U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Geothermal Technologies Office

Quarterly Update: September 17, 2020

Dr. Susan Hamm, Director

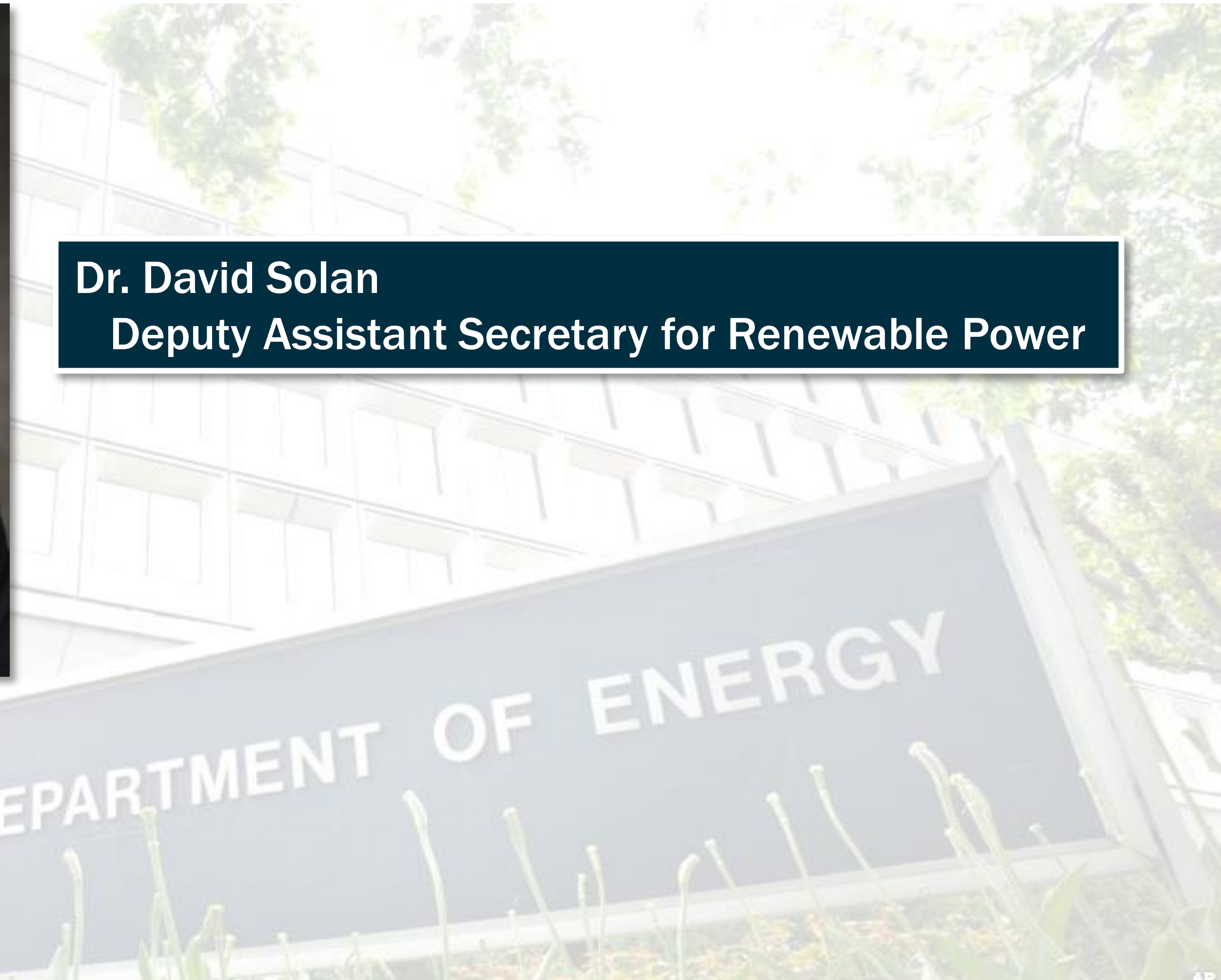
Image: Calpine

Q3 2020 Agenda

Webinar topics or suggestions? Contact us at: DOE.geothermal@ee.doe.gov

Topic	Speaker
Renewable Energy @ DOE	David Solan, Deputy Assistant Secretary
Office Updates	Susan Hamm, GTO
Deep Direct-Use R&D	Amanda Kolker, NREL
GeoDAWN: USGS and DOE	Mike Weathers, GTO Jonathan Glen, USGS
Q&A	Submit your question via WebEx chat

Renewable Power @ DOE



Dr. David Solan
Deputy Assistant Secretary for Renewable Power

GTO is Growing…

New Federal staff:

- Alexandra Prisjatschew – General Engineer / Golden CO
- Angel Nieto – General Engineer / Golden CO
- Zachary Frone – General Engineer / Washington DC

New Contractor/Fellow staff:

- George Stutz – Project Engineer / Golden CO
- Hannah Hughes - ORISE Fellow / Washington DC
- Jon Payne – Project Engineer / Golden CO
- Mike O'Connor – AAAS Fellow / Washington DC

FOA Awardees

Wells of Opportunity
- Cyrq Energy
- Ormat
- University of Oklahoma

Hydrothermal Resources
- University of Nevada-Reno

Low Temperature Resources
- Cornell University

Addresses the up-front risk of geothermal exploration

Addresses technologies critical to unlocking EGS potential

WOO
WELLS OF OPPORTUNITY
U.S. DEPARTMENT OF ENERGY

GTO – Upcoming Talks/Presentations

Society of Exploration Geophysicists
Annual Meeting & Exhibition / October 12, 2020

- Panel: Geophysicists of the Future – Industry and Government Perspective

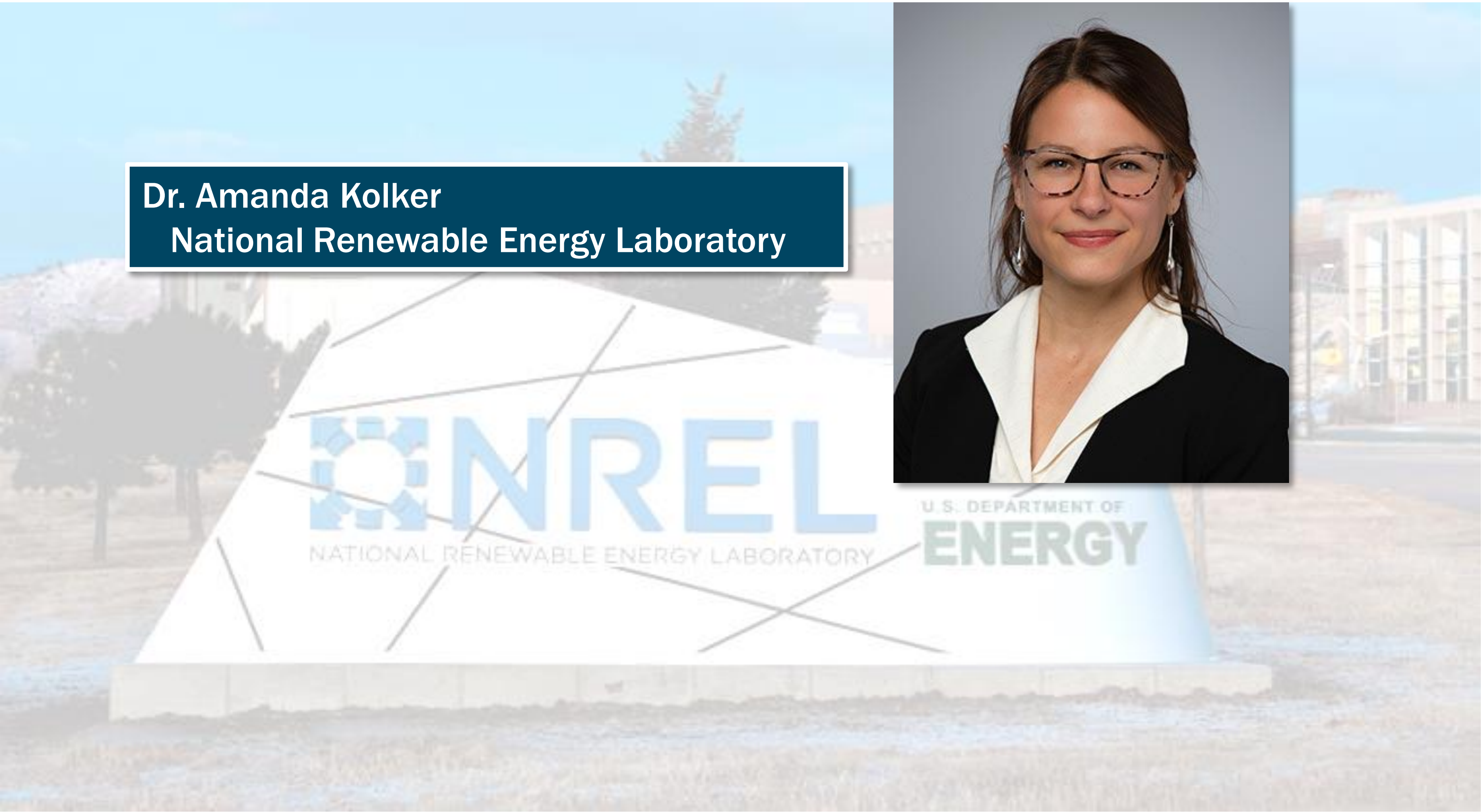
Geothermal Resources Council
Virtual Annual Meeting / October 18-23, 2020

- Advanced Materials for Drilling, Completion & Monitoring
- FORGE: Progress and Updates
- EGS Collab
- District Heating and Direct Use
- Machine Learning
- Mineral Extraction

Women's Bar Association of DC
October 27, 2020

- Renewable Energy: Panel Discussion

Deep Direct Use Feasibility Studies



Dr. Amanda Kolker
National Renewable Energy Laboratory

Overview of GTO's Deep Direct-Use Feasibility Studies:

Preliminary Takeaways From an Ongoing Techno-Economic Analysis

Amanda Kolker, Ph.D.

National Renewable Energy Laboratory

September 17, 2020

Coauthors: Koenraad Beckers & Hannah Pauling

Presentation Outline

1. What is Geothermal DDU?
2. Overview of Six Recent DOE-Funded DDU Projects
3. DDU Techno-Economic Parameters
4. Levelized Cost of Heating (LCOH) and Feasibility of DDU Projects
5. Next Steps: LCOH Scenario Analysis

Presentation Outline

1. **What is Geothermal DDU?**
2. Overview of Six Recent DOE-Funded DDU Projects
3. DDU Techno-Economic Parameters
4. Levelized Cost of Heating (LCOH) and Feasibility of DDU Projects
5. Next Steps: LCOH Scenario Analysis

What is Geothermal DDU?

- Deep Direct-Use (DDU) draws on lower temperature (< 300°F / 150°C) geothermal resources for multiple uses, including:
  - District heating and cooling
  - Commercial and residential applications
  - Industrial processes and agricultural uses.
- Includes subsurface thermal energy storage (TES).

Presentation Outline

DDU Awardees

Cornell U.

U. of Illinois

- University of Wisconsin-Madison
- Loudon Technical Services
- U.S. Army CER Laboratory
- MEP Associates
- Illinois Geothermal Engineering
- Trimeric

NREL (E. Texas)

- Southern Methodist University
- Eastman Chemical
- TAS Energy
- Electric Power Research Institute

West Virginia U.

- WVU Facilities Management
- West Virginia Geological & Economic Survey
- Lawrence Berkeley National Laboratory
- Cornell University

Sandia NL (Hawthorne)

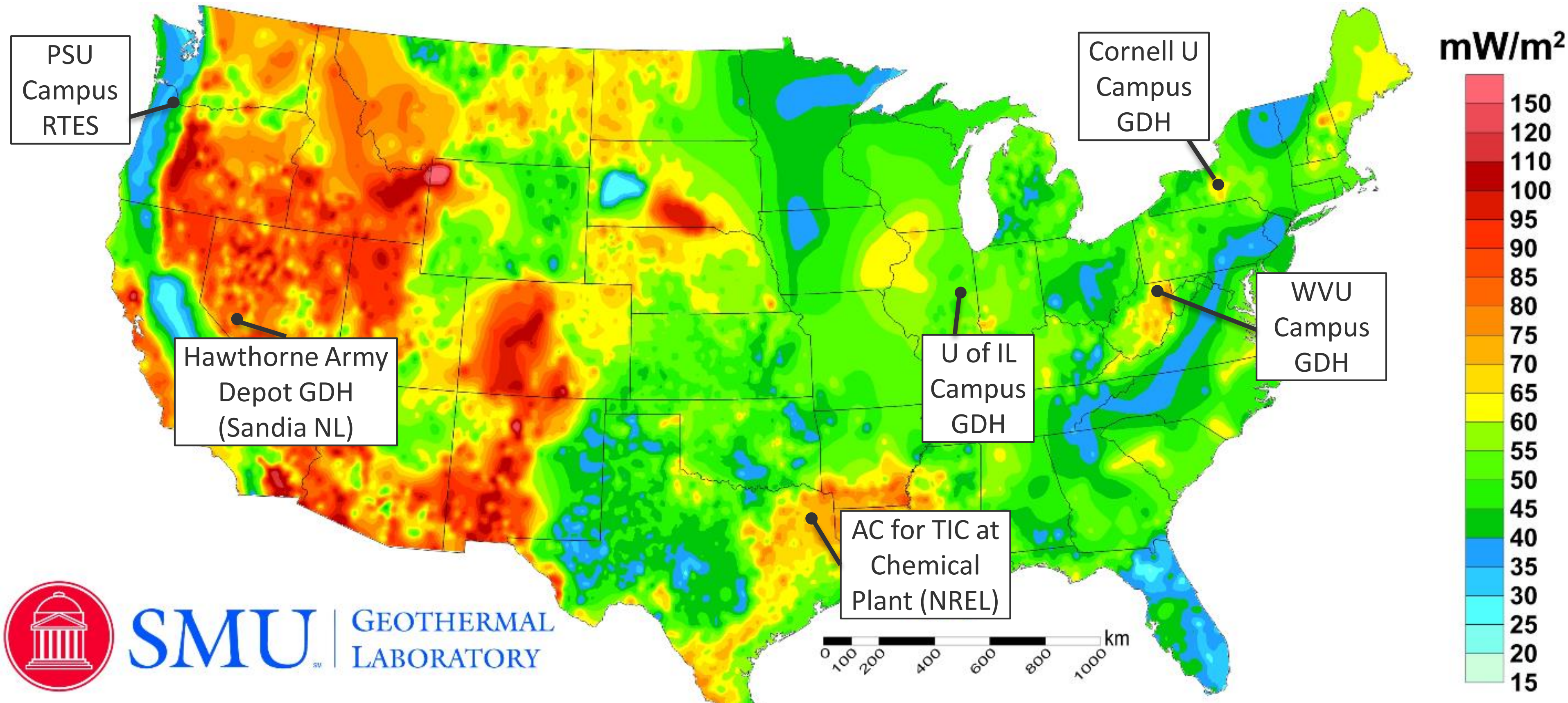
- U.S. Navy Geothermal Program
- Power Engineers, Inc.
- University of Nevada, Reno

Portland State U.

- AltaRock Energy
- City of Portland
- Oregon Health & Science University
- U.S. Geological Survey

For DDU-related publications, go to https://gdr.openei.org and search "DDU"

Map of DDU Project Locations and Surface Heat Flow



Acronyms

GDH = Geothermal District Heating

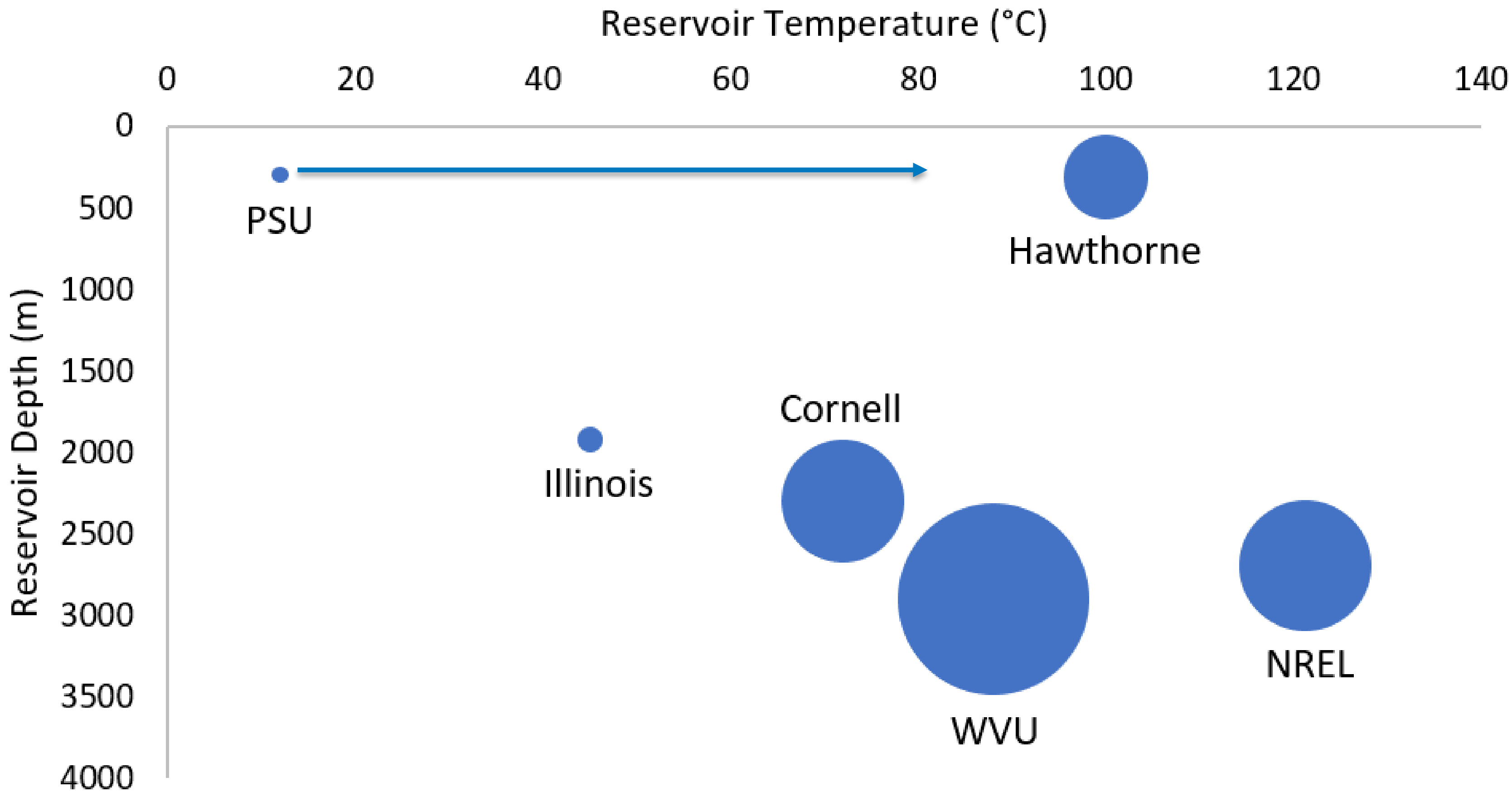
RTES = Reservoir Thermal Energy Storage

AC = Absorption Chilling

TIC = Turbine Inlet Cooling

Presentation Outline

Variability in Heat Supply and Demand in DDU Projects



Size of circle corresponds to size of DDU system (MW)

Range of Parameters Used in Six DDU Projects

GEOPHIRES TEA Simulator:

https://github.com/NREL/GEOPHIRES-v2

Model Input Parameter	Min	Max
Drilling depth	*0.3 km*	*2.9 km*
Reservoir temperature	*45°C*	*~120°C*
System size	*0.6 MW*	*32 MW*
Geothermal gradient	16.5°C/km	272°C/km
Number of wells	1 inj + 1 prod	5 inj + 10 prod
Well flow rate	11 kg/s	125 kg/s
Utilization factor	~45%	98%
Tax rate	0%	30%
Discount rate	0.8% (real)	7.5% (nominal)
Exploration costs	$0	$4.2M
Surface application	DH only	DH ± HP ± AC ± Solar TES
Surface capital costs	$381/kW	$6500/kW

Comparison with *GeoVision* study

	DDU Projects	*GeoVision* BAU (dGeo)	*GeoVision* IT (dGeo)
Drilling depth	0.3 km to 2.9 km	Varies throughout the country	Varies throughout the country
Reservoir temperature	12.5°C to 120°C	Based on Mullane et al. (2016) resource assessment	Based on Mullane et al. (2016) resource assessment
Geothermal gradient	16.5°C/km to 272°C/km	Varies throughout the country	Varies throughout the country
Number of wells	1 doublet to 15 wells	All systems are doublets	All systems are doublets
Well flow rate	11 kg/s to 125 kg/s	For hydrothermal: 31.5 L/s For EGS: 40 L/s	For hydrothermal: 31.5 L/s For EGS: 110 L/s
System size	0.5 MW to 32 MW	Average size of 9 MW	Average size of 18 MW
End-use efficiency	90% to 100%	80%	80%
Utilization factor	45% to 98%	25 to 35% depending on location	25 to 35% depending on location
Project lifetime	30 to 50 years	30 years	30 years
Discount rate	0.8% to 7.5%	6.5%	5%
Tax rate	0% to 30%	39.2%	39.2%
Exploration costs	\$0 to \$4.2M	For hydrothermal: \$3.3M + \$0.78M For EGS: \$5M+\$3.38M	15% decrease in exploration cost
Stimulation costs	\$0 to \$1.25M	For EGS: \$1.25M	For EGS: \$1.25M
Surface capital costs	\$381/kW to \$6500/kW	\$100/kW for plant + \$750/m for piping + \$50/kW for gas peaker + \$2000 system connection cost + \$1.5 to \$2.0/ft^2 system installation cost	\$100/kW for plant + \$750/m for piping + \$50/kW for gas peaker + \$2000 system connection cost + \$1.5 to \$2.0/ft^2 system installation cost
Drilling cost	\$1000/m to \$3000+/m	SNL Curves	SNL Curves × 50%

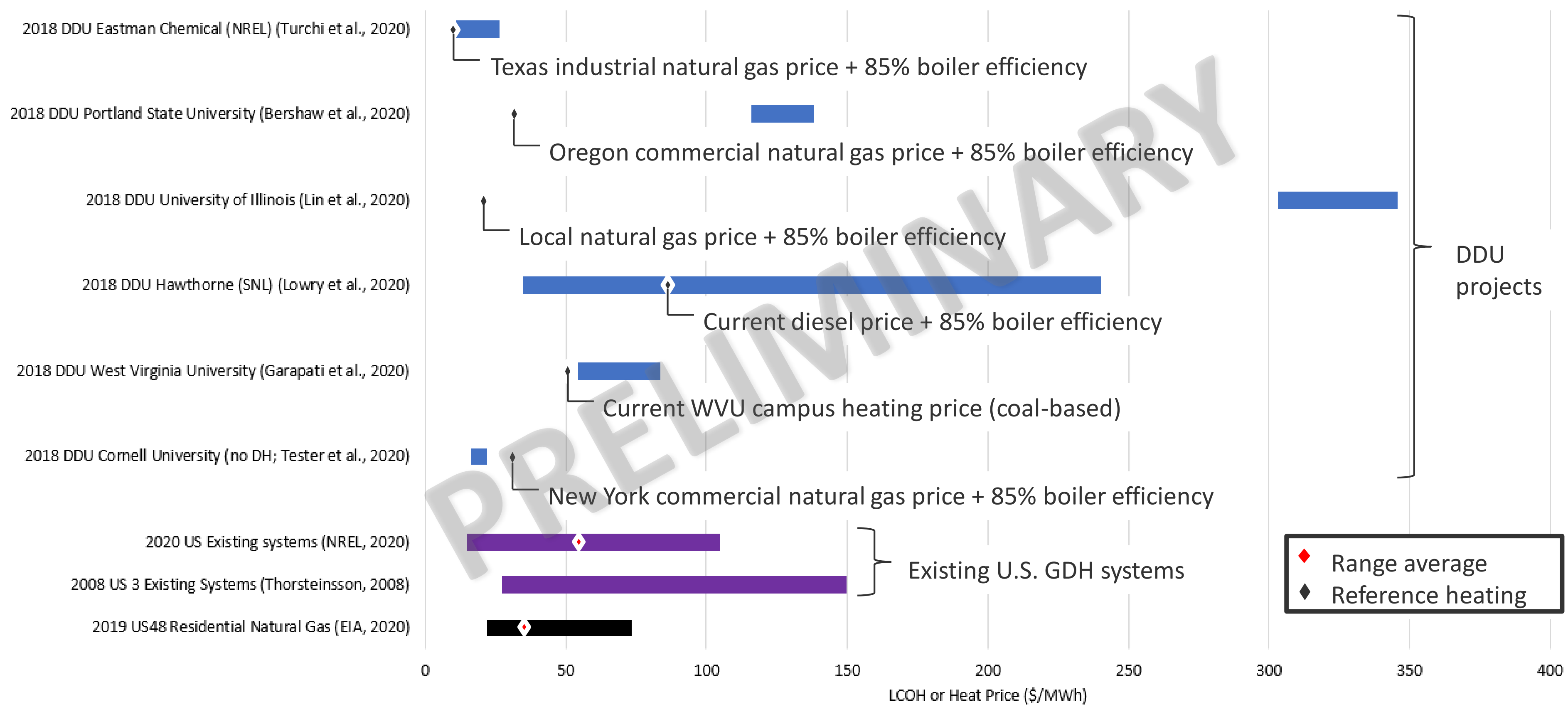
Presentation Outline

Base-Case LCOH of Six DDU Projects

	Cornell U.	U. Illinois	E. Texas	West Virginia U.	Hawthorne A.D.	Portland State U.
Drilling depth	2.5 km	1.9 km	2.7 km	2.9 km	0.3 km	0.3 km
Reservoir temperature	~72°C	45°C	~120°C	~88°C	~100°C	~12.5°C
Geothermal gradient	27.5°C/km	16.5°C/km	37.5°C/km	25.8°C/km	272°C/km	N/A
Number of wells	1 inj + 1 prod	1 inj + 1 prod	1 inj + 1 prod	5 inj + 10 prod	1 inj + 2 prod	1 inj + 1 prod
Well flow rate	50 kg/s	11 kg/s	125 kg/s	40 kg/s	36 kg/s	50 kg/s
System size	13 MW (incl. HP)	0.60 MW	15 MW	32 MW	6.2 MW	0.56* MW
Utilization factor	98%	~45%	90%	95%	48%	N/A for TES
Discount rate	2.5% (real)	5% (nom.)	5% (real)	7.5% (nom.)	7% (nom.)	0.8% (real)
Tax rate	0%	0%	0%	30%	0%	0%
Exploration costs	$0	$0	$3.4M	$4.2M	$1.02M	$0M
Surface application	DH + HP	DH + EH	Absorption Cooling	DH (+ AC in buildings)	DH	Building Solar TES
Surface capital costs	$560/kW (incl. HP + DH connection)	$5,000/kW (includes piping)	$381/kW (incl. only piping)	$1,300/kW (incl. piping)	$785/kW	$6500/kW (incl. piping + solar array)
Base-case LCOH ($/MMBtu)	**5.0**	**101***	**3.7**	**17.5***	**12***	**34**

**Nominal LCOH. All other LCOH are real values.*

Feasibility of DDU: LCOH Ranges From DDU Projects v. Reference Heating



Feasibility of DDU: Available Financing Incentives

United States (Federal)

- DOE grants and loans
  - Power focused, R&D focused
- Tax credits
  - ITC @ 10% for geothermal DU (30% for power)

United States (State)

- Grants and loans
  - E.g., CEC
- Cap and trade programs
  - RGGI power focused; DU eligible in CA, but accounting is difficult
  - Voluntary markets also power focused
- RPS: Renewable Portfolio Standards
  - Power focused (some states incorporate renewable thermal power for heat generation into their RPS, but non-electric renewable heating faces same accounting difficulty as cap-and-trade)
- Energy tax credits, tax exemptions
  - Applicability to DU depends on how projects are structured
- Energy efficiency standards/credits

Europe

- Up to 80% of capital costs for new GDH projects funded through state grants
  - Ave. ~30%
- Risk mitigation schemes for geothermal drilling in several countries
  - Mostly used for large-scale GDH projects
  - Drilling insurance, etc.
  - Source: https://www.georisk-project.eu/
- EU and national RE legislation focused on both heat and power sectors
- Emissions reductions programs impact DU
  - Energy Trading System (EU-wide cap and trade) includes renewable heating and cooling
  - National emissions targets for sectors outside the EU ETS
  - Incorporates energy efficiency standards/credits

Background: Past U.S. Programs Supporting Geothermal DU

Grants and Tax Credits

1979: Program Opportunity Notice

- Competitive grants for DU or combined power/DU projects. Required cost share.
- DU projects: 8 GDH (all still in operation), 7 buildings, 4 agribusiness, and 2 industrial projects

1978 & 2004: Investment/Production Tax Credits

- 10 to 30% for geothermal power; 10% for DU

2009: American Recovery and Reinvestment Act

- Approximately $400M for geothermal projects, including DU

Risk Mitigation Schemes

1975: Geothermal Loan Guarantee Program

- Loan guarantee for up to 75% of project costs with the federal government guaranteeing up to 100% of the amount borrowed
- Instrumental in bringing DU and power projects online

1976: Program R&D Announcement

- Provided funds for detailed feasibility studies.
- Targeted industrial processes, mineral extraction, and district heating

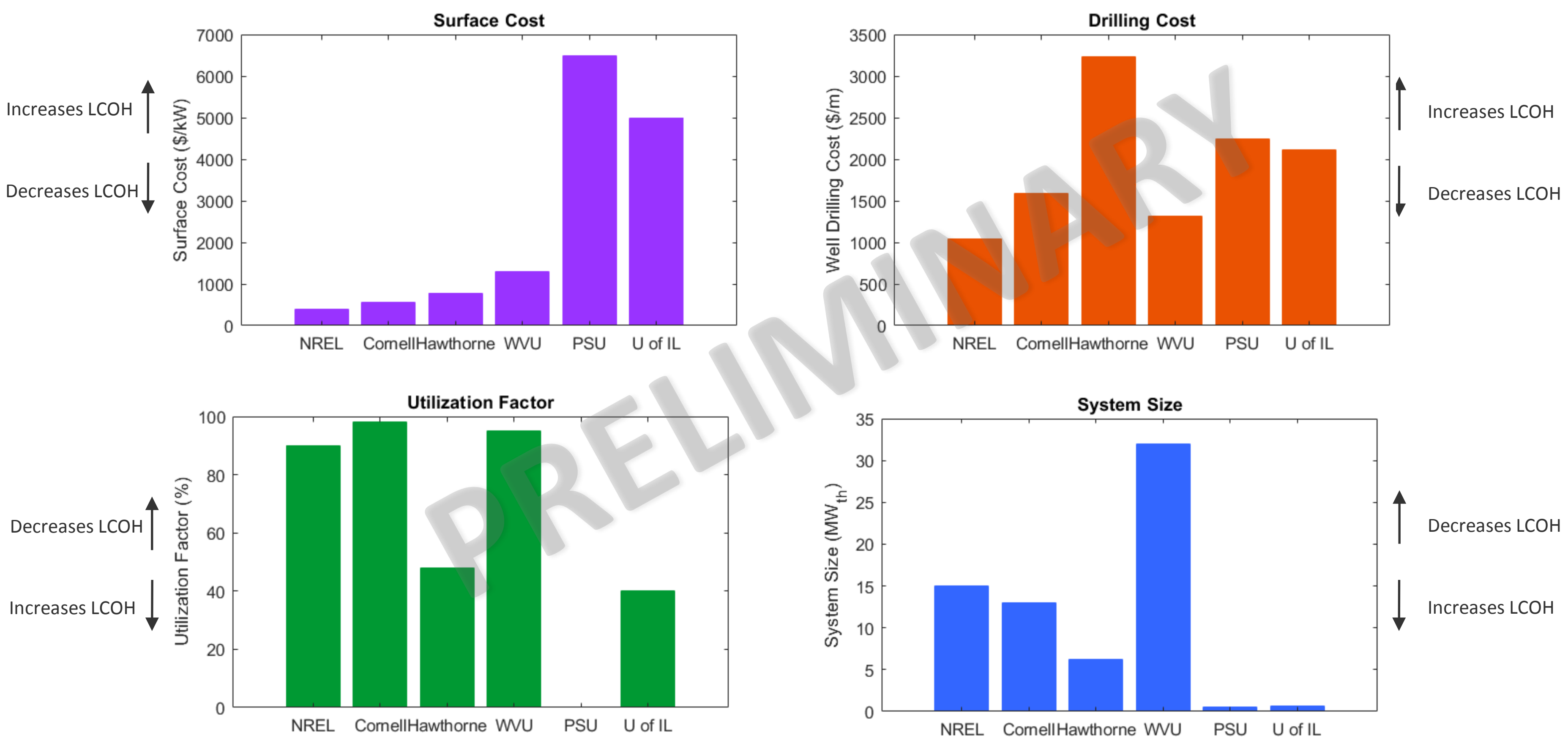
1980: User Coupled Confirmation Drilling Program

- Mainly for DU, but also for power projects
- Cost sharing with industry confirmation drilling (20% if successful; 90% if not successful)
- Loans up to $3,000,000

Source: Lund & Bloomquist (2012), Development of Geothermal Policy in the US: What Works and What Doesn't Work.

Presentation Outline

Impact of Key Techno-Economic Parameters on DDU LCOH



Next Steps: Scenario Analysis of DDU LCOH

GEOPHIRES Scenario	Discount Rate	Project Lifetime	Tax Rate	Exploration Cost	Drilling Cost	Surface CAPEX and OPEX	Surface Equipment	Utilization Factor	
Scenario 1 (QC)	As is	As is	As is	As is	As is	As is	As is	As is	*Objective: Streamline inputs to better compare projects*
Scenario 2 (Default Financing)	**5%**	**30 years**	**0%**	As is	As is	As is	As is	As is	
Scenario 3 (Default Cost + Financing)	**5%**	**30 years**	**0%**	**$0**	**Corrected**	As is	As is	As is	
Scenario 4 (Subsurface LCOH)	**5%**	**30 years**	**0%**	**$0**	As is	**$0**	**No HPs, heaters, HXs, etc.**	As is	
Scenario 5 (Low Drilling Cost)	**5%**	**30 years**	**0%**	As is	**70%**	As is	As is	As is	*Objective: Evaluate key factors impacting DDU deploy-ment*
Scenario 6–8 (Grants & Tax Credits 10, 20, 30%)	**5%**	**30 years**	**0%**	As is	As is	As is	As is	As is	
Scenario 9 (High Utilization Factor)	**5%**	**30 years**	**0%**	As is	As is	As is	As is	**95%**	
Scenario 10 (dGeo TI)	**5%**	**30 years**	**0%**	**$3.5M**	**50%**	As is	**80% End-Use Efficiency**	As is	

Thank You

For DDU-related publications, go to https://gdr.openei.org and search "DDU"

https://github.com/NREL/GEOPHIRES-v2

amanda.kolker@nrel.gov

www.nrel.gov

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Geothermal Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

NREL Transforming ENERGY

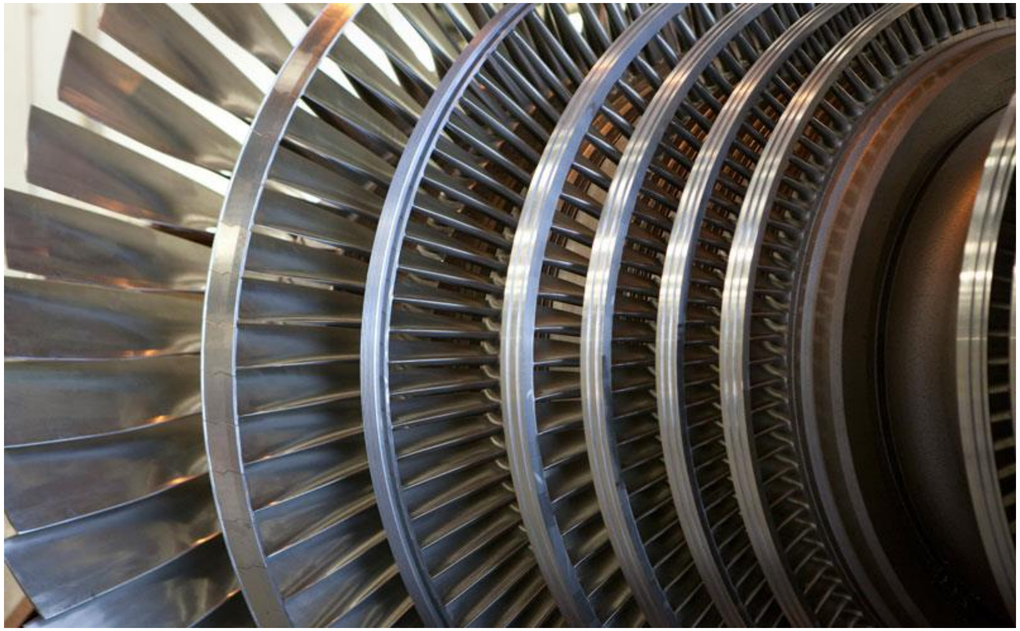
GeoDAWN: USGS and GTO

Mike Weathers
Geothermal Technologies Office

Jonathan Glen
U.S. Geological Survey

Geothermal Technologies Office

Geoscience Data Acquisition for Western Nevada



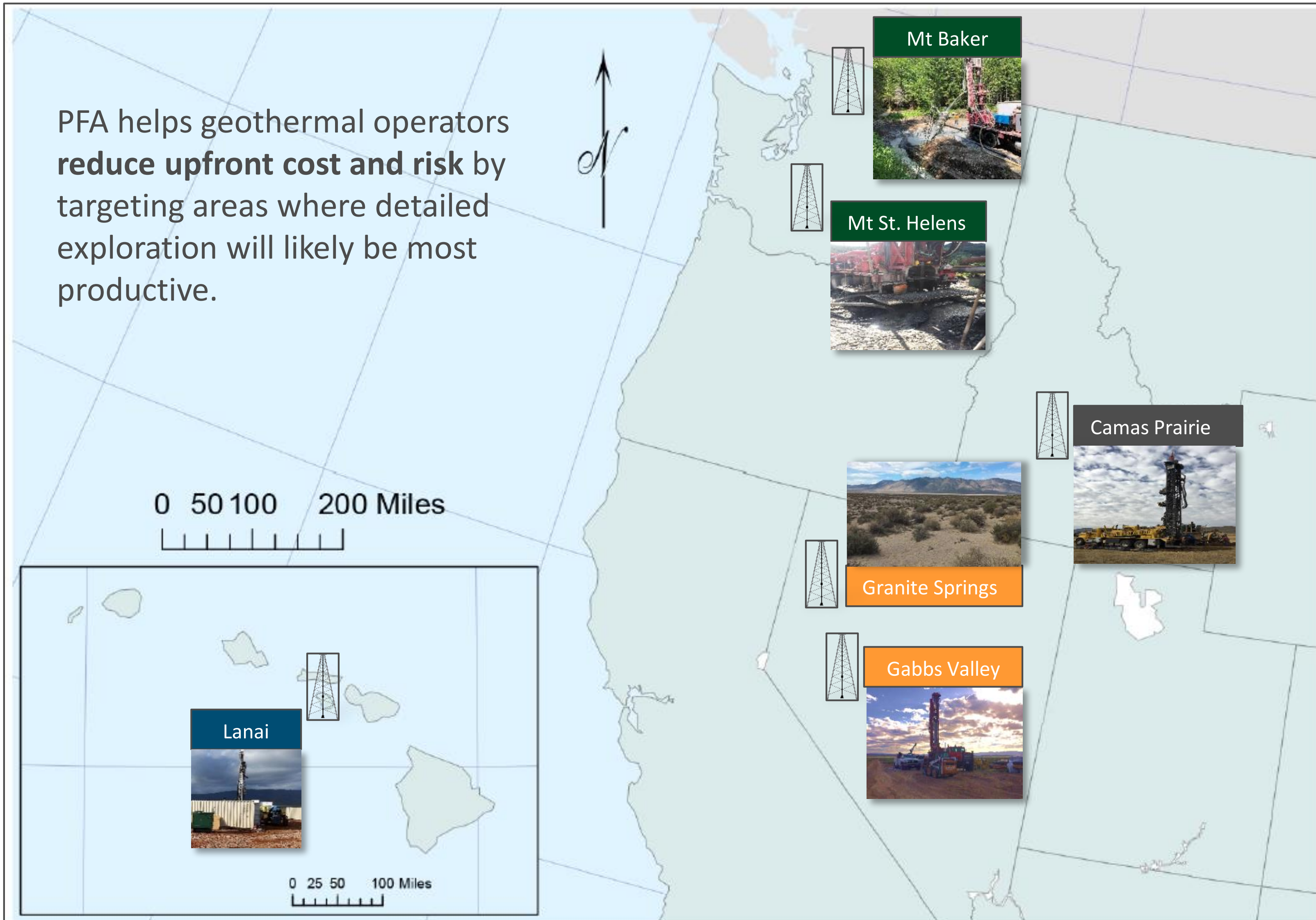
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

September 2020

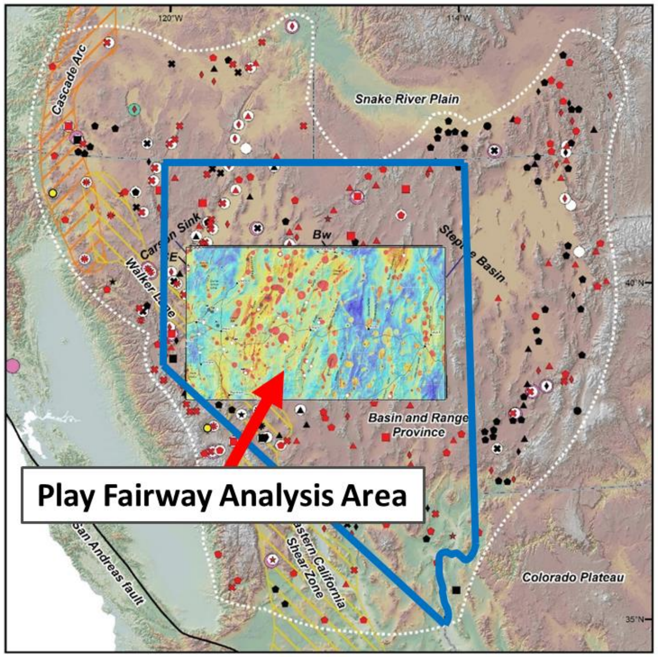
Background: Geothermal Play Fairway Analysis

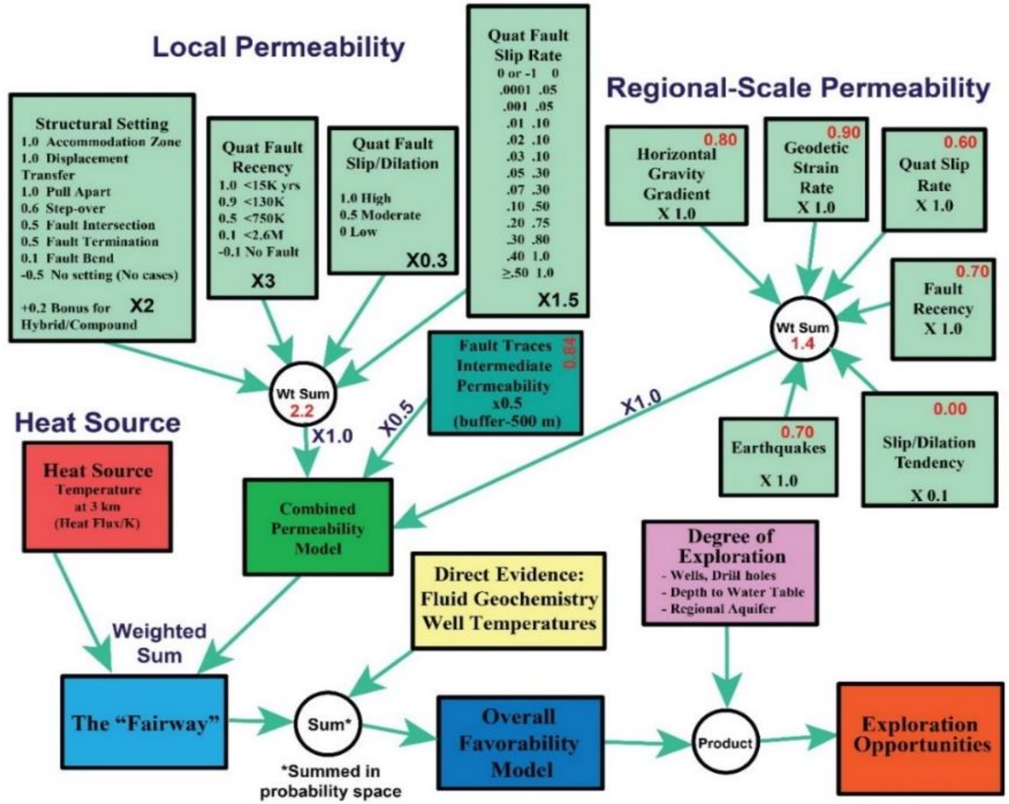
Background: Geothermal Play Fairway Analysis

PFA helps geothermal operators **reduce upfront cost and risk** by targeting areas where detailed exploration will likely be most productive.



Background: Geothermal Play Fairway Analysis

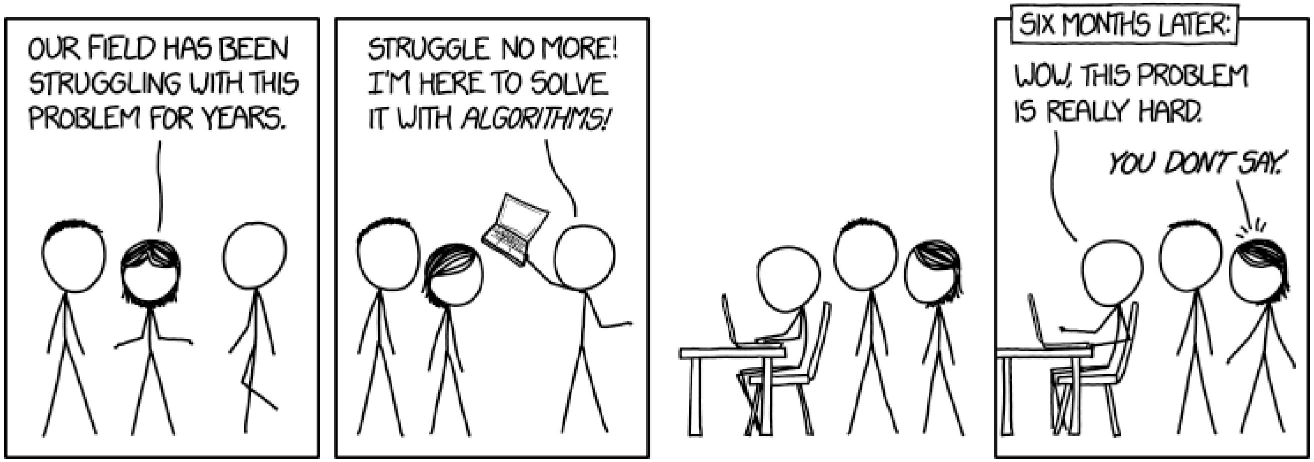




Example: Flow Chart of Nevada Play Fairway Analysis

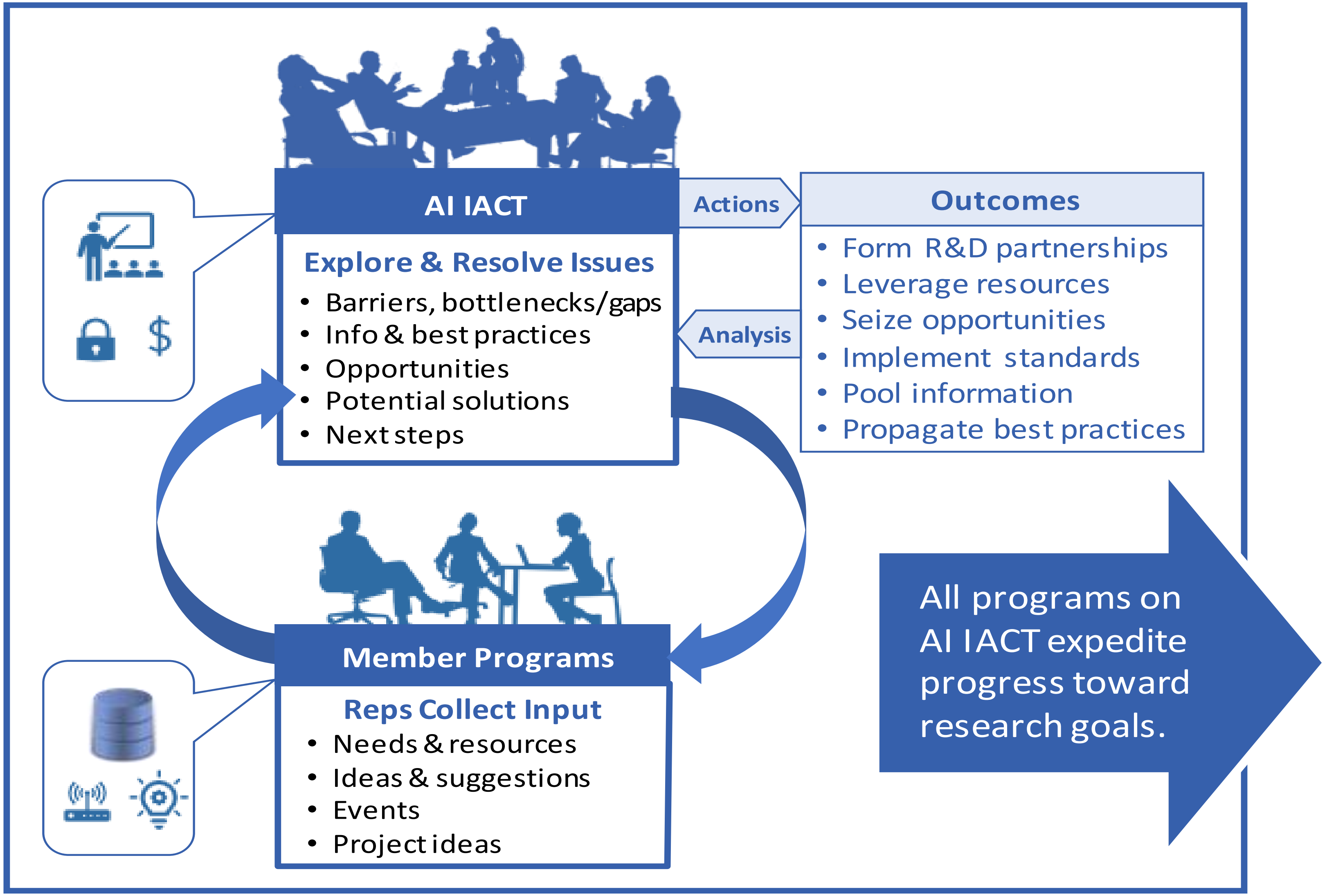
Recent GTO-sponsored AI / Machine Learning R&D

- **“Efficient Drilling for Geothermal Energy” (EDGE) April 2018**
- **“Machine Learning for Geothermal Energy and the Geosciences” July 2018**
- **“FY 2020 Subsurface Imaging Lab Call: Reducing Exploration Risk for Undiscovered Hydrothermal Resource Plays through Advanced Geophysical Imaging”**
- **“FY 2020 Geothermal Technologies Office Hydrothermal and Low Temperature Multi-Topic Funding Opportunity”**



https://xkcd.com/1831/

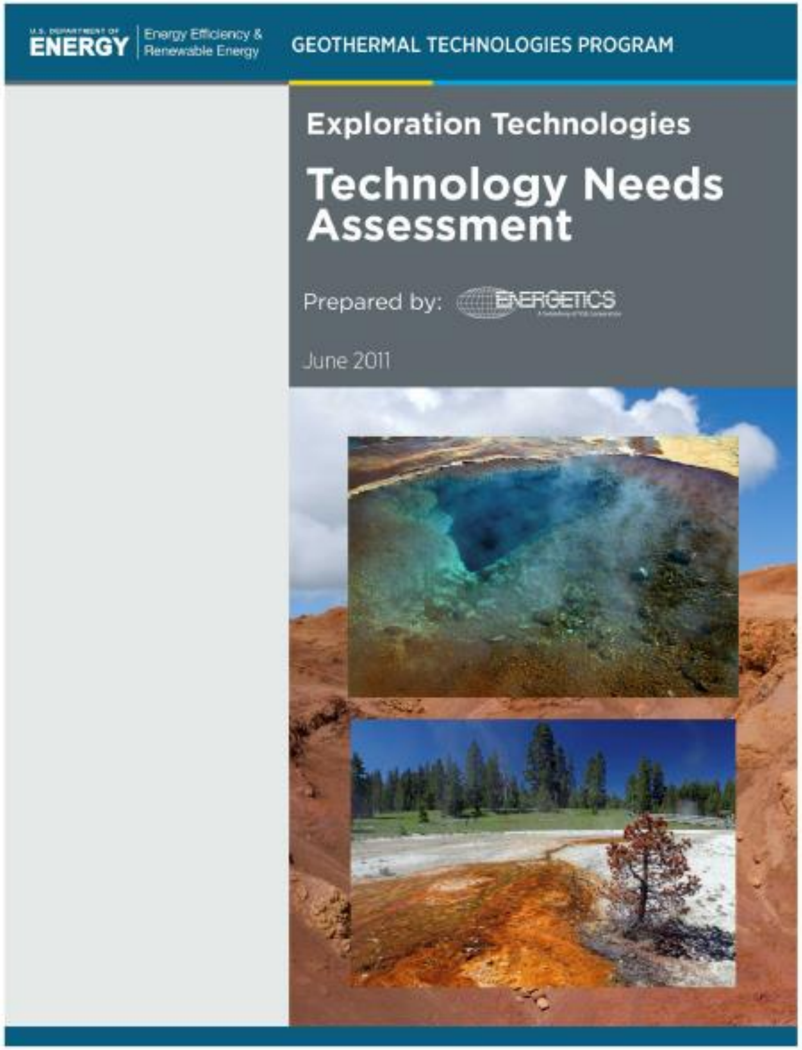
DOE Intra-agency AI Collaboration Teams



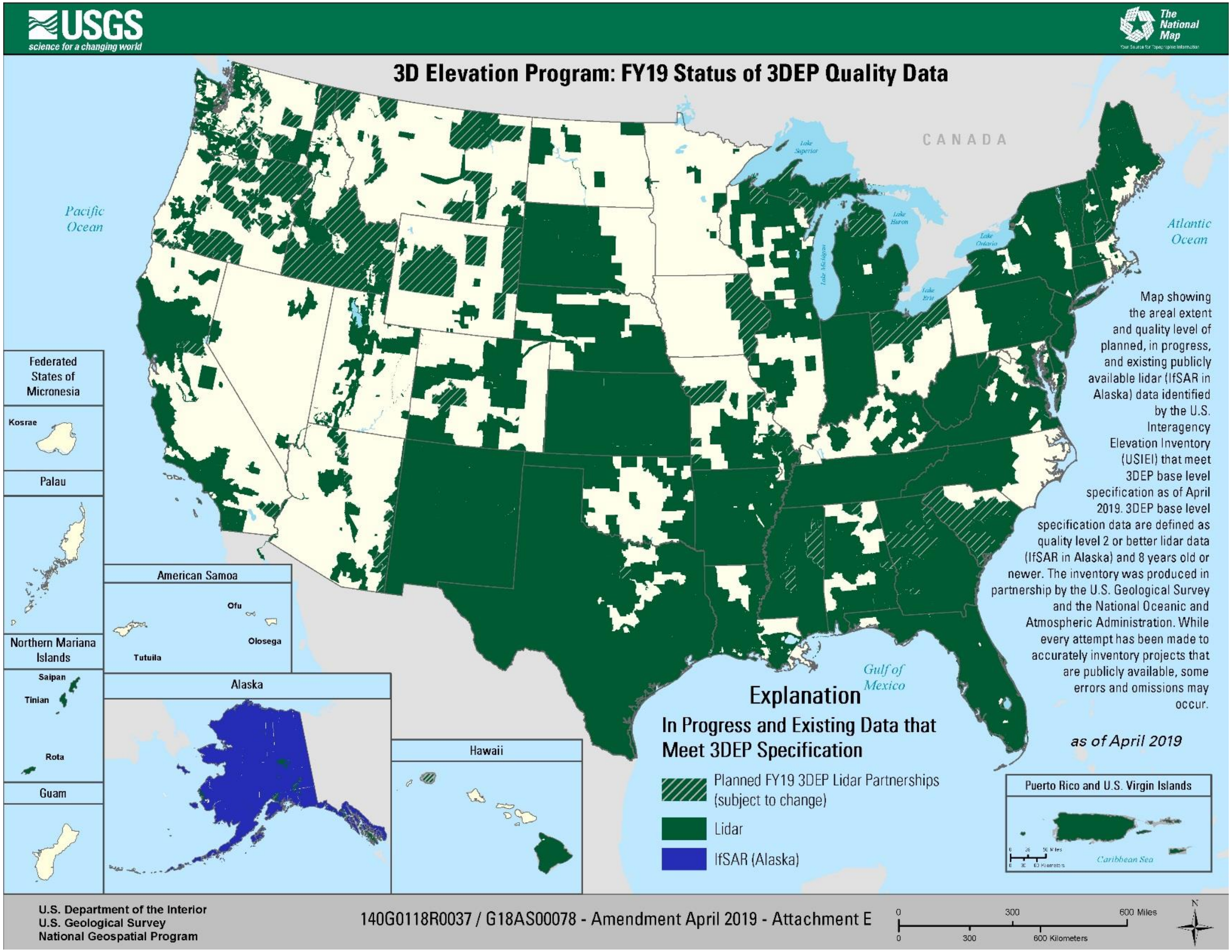
A Known Challenge: Availability of Data

High-Resolution Remote Sensing Data

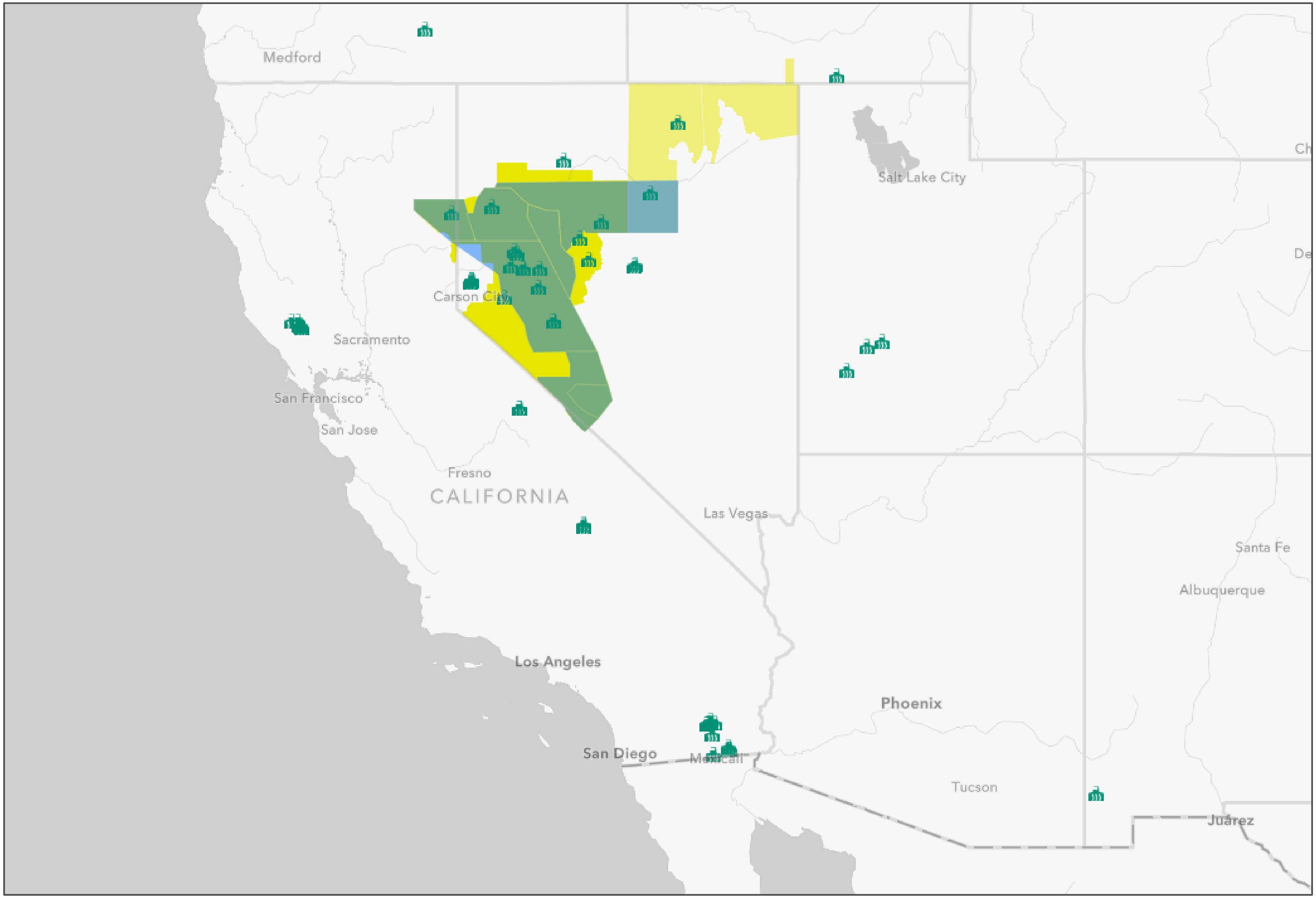
- Acquire airborne gravity, magnetics, hyperspectral, LIDAR, and similar data over 25-50% of known geothermal resource areas
- Links between data and resource potential need definition
- Make data publically available
- Prove automated processing for large area surveys



A Known Challenge: Availability of Data



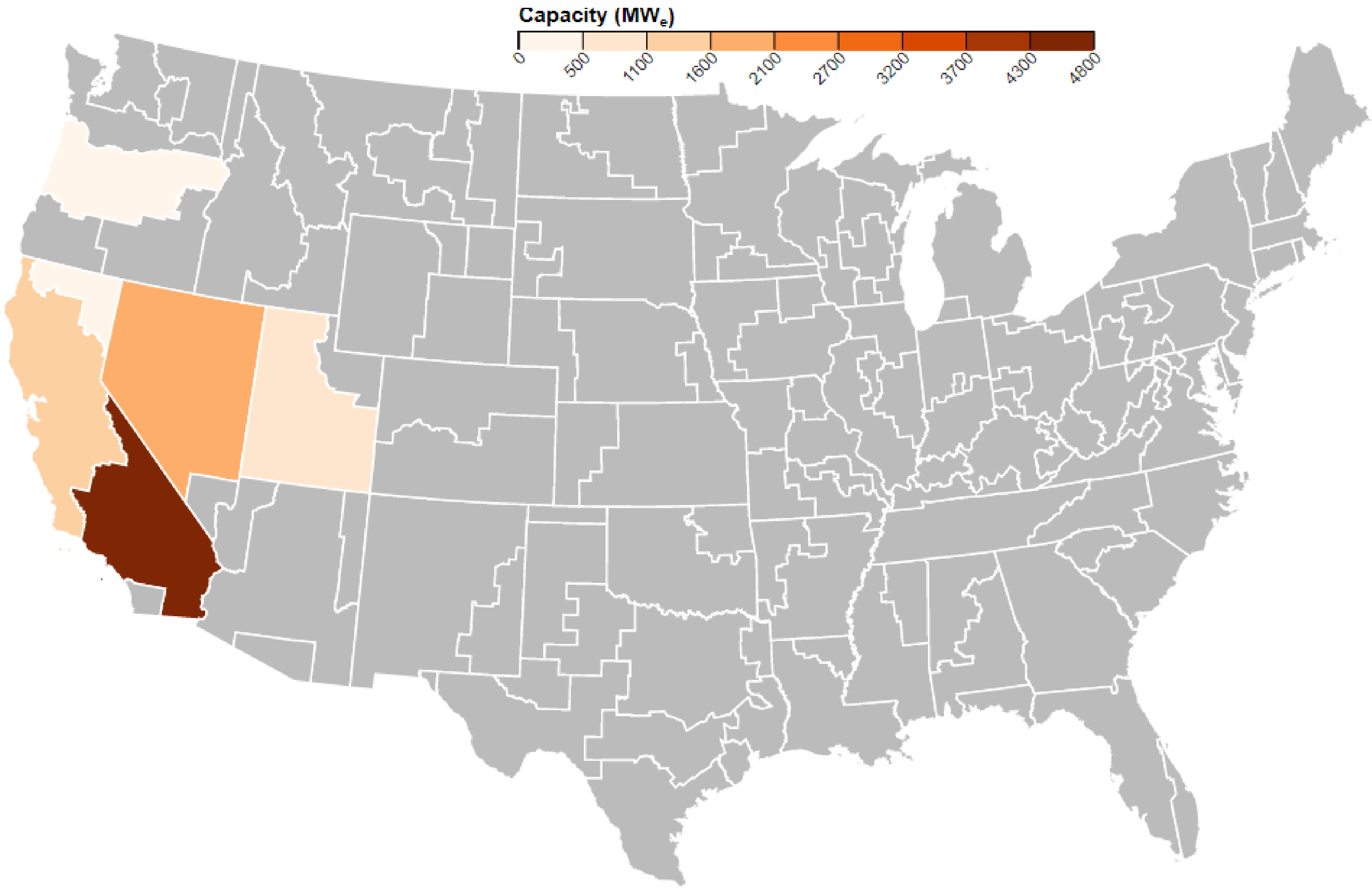
AOI: The Walker Lane



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

GeoVision Study – Undiscovered Hydrothermal

Deployment of Geothermal Technologies by Balancing Authority



https://openei.org/apps/geovision/

Overview of USGS-DOE's Geoscience Data Acquisition for Western Nevada Project (GeoDAWN)

Jonathan Glen

jglen@usgs.gov

GTO Webinar 9/17/2020

USGS science for a changing world

USGS Earth Mapping Resources Initiative (Earth MRI)

USGS's Response to EO 13817 and SO 3359:

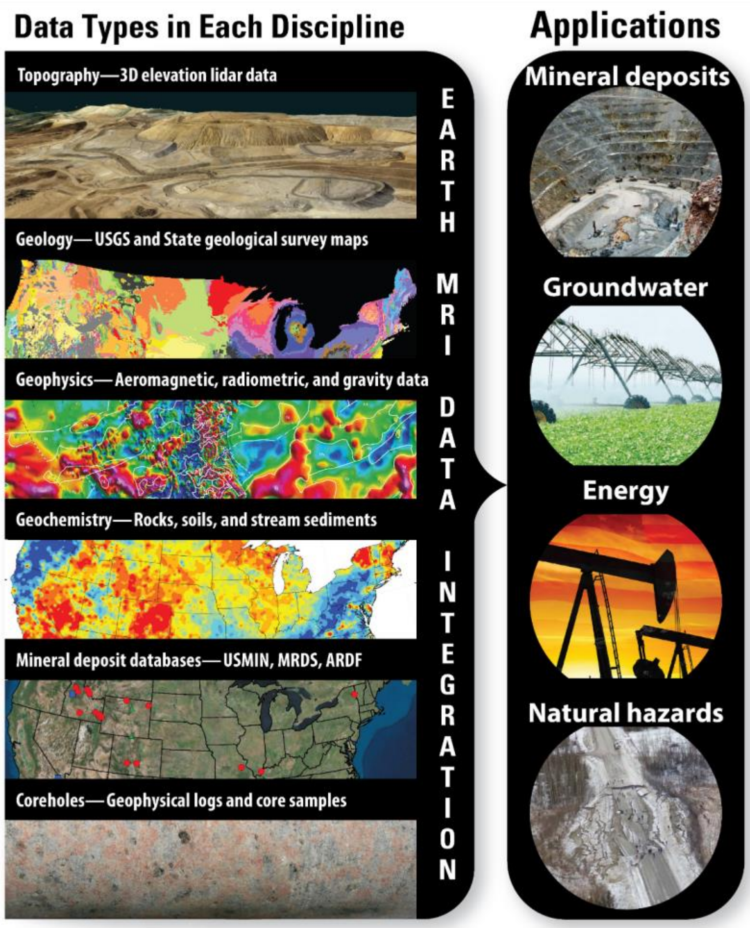
Earth MRI: Partnership between USGS and State Geological Surveys to generate state-of-the-art geologic mapping, geophysical surveys, and lidar data for the Nation in areas with critical mineral potential.

<u>**Earth MRI Budget**</u>

- **FY 2019**: $9.598M
- **FY 2019 State Matching Funds:** ~$2.9M from 29 States
- **FY 2020:** $10.598M
- **FY 2020 State Matching Funds:** ~$2.2M from 27 States
- Seeking Other Agency Partnerships to leverage funds

<u>**Activities**</u>

- **FY 2019:** Focused on rare earth elements
- **FY 2020:** Focused on rare earth elements and 10 more commodities: Al, Co, graphite, Li, Nb, PGEs, Ta, Sn, Ti, and W
- **FY2021+**: Expand to Sb, barite, Be, Cr, Fluorspar, Hafnium, Mg, Mn, potash, U, V, and Zr



Earth MRI Project Areas for Phase 2 Critical Minerals

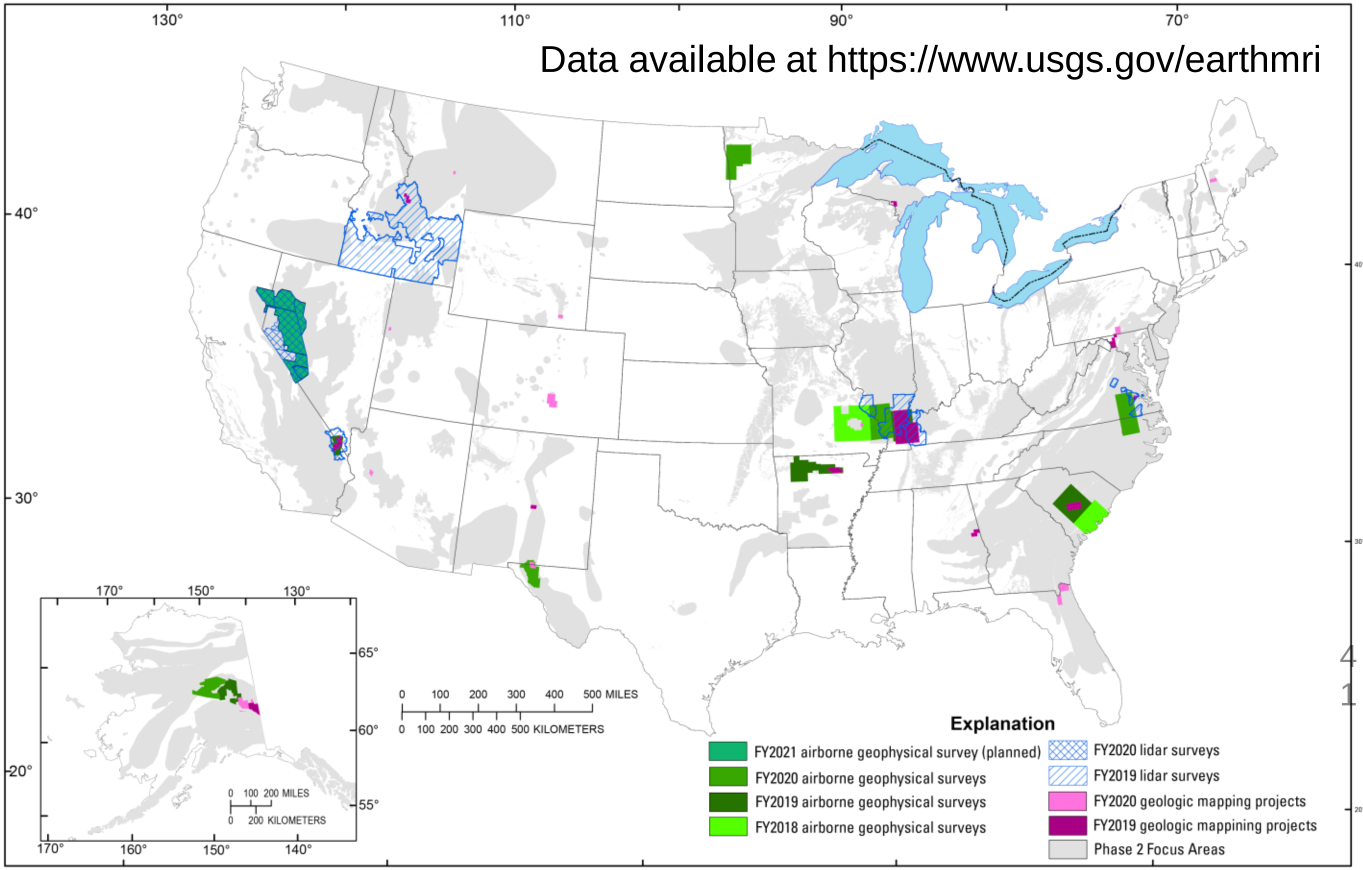
Aluminum, cobalt, graphite (natural), lithium, niobium, platinum group metals, rare earth elements, tantalum, tin, titanium, tungsten

FY19 Activities:
- 14 Geologic Mapping Projects
- 5 Airborne Geophysical Surveys
- 5 Lidar Surveys

FY20 Activities:
- 12 Geologic Mapping Projects
- 4 Geochemistry Reconnaissance Projects
- 6 Airborne Geophysical Surveys
- 1 Lidar Survey

The list of 35 critical minerals was broken into 4 groups (or "Phases") for ease in evaluating, prioritizing, and managing sites for new data acquisition.

Data acquisition for each group (or "Phase") of minerals will take multiple years to complete.



USGS

Geoscience Data Acquisition for Western Nevada (GeoDAWN) Project

Participating Agencies

- Department of Energy Geothermal Technology Office
- USGS Earth MRI
- USGS 3D Elevation (3DEP) Program
- USDA Natural Resources Conservation Service
- FEMA – previously planned lidar
- Bureau of Land Management
- US Bureau of Reclamation – previously collected lidar
- NV Bureau of Mines and Geology – technical support, geologic mapping

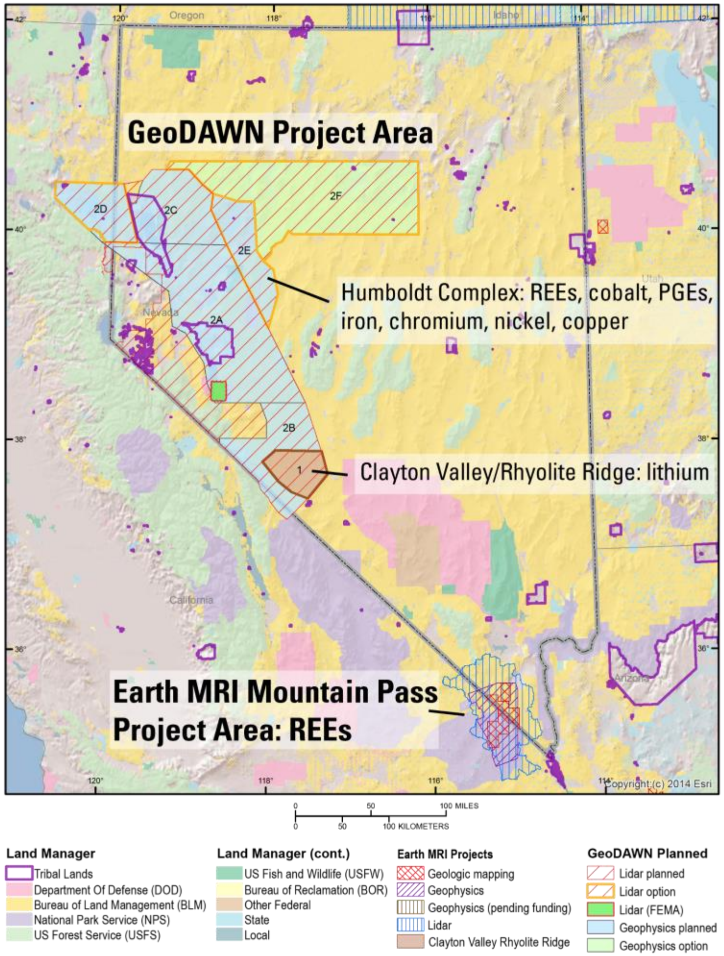
<u>USGS Earth MRI Components:</u>

1) Lidar
2) Airborne geophysical survey
3) Geologic mapping support to Nevada Bureau of Mines and Geology (planned for FY2021 start)

<u>Earth MRI's critical and other mineral commodities of interest:</u>

- Clayton Valley/Rhyolite Ridge area: lithium
- Humboldt Complex area: rare earth elements, cobalt, platinum group elements, iron, chromium, nickel, copper

➢Follows-on effort from Mountain Pass, NV-CA project (FY2019) (data on https://usgs.gov/earthmri)



Land management agency information from BLM , 2020 Surface Management Agency

USGS

Proposed surveys

Airborne Geophysical Surveys

- Flown with helicopter or specially modified fixed-wing aircraft (photo B) in rugged terrain
- Moderate relief flown with traditional fixed-wing aircraft
- Flights at low levels from 250-650 ft above the ground
- Aircraft flown in grid pattern with 650-1,312 ft between flight lines

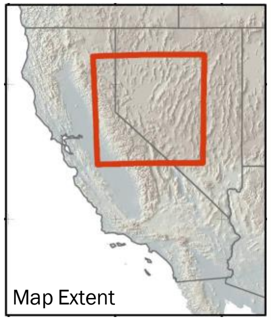
Helicopter platform (photo: D. Ponce, USGS)

Modified Fixed wing platform. Photo: D. Ponce, USGS

<u>Existing aeromagnetic survey coverage</u>

- Patchwork compilation
- Variable quality
- Mostly low-resolution surveys

➢ Generally not suitable for quantitative geologic interpretation, and in many cases of little or no utility for geologic interpretation



<u>Planned airborne geophysical surveys</u>

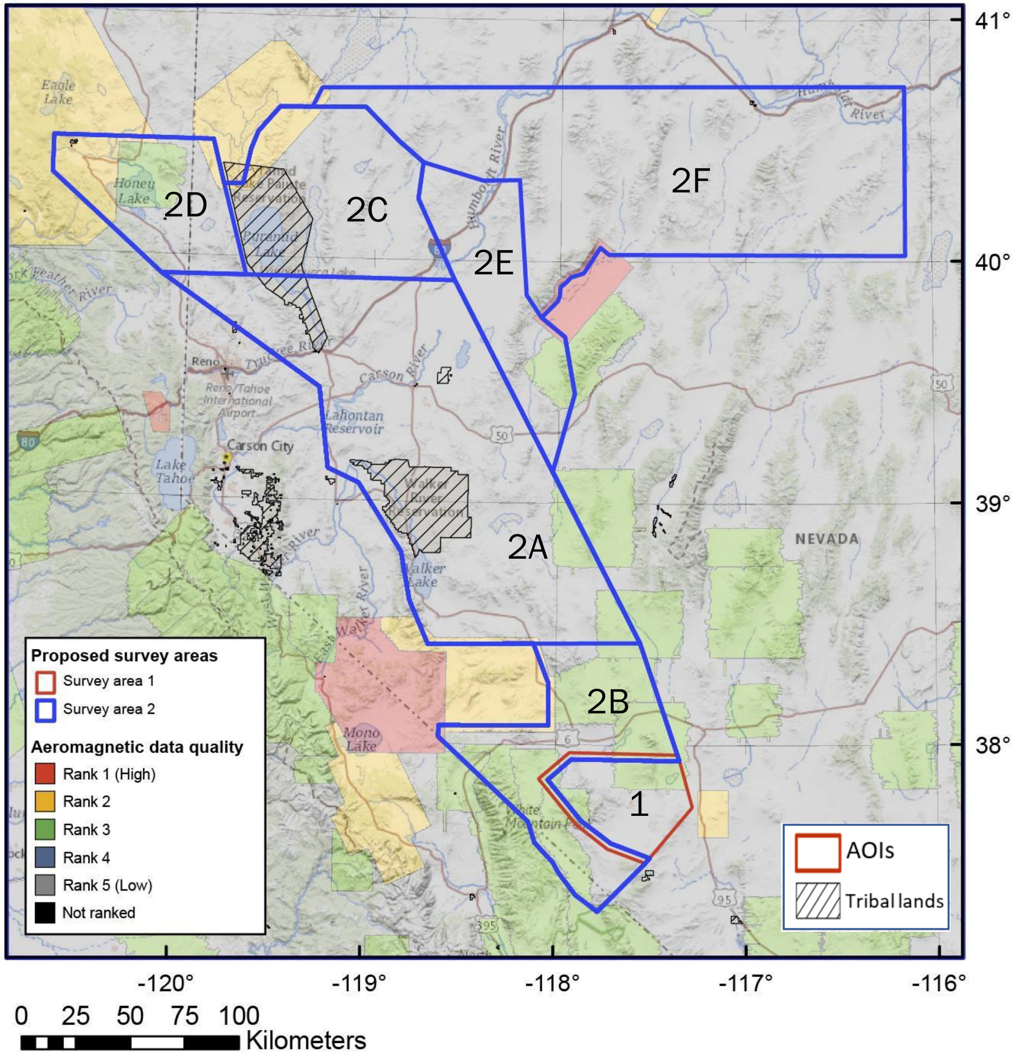
- Aeromagnetics
- Aeroradiometrics

<u>Area 1 (EarthMRI focus)</u>:
150m drape, 200m line spacing

<u>Area 2 (Geothermal focus)</u>:
200m drape, 400m line spacing

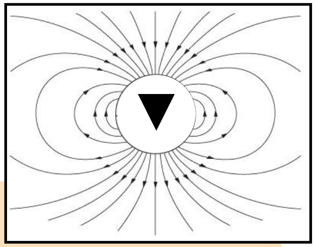
➢ Surveys are designed to yield high-res data sufficient for 3D-characterization of magnetic anomaly sources

Survey quality factors:
- Terrain clearance
- Flightline spacing
- Data quality
  (gps quality, digital data…)

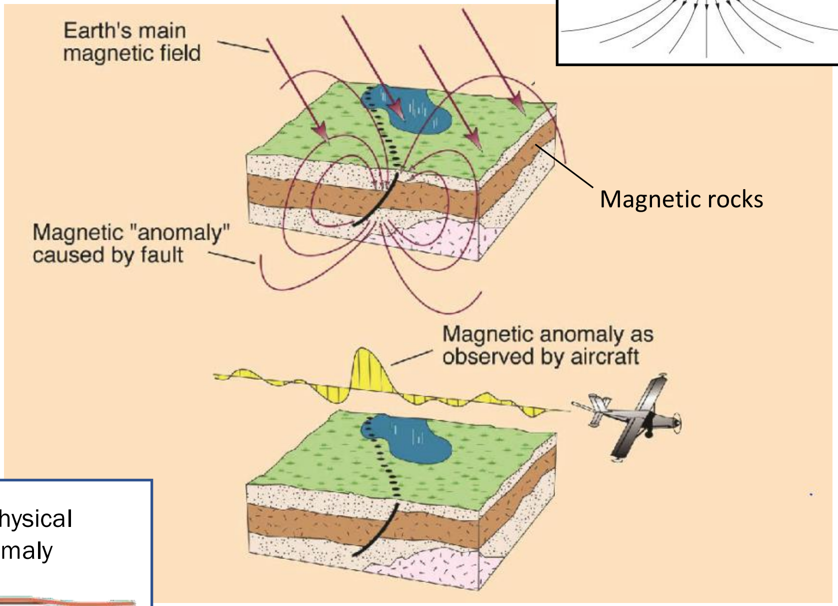


USGS

Magnetic methods

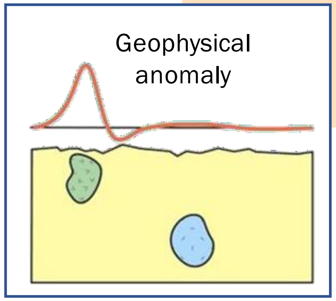


- Reflect contrasts in magnetic properties
- Applicable at local- and regional-scales
- Images subsurface geology and structure
  - Pertaining to the shallow- to mid-crust
  - Best in areas with contrasting rock-properties
- Useful in a wide range of applications



Applications:

- Geologic mapping
- Earthquake and volcanic hazards
- Archeology
- Environmental investigations
- Energy and natural resource potential
  - **Geothermal**
  - Water
  - Minerals
  - Hydrocarbons



- Map subsurface geology
- Identify structures (fault/fracture/contacts)
- Characterize reservoir geometry
- Map hydrothermal alteration
- Provide regional proxy for heatflow

USGS

Magnetic methods

Mapping

- Mapping shallow-to-deep structures

Basic Maps (CBA, ISO, TF)

Derivative and filtering methods

Difference (residual) maps – emphasizes near-surface sources

Match filter – isolates anomalies arising from different crustal levels

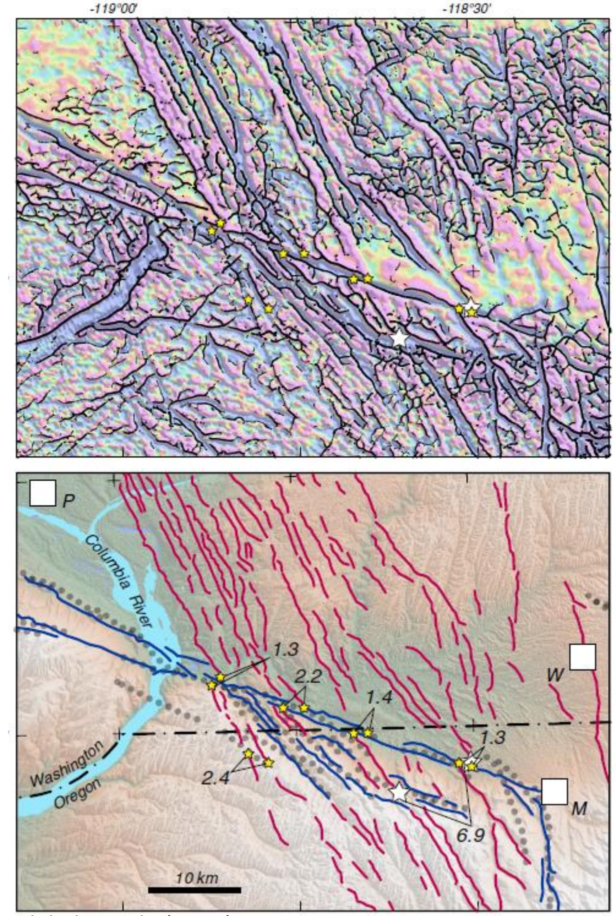
Maximum horizontal gradients – used to map the edges of sources

Reduced to Pole (R2P) – centers magnetic anomalies over their sources

Pseudogravity (PSG) – isolates broad magnetic features often masked by high-amplitude shallow magnetic sources

Depth to source estimations **(**Euler deconvolution, tilt derivative, …)

•simplify anomalies to aid interpretation
•resolve the edges source bodies
•constrain the depth to sources
•identify sense and magnitude of fault offset

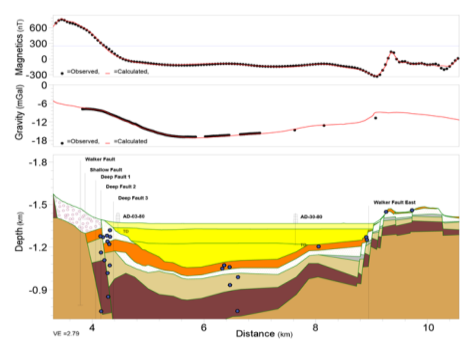


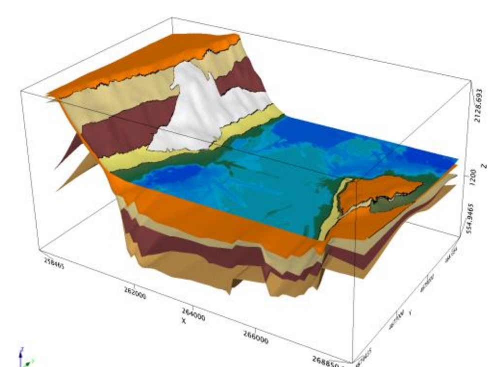
Blakely et al., (2014)

Mapping faults and geology with magnetics

Modeling Joint G&M ; 2&3D; forward and inverse methods

- Constrain subsurface structure geometry
- Provide basis for stress and hydrologic models





USGS

Applications to Geothermal Resource Studies

Regional Assessments

Heatflow proxy (*Curie temperature depth*)
Improving heatflow estimates (*depth to basement*)
Regional structures

Resource studies

Conventional Geothermal

Natural hydrothermal systems & Deep Sedimentary Basin Resources

- Direct Use
- Electric Power Generation

- Map subsurface geology
- Map structures (fault/fracture zones and contacts)
  -- Identify sense and magnitude of offsets
- Define reservoir geometry (*depth to basement*)
- Map hydrothermal alteration

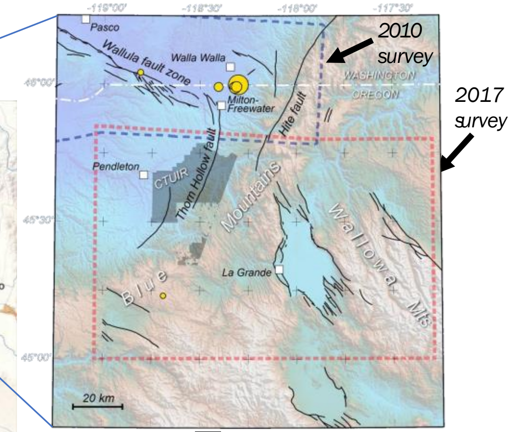
Unconventional Geothermal

Enhanced Geothermal Systems (EGS)

- Mapping structures
  -- to mitigate fluid loss, triggered seismicity
- Monitoring production (*temporal gravity*)

USGS

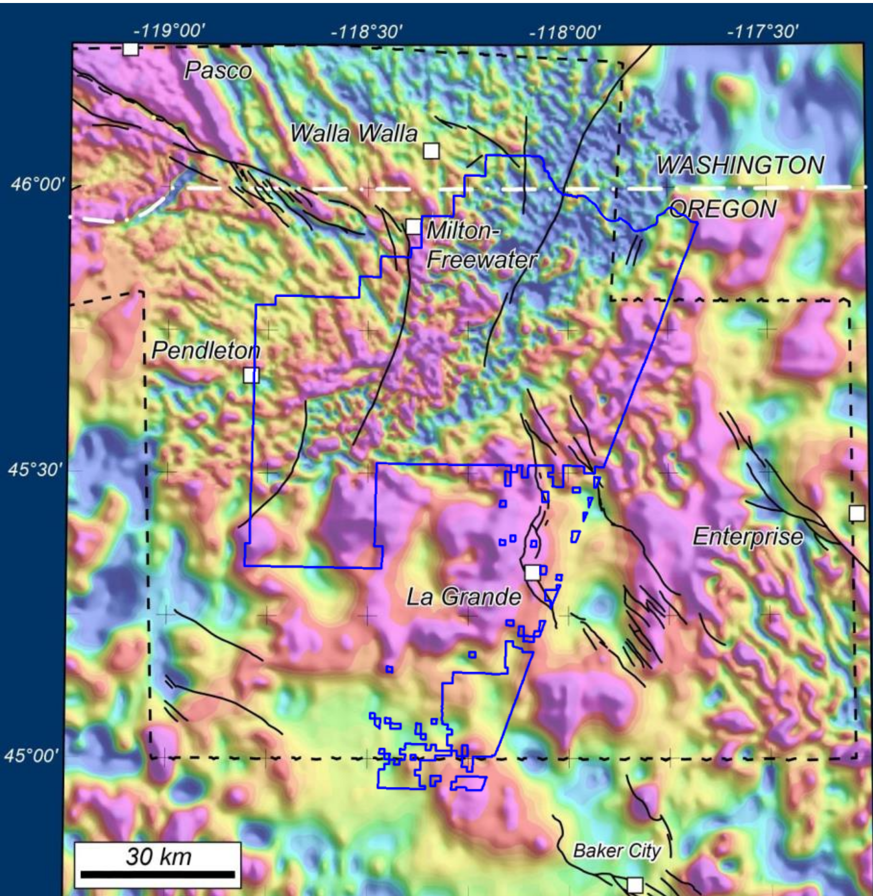
Example of old (lo-res) and new (mid-res) magnetic surveys



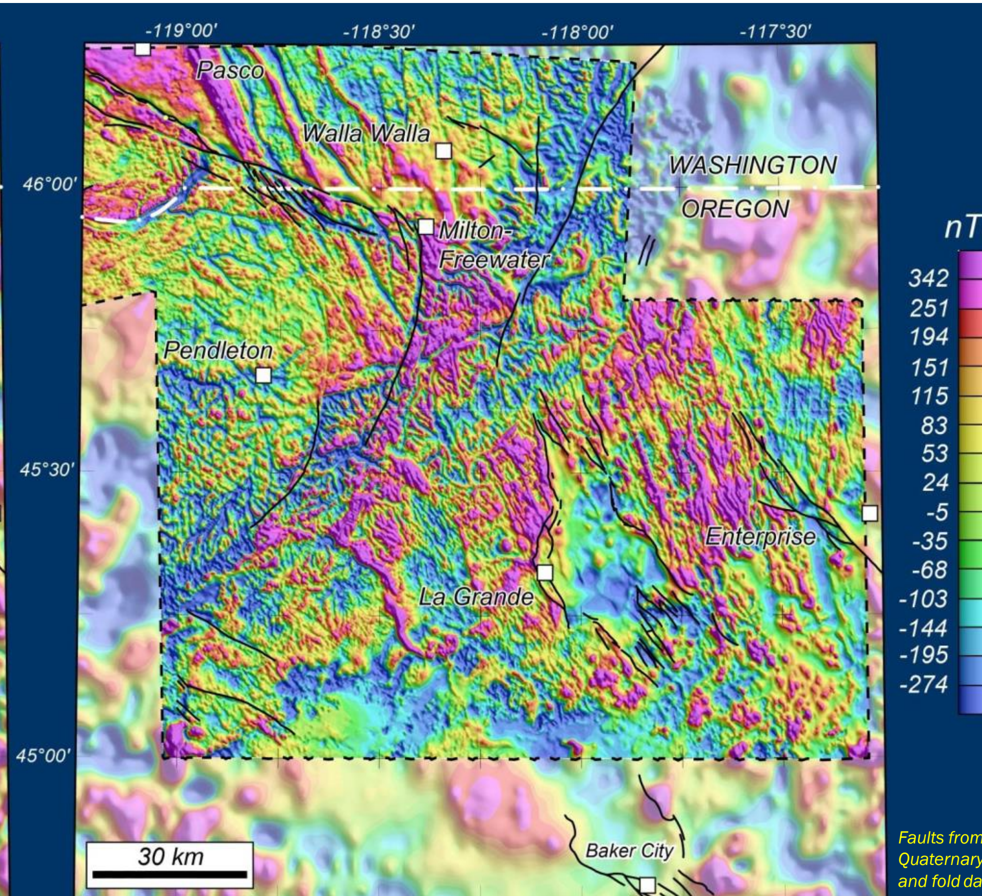
UIR (shaded area)

Umatilla Indian Reservation, OR

New survey boundary



Magnetic anomalies, as previously known



Faults from USGS Quaternary fault and fold database.

Magnetic anomalies, new data (reduced to pole)

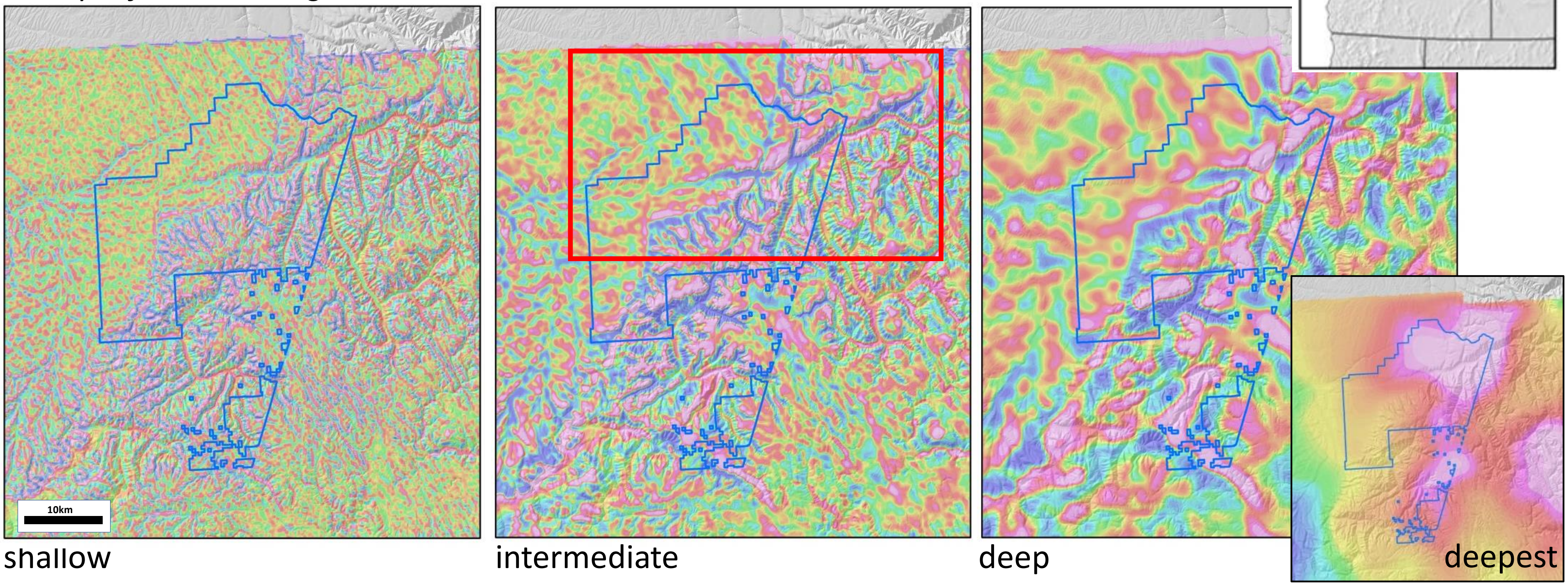
After Blakely et al. (2017)

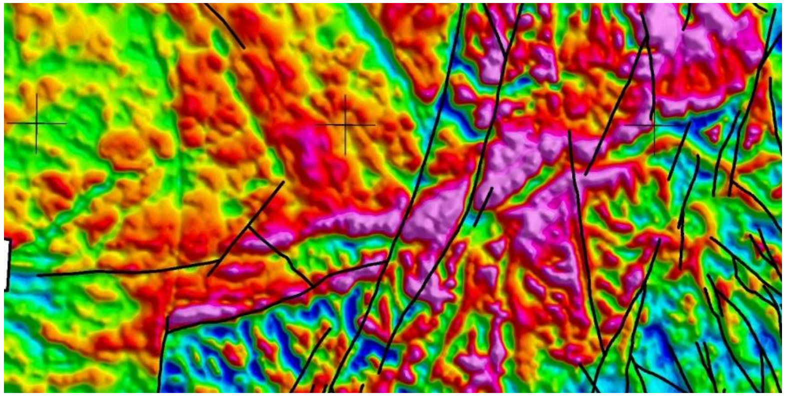
USGS

Match filtering

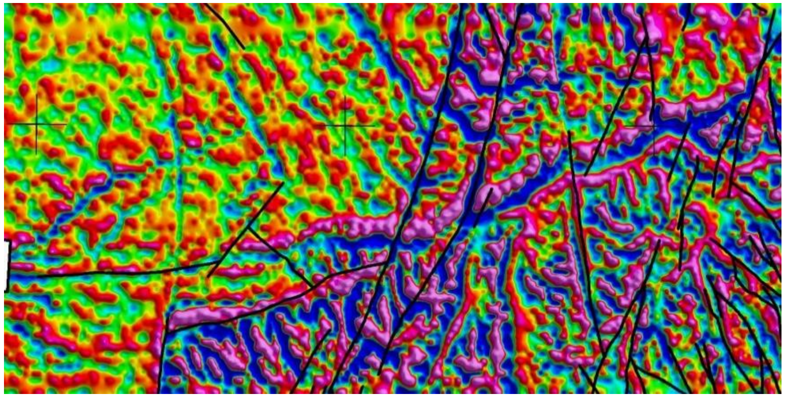
Magnetic anomalies filtered to distinguish anomalies sourced at different crustal depths

Example from NE Oregon





Total magnetic intensity



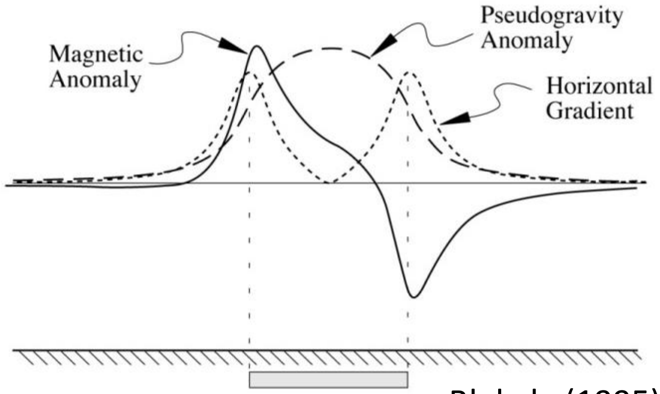
Filtered to emphasize shallow sources

Geophysical Structure

inferring geophysical contacts
from anomalies

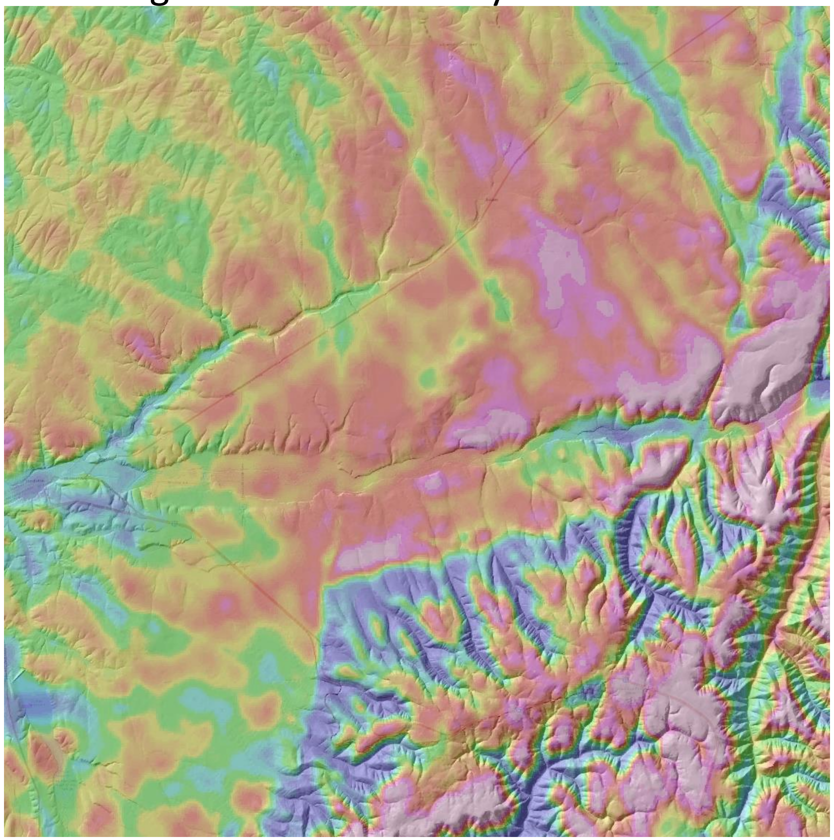
Structural features interpreted from Maximum Horizontal Gradients

Boundary analysis

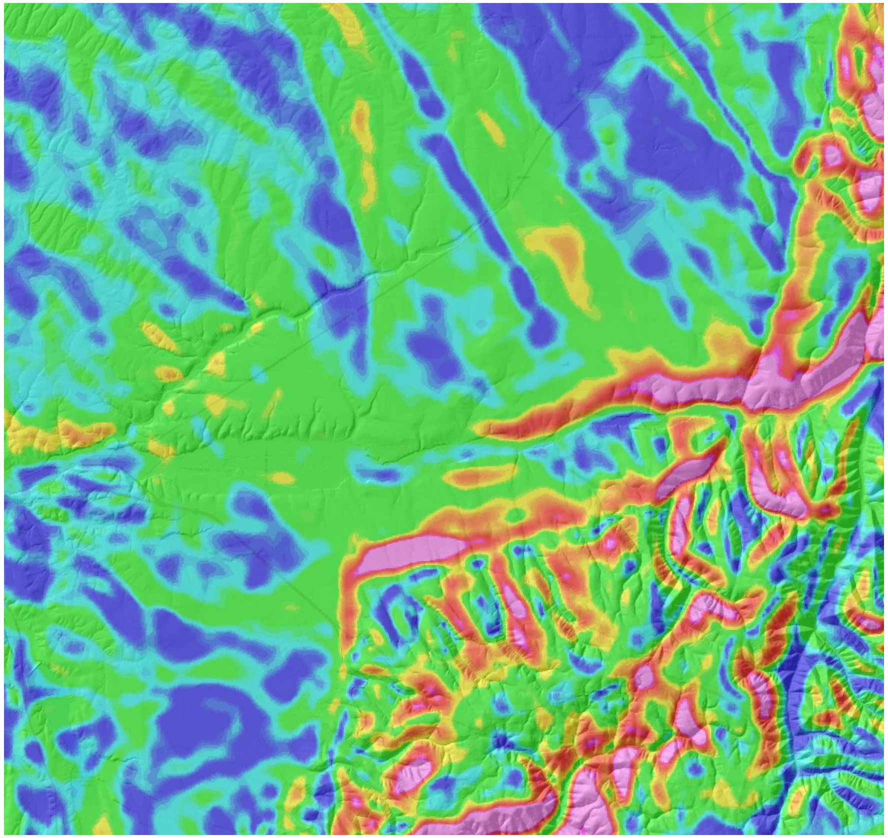


Blakely (1995)

Total Magnetic Field Intensity



Horizontal Gradient



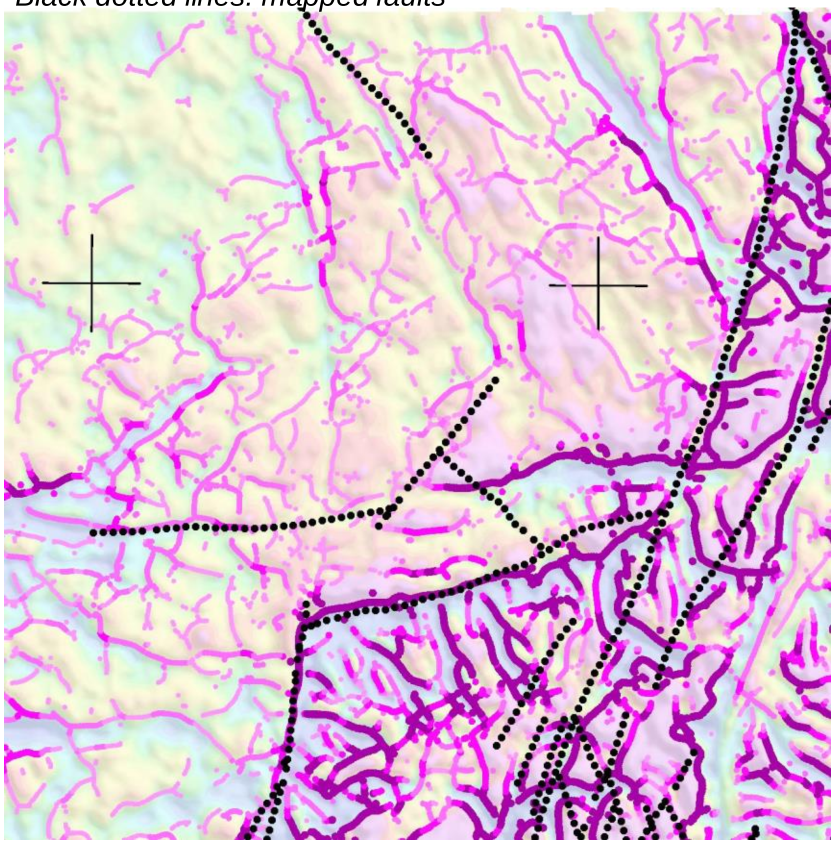
Geophysical Structure

inferring geophysical contacts from anomalies

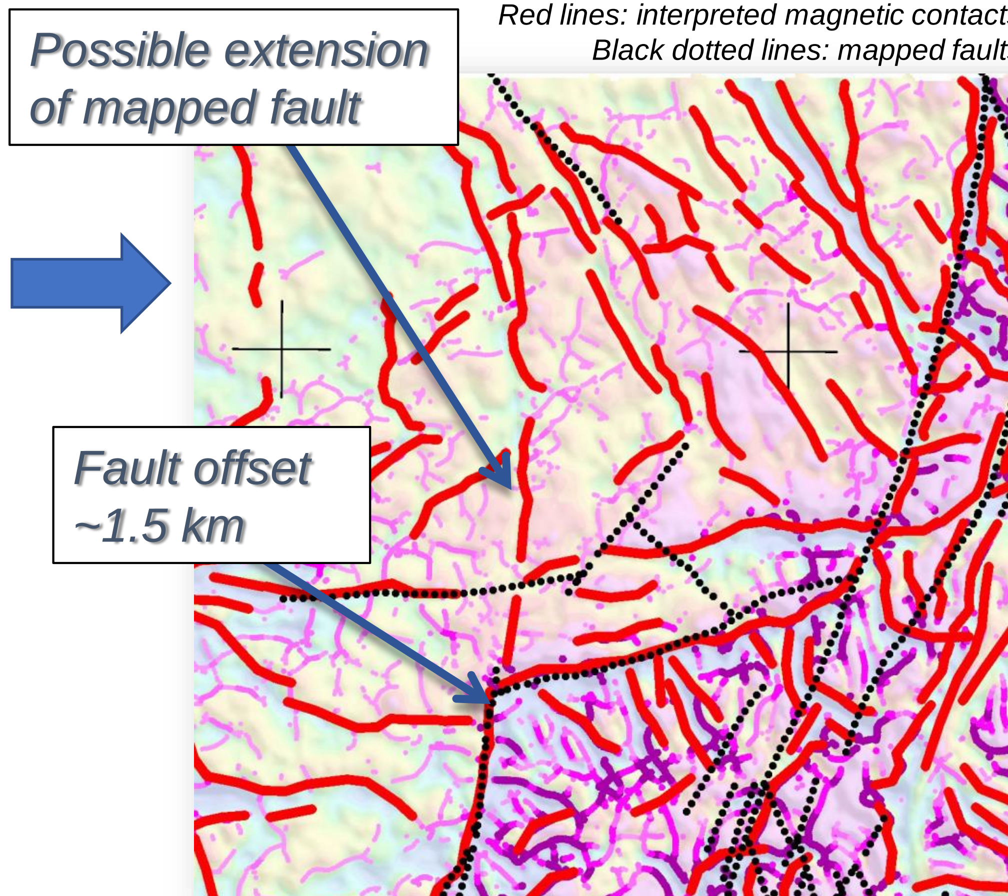
Structural features interpreted from Maximum Horizontal Gradients

magnetic contacts reflect features such as faults, dikes, flow margins, erosional features, …

Pink "lines": magnetic Horizontal Gradient Maxima
Black dotted lines: mapped faults

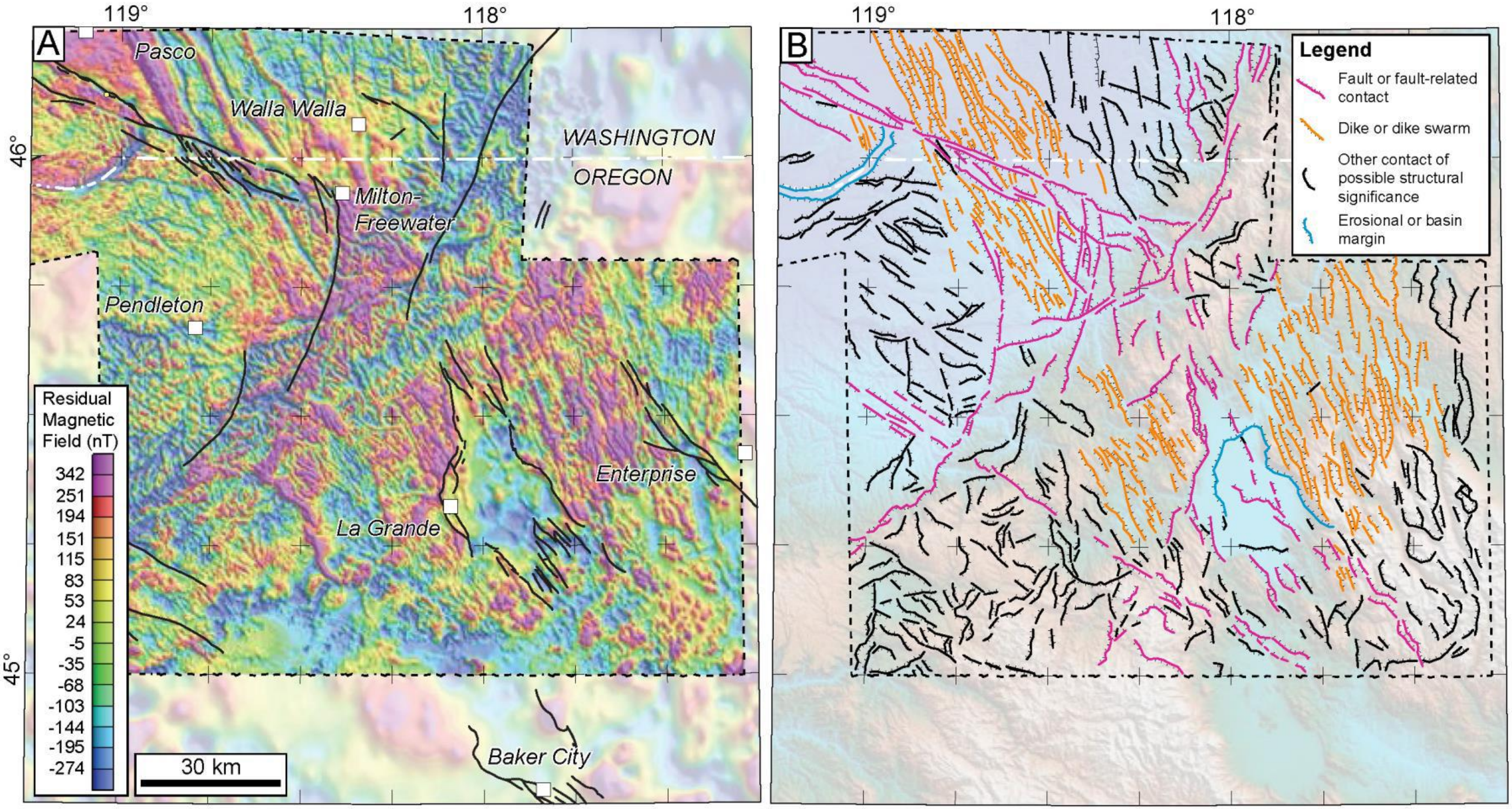


Red lines: interpreted magnetic contacts
Black dotted lines: mapped faults



Geophysical Structure

- *Map structural grain*
- *Map faults and dikes*
- *Delineate geophysical domains*
- *Identify cross-cutting relations*
- *Document piercing points and fault offsets*



USGS

Questions?

We always welcome your feedback.

DOE.geothermal@ee.doe.gov

The **Geothermal Technologies Office (GTO)** works to reduce the cost and risk associated with geothermal development by supporting innovative technologies that address key exploration and operational challenges.

By advancing the value stream for grid (electricity) production and deep direct-use, GTO aims to make geothermal energy a cost-competitive, widely available, geographically diverse component of the national energy mix.

Visit us at: www.energy.gov/eere/geothermal