4.6.8 Chemical Signatures of and Precursors to Fractures Using Fluid Inclusion Stratigraphy

Presentation Number: 035
Investigator: Dilley, Lorie (Hattenburg, Dilley and Linnell, LLC)
Objectives: To develop a method to identify fracture systems in wells using fluid inclusion gas analysis of drill chips.
Average Overall Score: 2.2/4.0

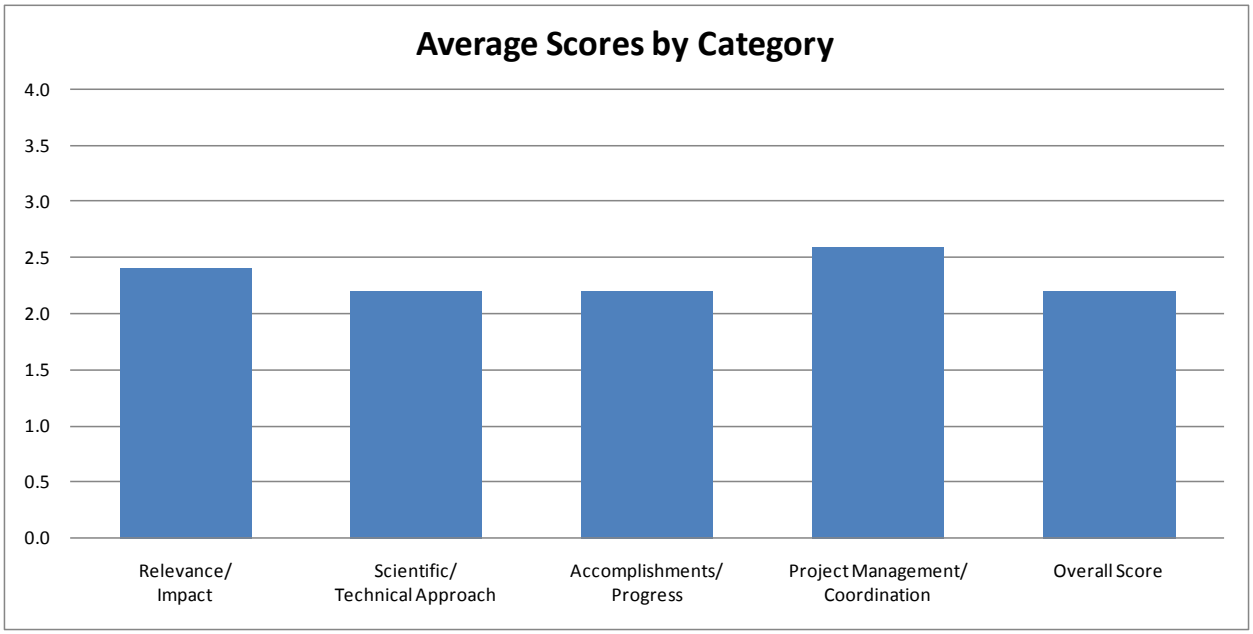

Figure 44: Chemical Signatures of and Precursors to Fractures Using Fluid Inclusion Stratigraphy

4.6.8.1 Relevance/Impact of the Research

Ratings of Five-member Peer Review Panel: Poor (1), Good (3), Good (3), Fair (2), Good (3)

Supporting comments:

- Although the fluid inclusion stratigraphy (FIS) results presented are intriguing and potentially of great value for understanding geothermal systems, the number of questions and concerns raised by Dilley's presentation and report weigh negatively on this project. The presentation and analysis of the multi-variate data were totally inadequate. Repeated comments that the statistics of gas concentrations (from FIS) were correlated with fracture density were utterly unconvincing. I would recommend that the PIs share the data collected with interested parties who would be more qualified to do the analysis and statistics.
- This project may provide a very low-cost way to identify open fracture systems by peaks in the fluid inclusion stratigraphy (FIS) signature during drilling. It is in line with the GTP goals.

- This research proposes to use fluid compositions and the abundance of fluids, extracted from trapped inclusions, to fingerprint the open fracture interval in geothermal systems. While this method has been used to target petroleum sources, it has not been applied to geothermal systems. Consequently, if successful, the project has potential to advance exploration techniques for geothermal target zones and could be highly useful. This work could provide a new, relatively inexpensive and fast technique for reservoir areas to target and enhance.

- The use of inclusion fluid stratigraphy to identify fracture zones and, possibly, fluid type in the reservoir could be a useful technique but thus far there seems to be considerable uncertainty in the interpretation of the results and a lack of quantitative assessment of the method.

- Investigator appears to have made good progress.

4.6.8.2 Scientific/Technical Approach

Ratings of Five-member Peer Review Panel: Fair (2), Fair (2), Fair (2), Fair (2), Good (3)

Supporting comments:

- FIS analyses of chips from drilling with a reported (as small as) 10-foot spacing were presented. The gas concentration units were never given. Plots were "average" plus "two times standard deviation" versus depth according to the verbal presentation. Given that the standard deviation was often as large as the average, the plots could be apparently dominated by noise or analytical uncertainty, a wholly unjustified method of presentation. Comparison to geology and mineralogy of segments along the core were apparently planned, but no results of such a comparison were given. Local mineralogy may have in fact been more important than "open fractures". It may have been that the fluid inclusion data were dominated by the local mineralogy, but this cannot be known from the results. The "open" fractures and "lost circulation" were based on inadequate observational data and questionable relationships to N2 and CO_2 ratios. Permeability of actual core samples should have been made for "ground truthing", but this was not done. The time of sealing of fluid inclusions and their formation time were implicitly assumed to be recent, which may not be true at all. The time of formation of the fluid inclusions is critically important for this study, but documentation of this seems impossible. Whether gas concentrations were above or below fractures was supposed to mean something, but no convincing statistical analysis was presented. For the multi-variate analysis, I would suggest that the PIs look into the open source free software "R" (http://www.r-project.org). I'm not even sure who did the actual gas analyses for this FIS. Was it done by the PIs, or was this outsourced?

- The methodology is not entirely clear from the provided documents. In particular, the rationale for focusing on specific chemical signatures while ignoring others is not entirely clear to me. The correlation between peaks in the FIS and open fracture systems is also not clear. The method has not yet demonstrated its ability to reliably predict open fracture system locations. In particular, it seems that in order to identify the location of fracture systems, one needs to

selectively filter through a very large number of measurements. This filtering does not seem systematic. Maybe the project would benefit from a deeper collaboration with statisticians.

- To acquire fluid chemistry, cores are sampled and the samples sent out to industry for analysis in a mass spectrometer (a bulk technique that averages the sample). Data returns to the PI for analysis. This approach is standard. Methods and procedures for fluid chemistry analysis are patented and, thus, unavailable. Sensitivity, errors are not listed.

  Plots are made of fluid compositions and amount per stratigraphic interval and used for interpretation. These plots are to be related to mineralogy of the corresponding zone. To date, there has been relatively little data analysis. A few plots were presented that contained many of the fluid species but all plots were qualitative (no numbers were attached). The amount of data returned might be immense, but the PI needs to explore other/new methods to interrogate the data and to display the results (the key data). For example, try plotting different scales, different components, multiple components, try tools for visual analysis of large datasets, and above all - keep quantitative data quantitative until you know the absolute values are not important.

  In addition, it is unclear why sealed fractures (those with fluid inclusions) in the wall rock adjacent to open fractures are key to current "open" fractures. The hypothesis needs to be tested and shown to be valid. How many generations of sealed fractures are present in the samples? Do the various "closed" fractures/fluid inclusion generations have the same chemical signature? How does averaging affect the overall result? Fluid inclusions are stable. These inclusions could be from the time the melt crystallized and not representative of the geothermal system. Fluid inclusions are stable - once they form, they remain. There are 3.6 billion year, three-phase fluid inclusions that remain in Archean ironstones. A significant amount of work needs to go into rigorous data analysis before this technique will be viable, but it holds promise.

- The approach seems largely one of empirical correlations of chemical signatures with fractures observed in boreholes. The project would be improved by more effort to achieve a better fundamental understanding of the mechanisms and their magnitudes. Although the approach generates a large amount of data, its interpretation seems unclear.

- Overall good approach and organization. PI needs to include more quantitative information on slides - - fracture numbers, permeability, etc. Too many qualitative indicators, when quantitative information should be available and would be more helpful.

4.6.8.3 Accomplishments, Expected Outcomes and Progress

Ratings of Five-member Peer Review Panel: Poor (1), Fair (2), Fair (2), Good (3), Good (3)

Supporting comments:

- The results themselves are interesting, but the underlying assumptions and the presentation of the data without rigorous statistical analysis render the accomplishment “poor”. See comments on #2 above.

- In my opinion, Phase I has not yet demonstrated the method's ability to reliably predict open fracture system locations. Phase II consists of performing a large number of measurements. It is not entirely clear to me how increasing the already colossal amount of data will improve the predictive abilities of the method. I would suggest that the project focus on improving the robustness of the prediction with a small amount of data before performing more measurements.

- a. Productivity: Phase 1 had five subtasks.
  1. Literature review was completed although not presented.
  2. Simple statistics are used to determine which chemical species is highest in known fractures. Some statistics have been done but no units were given - there are orders of magnitude changes in some of the species but it is unclear what this means. Specific FIS could not be positively linked to fracture zones.
  3. Minerals assemblages and changes to FIS are to be evaluated but no information was presented relating mineralogy to FIS.
  4. Fractures and non-fractured regions in epithermal systems are to be compared, again, no data were presented.
  5. Additional core sampling identified, this has been done. Perhaps this information was reported earlier but it was not contained in the review materials nor answered in the questioning.

  The project is stated to be 80% complete. Phase 2, 3 are additional sampling and analyses. Goals were to identify chemical species in active geothermal systems; evaluate FIS signatures based on mineral assemblages in the fracture and determine specific chemical signatures in rock above open fractures. It remains unclear how there can be an FIS signature in "open" fractures - they are open, hence they cannot contain fluid inclusions.

  Significant data analysis remains to be done. Quality of the resources and people appears to be adequate. Collaborations might include someone well versed in working with large datasets. One proceedings paper has resulted.

- Use of resources seems to be good, and much work has been done but its interpretation seems still uncertain. Productivity appears adequate although I would have expected that a project this far along (roughly 80%) had produced more papers or presentations.

- Appears to be some interesting initial results.

4.6.8.4 Project Management/Coordination

Ratings of Five-member Peer Review Panel: Poor (1), Good (3), Good (3), Good (3), Good (3)

Supporting comments:

- No project management plan or organization was given, so it was impossible to evaluate this item.
- The project management seems appropriate. Although it may be late at this stage of the project, I would recommend that the investigators seek deeper involvement of statisticians.
- Project management has been carried out effectively. Cores have been sampled, analyses performed and interactions with other team members have occurred.
- Project management and planning is adequate though it seemed to lack specific targets about the feasibility and usefulness and/or advantages of this method.
- Limited information on this metric, but no red flags.

4.6.8.5 Overall

Ratings of Five-member Peer Review Panel: Poor (1), Fair (2), Fair (2), Good (3), Good (3)

Supporting comments:

- See comments above. I hope DOE can extract the usable data from this study and make it available (gas concentration versus depth for all boreholes analyzed) to investigators who may be able to make sense of the measurements.
- While I would not rule out the idea of using Fluid Inclusion Stratigraphy to identify open fracture systems, I would not consider that this project has proved or is on track to prove the viability of this approach.
- Because the success of the project relies heavily on the quality of data analyses which has largely been minimal, the project needs attention. No mineralogic analysis nor direct observation of cores being sampled has occurred but is critical for making the case and may bring to light new lines of evidence to support the hypothesis. This project has significant potential but is currently unconvincing. Conclusions need to be supported by data. No peer reviewed publications have resulted, as of yet, with the exception of conference proceedings.
- A good project that has produced much data and some interesting results but I think it needs to be a bit more vigorous in its approach to assessing and understanding the method.
- Useful project for geothermal energy.

4.6.8.6 PI Response

No response.