ADVANCED HYDROCARBON STRATIGRAPHY (AHS)

Geothermal Applications of RVS Initial Results from FORGE 58-32 Well

Christopher Smith (PhD)
Senior Chemist for Advanced Hydrocarbon Stratigraphy
+1.918.520.3077/Christopher@advancedhydrocarbon.com

RVS for Geothermal Applications

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- **AHS's patented technology offers the opportunity to "log" high temperature wells gaining a suite of detailed geochemical measurements that can be related to traditional petrophysics, the subsurface geothermal system, and used to inform on completions.**
- **Using cuttings, a free byproduct of the drilling process, key information and insights can be collected with no additional risk at temperatures where downhole tools are extremely challenged.**
- **The collection of such data from cuttings is unique to AHS's patented technology, the basis for Rock Volatile Stratigraphy (RVS) analysis.**

What is RVS?

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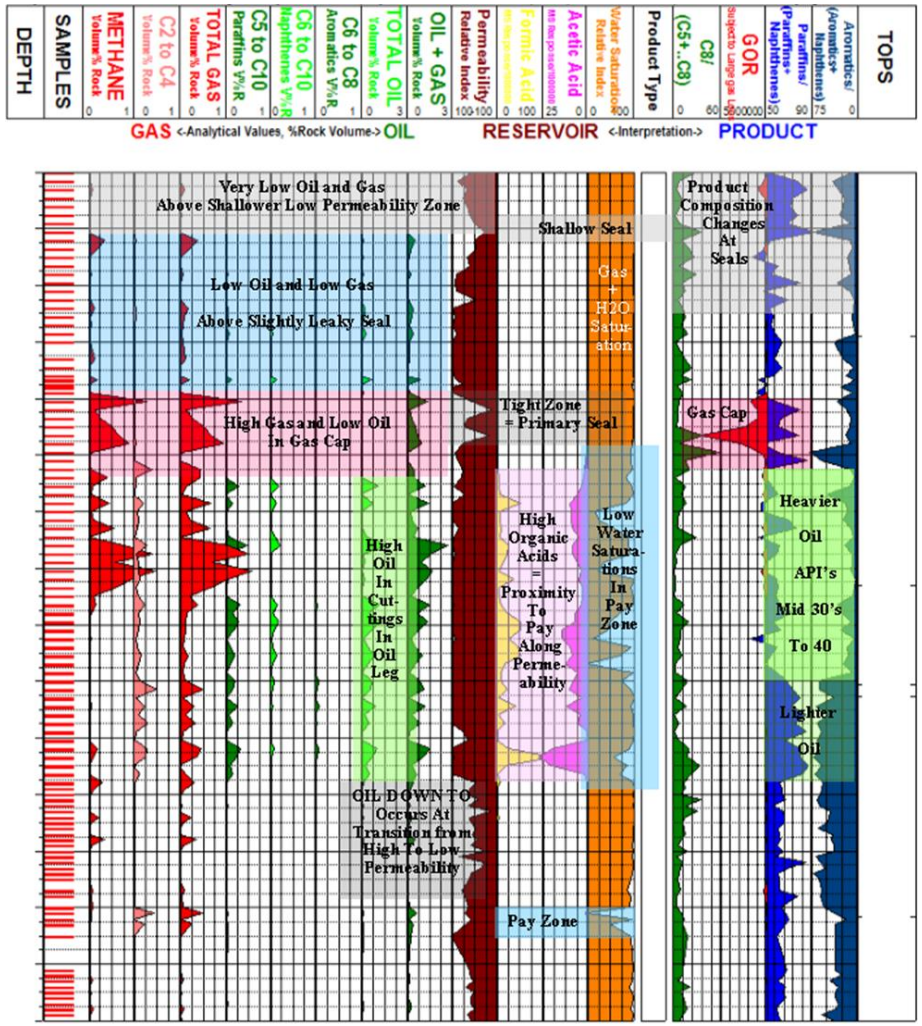

- **This non-intrusive technique uses a novel cyro-trap mass spectrometry system developed by AHS to gently extract, identify, and quantify volatiles in geological materials.**
- **Lab-based analysis can be completed in 36 hours or less for operational decisions.**
- **PDC/rock bit/cable tool cuttings, core, side wall core, outcrop, muds, and produced fluids, regardless of mud system and retrieval age (fresh or legacy), can be used as samples for analysis.**

Applications of RVS

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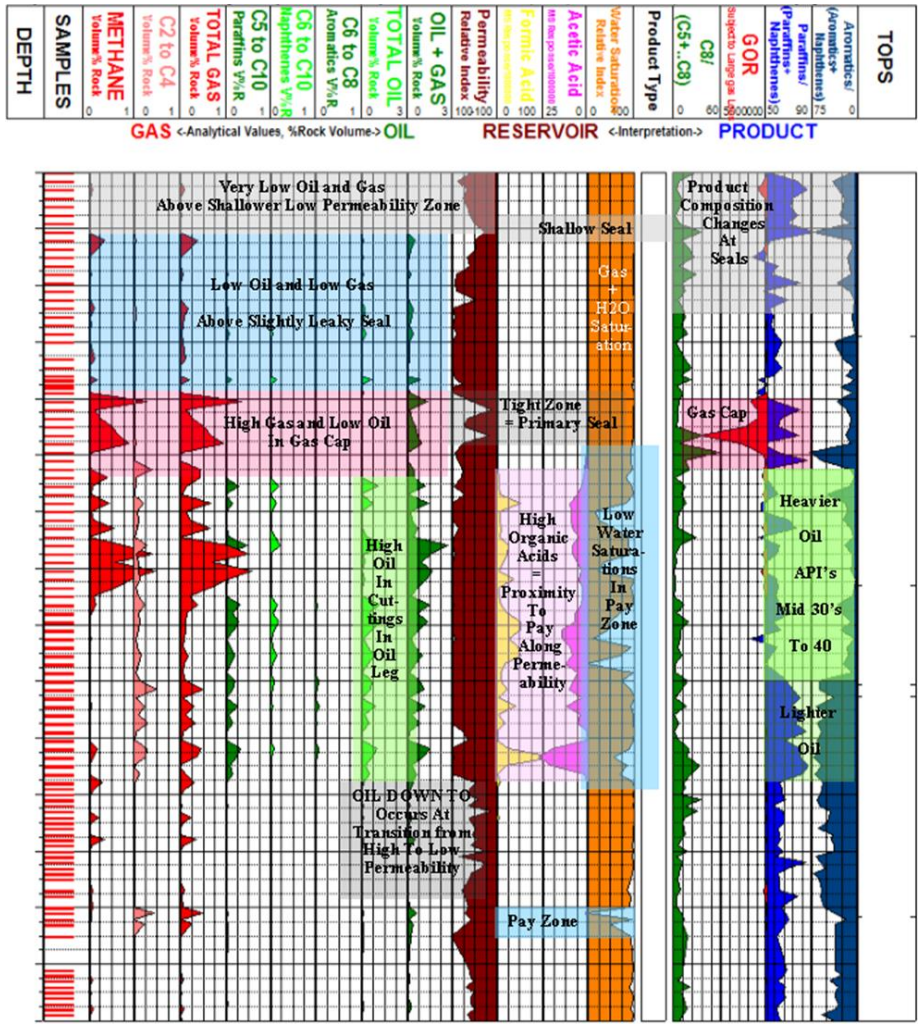

Areas: **Geothermal**
Helium
Oil and Gas
Carbon Capture Utilization & Storage (CCUS)

Detailed Subsurface Assessments:

- **Migration**
- **Seals**
- **Accumulations**
- **Compartments**
- **Resource Quality**
- **Thermal Maturity**
- **Rock Properties**
- **Production Allocation**

Post-mortems:

- **Seal Failure**
- **Resource Fractionation**
- **Parent-Child Relationships**
- **Mapping Previous Drainage**
- **Over-pressure**
- **Tar**

Operational Decisions:

- **Perforations**
- **Landing Zones**

RVS Method

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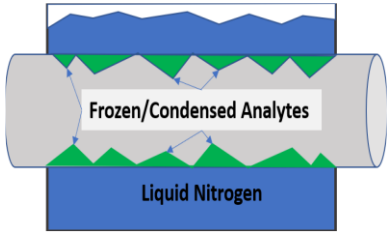

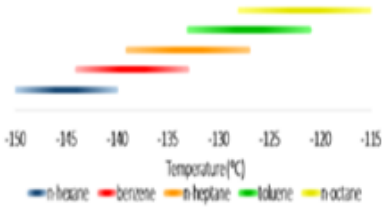

1-1.5 g of rock sample is subjected to a gentle vacuum extraction at room temperature.

All compounds are measured at two different vacuum extraction conditions.

Mechanical strength of the rock is also measured by uniaxial crushing.

Over 120 different *direct* measurements per sample provide a detailed description of the subsurface geochemistry.

What is measured by RVS?

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- **Small Molecules**
  - Carbon Dioxide
  - Molecular Oxygen
  - Molecular Nitrogen
- **Noble Gases**
  - Helium
  - Argon
- **Hydrocarbons**
  - C1-C4 Gases
  - C5-C10 Paraffins
  - C6-C10 Naphthenes
  - C6-C9 Aromatics
- **Sulfur Compounds**
  - Hydrogen Sulfide
  - Carbon Disulfide
  - Carbonyl Sulfide
  - Sulfur Dioxide
  - SO- (Sulfate Proxy)
- **Biological Byproducts**
  - Formic Acid
  - Acetic Acid
  - Methyl Ethyl Ketone
- **Diagnostic Signatures**
  - Ethene
  - 2-Trans-Butene

Isomers, isotopes, and additional signatures may be possible upon request.

What is needed for RVS analysis?

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- **0.4 cc (1-1.5 g) of rock sample (cuttings, core, side wall core, outcrop, etc.) used per sample**
- **Samples can be either collected and sealed on site (sealed at well) or prepared in the lab (lab loaded) allowing different types of analysis**
- **Ideal sampling: collecting directly from the flow line on depth, sampling density 10 ft in verticals and curves, every 30 ft. in laterals**
- **RVS can utilize legacy materials. These can be several decades old. Core chips and cuttings from wells drilled in the 1930s in Alaska have been analyzed as part of exploration programs.**

RVS Analysis for Geothermal Applications

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Traditional Geothermal Projects

- **Does not require the deployment of down hole tools and can "log" high temperature wells.**
- **RVS information on helium and CO_2 can be related to convective hydrothermal systems/heat flux.**
- **RVS water data can be used to understand saturations and possible phase changes.**
- **RVS sulfur data can be related to hazards/corrosion.**
- **RVS fracture signatures can be used to identify fractures, understand their distribution, and potential communication with the deeper hydrothermal system.**
- **Mechanical strength can provide insights into borehole stability and fractures.**

RVS Analysis for Geothermal Applications

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Enhanced Geothermal Systems (EGS) Geothermal Projects

- **All of the applications listed for Traditional Geothermal Projects**
- **+Opportunities to understand inter-well communication of the fracture networks from subsurface compounds and possibly injected tracers**
- **RVS geochemical signatures that correlate to subsurface porosity vs wireline**
- **Opportunities to understand mechanical strength, fracture networks, and communication, especially in the case of potential "short circuits" become even more important**

FORGE Test Site

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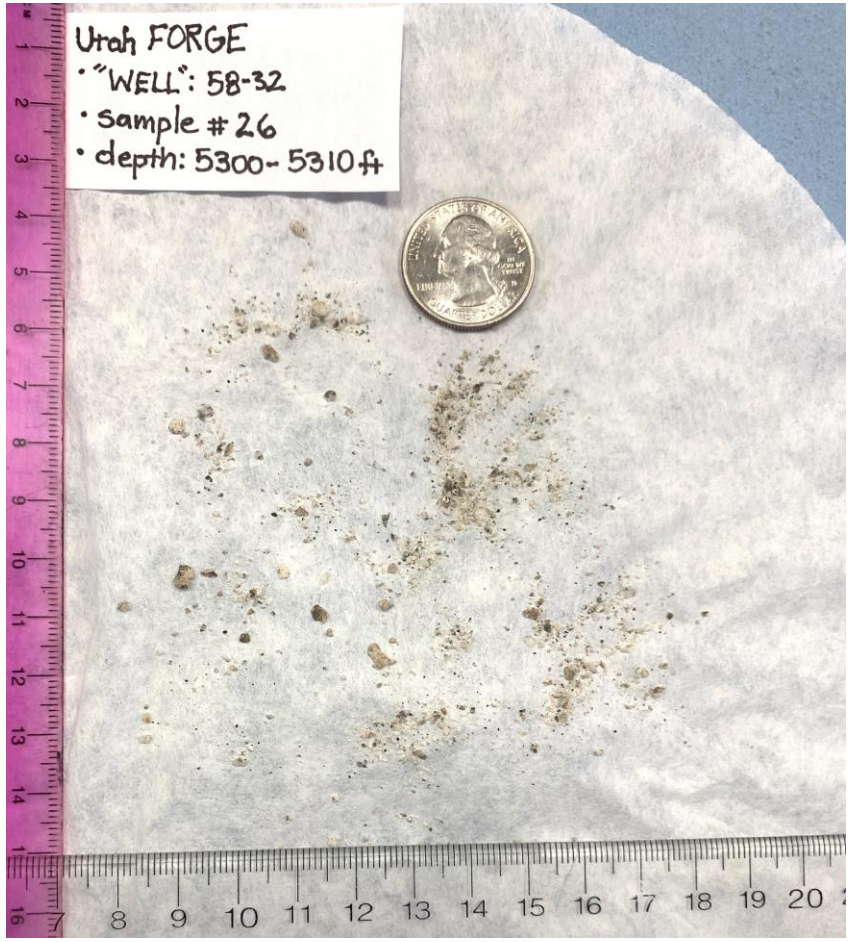
To better understand the utility of RVS data for geothermal applications, cuttings samples were obtained from the FORGE test site well 58-32.

The RVS data were paired with other FORGE datasets and showed strong relationships in areas of interest to FORGE such as fracture mapping and mechanical strength.

RVS geochemical data from the volatiles entrained in small quantities (1-1.5 g) of heavily traumatized legacy PDC bit cuttings, including water content, are unique and represent a capability no other lab in the world besides AHS can produce.



FORGE Test Site

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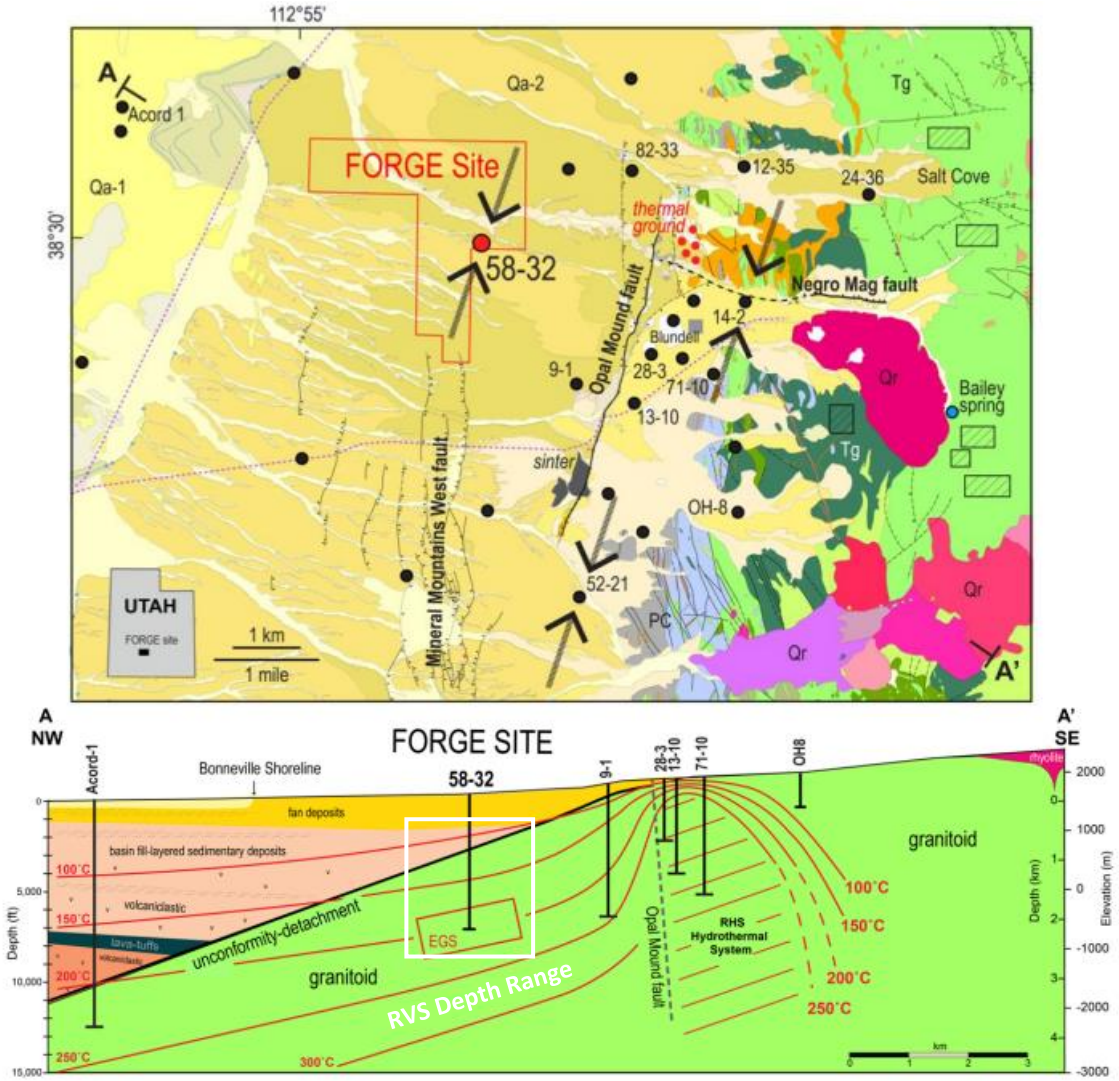
The FORGE test site is in southern Utah adjacent to other active geothermal areas such as the Roosevelt Hot Springs (RHS). Geothermal plants like Blundell take advantage of the convective hydrothermal heat flow found at RHS. FORGE however does not use conventional geothermal systems and seeks to flow water through stimulated fractured granite at temperatures of 175-225˚C for EGS.

Learn more at:

US DOE Geothermal Data Repository
https://gdr.openei.org/

Utah Geological Survey- Misc. Pub. 169
https://geology.utah.gov/publication-details/?pub=mp-169



Frontier Observatory for Research in Geothermal Energy
Milford Site, Utah
Phase 2B Final Topical Report (Modified)

FORGE Test Site

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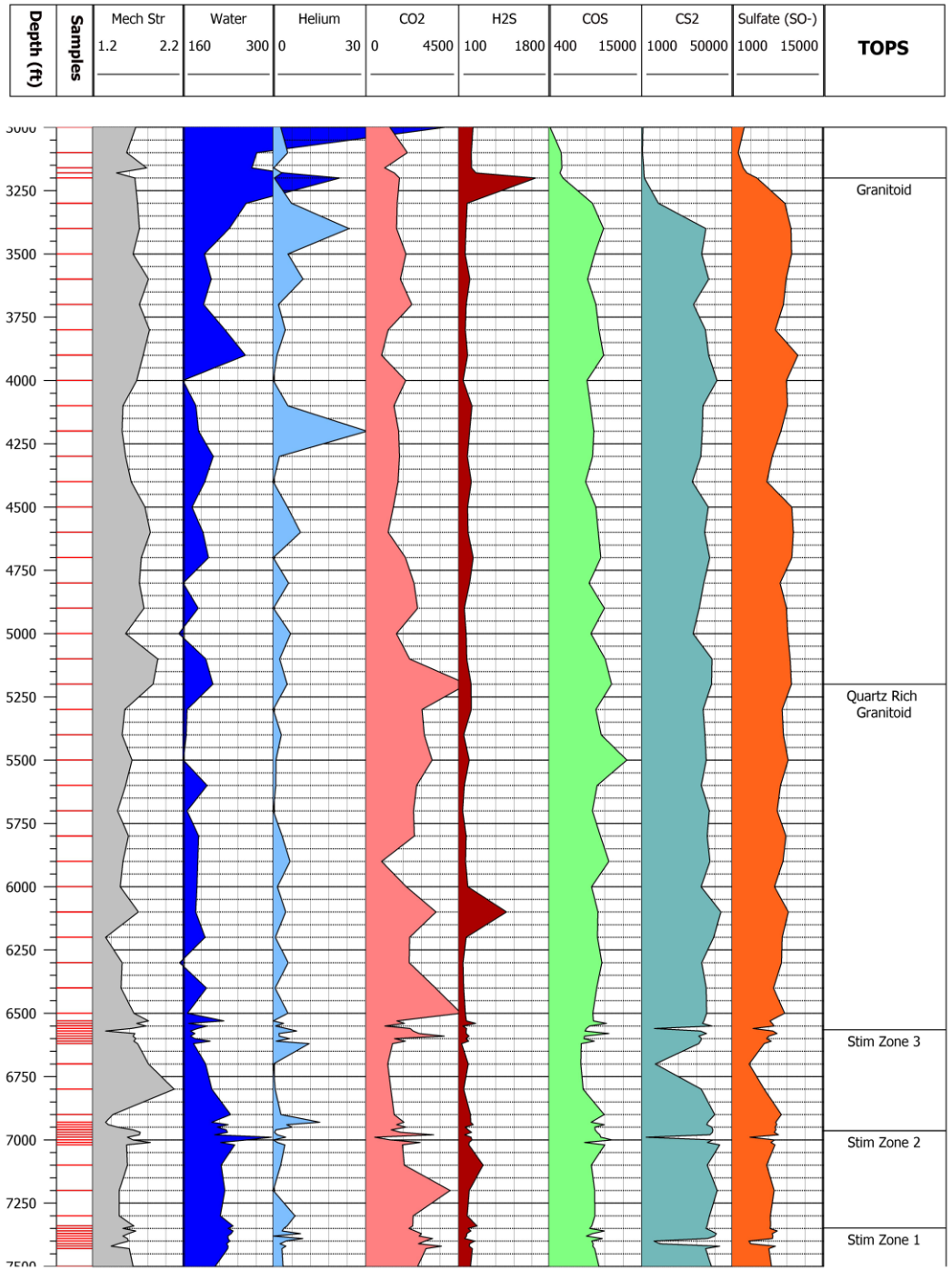
- RVS data show correlations to changes in rock types, fractures and faults, and fracture density/porosity.
- RVS water content responses correlate with wireline porosity. Deeper in the well it tracks with fracture density.
- Key observation: available porosity is predominantly water filled and RVS water content tracks porosity.
- Increased CO_2 and decreased mechanical strength observed in quartz-rich granitoid. Sulfur species also show a distinct transition responding to the granitoid.
- RVS high helium responses are indicative of very tight baffles/sealing features.
- Discrete high and low RVS responses of volatiles in fractured or faulted portions of the well are indicative of faults/fractures, what those features contain, and what migrates in and out.



FORGE Test Site: RVS Water Content

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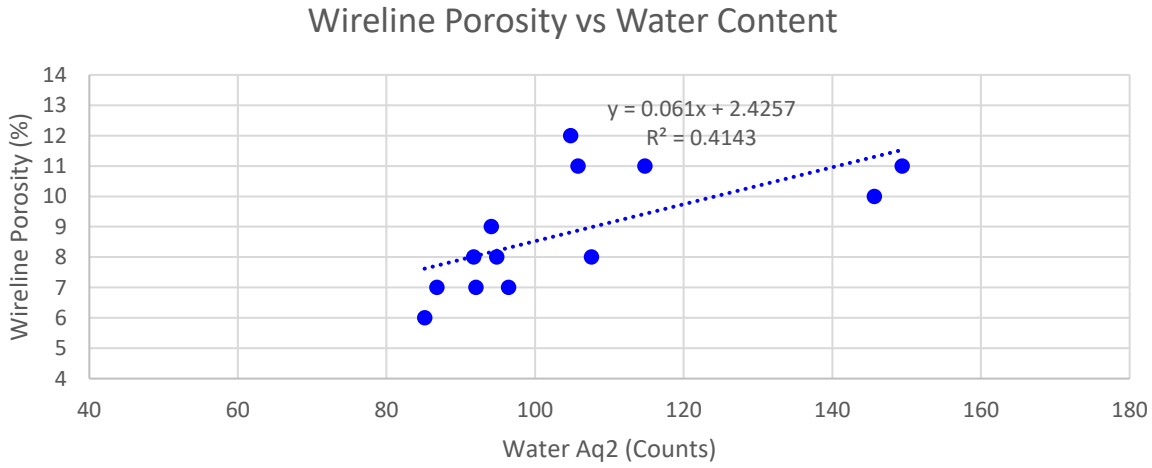
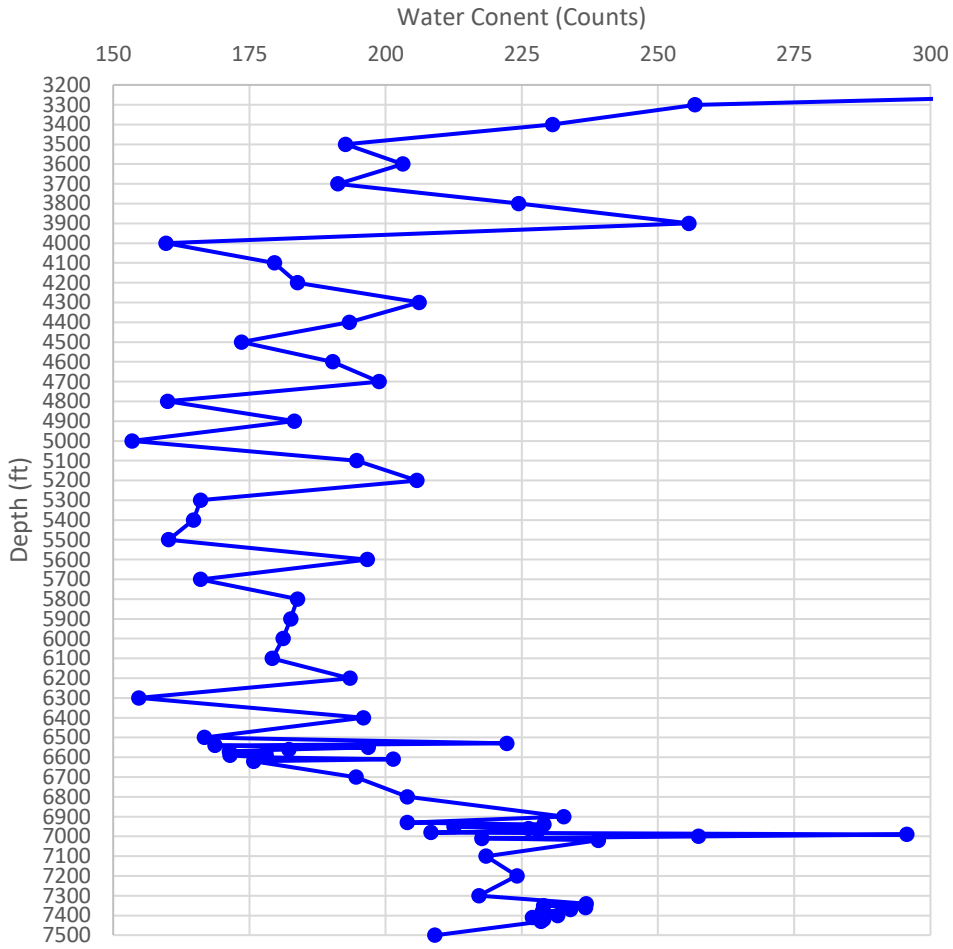
- **RVS water data from cuttings show strong correlations to traditional measurements of water in the subsurface.**
- **Water measurement is representative of subsurface water *volume*.**
- **Water data at top of section show correlations with wireline porosity.**





FORGE Test Site: RVS Water Content

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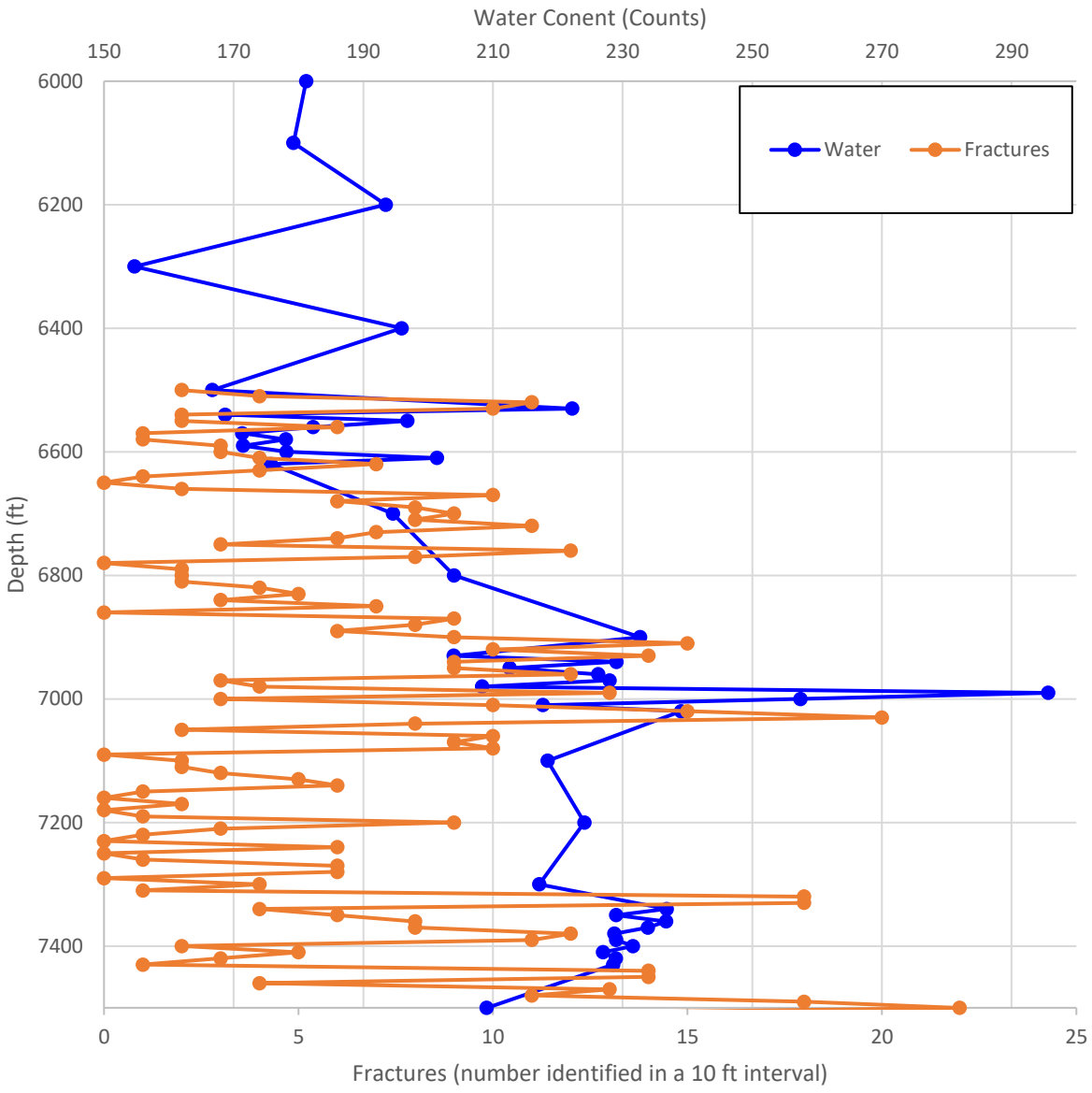
RVS water content in the stimulation zones responds to fracture density when compared to image log.

Fractures represent the only significant porosity in the granite at these depths and appear to be filled with water.

For reference, in absolute terms the quantities of water being measured are minimal compared to most subsurface conditions.

Higher water responses are observed where greater fracture density is present.



FORGE Test Site:
RVS Mechanical Strength

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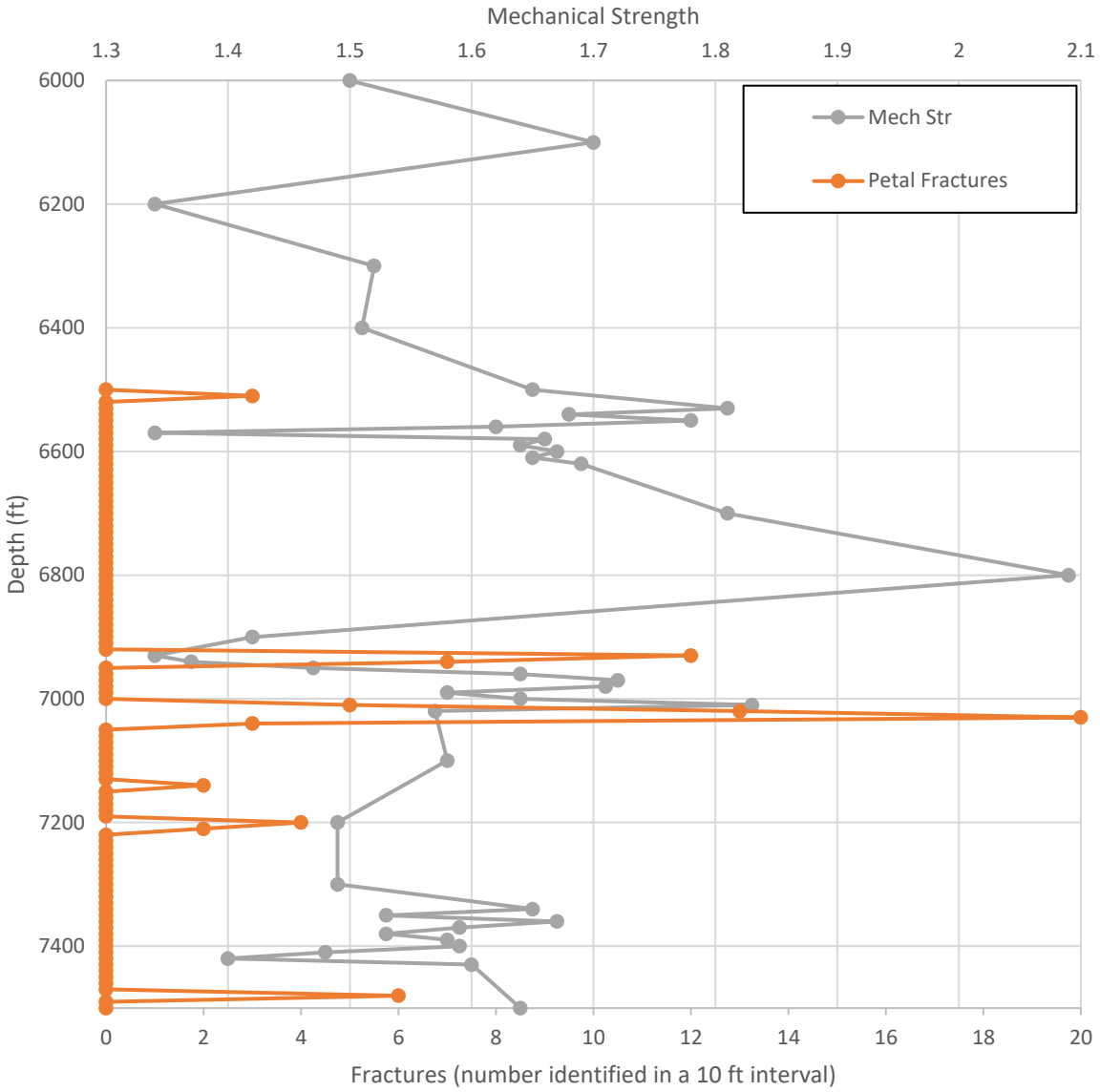
Mineralogy can be employed to estimate brittleness/ductility of rocks. However, the physical strength of the rock can be affected by subsurface features such as faults, fractures, and cementation. RVS measurements of the mechanical strength of cuttings allows for directly assessing the grain strength of the rock in a way that responds to these subsurface features which can impact completions and/or borehole stability.

Weak mechanical strength values are observed in relation to petal fractures, some low strength values show relation to increase weight on bit, others do not; likely indicative of formation damage and physically weaker rock, respectively.



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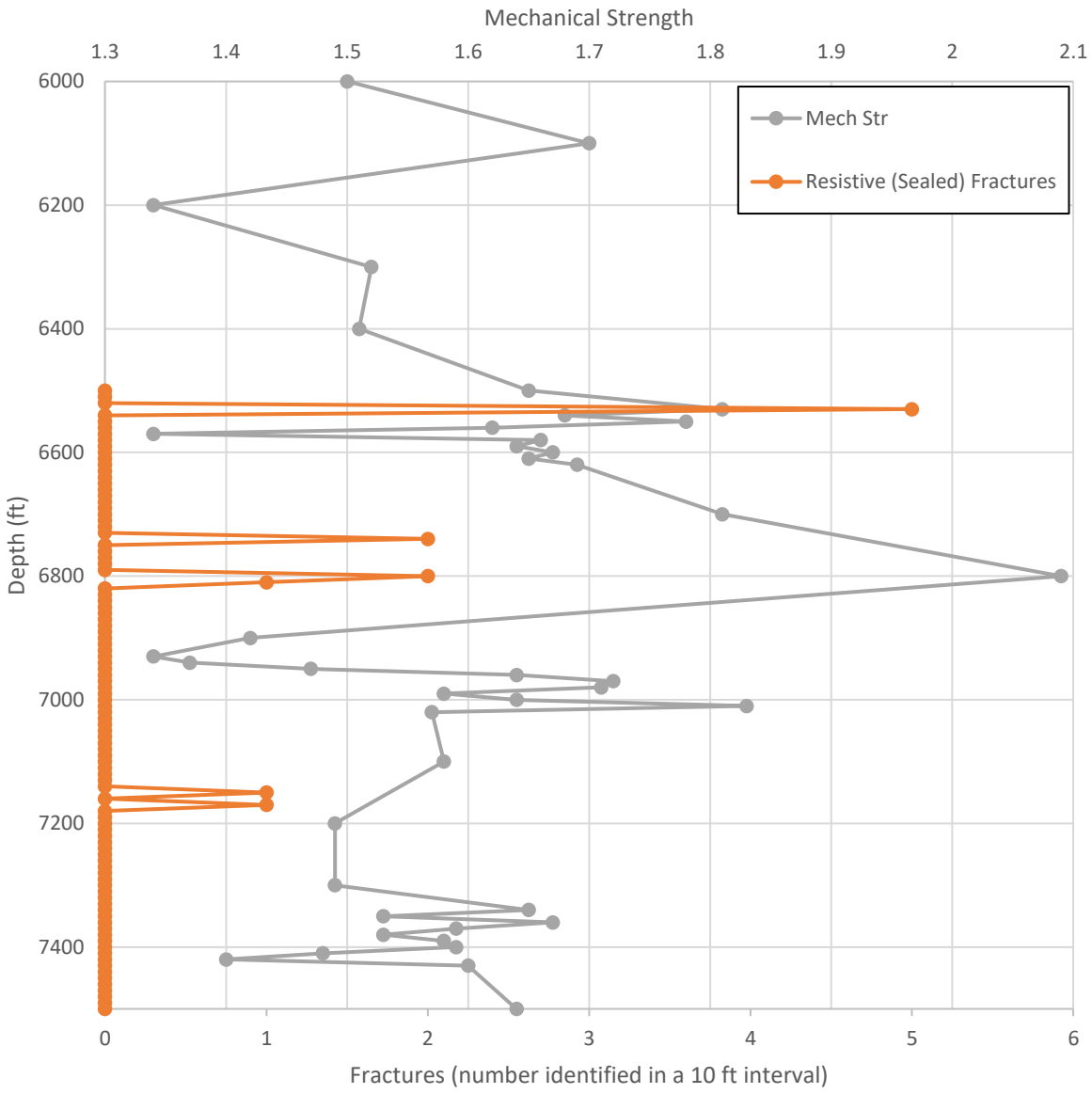
High mechanical strength is observed at resistive (assumed sealed) fractures suggesting likely mineralization and difficulty in successfully stimulating these sections of the well.



FORGE Test Site:

RVS Implications for Completion

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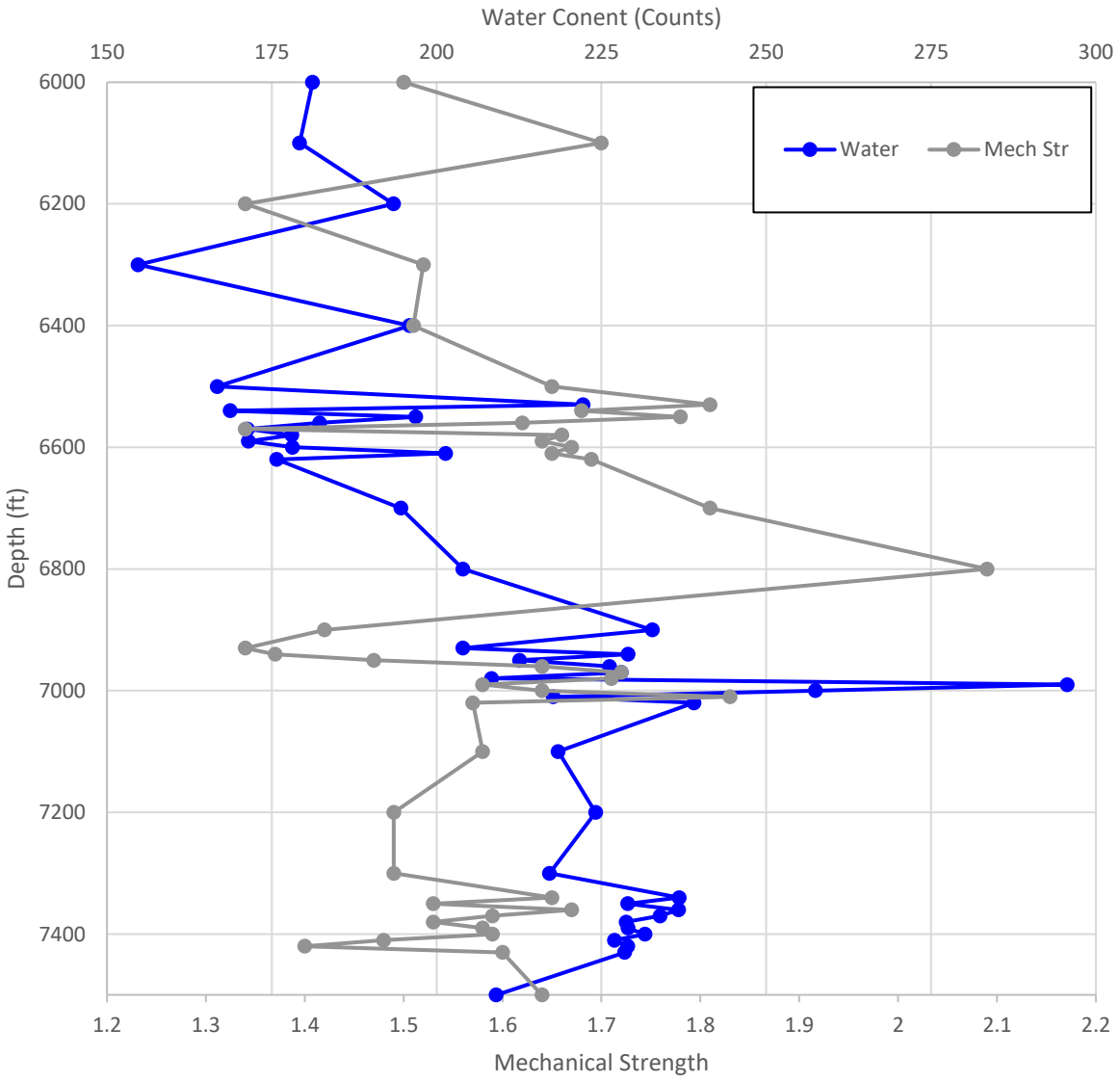
Stim Zone 3 was not expected to be effectively stimulated due to a lack of fractures and their characteristics (stress states); it was not successfully stimulated.

RVS water data show less fracture density/ fracture associated porosity in Stim Zone 3 than the deeper two zones.

RVS mechanical strength in Stim Zone 3 is statistically significantly higher at the 99.5% confidence interval than the deeper two zones. Stronger mechanical strength has previously been correlated to failed stimulations.

RVS data inform on the likelihood of successful stimulations in the granitoid.



FORGE Test Site:
RVS Identifying Communication Pathways

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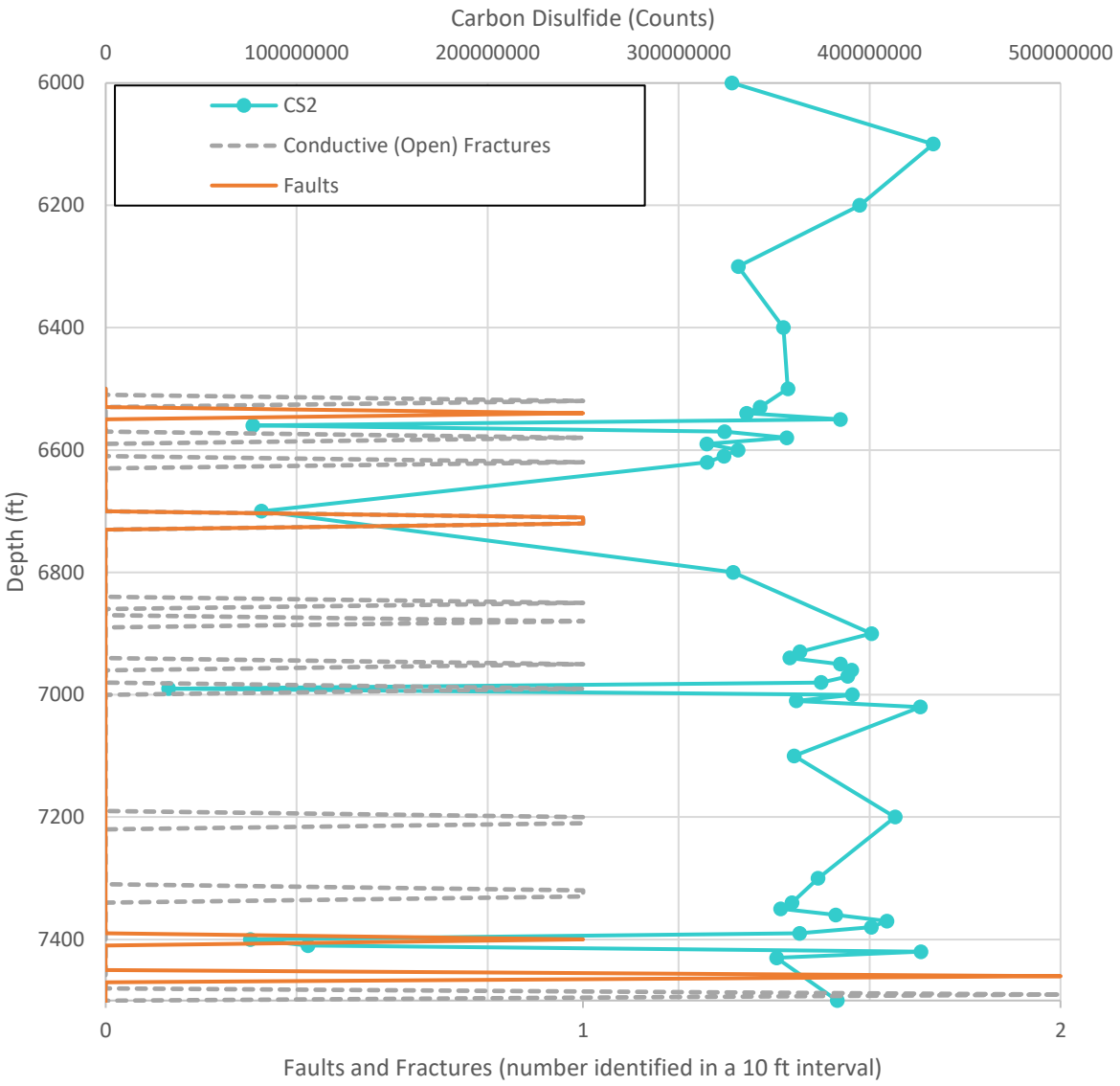
At several depths, the RVS carbon disulfide (CS_2) data are significantly depressed below base line.

Each of the low response depths can readily be associated with a fault or conductive fracture at or proximal to the depth of the depressed value.

RVS CS_2 data demonstrate apparent pathways for communication out of the granitoid.



FORGE Test Site:
RVS Identifying Communication Pathways

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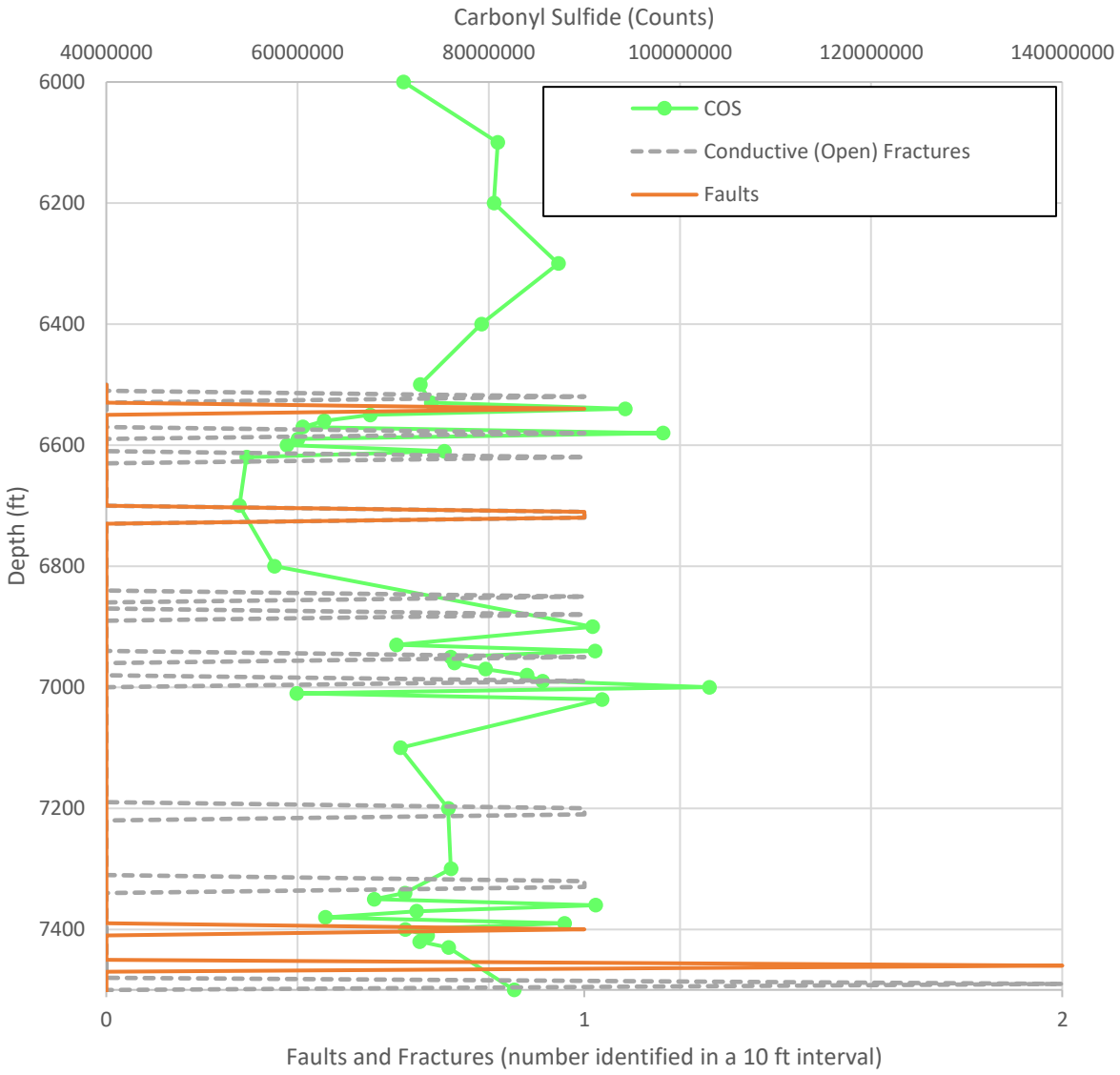
At several depths, the RVS carbonyl sulfide (COS) data are discretely enhanced.

9 of the 11 discretely enhanced COS responses are associated with a fault or conductive fracture near the depth of interest; the other two appear associated with partially conductive fractures.

RVS COS data demonstrate apparent pathways for communication into the granitoid.

RVS data for helium, CO_2 and H_2S demonstrate similar relationships to CS_2 and COS; RVS data can be used to gain insights into communication pathways along faults and conductive fractures.



FORGE Test Site: RVS Helium Content

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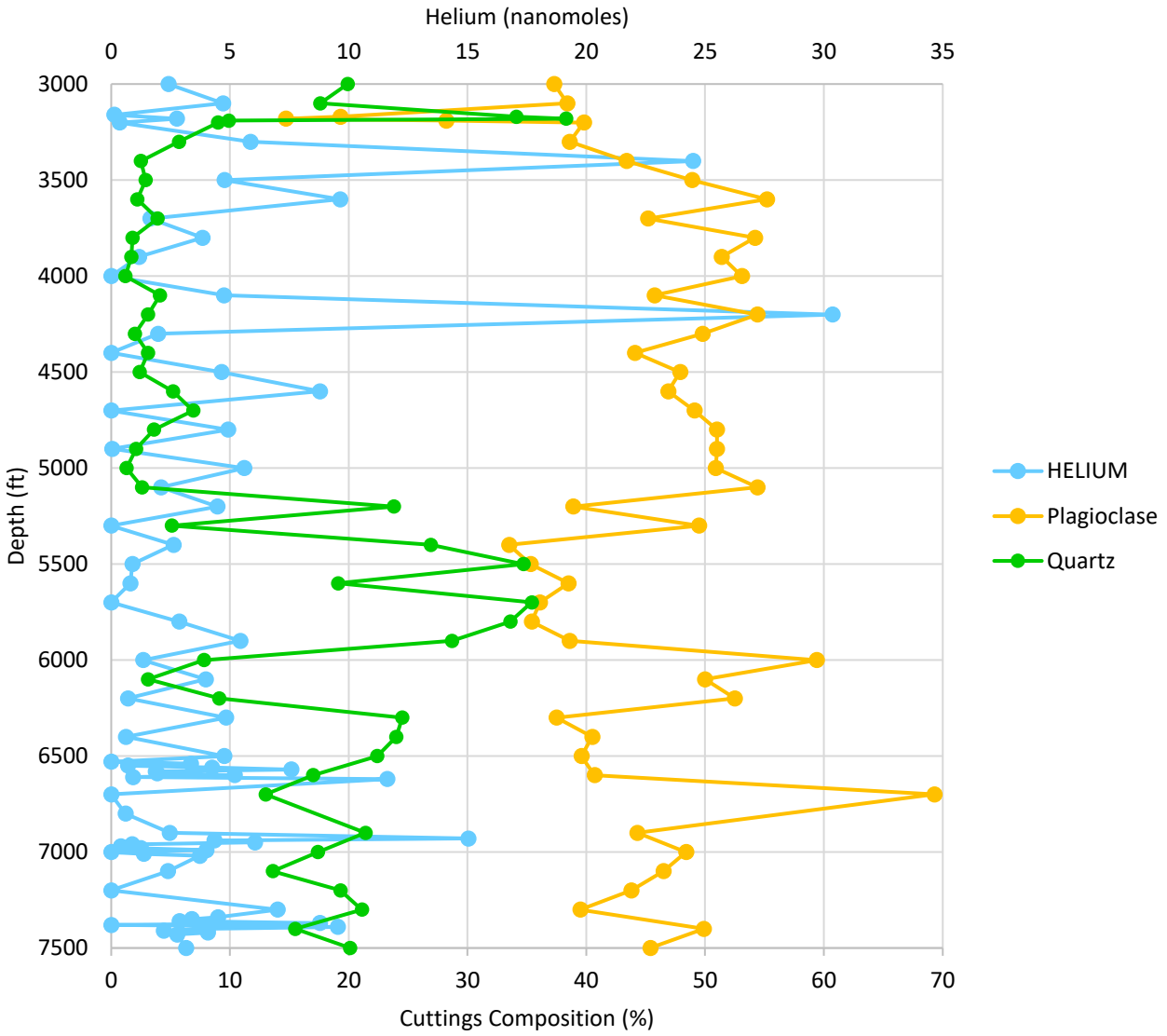
The two RVS high helium responses that are shallower in the well correlate to changes in mineralogy and wireline porosity (not shown).

These high helium responses are helium accumulations below low permeability baffles obstructing upward movement.



FORGE Test Site: Initial Takeaways

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- **RVS water responses correlate to the available porosity, including porosity associated with fractures observed in the image log in the stimulation zone. Fracture density is being mapped by water content because fracture porosity appears to be saturated with water. Mechanical strength measurements allowed evaluating effects of various features identified in the image log on rock strength which can have implications in selection of stimulation zones and understanding formation damage. The combination of lower water responses and higher mechanical strength in Stim Zone 3 is consistent with the observations by the FORGE team of not successfully stimulating Zone 3 compared to the deeper two.**
- **Beyond understanding the distribution of sulfides and CO_2, RVS geochemical signatures like H_2S, COS, CS_2, He, and CO_2 appear to allow for the identification of communication pathways (faults and fractures) and importantly what those pathways communicate. If these data from an injection well were paired with RVS data from a production well, then communication pathways between the two wells may be identified and understood allowing for better fracture modeling and stimulation strategies in subsequent wells.**

Supporting Materials

AHS

RVS Water and Permeability: Using PDC Bit Cuttings (Delaware Basin, NM)

Relative Index Measurements of Water Saturation (Sw) and Permeability

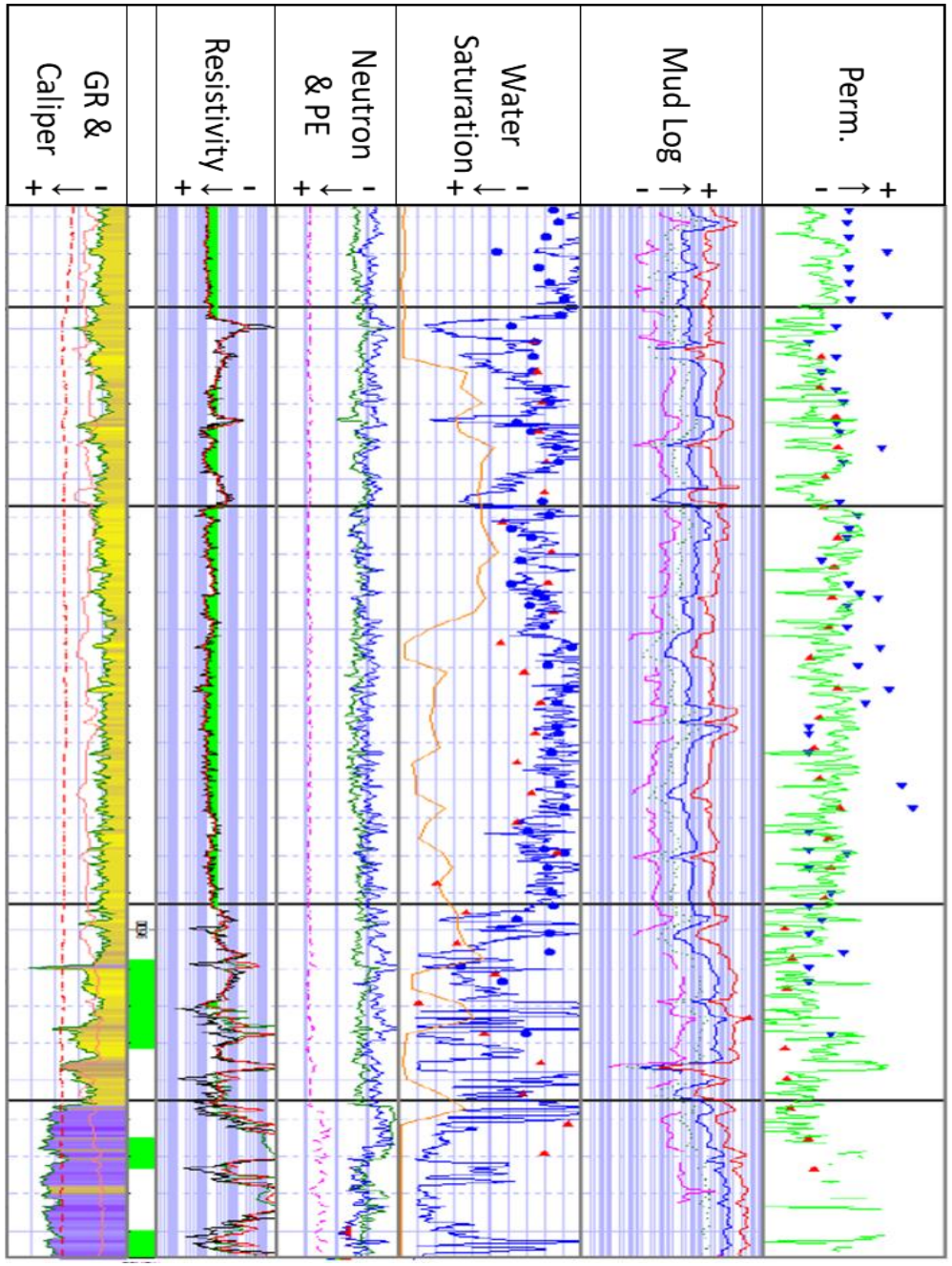
Postmortem analysis of well targeting the Bone Springs Sands

The lateral failed to produce meaningful quantities of HCs, landed in water leg, and produced large quantities of water.

Operator paid ~750K to assess well (logs and side wall cores).

AHS assessed well using 30 legacy PDC bit cutting samples for two orders of magnitude less cost. AHS correctly assessed normalized Sw and permeability compared to traditional methods. Red dots represent RVS vs continuous lines as petrophysics and blue dots as side wall cores.

Similar Sw and/or permeability comparisons have been proven correct in multiple other regions, play types, formations/lithology types, and other rock sample types (rock bit/tricone cuttings, side wall cores, and core).



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Thank You.
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