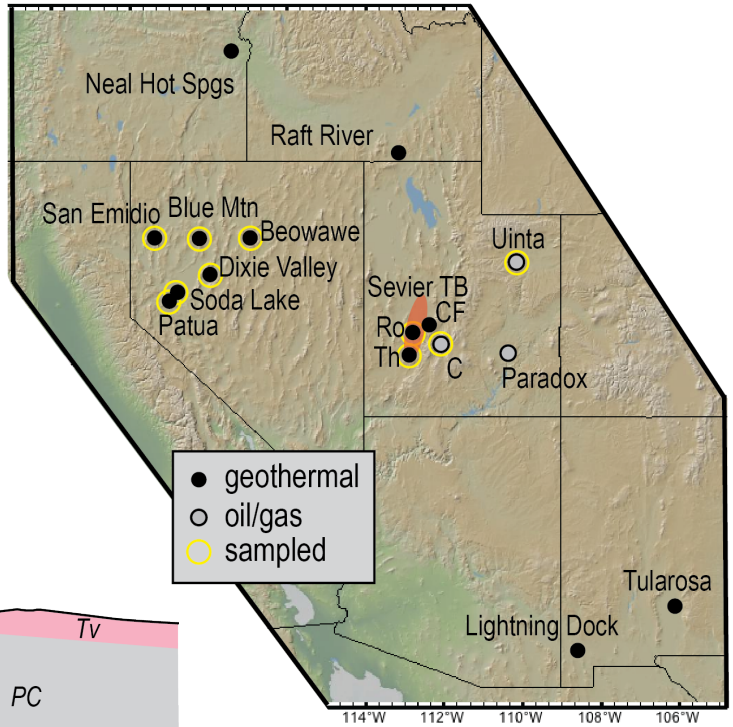
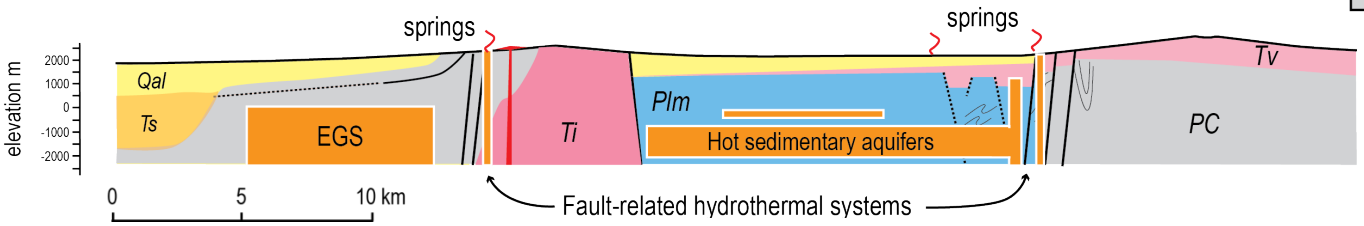
Strategic, Critical and Valuable Materials
Produced Waters-Geothermal & Oil-Gas Wells

metals:	Ag, Co, Ga, Ge, In, Ir, Nb, Os, Pd, Pt, Re, Rh, Ru, Se, Te
REE:	Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Pr, Nd, Sc, Sm, Tb, Tm, Y, Yb
alkali metals :	Li
noble gases:	He, ^{3}He





Western USA Assessment of High Value Materials in Geothermal & Produced Fluids

Project Officer: Holly Thomas
Total Project Funding: $606,701
November 15, 2017

Stuart Simmons
EGI, University of Utah

Mineral Recovery

Relevance to Industry Needs and GTO Objectives

Objectives

- Quickly build a public, western USA resource assessment of dissolved critical and high-value materials in production fields, using expertise in geologic regimes as well as sampling and analysis.
- Advance geothermal energy conversion processes by characterizing the concentrations and availabilities of SCVM in geothermal and hydrocarbon reservoirs in the western USA.
- Sample and analyze production fluids and rocks from a number of fields, ranging from 50-250° C.
- Integrate results with information on reservoir volumes to calculate the grades and inventories of strategic, critical, and valuable minerals (SCVM) across the Great Basin, in the Colorado Plateau, and in the Rio Grande Rift.

Relevance to Industry Needs and GTO Objectives

- The results provide insights to chemical, thermal, and geological controls on dissolved SCVM.
- These data and interpretations are being compared to geological information of known SCVM deposits in the USA.
- The project aims to provide fundamental knowledge that may add revenue streams to production of intermediate to low grade geothermal resources, in addition to basic energy production

Strategic, Critical and Valuable Materials Produced Waters-Geothermal & Oil-Gas Wells

alkali metals :	Li
noble gases:	He, ^{3}He
metals:	Ag, Co, Ga, Ge, In, Ir, Nb, Os, Pd, Pt, Re, Rh, Ru, Se, Te
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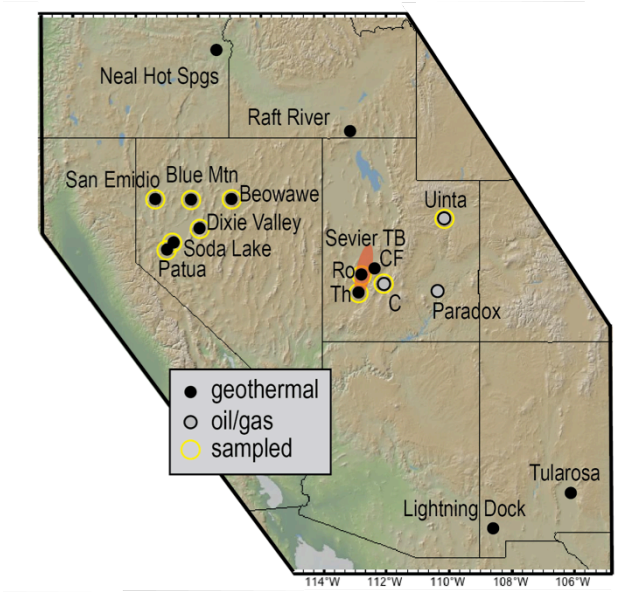

Methods/Approach

- Sample and analyze production fluids and rocks from a number of fields, ranging from 50-250° C.
- Integrate concentration data with information on reservoir volumes to calculate the grades and inventories of SCVM in the Great Basin, the Colorado Plateau, and the Rio Grande Rift reservoirs.
- Evaluate the chemical, thermal, and geological controls on hydrothermal transport of SCVM through comparative analysis.
- Assess data and interpretations with geological information and origins of SCVM deposits in the USA and the rest of the world.

Methods/Approach

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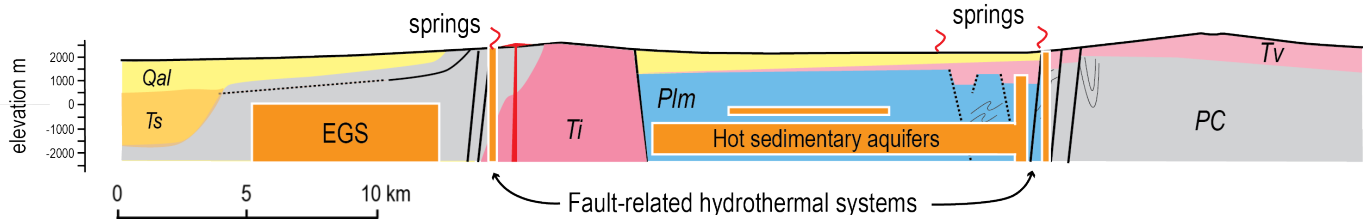
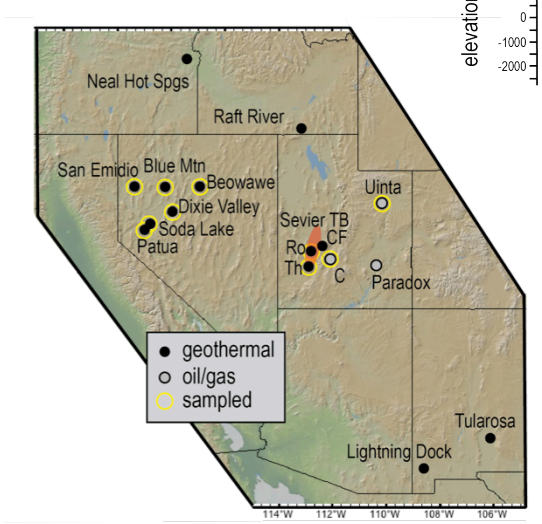
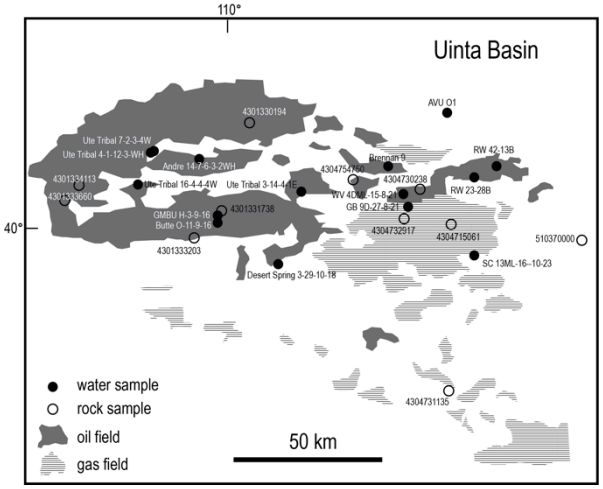
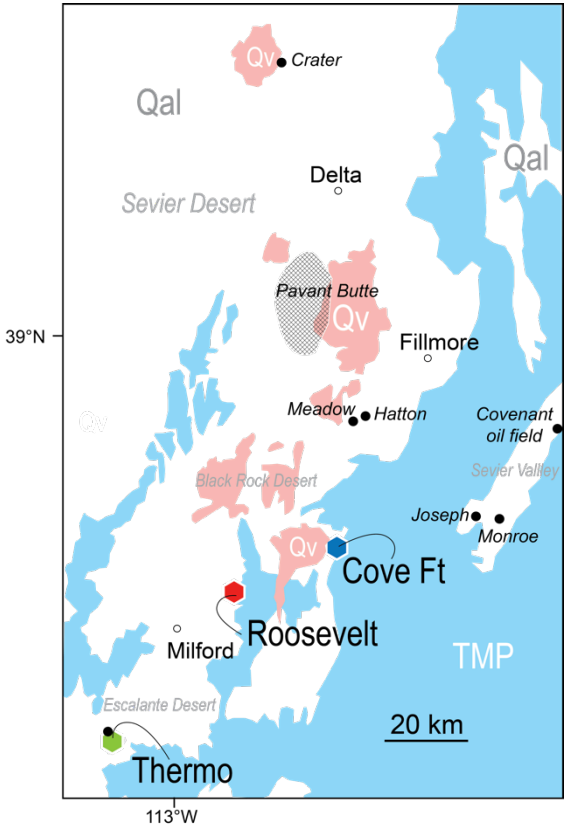
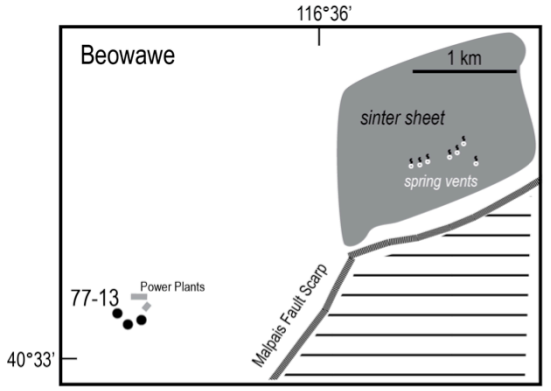
Study Areas

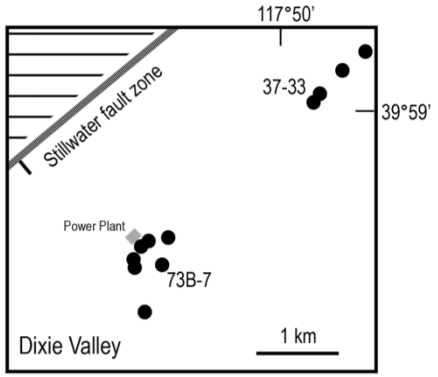








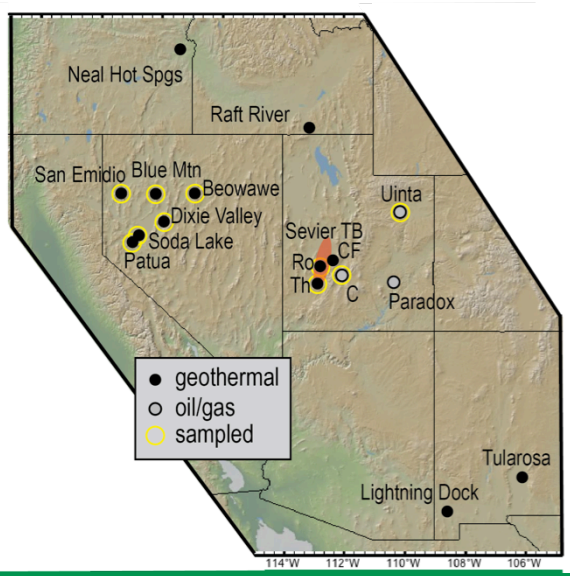




Methods/Approach

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

- The inventories and grades of SCVM in geothermal reservoirs from eight sites in Nevada and Utah have been measured, calculated and tabulated.
- The inventories and grades of SCVM in the Uinta basin are measured, calculated, and tabulated.
- All first year Milestones achieved, all data uploaded to GDR



Analytes-Fluids (48 samples)

Major species: pH, Li, Na, K, Ca, Mg, SiO_2, Cl, F, SO_4, HCO_3
Trace Elements: Rb, Sr, Cs, Al, Sc, Mn, Fe, Co, Ni, Cu, Ga, Ge, As, Se, Y, Nb, Mo, Ru, Rh, Pd, Ag, Cd, In, Sb, Te, Ta, W, Re, Ir, Pt, Au, Tl, Pb, U, Th
Gases: H_2O, CO_2, H_2S, CH_4, H_2, O_2, He, Ar, N_2
noble gas isotopes: $^3He/^4He$

University of Minnesota Geochemistry Lab

Ion chromotography: Cl, F, SO_4
ICP-OES: Li, Na, K, Ca, Mg, SiO_2
ICP-MS (HNO_3-HCl-HF matrix): Ge, Sr, Nb, Mo, Ru, Rh, Pd, In, Sb, Te, Ta, W, Re, Ir, Pt & Au
ICP-MS (HNO_3 matrix): Al, Sc, Mn, Fe, Co, Ni, Cu, Ga, As, Se, Rb, Y, Ag, Cd, Cs, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Tl, Pb, Th, & U

Utah Public Health Laboratory

Alkalinity titration & electrode: pH & HCO_3

University of New Mexico Geochemistry Lab

Wet chemical titration: CO_2, H_2S,
Gas chromotography: CH_4, H_2, O_2, He, Ar, N_2

University of Utah Noble Gas Lab

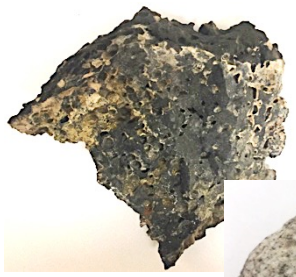
Mass spectrometry: noble gases & $^3He/^4He$

Analytes-Rocks (73 samples)

Lithology, Mineralogy, & Trace Elements:
Drill cuttings: Beowawe, Dixie Valley, & Roosevelt Hot Springs
Calcite scales: Dixie Valley
Travertine: Hatton-Sevier Thermal Belt
Drill core-reservoir & source rocks: Uinta Basin

Trace Elements: Sc, Co, Cu, Zn, Ga, Ge, As, Se, Y, Nb, Ru, Rh, Pd, In, Sb, Te, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Re, Ir, Pt, Au, Pb

EGI University of Utah & University of Minnesota Geochemistry Lab



Cove Ft-lava

RHS-granodiorite

Uinta Basin-organic rich carbonate

Beowawe

Dixie Valley

Dixie Valley-Scales

Technical Accomplishments and Progress

- Report on concentrations & inventories of strategic, critical and valuable materials (SCVM) in geothermal & hydrocarbon reservoirs (50-250°C)
- 34 Production well sampled: 8 geothermal fields, Uinta Basin, Covenant oil field, hot springs in the Sevier Thermal Belt; Nevada-Utah.
- Most SCVM aqueous concentrations range from <0.1 to 100 ug/kg

Lithium	1000	to	25,000	ug/kg
Gallium	5	to	10,000	ug/kg
Germanium	2	to	200	ug/kg
Scandium	0.03	to	0.4	ug/kg
Selenium	1	to	80	ug/kg
Tellurium	0.1	to	100	ug/kg
Rhodium	0.1	to	6.0	ug/kg
Iridium	0.1	to	0.3	ug/kg
REEs-Uinta	0.05	to	5.0	ug/kg
REEs-Geothermal	<0.01			ug/kg

Analytical accuracy & precision above detection limits are to within 20%; except As, Ru, Rh, Sb, Te ~50%.

- Roosevelt Hot Springs: 20,000 kg Ge & 7,000,000 kg Li
- Patua: 25,000 kg Ga, 220 kg Sc, 47,000 kg Se & 6.5 kg Te
- Uinta: >100,000 kg Ga
- Ga, Ge, Li, Sc, Se, Te concentrations show moderate to strong correlation with temperature and TDS
- High Li in Roosevelt Hot Springs may relate to granitic-gneissic host rocks

All first year Milestones achieved, all data uploaded to GDR

Technical Accomplishments and Progress

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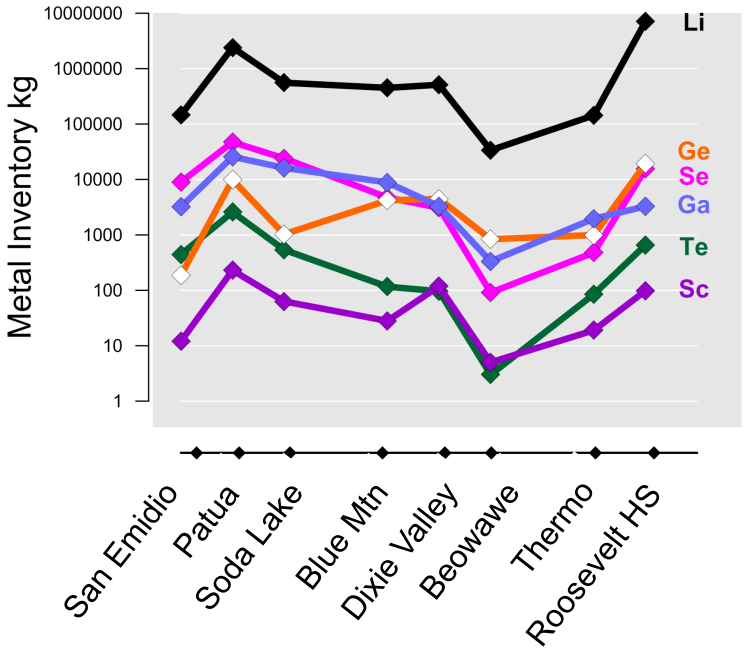
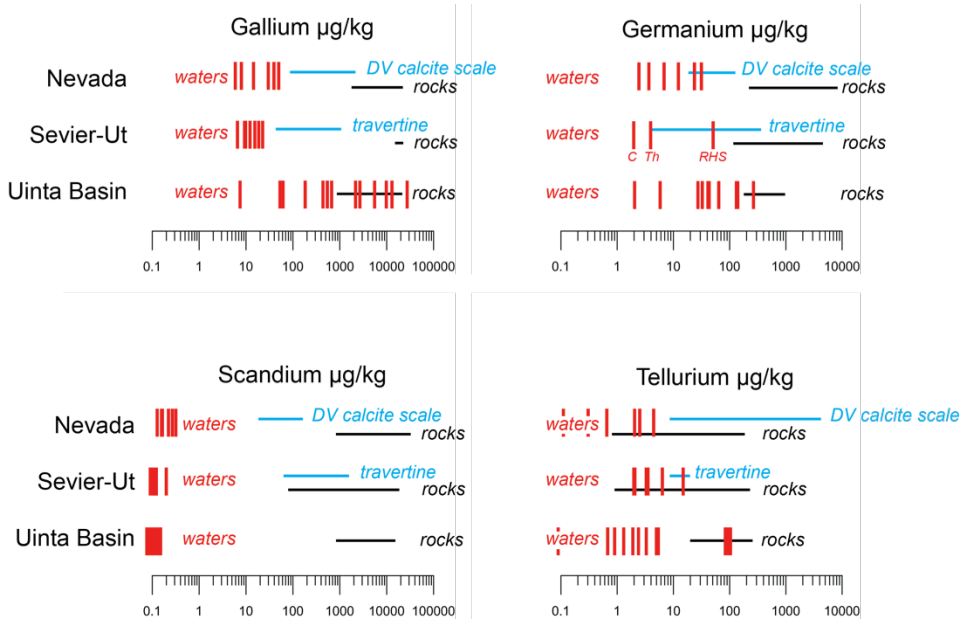
- Calcite scales (Dixie Valley) contain Co, Ga, Au, Pd, Se & Te-boiling
- Comparisons with SCVM deposits suggest brines enable aqueous transport of Ga, Ge, and Li
- Data compiled in 5 Tables-separate Excel Spreadsheets with multiple tabs:
  - Table 1. Field Characteristics
  - Table 2. Geochemistry produced fluids Nevada-Utah
  - Table 3. Geochemistry of Reservoir Rocks, and Calcite Scales, Nevada-Utah
  - Table 4. Lithology and Mineralogy of Drill Cuttings
  - Table 5. Geological Settings of Critical Metal Mineral Deposits.





Results-Waters & Rocks

Technical Accomplishments and Progress

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
1.1: Tabulated analytical results in produced thermal fluids from Nevada and Utah	1.1: Tabulated analytical results in produced thermal fluids from Nevada and Utah	8/17
1.2: Tabulated analytical results in reservoir rocks from Nevada and Utah.	1.2: Tabulated analytical results in reservoir rocks from Nevada and Utah.	8/17
1.3 Tabulated SCVM grades/ inventories in Nevada and Utah geothermal reservoirs.	1.3 Tabulated SCVM grades/ inventories in Nevada and Utah geothermal reservoirs.	8/17

Technical Accomplishments and Progress

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
2.1: Tabulated analytical results of fluids from the Sevier thermal belt.	2.1: Tabulated analytical results of fluids from the Sevier thermal belt.	8/17
2.2: Tabulated analytical results of rocks from the Sevier thermal belt.	2.2: Tabulated analytical results of rocks from the Sevier thermal belt.	8/17
2.3: Topical report on processes controlling SCVM hydrothermal transport in the Sevier thermal belt. Part 1	2.3: Topical report on processes controlling SCVM hydrothermal transport in the Sevier thermal belt. Part 1	8/17

Technical Accomplishments and Progress

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
3.1: Tabulated analytical results in formation fluids from Uinta basin	3.1: Tabulated analytical results in formation fluids from Uinta basin	8/17
3.2: Tabulated analytical results in reservoir rocks from Uinta basin.	3.2: Tabulated analytical results in reservoir rocks from Uinta basin.	8/17
3.3: Tabulated SCVM grade/ inventory for Uinta basin	3.3: Tabulated SCVM grade/ inventory for Uinta basin	8/17
4.1: Topical report on comparison of results with other SCVM deposits. Part 1	4.1: Topical report on comparison of results with other SCVM deposits. Part 1	6/17

Research Collaboration and Technology Transfer

- A paper on preliminary results will be presented at the Stanford Geothermal Workshop

- There are no efforts underway to transition technology to the private sector, as this project involves resource assessment only.

Future Directions

- Execute year two planned activities, including sampling and analysis of fluids from Neal Hot Springs, Raft River, Lightning Dock, Tularosa, and the Paradox Basin, as summarized in the milestones tabulated below.

Milestone or Go/No-Go	Status & Expected Completion Date
5.1: Tabulated analytical results in produced thermal fluids from Idaho, New Mexico, and Oregon	field work is underway; 4/18
5.2: Tabulated SCVM grades/ inventories in Idaho, New Mexico, and Oregon geothermal reservoirs	waiting for samples and analyses; 6/18
6.1: Topical report on processes controlling SCVM hydrothermal transport in the Sevier thermal belt. Part 2.	analysis is underway; 1/18

Future Directions

Milestone or Go/No-Go	Status & Expected Completion Date
7.1: Tabulated analytical results in formation fluids from Paradox basin.	field work is underway; 4/18
7.2: Tabulated analytical results in reservoir rocks from Paradox basin	waiting for samples and analyses; 6/18
7.3: Tabulated SCVM grade/ inventory for Paradox basin	waiting to complete 7.1 & 7.2; 1/18
8.1: Topical report on comparison of results with other SCVM deposits. Part 2	analysis in progress; 6/18

Mandatory Summary Slide

- All year one milestones achieved, including sampling, analysis, and preliminary interpretation of results from 8 geothermal fields (NV-UT) and the Uintah basin
- No impediments to completing year two milestones, including sampling, analysis, and interpretation of results from 4 geothermal fields (ID, NM, OR) and the Paradox basin.

Additional Information

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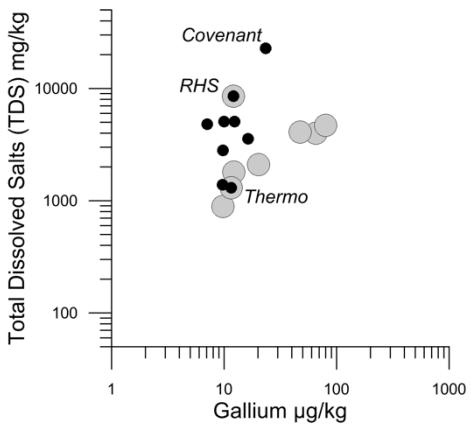

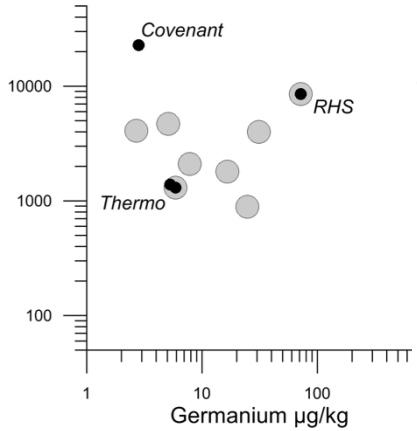

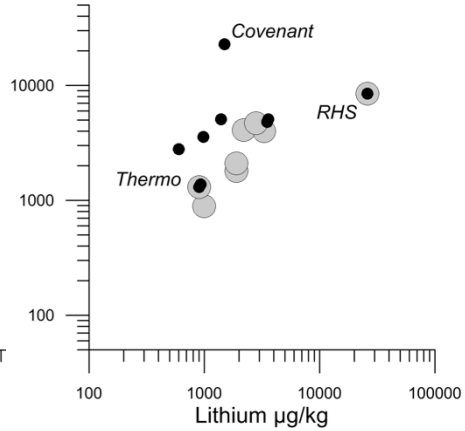

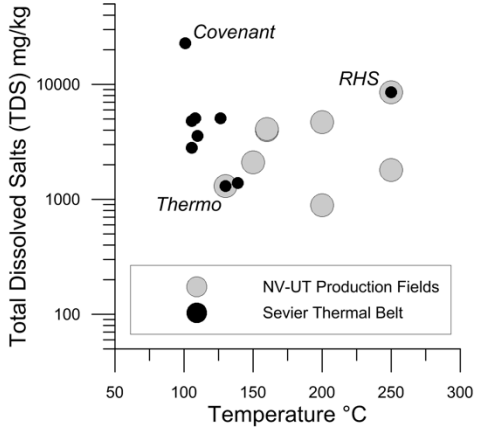

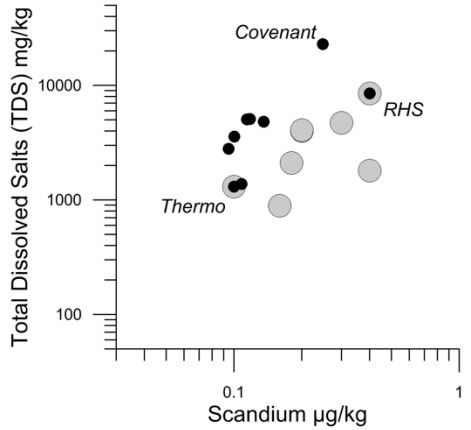

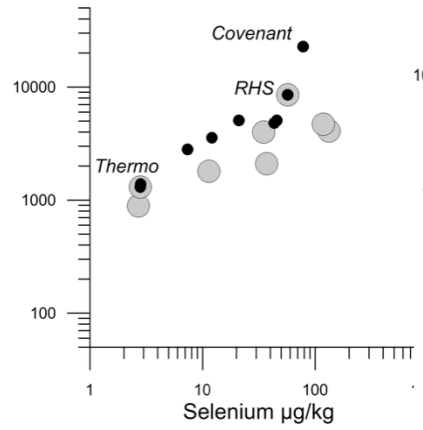

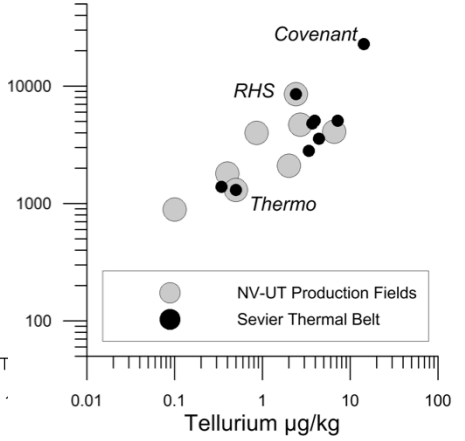

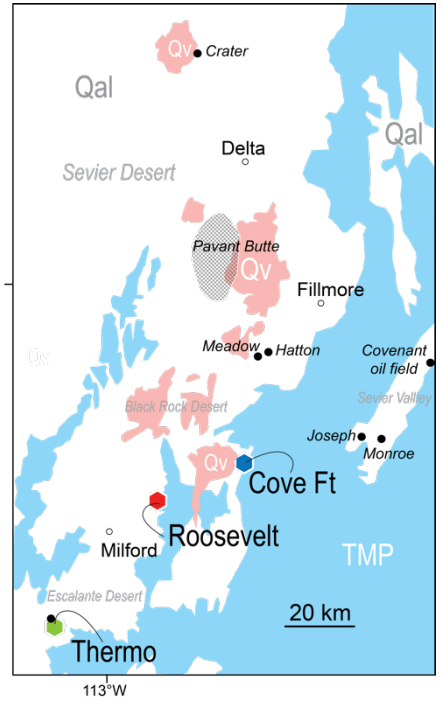

- Te shows strongest correlation with TDS (Covenant), followed by Sc & Se
- Li shows strong correlation with TDS, omitting Covenant
- Ga & Ge show poor correlation with TDS