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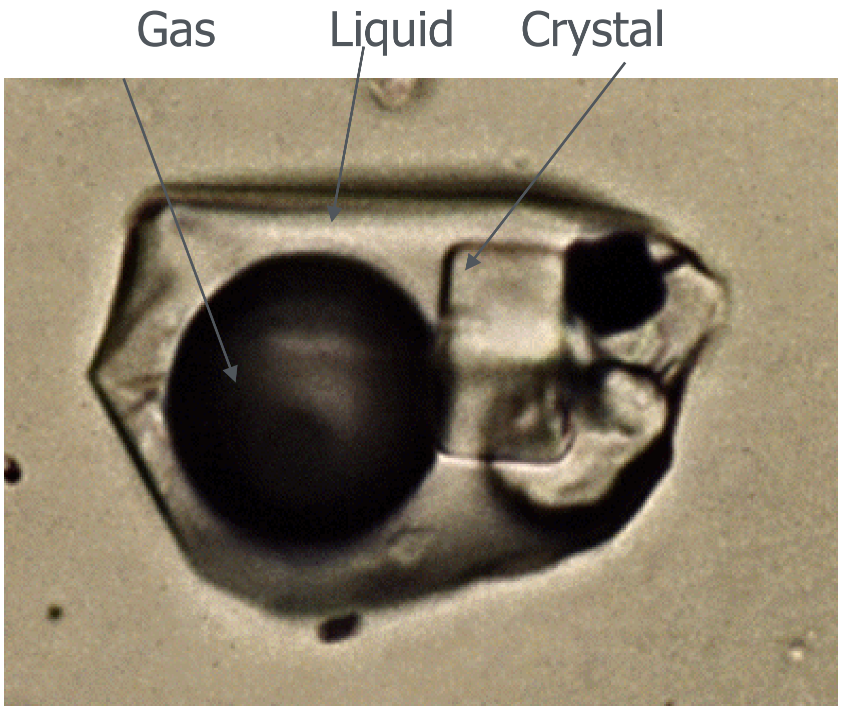

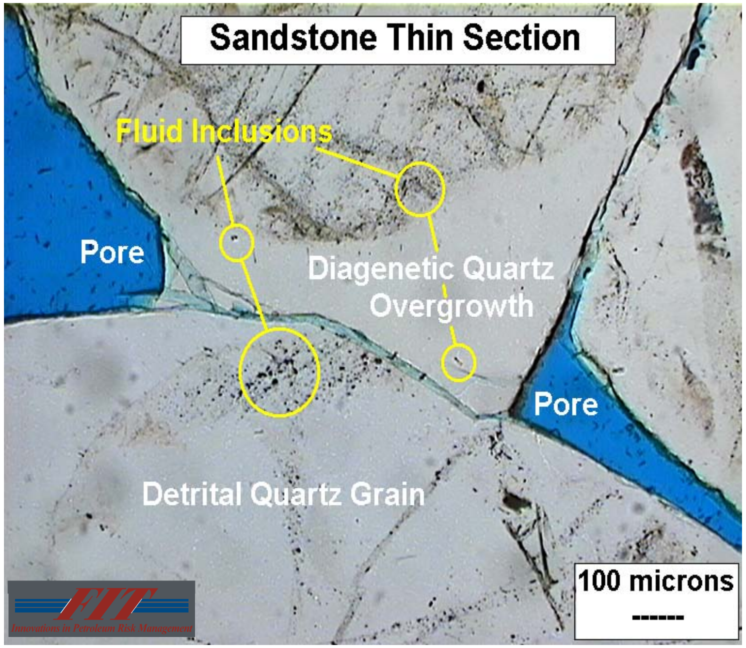

Chemical Signatures of and Precursors to Fractures Using Fluid Inclusion Stratigraphy

May 19, 2010

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Mandatory Overview Slide

- The purpose of this research is to develop a method to identify fracture systems in wells using fluid inclusion gas analysis of drill chips.
  - Timeline
    - Project start date: January 19, 2009
    - Phase 1 completed: January 28, 2010
    - Project end date: June 30, 2010
    - Percent complete: 80%
  - Budget
    - Total project funding: $394,858
    - DOE share: $313,858
    - Awardee share: $81,000
    - Funding received in FY09: $114,668
    - Funding for FY10: $280,190
  - Partners : Energy & Geoscience Institute

Relevance/Impact of Research

•**Primary Objective**: Open fracture systems can be identified by peaks in the fluid inclusion stratigraphy (FIS) signature; that there are differences based on the mineral assemblages and geology of the system; and that there are chemical precursors in the wall rock above open, large fractures.

•**Specific goals for this project are:**

•To build on the preliminary results which indicate that there are differences in the FIS signatures between open and closed fractures by identifying which chemical species indicate open fractures in both active geothermal systems and in hot, dry rock.

•To evaluate the FIS signatures based on the geology of the fields.

•To evaluate the FIS signatures based on the mineral assemblages in the fracture.

•To determine if there are specific chemical signatures in the wall rock above open, large fractures.

Relevance/Impact of Research

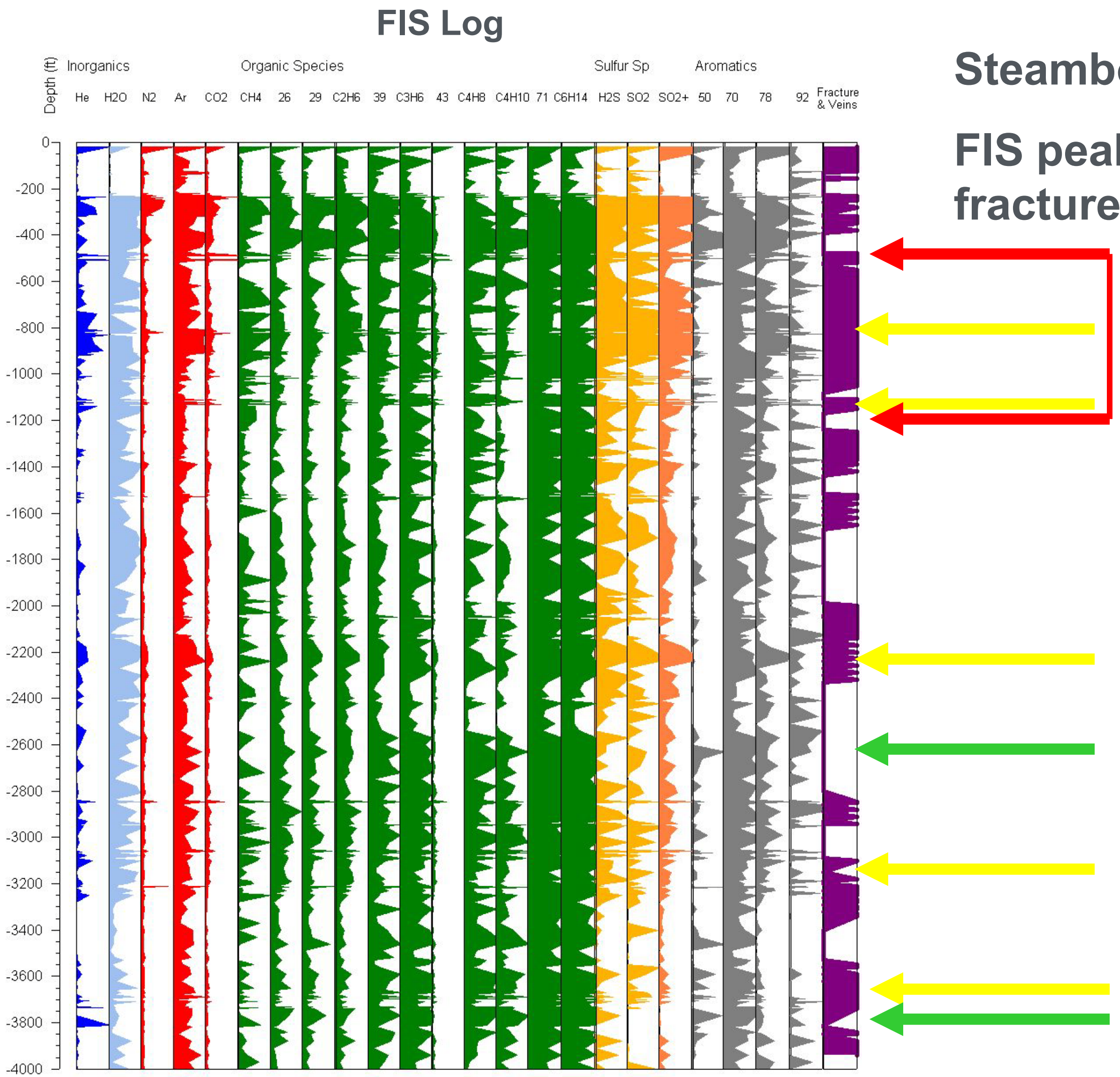
- FIS method is on the order of $5000 to $8000/well. Develop into a low-cost, while drilling tool to identify fractures.
- The FIS method analyzes volatiles in fluid inclusions by mass spectrometry in a highly automated, commercial process. FIS is used in petroleum exploration. Drill cuttings are analyzed and the laboratory analysis and subsequent interpretation can be made in few weeks.
- Knowledge of fracture locations will assist in well testing decisions, completion strategies, resource characterization, and targeting areas for future fracture enhancement.

Scientific/Technical Approach

- Fluid Inclusions are faithful indicators of pore fluid chemistry and are not subject to loss by evaporation.
- Chemical signature of the fluids can be determined by fluid inclusion gas analysis by mass-spectrometery
- Phase 1: Five subtasks:
  - Subtask 1 Review of existing data
  - Subtask 2 Using simple statistics determine which chemical species is highest in known fractures
  - Subtask 3 Evaluate mineral assemblages and changes to the FIS signature
  - Subtask 4 Conduct literature review of epithermal systems to identify potential differences in chemistry between fractures and non-fractures
  - Subtask 5 Identify additional core sampling.
  - Phase 1 report submitted January 2010

Scientific/Technical Approach

- Phase 2: Two tasks:
  - Task 2 Additional Core Logging
    - Sampling of core at 10 foot spacing – Evaluate how the method would work with standard sampling interval during drilling and to determine if fractures could be identified from 10 feet away.
    - Samples collected from additional wells in same field to evaluate how the geology and nature of the field affects the FIS signature.
  - Task 3 Additional Analysis
    - Conduct similar analysis as in Task 1 on new samples
    - Plot noted fractures versus FIS signature to evaluate how often the signature identifies a fracture.
- Completion date is June 30, 2010 but may need an additional quarter to finalize report.



Steamboat Springs Well 87-29

FIS peaks correspond to fracture locations

Yellow arrows indicate FIS peaks corresponding to fractures

Green arrows, FIS peaks but no corresponding fracture

Accomplishments, Expected Outcomes and Progress

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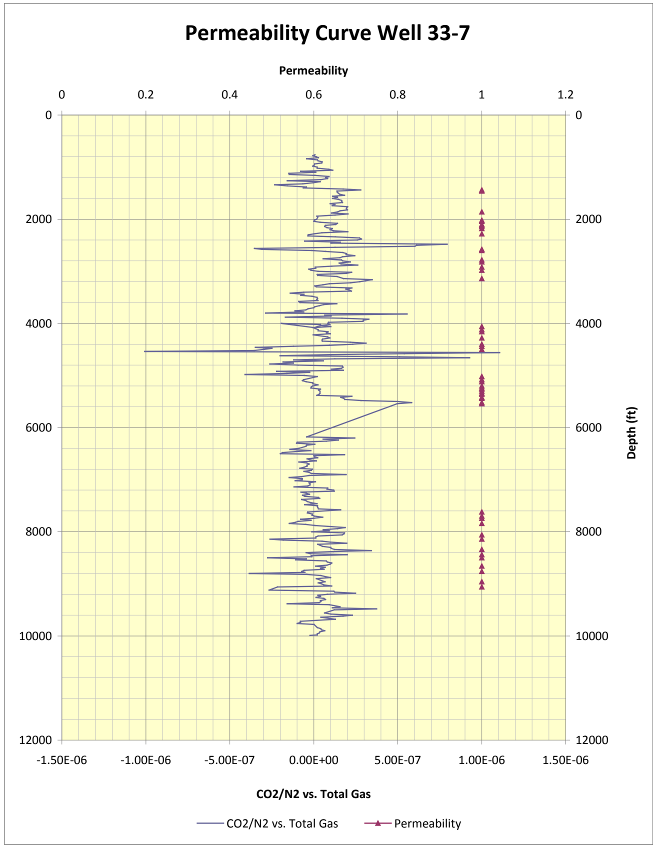
87-29 Steamboat	16 CH4	18 H2O	28 N2/CO	34 H2S	44 CO2	Total Gas -CO2
Fractures						
Average	2.68E+06	7.28E+06	2.17E+06	1.53E+05	5.72E+06	2.36E+06
Std Dev	3.22E+06	5.62E+06	1.57E+06	1.28E+05	3.68E+06	1.90E+06
Avg + std	5.89E+06	1.29E+07	3.74E+06	2.81E+05	9.40E+06	4.25E+06
No Fracture						
Average	1.07E+06	7.75E+06	1.10E+06	4.71E+04	3.13E+06	2.51E+06
Std Dev	1.78E+06	4.74E+06	6.20E+05	8.98E+04	2.87E+06	2.54E+06
Avg + std	2.85E+06	1.25E+07	1.72E+06	1.37E+05	5.99E+06	5.05E+06
% Difference for Average	150	-6	98	225	83	-6
% Difference for Avg+std	107	3	118	105	57	-16

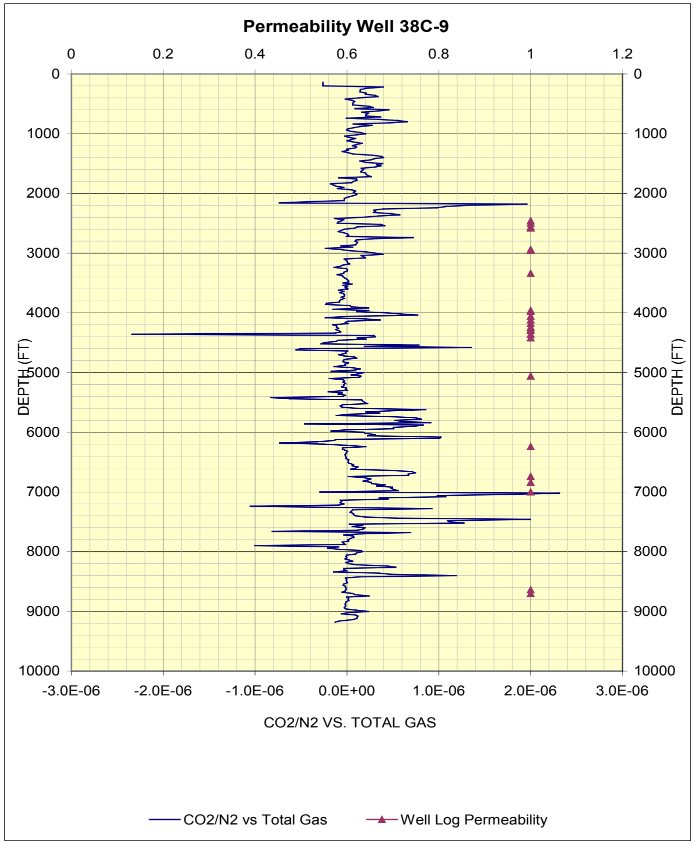
T2 Karaha	16 CH4	18 H2O	28 N2/CO	34 H2S	44 CO2	Total Gas -CO2
Fractures						
Average	7.47E+05	2.72E+06	1.14E+06	6.12E+03	1.33E+06	2.66E+06
Std Dev	1.27E+06	3.26E+06	6.49E+05	9.96E+03	1.33E+06	1.79E+06
Avg + std	2.02E+06	5.98E+06	1.79E+06	1.61E+04	2.67E+06	4.45E+06
No Fracture						
Average	2.76E+05	8.76E+05	1.14E+06	1.64E+03	1.14E+06	2.02E+06
Std Dev	6.55E+05	1.46E+06	1.03E+06	2.93E+03	9.89E+05	1.44E+06
Avg + std	9.31E+05	2.34E+06	2.17E+06	4.57E+03	2.13E+06	3.46E+06
% Difference for Average	171	211	0	272	17	32
% Difference for Avg+std	117	156	-18	251	25	29

There is a statistical difference in the average concentration of select species for fracture areas versus non-fracture areas.

In addition, there are differences in which species have the highest percent difference – H_2O and CO_2.

Accomplishments, Expected Outcomes and Progress





The change in the ratio of CO_2/N_2 versus total gas indicates boiling in open fractures. This change is plotted as a blue line against lost circulation zones from well logs. Peaks either negative or positive indicate greatest change in ratio and therefore areas of fractures which corresponds to lost circulation zones. Additional peaks may indicate closed fractures.

Accomplishments, Expected Outcomes and Progress

Additional avenues currently being explored:

- Ternary diagrams to identify fluid types and compare to FIS concentrations and fracture locations to evaluate the affect of fluid types, ie production fluids versus cold meteoric fluids have certain FIS signatures which may affect how a fracture is identified.
- 10-foot sampling of core to evaluate how far from a fracture are the FIS signatures indicating a fracture and also if the sampling interval is appropriate to identify a fracture.
- Which species have significant FIS peaks prior to a fracture to determine which chemical species can be used a possible precursors to a fracture location.
- Evaluate how a certain processes and/or geology of the field may affect the FIS signature and identification of peaks such as the difference in which species had higher concentrations in Steamboat Springs and Karaha.

Project Management/Coordination

- The project was divided into two phases with a total of three tasks.
- The first task was preliminary data analysis with five subtasks. The completion of this task was the end of Phase 1. A Phase 1 report was prepared and submitted January 2010.
- The second phase consisted of two tasks: additional core logging and additional analyses. We are currently in Phase 2, Task 3.
- Currently we are on-schedule to about one quarter behind. The end of the project is set June 30, 2010
- We have expended approximately 65% of the overall budget.
- We have coordinated this project with our team member (Joe Moore of Energy & Geoscience Institute) throughout the project life and have included them in the process.

Future Directions

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- The next key milestone is to complete the project and prepare the final report.
- This project is developing a useful tool to identify fractures in a borehole using geochemical methods.
- The ability to identify fracture locations leads to a better understanding of the permeability of the well and ultimately to areas for future enhancement to increase permeability within a well. This combined with prior research as to the nature of the fluids encountered in a well can present an overall fluid and permeability model of a geothermal field.
- Next step is to field-test this method on a new well being drilled or recently completed.
- The ultimate goal is to create a user friendly program that will allow this method to become commercially viable.

Mandatory Summary Slide

Results to date indicate:

- Fractures, veins and vuggy areas can be identified on FIS logs by distinct strong peaks (increase concentration) in multiple chemical species.
- The bulk analysis of volatiles within fluid inclusions corresponds with several types of fracture infilling minerals including quartz, calcite, stibnite, and pyrite.
- The concentration of H_2O correlated with fractures, veins and vugs in the felsic rocks in Glass Mtn. and Karaha. In Steamboat where the H_2O was more pervasive, the concentration of H_2O did not always correlate with fractures, veins and vugs.

Mandatory Summary Slide

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- The concentration of CO_2, H_2O, Ar, N_2 and sulfur species increase significantly when the fractures, veins and vuggy areas are in a producing zone or zone of higher temperatures suggesting active, open fractures.
- The change in the ratio of CO_2/N_2 versus total gas corresponds to lost circulation zones and perhaps older veins in a well indicates a means to identify fracture areas or permeable zones.

Mandatory Summary Slide

- Based on the wells studied there is a statistical difference in the average fluid inclusion gas concentration of select species between fracture and non-fracture zones. Select chemical ratios can also indicate fracture locations.
- FIS analysis can be used to find fracture zones within wells and be used to identify areas for fracture simulation in Enhanced Geothermal Systems.

Supplemental Slides

Optional Slide

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- Dilley, Lorie M., and Michelle Wilber (2010) “Chemical Signatures and Precursors to Fractures using Fluid Inclusion Stratigraphy”, Proceedings Thirty-Fifth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford California

- Dilley, Lorie M., David I. Norman, and Lara Owens, (2008) "Identifying Fractures and Relative Ages Using Fluid Inclusion Stratigraphy” Department of Energy Report. DE-FG36-06GO16057 A000

- Dilley, Lorie M. (2010), “Chemical Signatures of and Precursors to Fractures Using Fluid Inclusion Stratigraphy Phase I Report” Department of Energy Report. DE-FG36-08GO18188 A000