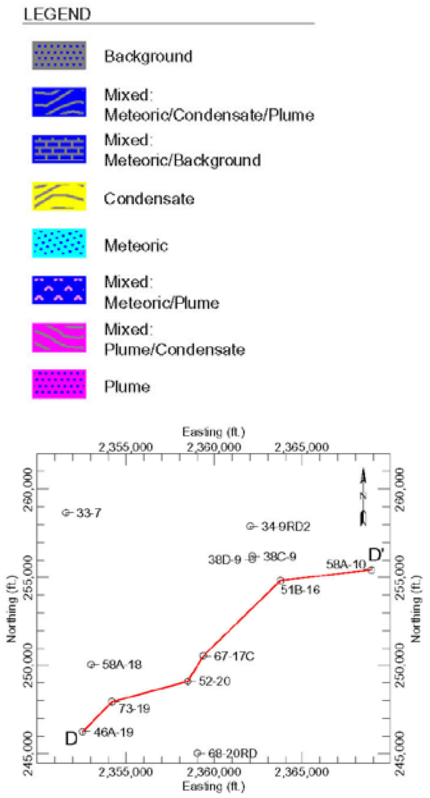
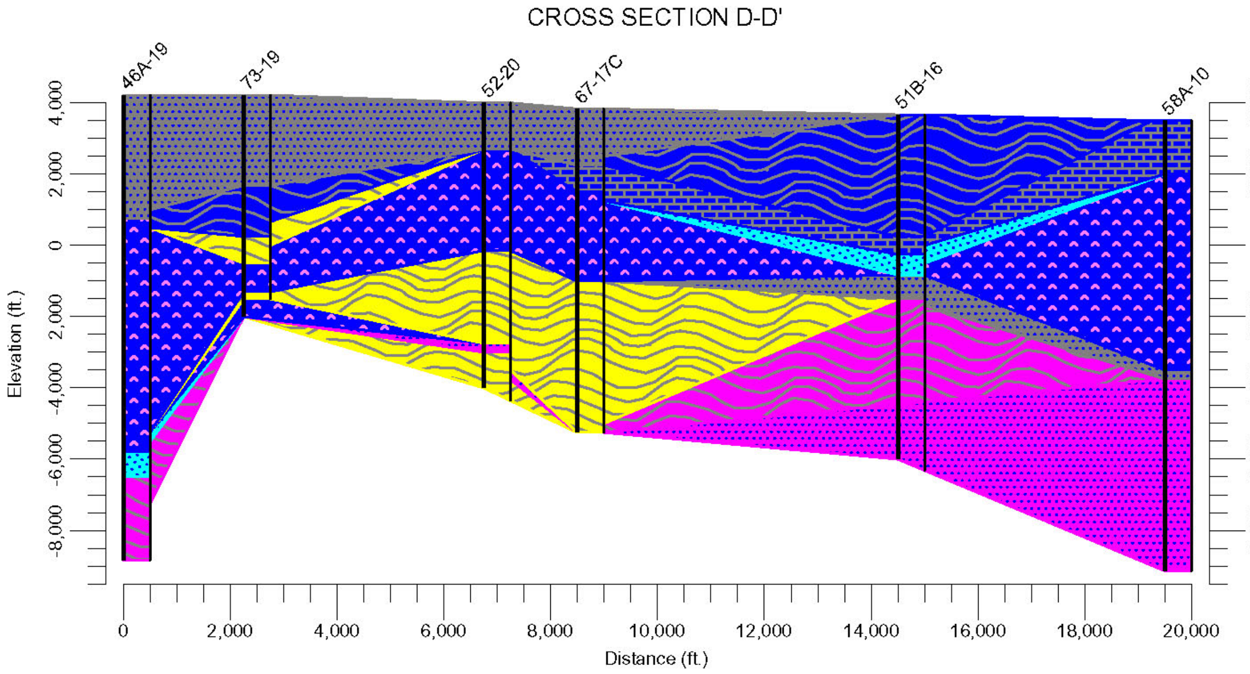




Fluid types interpreted from fluid inclusion gas chemistry across Coso geothermal system

Methodologies for Reservoir Characterization Using Fluid Inclusion Gas Chemistry

Project Officer: Ava Coy

Total Project Funding: $414,000

April 25, 2013

Lorie M. Dilley

Hattenburg Dilley & Linnell

Track Name: Geochemistry

Relevance/Impact of Research

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

- Purpose of this project is to test and validate the application of fluid inclusion gas signatures as a tool for evaluating the chemical, thermal, and permeability characteristics of geothermal reservoirs:
- GOALS:
  - ➢Gather existing well data into a data template and submit to the National database
  - ➢Evaluate existing well data and determine if additional sampling is needed, conduct additional sampling.
  - ➢Evaluate Fluid Inclusion Stratigraphy (FIS) signatures based on processes affecting the fluids (boiling, mixing, condensation, and conductive cooling) and fluid/rock interactions.
  - ➢Evaluate the differences between low temperature and high temperature systems in terms of the fluid processes.
  - ➢Evaluate the relationship between the fluid inclusion gas signatures and rock types, vein mineralogy, geologic environment and temperature.
  - ➢Develop methodologies for interpretation of the fluid inclusion gas data in order to identify fluid types, regions of permeability, and geothermal processes.

Relevance/Impact of Research

- Stated Goal of FOA was to gain an understanding of permeability using chemical signatures and fluid/rock interactions to improve reservoir sustainability.
  - We will through this project determine how various geochemical processes including boiling, mixing, and condensation are represented by gas signatures
- Project will assist GTP in meeting strategic goal of decreasing the levelized cost of electricity.
  - Fluid inclusion gas chemistry can provide information on fluid types, reservoir processes and locations of productive fractures
  - This information will allow geothermal operators to optimize well testing decisions, well completion strategies, and resource calculations and assist in targeting fracture enhancement locations.
  - Already has in several cases.

Scientific/Technical Approach

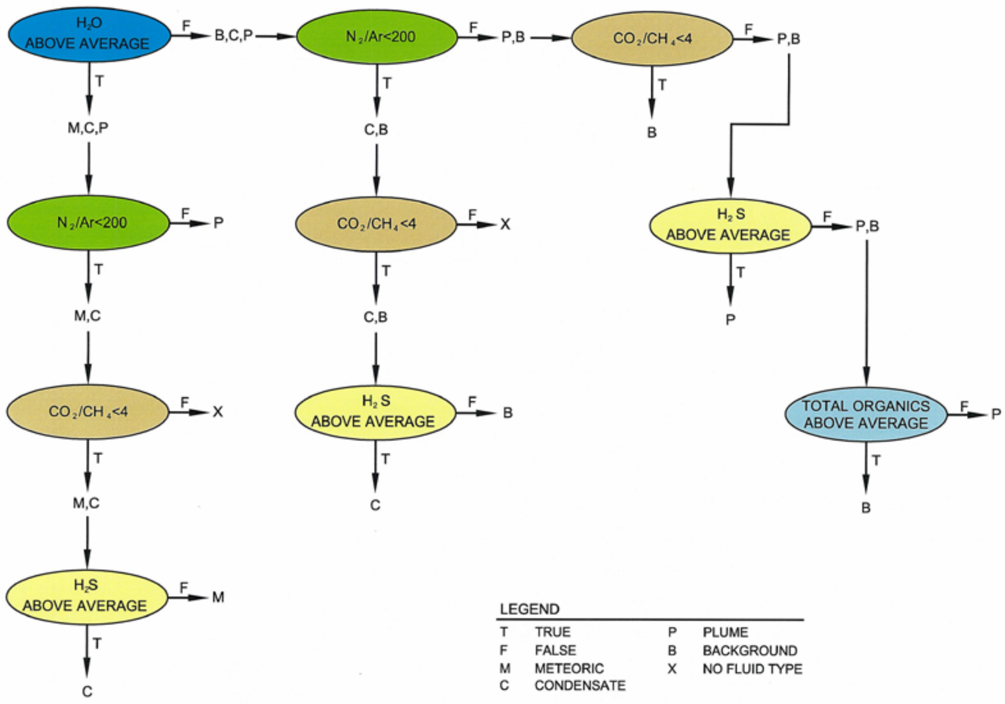
- The tasks for this project include:
  - Gathering of data and collection of additional samples if needed
  - Geochemical analyses – fluid inclusion gas analysis identifies fluid types – does FIS arrive at same conclusion as other geochemical methods developed for gases from wells and vents
    - Timing of fluid inclusions – how young are these inclusions – are we using present day fluid inclusions
    - Ratios of CO2/CH4, N2/Ar, and H2S identify fluid types
    - Identify boiling, meteoric, plume fluids
    - Role of hydrocarbons – identify temperatures based on alkane/alkene ratios or aromatics
    - Behavior in different systems
  - End of Phase 1 Go/No go decision

Scientific/Technical Approach

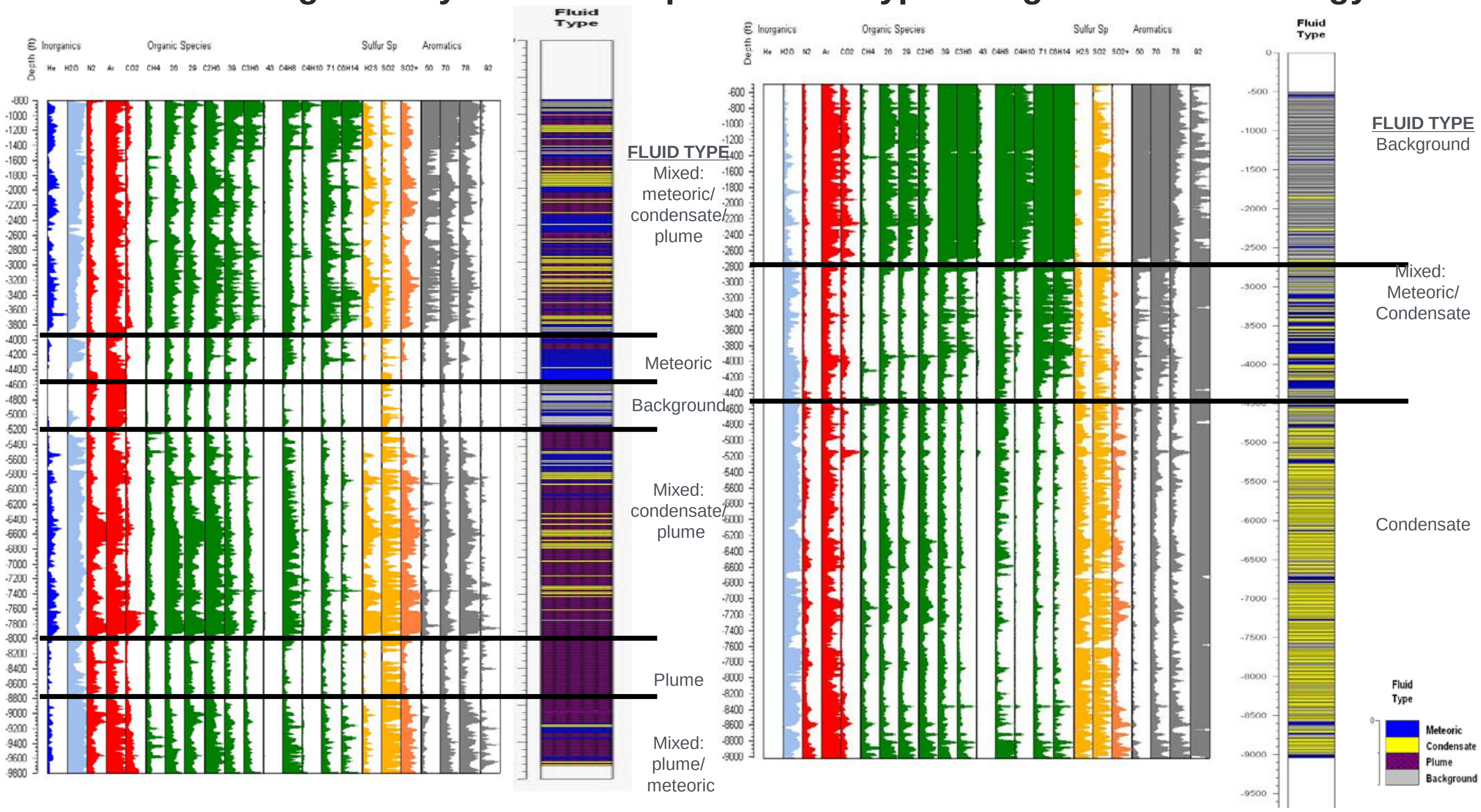
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Phase 2:
  - Geologic interpretation of fluid inclusion data – different gas signatures for different environments
  - Data Integration – Assess the relationship between gas compositions, rock type, degree of alteration, temperature, and FIS signatures
  - Create Methodologies

Methodology for Coso



Fluid inclusion gas analysis and interpreted fluid type using Coso Methodology



Accomplishments, Results and Progress

COMPLETED: TASK 1: Organized data from existing fields – 10 years of research and various data from multiple geothermal fields:

Systems hosted in granite, basalts, metamorphic rock, and sedimentary rocks. Currently have Coso, Steamboat Springs, Beowawe, Hawthorne, Fallon, El Centro, Salton Sea, Iceland, Medicine Lake, Karaha-Telaga Bodas

- Develop spreadsheet for each well to submit the data to National Database
- Fluid inclusion gas data is in the form of mass spectrometer counts on 160 species for each sample - samples were typically collected every 20 feet in wells. There are over 30 wells. – Excel spreadsheets
- Completed submission of data – done with Task 1

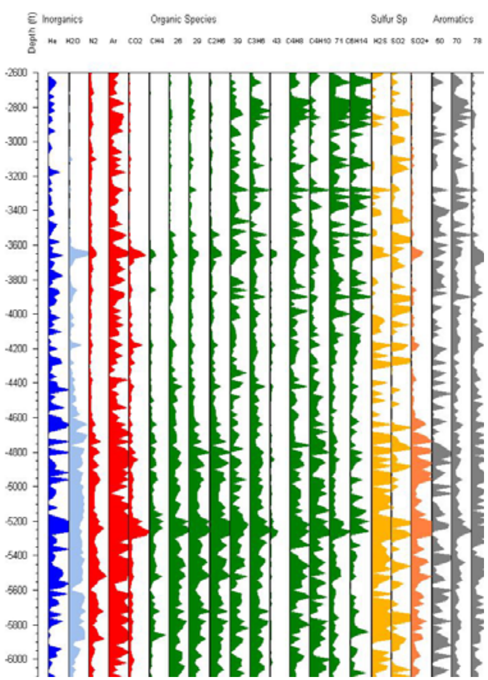
70% COMPLETED – TASK 2 – Evaluate existing data determine data gaps and what systems were lacking

- sample only one more system – Hawaii – high temperature basalt
- started in March complete – May
- Additional wells from US Navy program – June/July – useful but not waiting on them.

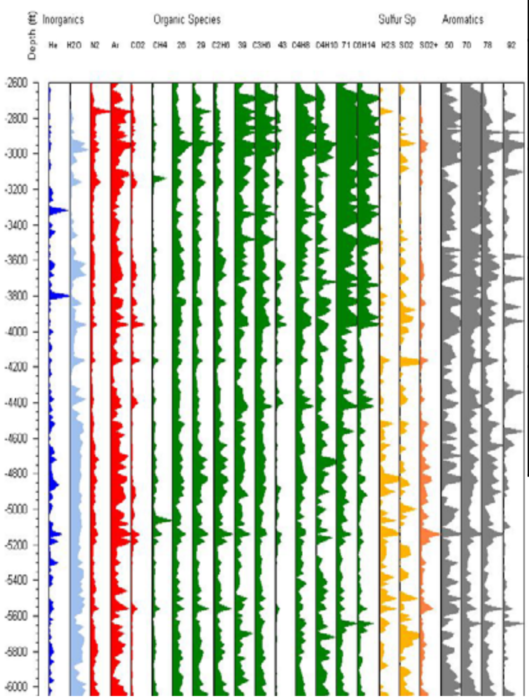
Accomplishments, Results and Progress

50% COMPLETED – TASK 3: GEOCHEMICAL ANALYSES – Timing of fluid inclusions and impact on fluid types: FIS analysis is using modern day fluid inclusions not inclusions from prior events:

Well 68-20



Well 68-20RD



Species	Original Well	Redrill Well	% Change
H_2O (overall)	3.3×10^6	5.7×10^6	+74
CO_2 (overall)	2.6×10^6	2.1×10^6	-18
H_2O (break)	4.68×10^5	4.26×10^6	+810
CO_2 (break)	9.92×10^5	2.11×10^6	+113

Drilled 7 years apart in same location Break in casing from 2700 to 3200 feet – injection sited

Changes in inclusion contents are most pronounced in areas of high fluid flux - Implies that seeing most recent changes in the system

Accomplishments, Results and Progress

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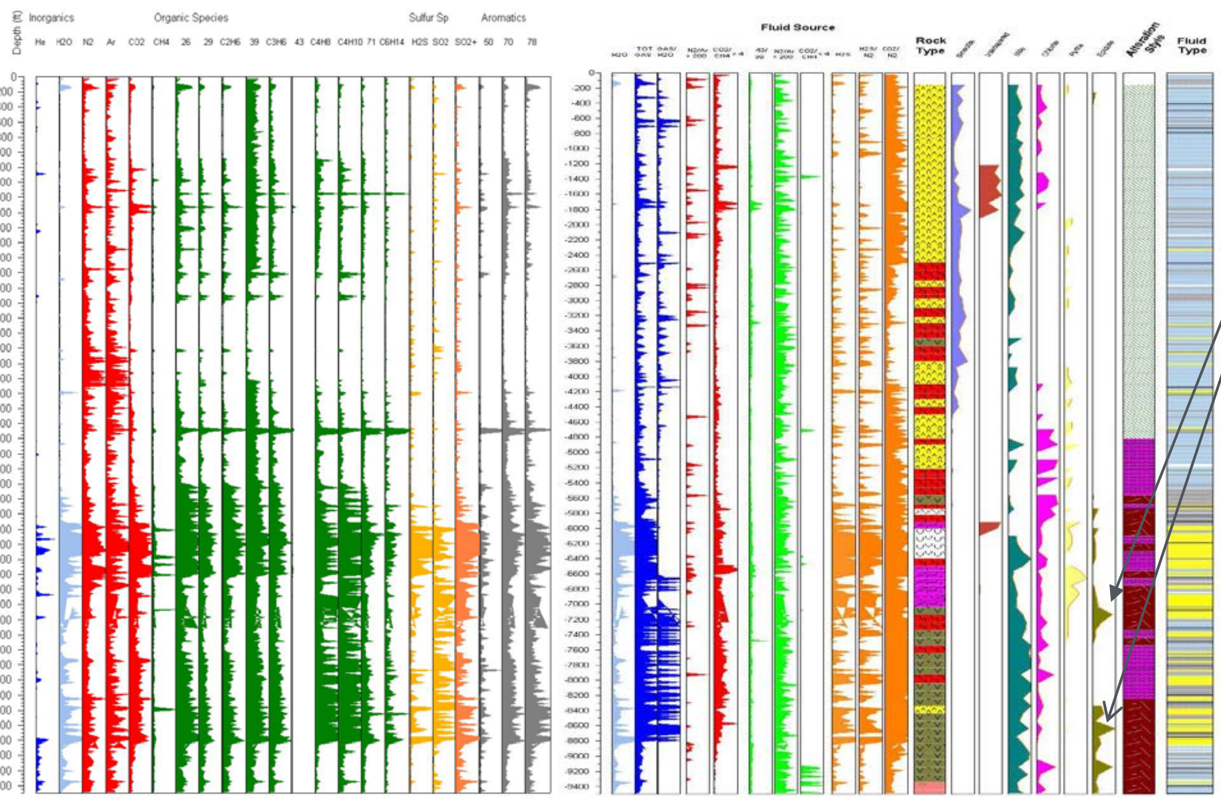
Evaluating low to moderate temperature fields: Fallon and Hawthorne – identified condensate fluids using FIS however fields are not hot enough to produce condensate fluids



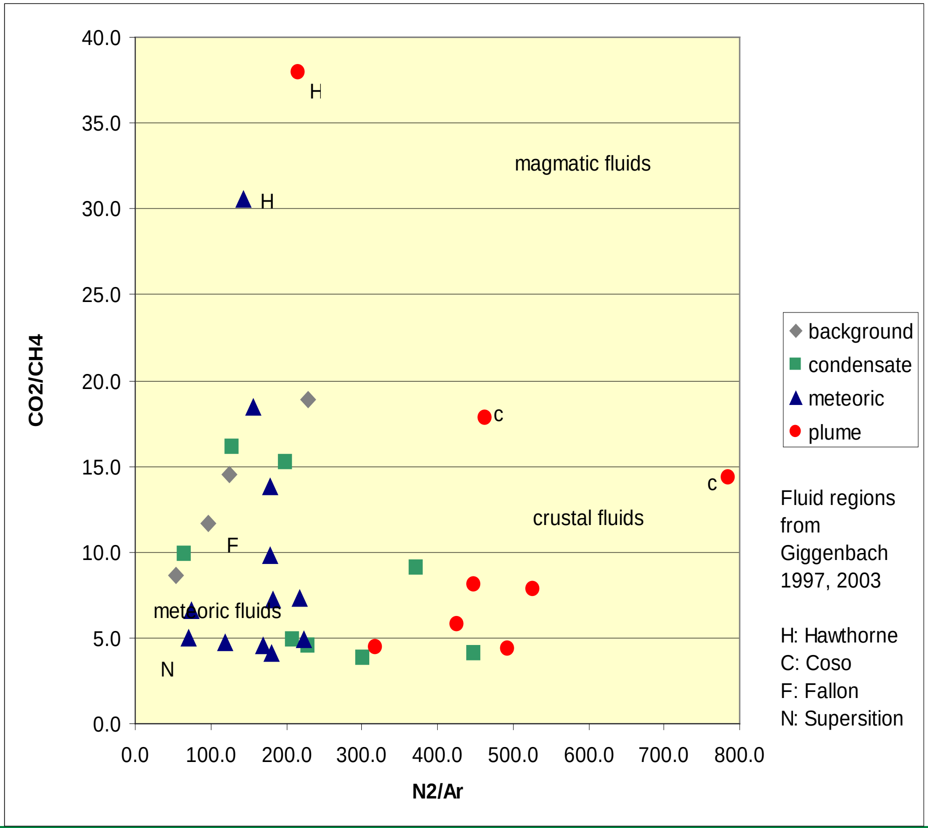
Epidote occus at depth indicating a high temperature event in the past

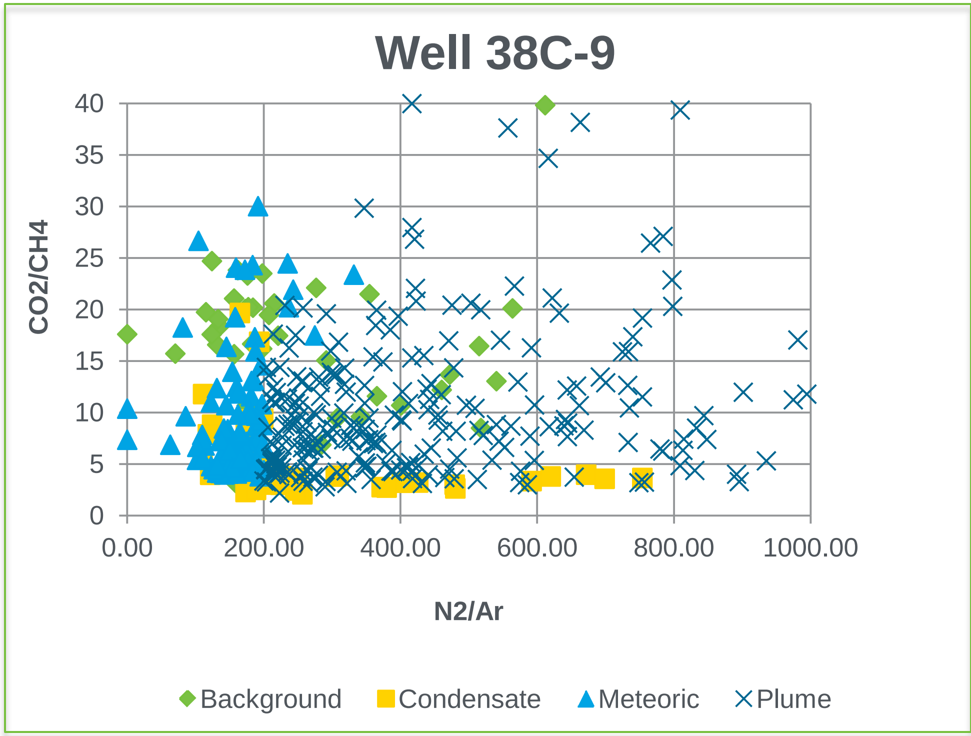
In the case of low-moderate temperature systems: perhaps the fluid inclusions are not destroyed and replaced like in high temperature systems like Coso: Applicability of FIS to low temperature systems

50% COMPLETED – TASK 3: GEOCHEMICAL ANALYSES – compare results from fluid inclusion gas analysis to other methods

Fluids named by FIS analysis based on CO2/CH4 and N2/Ar ratios fit within Giggenbach's 1997 plots of similar ratios for volcanic gases and geothermal wells.

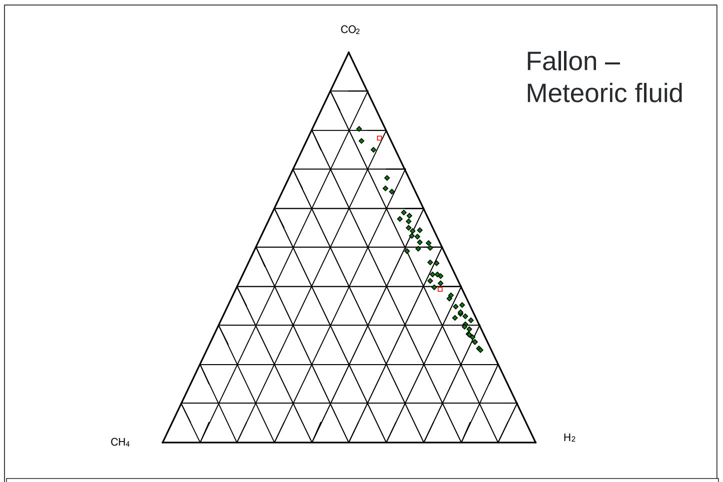
Average value for wells in different fields

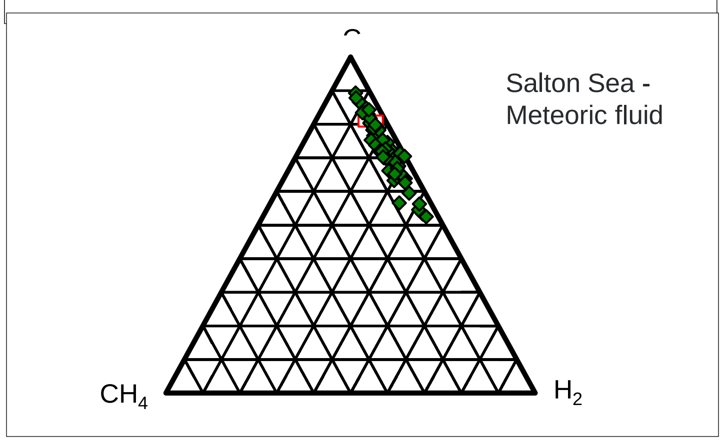


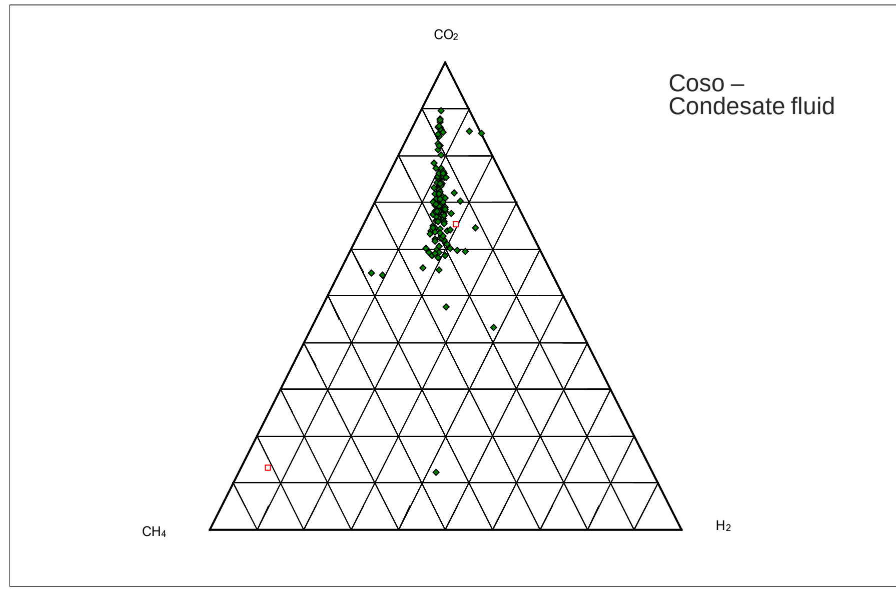


50% COMPLETED – TASK 3: GEOCHEMICAL ANALYSES – compare results from fluid inclusion gas analysis to other methods

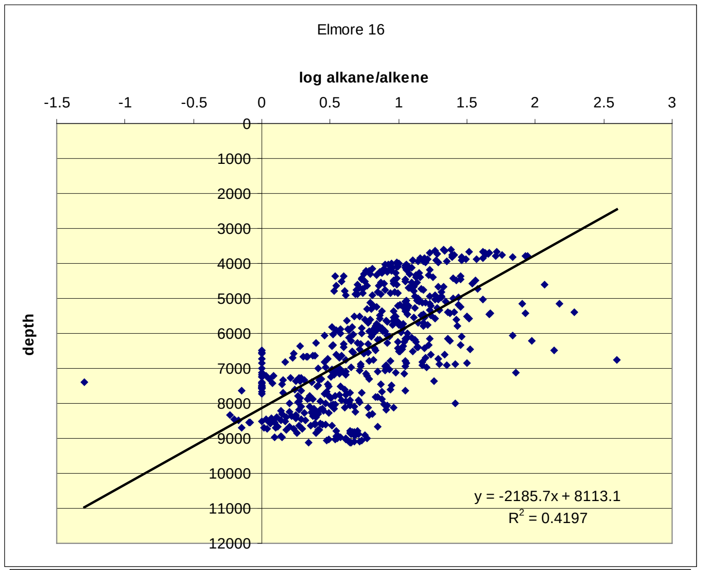
Condensate fluids plot on Ternary diagram as condensate fluid and other fluids are indicated on ternary diagrams.

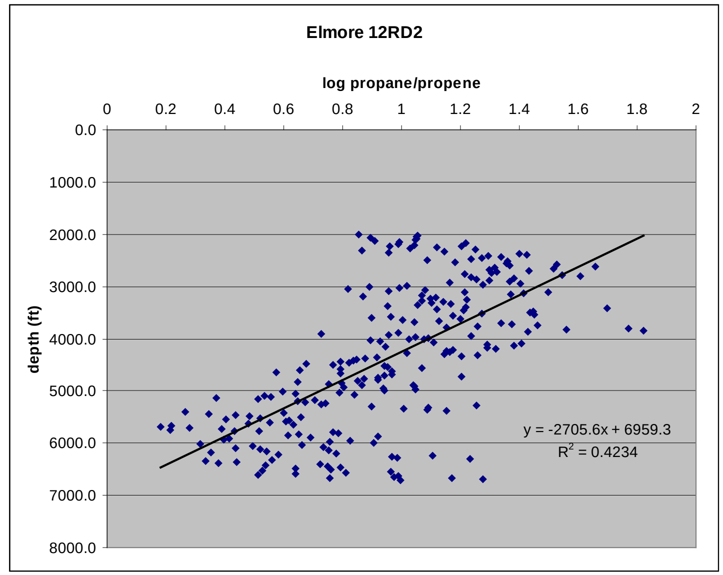


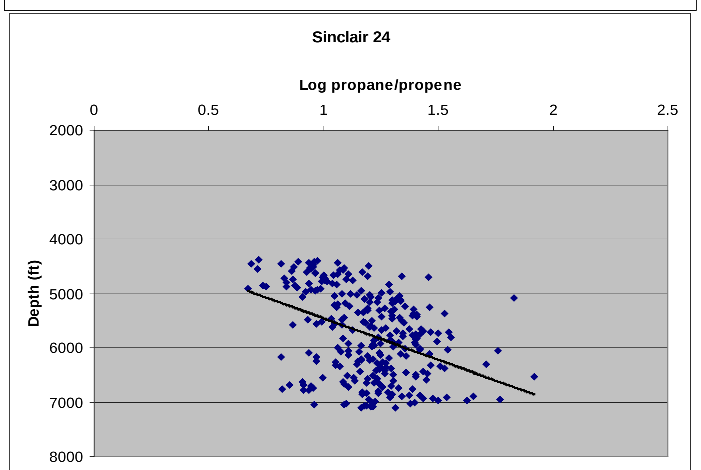




50% COMPLETED – TASK 3: GEOCHEMICAL ANALYSES – Presence of organics at depth in many of the wells – Salton Sea wells since the organics are most likely from the sediments and biogenic.







Elmore wells occur in the hotter portion of the field than the Sinclair well - can this be used for obtaining temperature of fluid based on these ratios. – Depth increases – propane increases

Sinclair propene increase with depth

Accomplishments, Results and Progress

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Organize and create database of existing well data	Created database and submitted to National database	March 2013
Evaluate existing data and determine if additional sampling is needed, conduct sampling	Evaluated data – sample only one field – currently in process of determining which wells to sample	May 2013
Geochemical analysis	Evaluated timing, fluid ratios, fluid types, organics, different systems 50% complete	June 2013

Future Directions

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- Key Activities for Remainder of Project
  - Understand role of organics in systems – can use to obtain temperature and identify fluid
  - Compare data to existing fluid inclusion thermometry data
  - Low temperature systems versus high temperature systems - role of ratios and H_2S, use different ratios – perhaps organics,
  - Evaluate relationship of fluid ratios in other systems – use of N_2/Ar, CO_2/CH_4, H_2S, alkane/alkene, aromatics, other ratios
  - Compare fluid types to alterations, mineralogy, fluid inclusion data, geological environment
  - Develop methodologies based on different systems.

Milestone or Go/No-Go	Status & Expected Completion Date
Task 3: Geochemical Analysis – Go/No-Go decision	50 % complete – end of June 2013
Evaluate geological relationship	10% complete – December 2013
Develop Methodologies	0% complete – March 2014

Mandatory Summary Slide

- FIS is a useful tool for identifying fluid types in high temperature systems
  - boiling/condensate fluids can be identified
  - Ratios of N2/Ar, and CO2/CH4 can be used to identify fluid types
- Organics may be useful tool to estimate temperatures at depth and hence fluid temperatures – may serve a role in low temperature systems to identify fluid types
- Present day fluid inclusions are used in gas analysis in high temperature systems however in low temperature systems may need a different methodology

Project Management

Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
1/1/2012	12/31/2013	3/1/2012	6/1/2014

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$331,000	$82,800	$132,000	$84,000	$157,200	$327,000

- Management of project is streamline – main investigator with additional assistance as needed from support scientist.
- Project is approximately 2 quarters behind schedule due to later start and also evaluations during Task 3 requires additional time.

Additional Information

- This slide is provided in order to allow space for any additional information/images that you would like to share with the Peer Review Panel. Insert this slide wherever you deem it most appropriate.