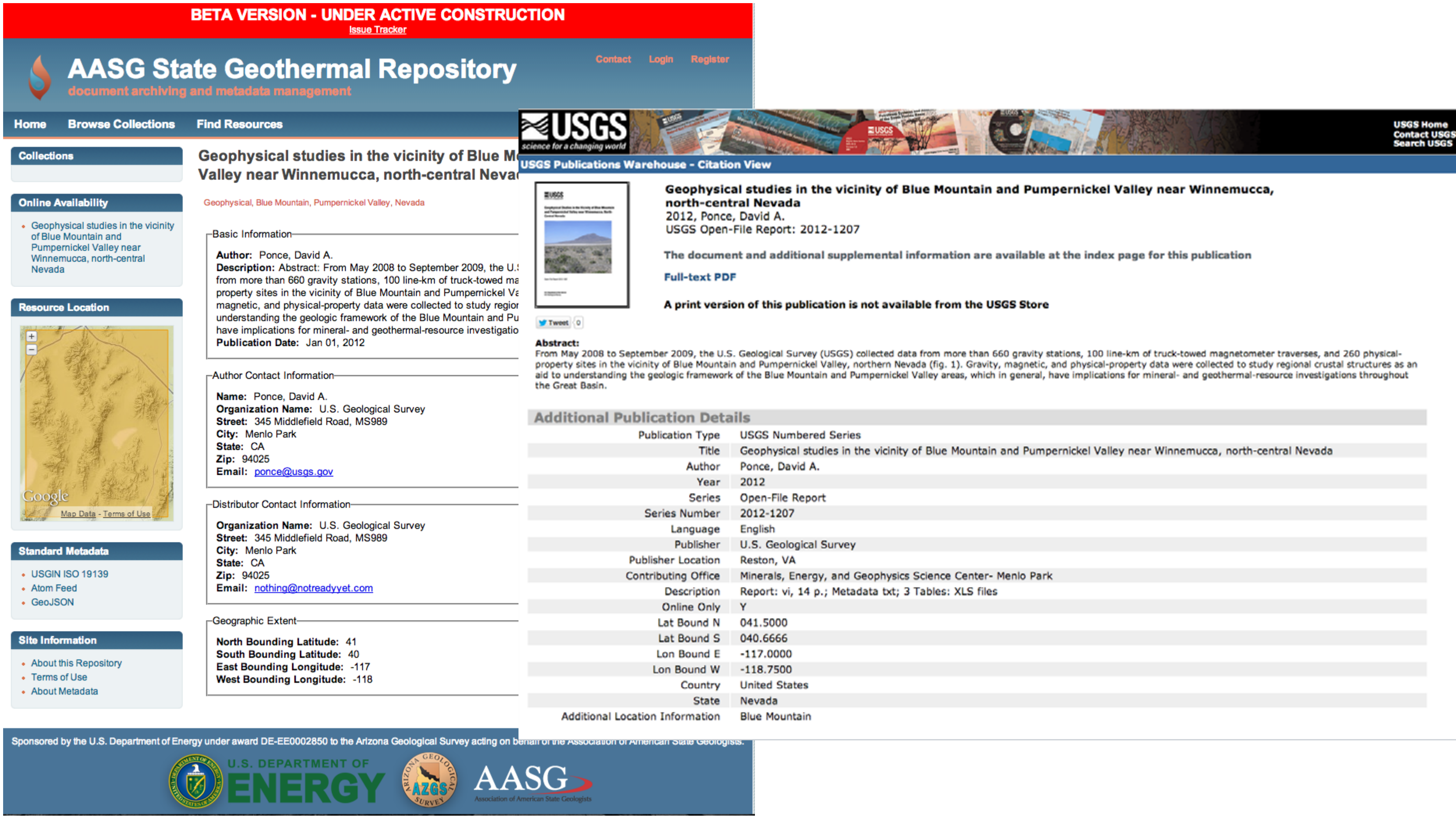


An updated comparison including new data indicates consistency with higher sensitivity models and that stimulation achieve permeability equivalent to natural geothermal reservoirs at relatively shallow depth. Ongoing developments suggest that limited stimulation permeability at depth can be compensated for by increasing permeability-thickness through multi-zone stimulation.

Evaluating EGS Permeability Creation - 2013



- NGDS Data Contributions – Results from this project



BETA VERSION - UNDER ACTIVE CONSTRUCTION
Issue Tracker

AASG State Geothermal Repository
document archiving and metadata management

Contact Login Register

Home Browse Collections Find Resources

Collections

Online Availability
- Geophysical studies in the vicinity of Blue Mountain and Pumpernickel Valley near Winnemucca, north-central Nevada

Resource Location

Google
Map Data - Terms of Use

Standard Metadata
- USGIN ISO 19139
- Atom Feed
- GeoJSON

Site Information
- About this Repository
- Terms of Use
- About Metadata

Geophysical studies in the vicinity of Blue M
Valley near Winnemucca, north-central Neva

Geophysical, Blue Mountain, Pumpernickel Valley, Nevada

Basic Information

Author: Ponce, David A.
Description: Abstract: From May 2008 to September 2009, the U.S
from more than 660 gravity stations, 100 line-km of truck-towed ma
property sites in the vicinity of Blue Mountain and Pumpernickel Va
magnetic, and physical-property data were collected to study regior
understanding the geologic framework of the Blue Mountain and Pu
have implications for mineral- and geothermal-resource investigatio
Publication Date: Jan 01, 2012

Author Contact Information

Name: Ponce, David A.
Organization Name: U.S. Geological Survey
Street: 345 Middlefield Road, MS989
City: Menlo Park
State: CA
Zip: 94025
Email: ponce@usgs.gov

Distributor Contact Information

Organization Name: U.S. Geological Survey
Street: 345 Middlefield Road, MS989
City: Menlo Park
State: CA
Zip: 94025
Email: nothing@notreadyyet.com

Geographic Extent

North Bounding Latitude: 41
South Bounding Latitude: 40
East Bounding Longitude: -117
West Bounding Longitude: -118

Sponsored by the U.S. Department of Energy under award DE-EE0002850 to the Arizona Geological Survey acting on behalf of the Association of American State Geologists.

U.S. DEPARTMENT OF ENERGY AZGS AASG Association of American State Geologists

USGS science for a changing world

USGS Home
Contact USGS
Search USGS

USGS Publications Warehouse - Citation View

Geophysical studies in the vicinity of Blue Mountain and Pumpernickel Valley near Winnemucca, north-central Nevada
2012, Ponce, David A.
USGS Open-File Report: 2012-1207

The document and additional supplemental information are available at the index page for this publication

Full-text PDF

A print version of this publication is not available from the USGS Store

Tweet 0

Abstract:
From May 2008 to September 2009, the U.S. Geological Survey (USGS) collected data from more than 660 gravity stations, 100 line-km of truck-towed magnetometer traverses, and 260 physical-property sites in the vicinity of Blue Mountain and Pumpernickel Valley, northern Nevada (fig. 1). Gravity, magnetic, and physical-property data were collected to study regional crustal structures as an aid to understanding the geologic framework of the Blue Mountain and Pumpernickel Valley areas, which in general, have implications for mineral- and geothermal-resource investigations throughout the Great Basin.

Additional Publication Details

Publication Type	USGS Numbered Series
Title	Geophysical studies in the vicinity of Blue Mountain and Pumpernickel Valley near Winnemucca, north-central Nevada
Author	Ponce, David A.
Year	2012
Series	Open-File Report
Series Number	2012-1207
Language	English
Publisher	U.S. Geological Survey
Publisher Location	Reston, VA
Contributing Office	Minerals, Energy, and Geophysics Science Center- Menlo Park
Description	Report: vi, 14 p.; Metadata txt; 3 Tables: XLS files
Online Only	Y
Lat Bound N	041.5000
Lat Bound S	040.6666
Lon Bound E	-117.0000
Lon Bound W	-118.7500
Country	United States
State	Nevada
Additional Location Information	Blue Mountain

Accomplishments, Results and Progress

- NGDS Data Contributions – Results from legacy projects – 768 pubs

	A	B	C	D	E	F	G	H
1	version1.3.4							
2	*Required basic fields; other required fields are in pink in their respective sections.*			*Intellectual Originator: at least one of individual, organization, or position name is required in each metadata record.*				*Keywo*
3	title	descriptio n	publicatio n_date	originator _contact_ org_name	originator _contact_ person_n ame	originator _contact_ position_ name	resource_ type	keywo _them
4	1DT; an interactive, screen-oriented microcomputer program for simulation of 1-dimensional geothermal histories	ND	1986	U.S. Geolog		ND	USGS Open	ND
5	40Ar/39Ar geochronology of hypabyssal igneous rocks in the Maranon Basin of Peru - A record of thermal history, structure, and alteration	ND	2005			ND	USGS Scien	ND
6	A chromatographic system for the analysis of selected light gases in geothermal and volcanic systems	ND	1986	U.S. Geolog		ND	USGS Open	ND
7	A control and data acquisition system for use with a hydrothermal diamond-anvil cell	ND	1994	U.S. Geolog		ND	USGS Open	ND
8	A field-trip guide to Yellowstone National Park, Wyoming, Montana, and Idaho; volcanic, hydrothermal, and glacial activity in the region	ND	1994	U.S. G.P.O.		ND	USGS Bulle	ND
9	A heat-pulse flowmeter for measuring minimal discharge rates in boreholes	ND	1982	U.S. Geolog		ND	USGS Open	ND
10	A helicopter-borne magnetic survey over Dixie Valley geothermal field, Nevada; a web site for distribution of data	ND	2002			ND	USGS Open	ND
11	A magnetotelluric study of the Stillwater Soda Lakes, Nevada, geothermal area	ND	1976	U.S. Geolog		ND	USGS Open	ND
12	A new heat-flow contour map of the conterminous United States	ND	1976	U.S. Geolog		ND	USGS Open	ND
13	A Review of Methods Applied by the U.S. Geological Survey in the Assessment of Identified Geothermal Resources	ND	2008	U.S. Geolog		ND	USGS Open	ND
14	A tabulation of meteorological variables and concentrations of helium, carbon dioxide, oxygen, and nitrogen in soil gases collected regularly from four sites at t	ND	1988	U.S. Geolog		ND	USGS Open	ND
15	A theoretical analysis of fluid flow and energy transport in hydrothermal systems	ND	1977	U.S. Geolog		ND	USGS Open	ND
16	A thermal flowmeter for measuring velocity of flow in a well	ND	1962	U.S. G.P.O.,		ND	USGS Wate	ND
17	A thermal profile method to identify potential ground-water discharge areas and preferred salmonid habitats for long river reaches	ND	2006			ND	USGS Scien	ND
18	Abrupt physical and chemical changes during 1992-1999, Anderson Springs, SE Geyser Geothermal Field, California	ND	2000	U.S. Geolog		ND	USGS Open	ND
19	Additional audio-magnetotelluric soundings in the Lassen Known Geothermal Resource Area, Plumas and Tehama counties, California	ND	1981	U.S. Geolog		ND	USGS Open	ND
20	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Overview	ND	2008	Geological		ND	USGS Fact S	ND
21	Aerial infrared images of The Geysers geothermal steam field and vicinity, Samoa County, California	ND	1968	U.S. Geolog		ND	USGS Open	ND
22	Aerial infrared surveys at The Geysers geothermal steam field, California	ND	1968	U.S. Geolog		ND	USGS Open	ND
23	Aerial infrared surveys in the investigation of geothermal and volcanic heat sources	ND	1995	U.S. Geolog		ND	USGS Fact S	ND
24	Aeromagnetic and gravity anomaly maps and a hydrothermal veins favorability map of the Wallace 1 degree by 2 degrees Quadrangle, Montana and Idaho	ND	1988			ND	USGS Misce	ND
25	Aeromagnetic map and interpretation of the Salton Sea geothermal area, California	ND	1971			ND	USGS Geop	ND
26	Age of the Lospe Formation (early Miocene) and origin of the Santa Maria Basin, California. Petroleum source potential and thermal maturity of the Lospe Forr	ND	1996			ND	USGS Bulle	ND
27	Ages and geochemistry of magmatic hydrothermal alunites in the Goldfield district, Esmeralda County, Nevada	ND	2005			ND	USGS Open	ND
28	Alaska; basic data for thermal springs and wells as recorded in Geotherm	ND	1983	U.S. Geolog		ND	USGS Open	ND
29	Ammoniated thermal waters of Lake and Colusa Counties, California	ND	1961	U.S. Govt. F		ND	USGS Wate	ND
30	An Analysis of thermal data from the vicinity of Cajon Pass, California	ND	1986	U.S. Geolog		ND	USGS Open	ND
31	An economical, portable apparatus for conducting static thermal and chemical toxicity tests on amphibian eggs and larvae	ND	1998			ND	USGS	ND
32	Analysis and interpretation of data obtained in tests of the geothermal aquifer at Klamath Falls, Oregon	ND	1984	U.S. Geolog		ND	USGS Wate	ND
33	Analysis of Geomorphic and Hydrologic Characteristics of Mount Jefferson Debris Flow, Oregon, November 6, 2006	ND	2008	Geological		ND	USGS Scien	ND
34	Analysis of MASTER Thermal Data in the Greeley Area of the Front Range Urban Corridor, Colorado--Delineation of Sites for Infrastructure Resource Characteri	ND	2002			ND	USGS Bulle	ND
35	Analysis of seismic noise at The Geysers geothermal area, Caifornia	ND	1972	U.S. Geolog		ND	USGS Open	ND
36	Analysis of thermal data from drill holes UE25a-3 and UE25a-1, Calico Hills and Yucca Mountain, Nevada Test Site	ND	1980	U.S. Dept o		ND	USGS Open	ND
37	Analytical results for soil samples and plots of results of R-mode factor analysis of soil and soil-gas data; Dixie Valley Known Geothermal Resource Area, northe	ND	1995	U.S. Geolog		ND	USGS Open	ND
38	Analytical results for soil samples collected at the Roosevelt Hot Springs Known Geothermal Resource Area, Utah; 1976-1987	ND	1993	U.S. Geolog		ND	USGS Open	ND
39	Analytical results, basic statistics, and locality map of rabbitbrush (genus Chrysothamnus) samples from the Mineral Hot Springs and Valley View Hot Springs Kr	ND	1993			ND	USGS Open	ND
40	Analytical results, basic statistics, and locality map of rabbitbrush (genus Chrysothamnus) samples from the Mineral Hot Springs and Valley View Hot Springs Kr	ND	1993			ND	USGS Open	ND
41	Annotated bibliography of studies on the density and other volumetric properties for major components in geothermal waters, 1928-1974	ND	1975	U.S. Govt. F		ND	USGS Bulle	ND
42	Annotated bibliography of the hydrology, geology, and geothermal resources of the Jemez Mountains and vicinity, north-central New Mexico	ND	1986	U.S. Geolog		ND	USGS Open	ND
43	Annotated bibliography; volcanology and volcanic activity with a primary focus on potential hazard impacts for the Hawaii Geothermal Project	ND	1993	U.S. Geolog		ND	USGS Open	ND
44	Application of airborne thermal imagery to surveys of Pacific walrus	ND	2006			ND	USGS	ND
45	Application of heat flow equation to analyses of bottom simulation reflections	ND	1995	U.S. Geolog		ND	USGS Open	ND
46	Application of heat-flow techniques to geothermal energy exploration, Leach Hot Springs area, Grass Valley, Nevada	ND	1977	U.S. Geolog		ND	USGS Open	ND
47	Application of infrared imagery in the evaluation of thermal loading of Roxboro Lake, North Carolina	ND	1970			ND	USGS Open	ND
48	Application of thermal imagery and aerial photography to hydrologic studies of karst terrane in Missouri	ND	1977	U.S. Geolog		ND	USGS Wate	ND
49	Arizona; basic data for thermal springs and wells as recorded in Geotherm	ND	1983	U.S. Geolog		ND	USGS Open	ND

About | Notes | DatasetMetadata | MetadataTemplate | FieldList | DataValidTerms | ReviewerComments

Future Directions

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Low-Temperature Geothermal Resources
  - Assessment analysis complete 2012. Follow-up with digital release of new and legacy data timed with publication and addition of electric power estimates.
- Geothermal Resource Classification System
  - Add supplemental report relating USGS geothermal classification to UN Framework Classification for mineral and petroleum resources
- Improved EGS Assessment Methodology
  - Test impact of revised methodology against results from USGS 2008 provisional EGS assessment
- Sedimentary Basin Resource Assessment
  - Complete and integrate with other assessment components by December, 2013.

Summary

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- USGS work under this project will provide a comprehensive portfolio of geothermal resource assessments for the entire United States, covering conventional and unconventional resources from low-temperature to high-temperature applications.
- Field and modeling studies will support new and revised assessment methodologies that will be applied in developing progressively more reliable assessment results.
- In addition to stimulating geothermal development, results will be incorporated into latest series of energy and market penetration modeling.

Project Management

Timeline:	Planned Start Date	Planned End Date	Actual Start Date	Actual /Est. End Date
	3/3/2010	12/31/2012	7/30/2010	12/31/2013

Budget:	DOE Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
	$2,830,000	$6,375,000	$1,828,000	$1,503,000	$1,795,500	$1,337,000

- Meetings – Regular bimonthly project meetings to track progress
- Budget – Monthly budget review. Expenditures coordinated with Federal procurement deadlines. Expenditures of DOE funds approved by PI in advance.
- Web and phone conferences with DOE staff on project activities, and with NGDS staff on data system topics, supplemented by personal meetings.
- Internal Review – Annual review of project by USGS Energy Resources Program
- Variance – Delay in project start from March, 2010 to late August, 2010 due to need to substitute ARRA funds with Fiscal Year funds. Primary impacts on Resource Classification and Low Temperature Assessment. Moved Resource Classification back to February, 2011. Additional problems with data pushed Low Temperature Assessment 2012, when PI moved to a management position, reducing time on project. Reduced scope of field activities in order to keep to revised December, 2013 project end date. Also reduced budget ~$1M.

Supplemental Slides:

Highlights of USGS Investigations in FY13

Collaborations

- Collaborators:
  - Temple University – EGS and Hydrothermal System Evolution
  - LBNL – Assistance with Toughreact and System Modeling
  - NGDS Institutions (Boise State, EGI, AZ Geological Survey, Univ. of Nevada-Reno, Oregon Institute of Technology) – NGDS Collaboration and Data Dissemination Efforts
  - Great Basin Consortium (Utah Geological Survey, Nevada Bureau of Mines and Geology, DOGAMI, Idaho Geological Survey)
  - University of Alaska-Fairbanks – Pilgrim Springs field study
  - Nevada Geothermal – Warner Valley and Blue Mt. field studies
  - US Navy GPO – Seismic and related data for Coso study
  - DOE (Arlene Anderson) and Sandia (Dave Cuyler) on Geothermal Resource Classification
  - UC Davis – Mono Basin field study

Data Sharing

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

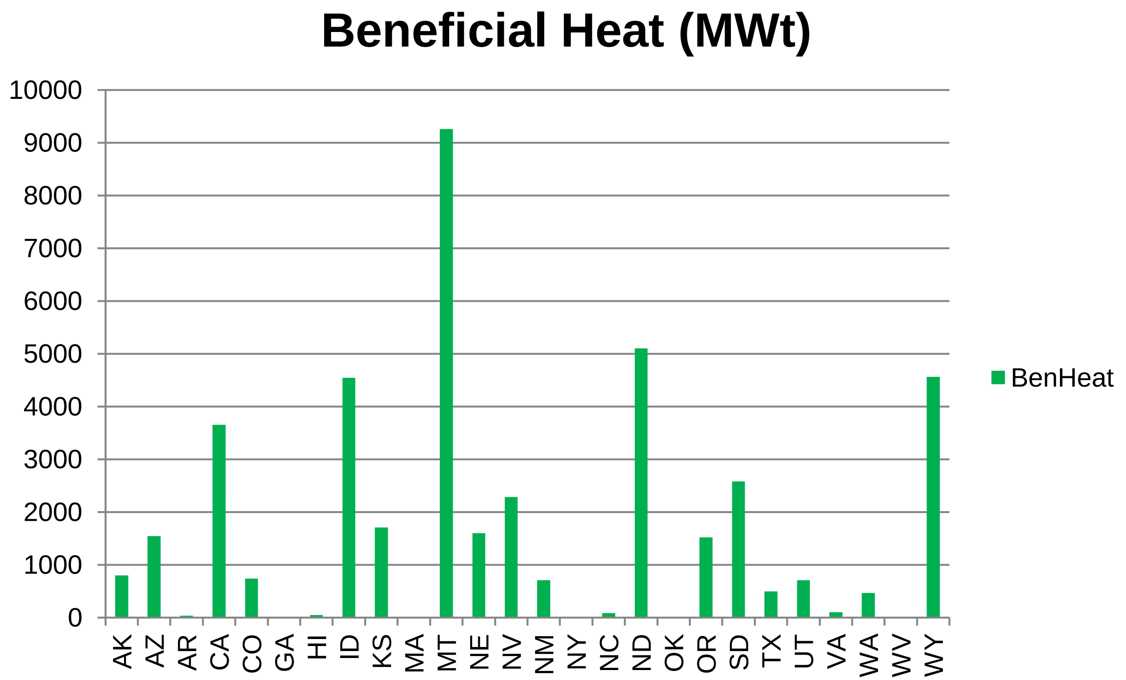
Data Types

- Data types include gravity and magnetic (both ground and air) data, relocated seismicity catalogues, subsurface temperature measurements, rock thermal properties measurements, geologic maps, GIS maps and related spatial analyses, thermal, structural and fluid flow models derived from field data, spreadsheets of chemical analyses. New data from field studies and compilations of older data released through USGS Data Series or Open-File Reports. Models and interpretive results described in scientific publications and USGS reports.

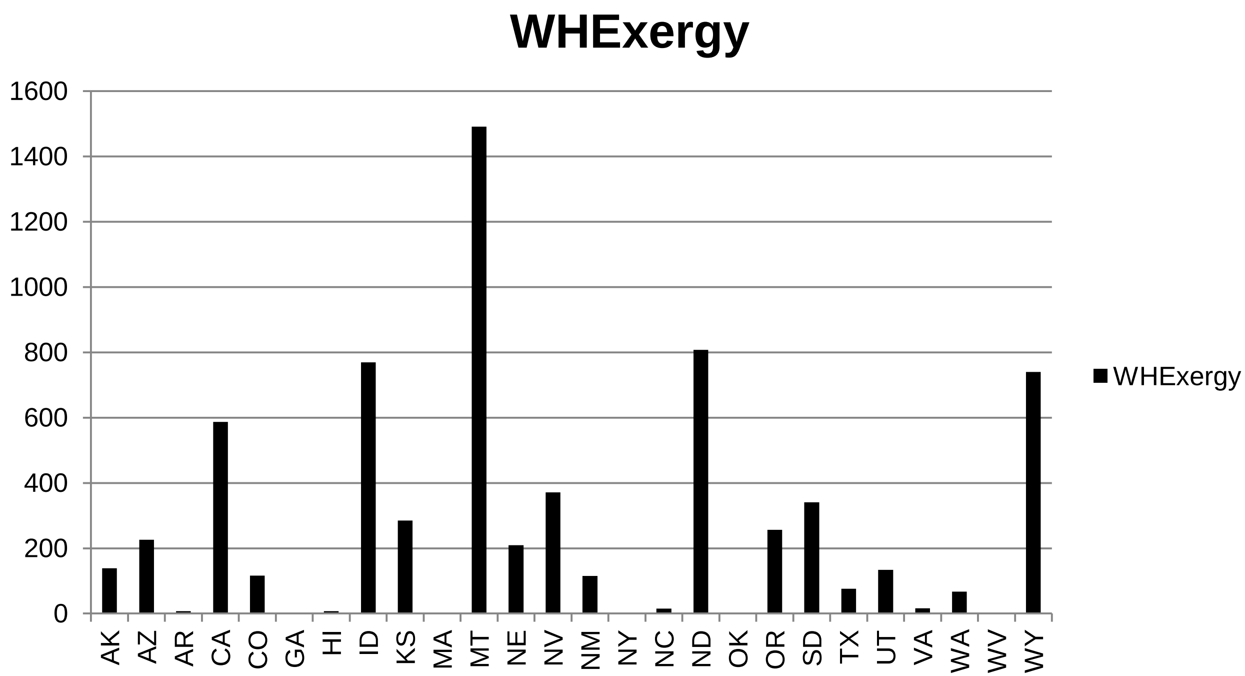
Integration with NGDS

- USGS project staff have worked with NGDS personnel to provide input on metadata standards for various data types and to understand how to provide access to USGS data through NGDS portals. USGS staff have compiled bibliography of past USGS geothermal publications and are building links to those studies through the NGDS. (Example Data Series available through State Geothermal Data Portal – Data Series 523: Temperature Data from Wells in the Long Valley Caldera, California - http://pubs.usgs.gov/ds/523/)

Low Temperature Assess Results by State

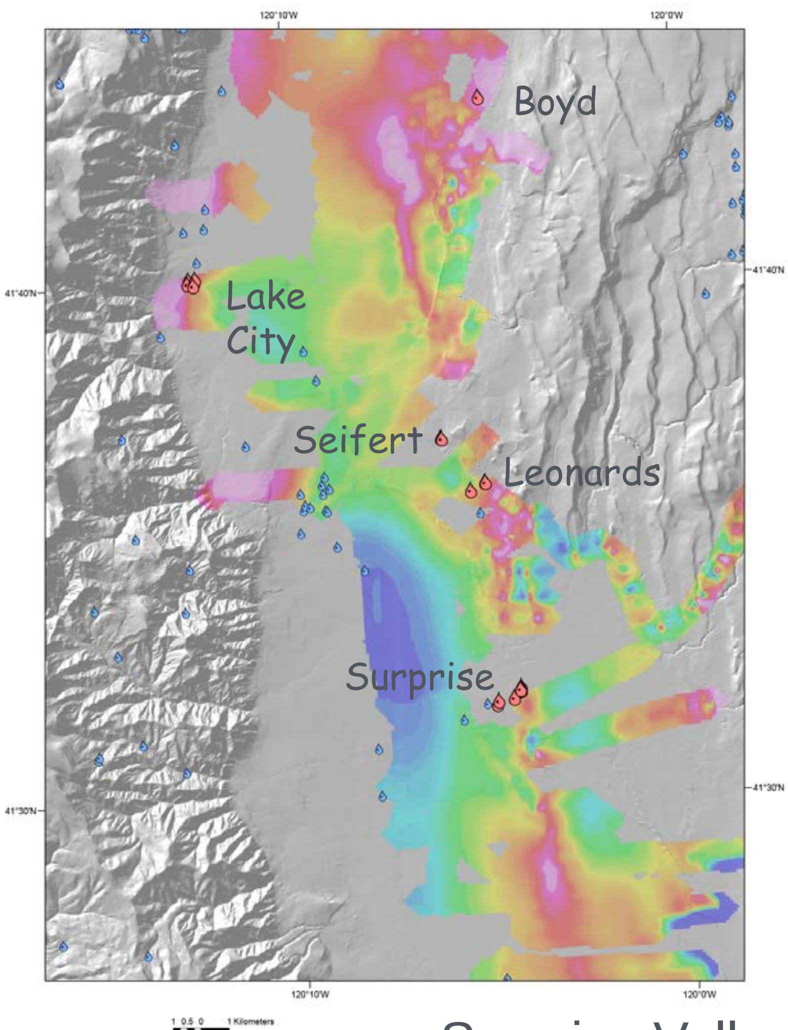


Low Temperature Assess Results by State

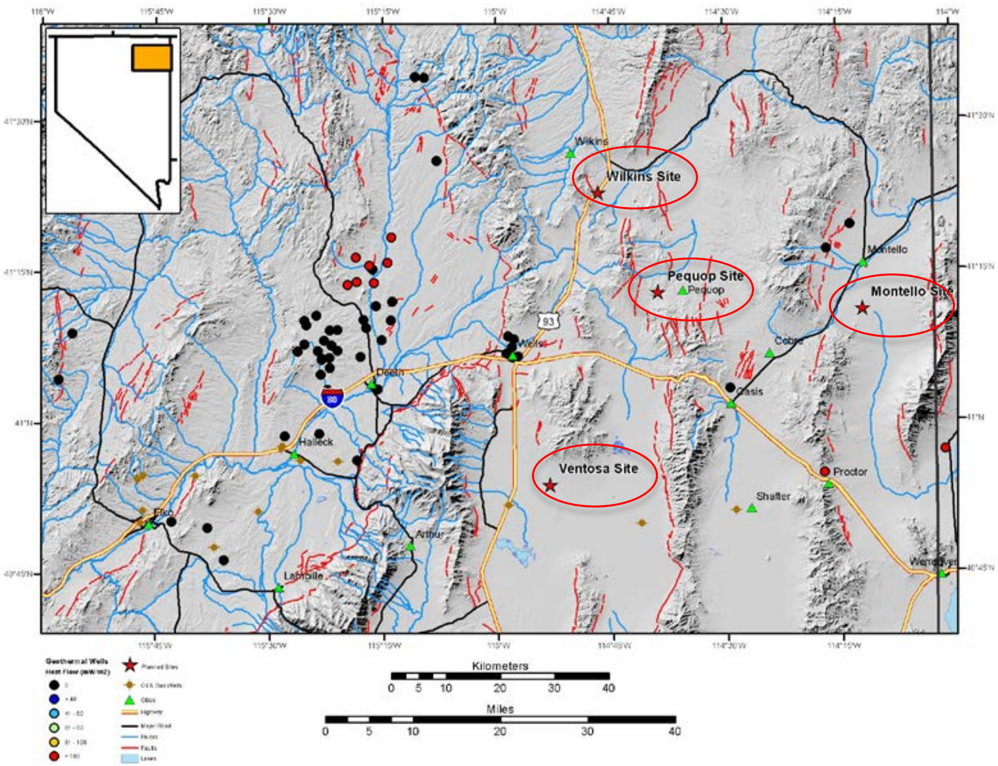


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

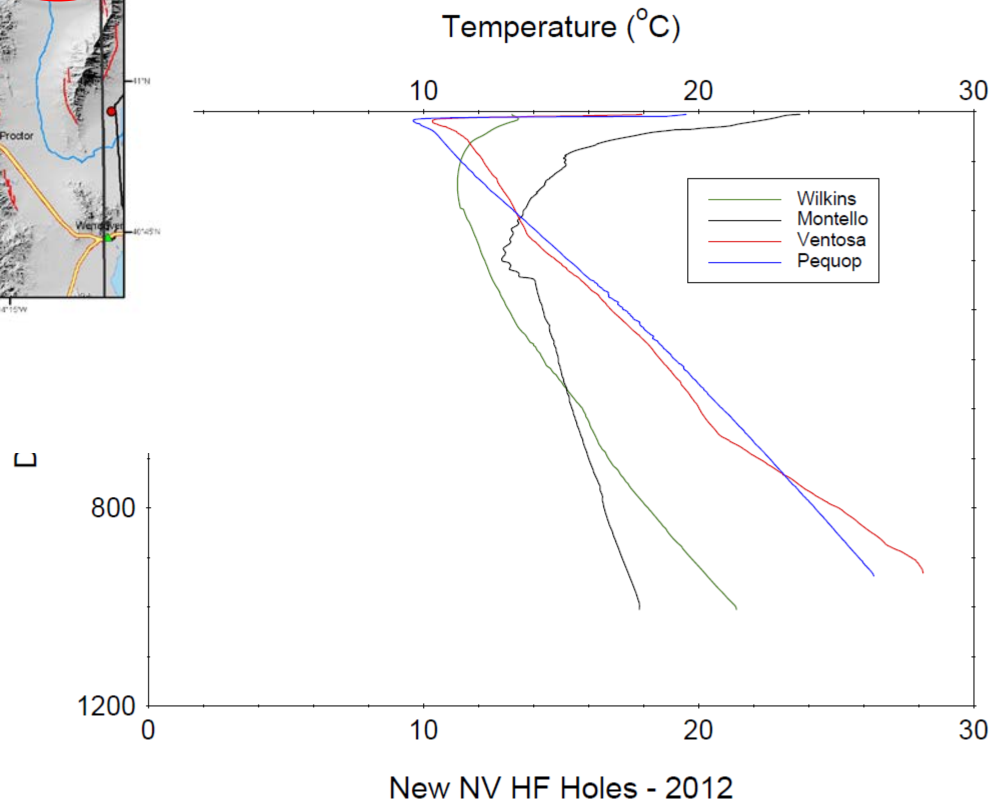
Innovative Airborne Geophysical Data Collection with NASA



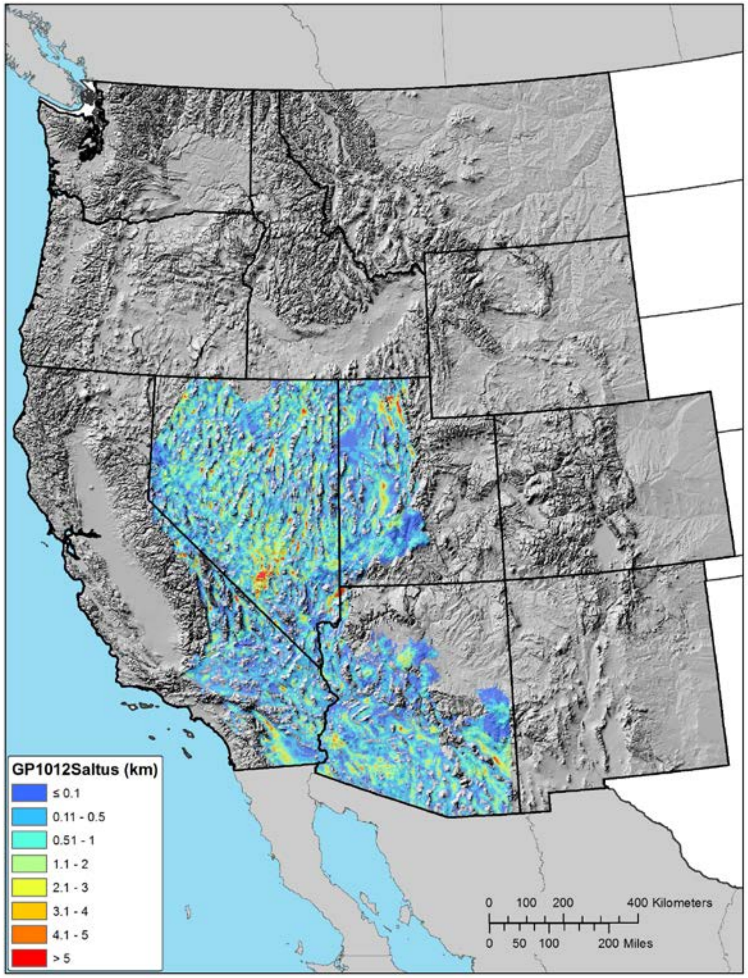
Surprise Valley Magnetic Map from UAS Survey (J. Glen)

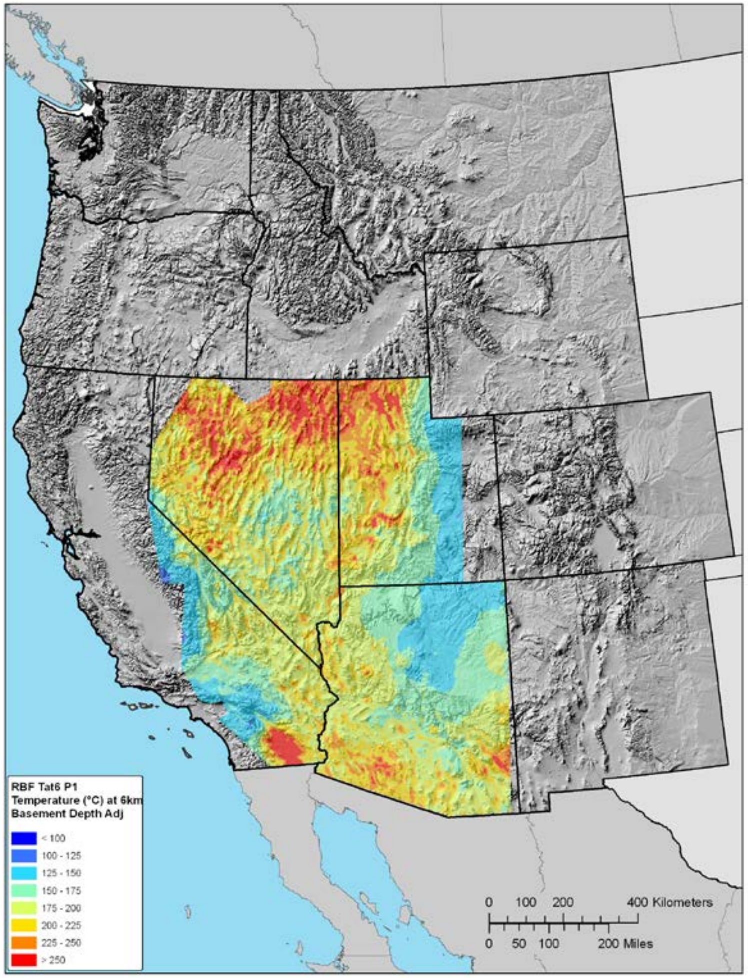


Confirming Deep Temperatures – New Heat Flow Measurements in Areas with Significant Data Gaps



- Sedimentary Basin Assessments – Correction of Temperatures in Great Basin using sediment thickness derived from geophysics and drilling

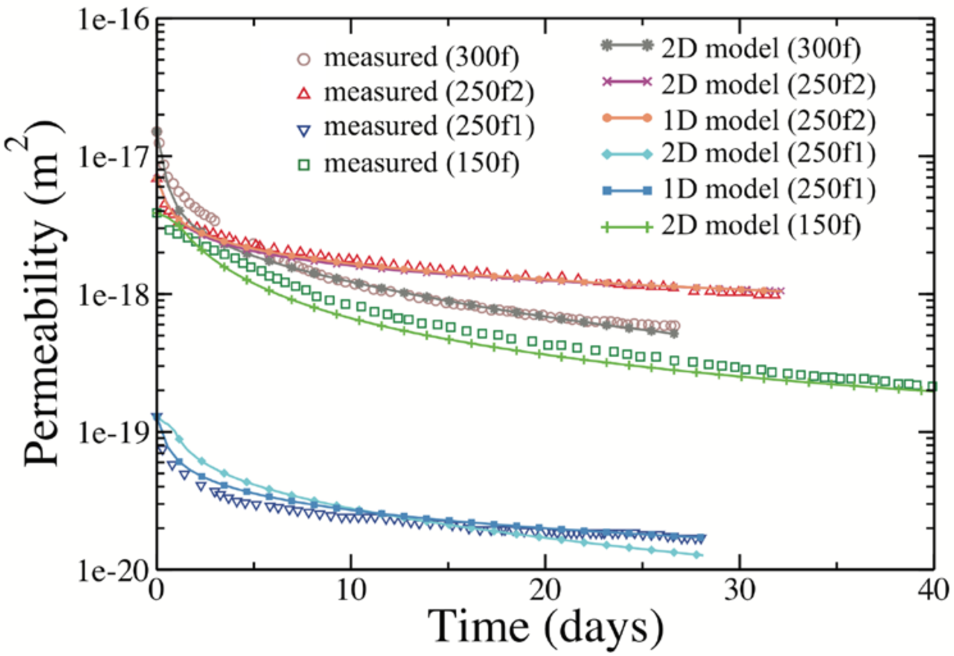




Permeability Evolution in Fractured Granite

- Coupled heat, fluid, and chemical transport modeling using a modified version of Toughreact is able to replicate laboratory observations for permeability evolution and alteration mineralogy in fractured granite by incorporating the effects of alteration on reactive surface area.
- The results have significant implications for the potential longevity of permeability in natural hydrothermal systems
- Future work will incorporate permeability changes due to deformation and fault slip

Issue for Assessing Undiscovered Geothermal Resources – How to quantify the temporal evolution of permeability in fractured hydrothermal systems?



From Palguta et al. (2011)