ADVANCED HYDROCARBON STRATIGRAPHY (AHS)

Rock Volatiles Analyses of the B.A. Saskatchewan Landing Well Core. Detailed Fluid, Reservoir, and Cap Rock Insights from the C1-C10 Hydrocarbons, Organic Acids, CO_2, Formation Water, Helium, Various Sulfur Gases, and Mechanical Strength; Implications for Helium System Analysis

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SASKATCHEWAN GEOLOGICAL SURVEY 19 48

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Background/Motivation

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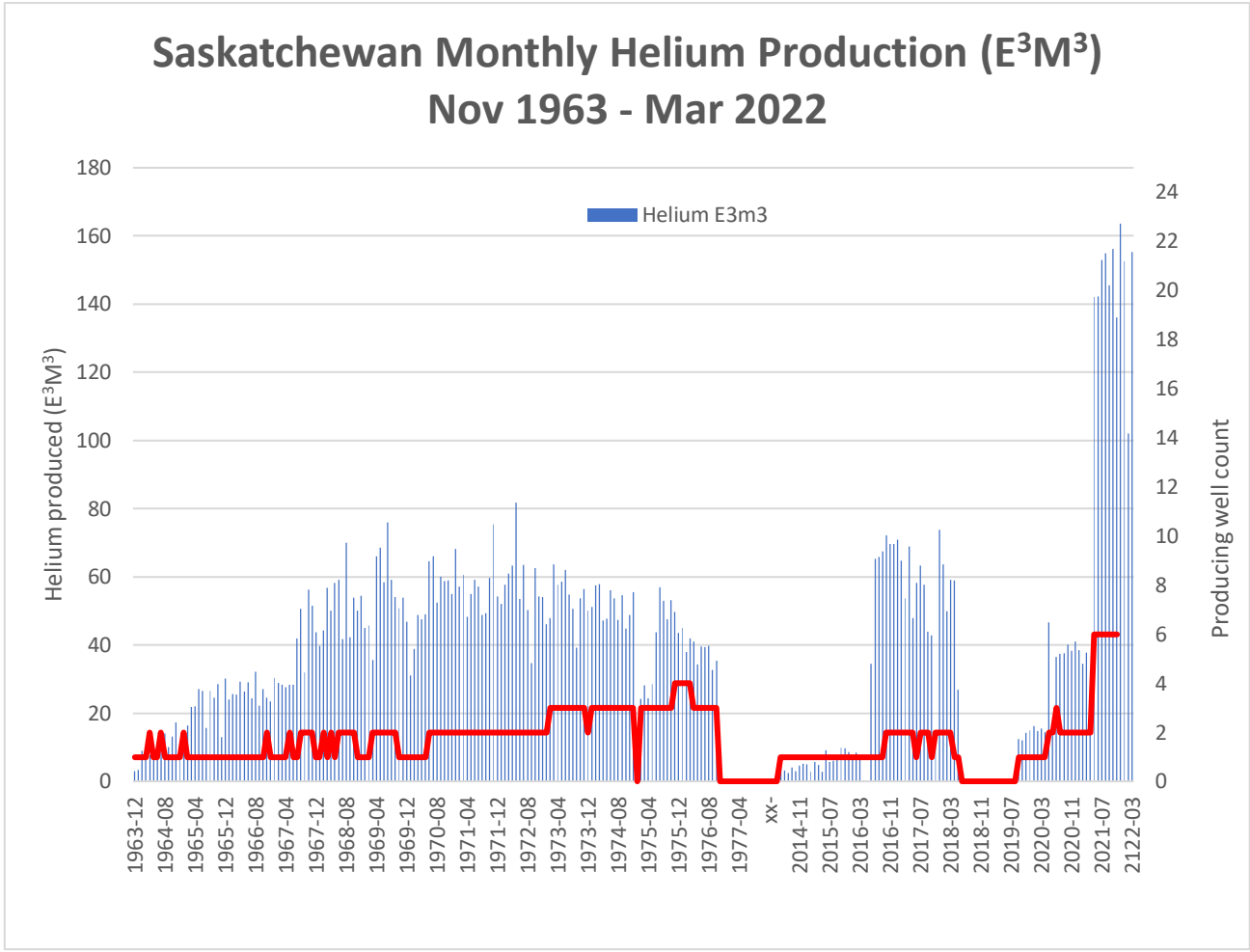
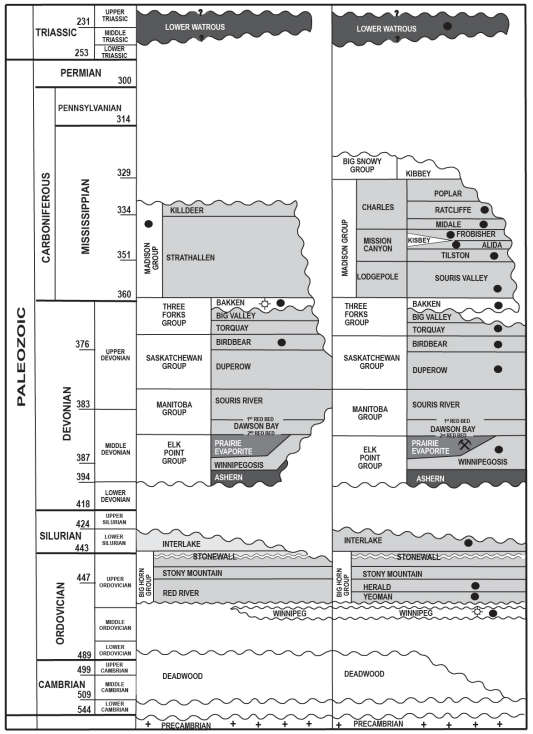
- Throughout the 1960-70s helium, typically not associated with hydrocarbons, was produced in Saskatchewan; production was driven by United States aerospace and space programs
- In the last several years there has been a renewed interest on helium production – helium was added to the Canadian and United States Critical Minerals lists, driven by changing economic/regulatory policies in the US and geopolitical concerns
- "Green" non-hydrocarbon associated helium has also become prized from an ESG perspective by operators like North American Helium, Desert Mountain Energy, and Helium One
- With even small concentrations of helium (0.3%) in a gas stream being considered economically viable targets there is renewed interest in the helium resources of Saskatchewan
- Analysis of the core from B.A. Saskatchewan Landing was carried out to gain insights into the subsurface helium system of Saskatchewan

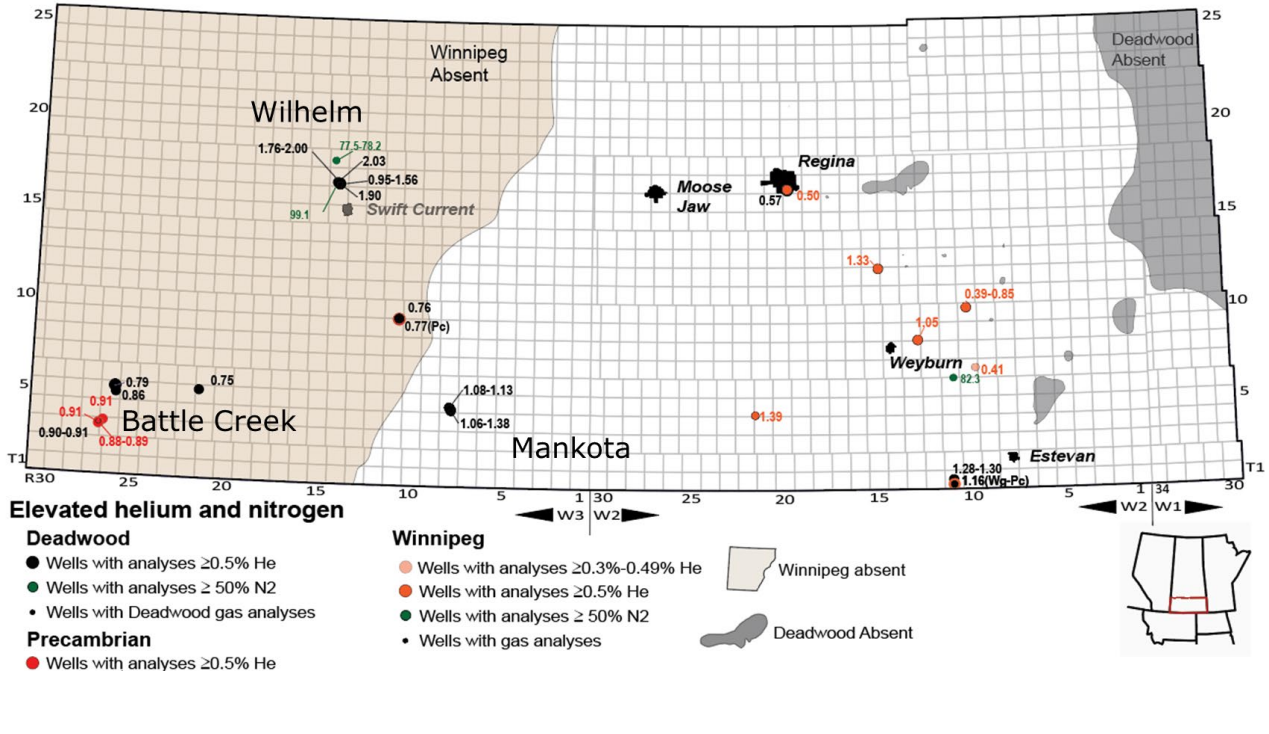


Background/Setting

ADVANCED HYDROCARBON STRATIGRAPHY

- B.A. Saskatchewan Landing (Wilhelm) was drilled in 1962
- The well tested 1.8-2% helium content in the Cambrian aged Deadwood - “Dolomite Pay Zone”
- A core covering the bottom 254 ft of the well including the whole “Dolomite Pay Zone”, the likely seal, and the top 9 ft of the Precambrian was collected and is at the SGS
- Produced 107,250 MSCF of helium from 1963-77 (1.3% He production)





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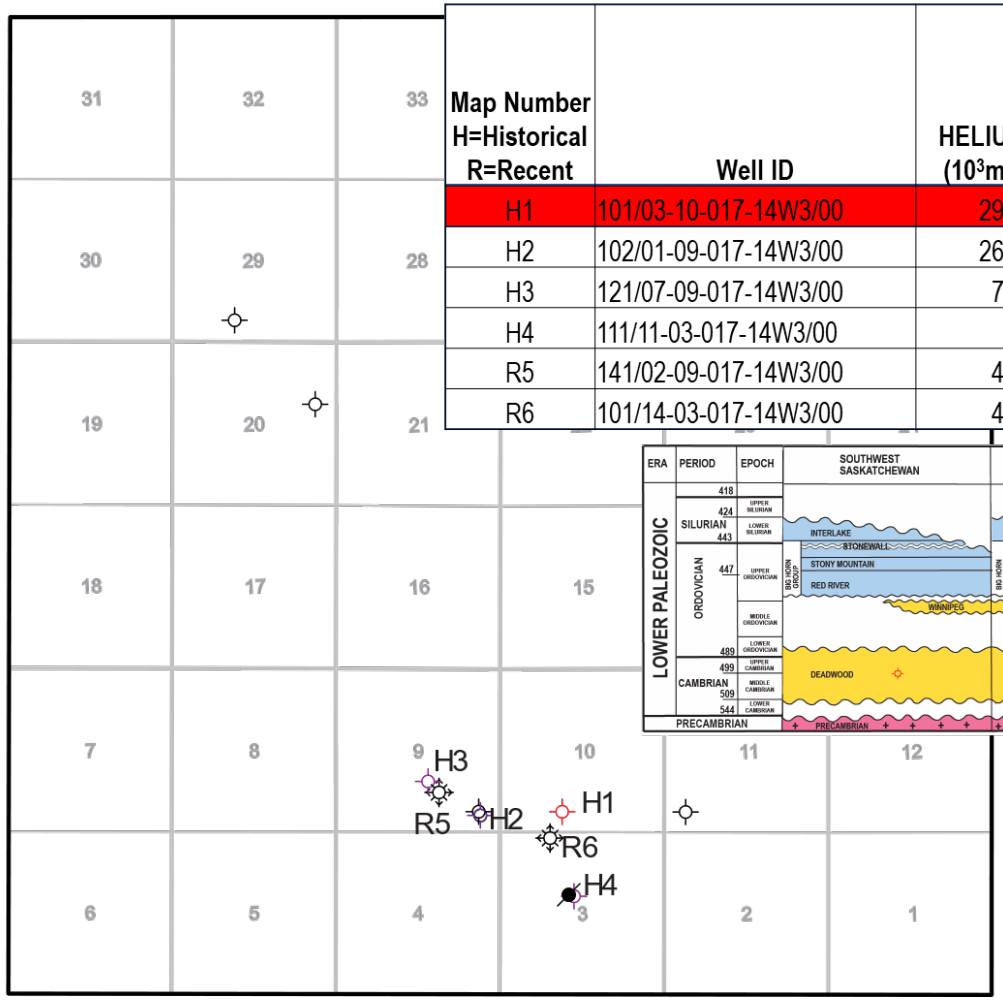
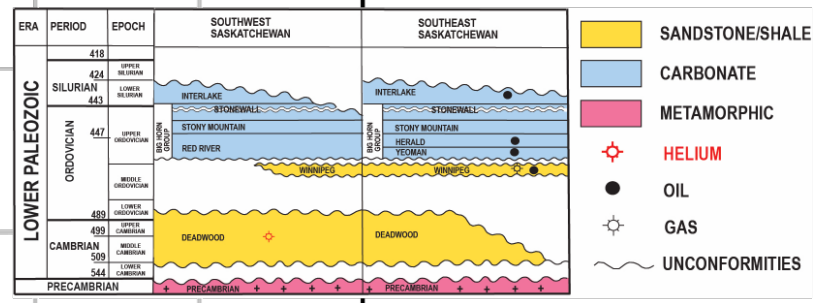
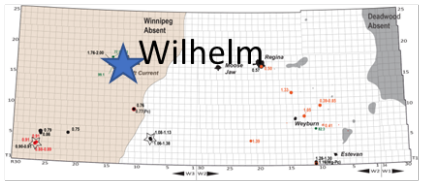
R14W3

T17

Map Number H=Historical R=Recent	Well ID	HELIUM (10^3m^3)	TOTAL GAS (10^3m^3)	Helium %	Months on Production
H1	101/03-10-017-14W3/00	2994.7	214886.7	1.39	142
H2	102/01-09-017-14W3/00	2689.5	190172.9	1.41	1
H3	121/07-09-017-14W3/00	776.4	56704.9	1.37	51
H4	111/11-03-017-14W3/00	36.2	2668.9	1.35	5
R5	141/02-09-017-14W3/00	429.2	28422.0	1.51	52
R6	101/14-03-017-14W3/00	461.3	45391.6	1.02	9







What is Rock Volatiles Stratigraphy (RVS)

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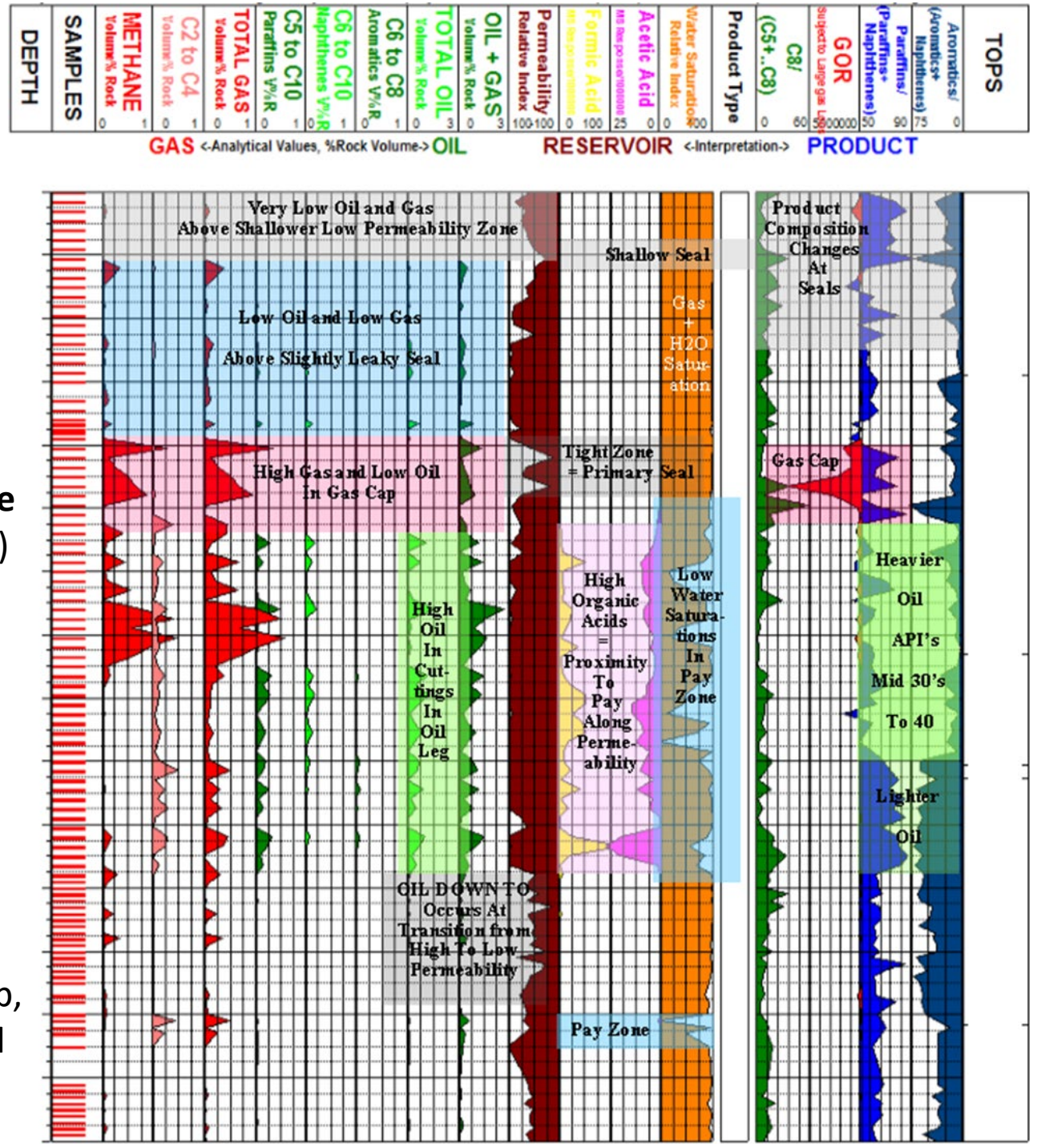
A *non-intrusive* technique using a novel cryo-trap mass spectrometry system developed by AHS to gently extract, identify, and quantify volatiles in geological materials.

Used for a variety of applications (**Oil and Gas**, **Carbon Capture Utilization and Storage [CCS/CCUS]**, **Helium**, and **Geothermal**) for detailed subsurface assessments (**migration**, **seals**, **accumulations**, **compartments**, **resource quality**, **thermal maturity**, **rock properties**, **production allocation**) and post-mortems (**seal failure**, **resource fractionation**, **parent-child relationships**, **mapping previous drainage**, **over-pressure**, **tar**) to operational decisions (**perforations** and **landing zones**)

Lab based analysis can be completed in 36 hours or less for operation decisions.

Works on PDC/rock bit/cable tool cuttings, core, SWC, out crop, muds, and produced fluids samples regardless of age and mud system.



What is Measured by RVS?

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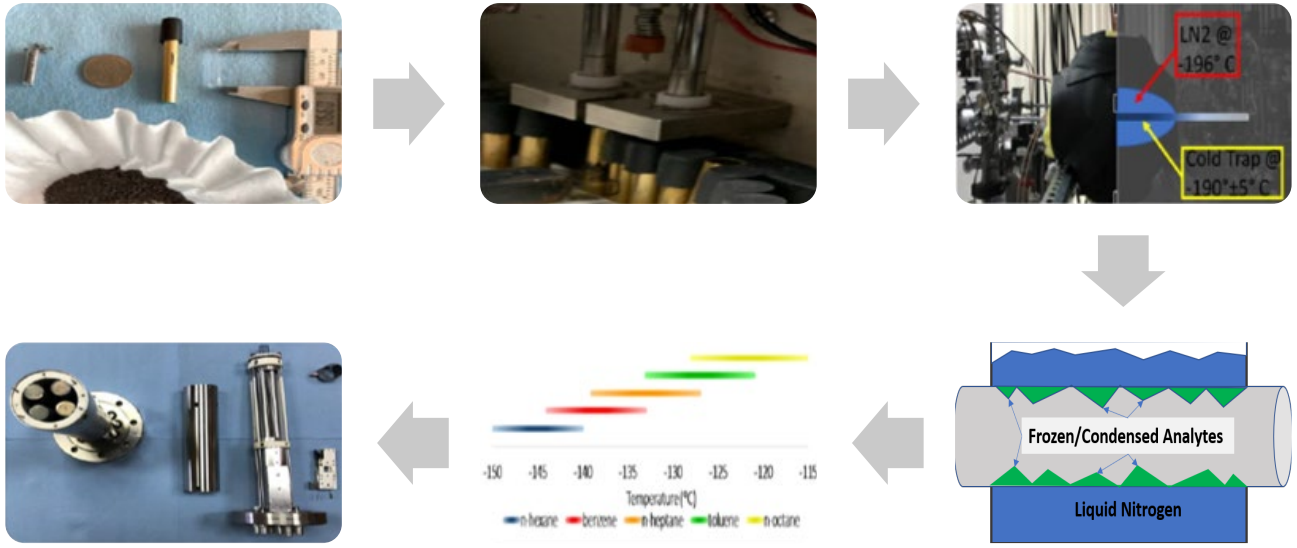

Instrumentation Workflow

1) Legacy and unsealed samples are high graded and prepared in lab, sealed at well samples are prepared at site
2) Samples are treated gently, no solvents or heating, and are interfaced to vacuum system
3) Volatile chemistries evolve into vacuum system and are frozen on a LN2 cryo-trap
4) After extraction and condensation finish trap is warmed and compounds sequentially sublimate and are analyzed by a mass spectrometer – noncondensible volatiles are analyzed by bursting a head space sample into MS prior to warming

Small Molecules	**Sulfur Species**	**Hydrocarbons**
Water	Hydrogen Sulfide	C1-4 Gases
Carbon Dioxide	Carbonyl Sulfide	C5-10 Paraffins
Carbon Monoxide	Carbon Disulfide	C6-10 Naphthenes
Nitrogen	SO- (Sulfate Proxy)	C6-9 Aromatics
Oxygen	Sulfur Dioxide	
Ammonia		**Biological Compounds**
Nobel Gases	**Bit Burn**	Formic Acid
Helium	Ethene	Acetic Acid
Argon	2-Transbutene	Methyl Ethyl Ketone
	Stimulation Chemicals	
	Trichloroethylene	

With all compounds measured at two different extraction conditions, and the mechanical strength of the rock, **over 120 different *direct* measurements per sample provide a detailed description of the subsurface geochemistry using only 1-1.5 g of rock sample per depth**

Isomers, **isotopes**, and **additional signatures** are possible but not standard

RVS Helium

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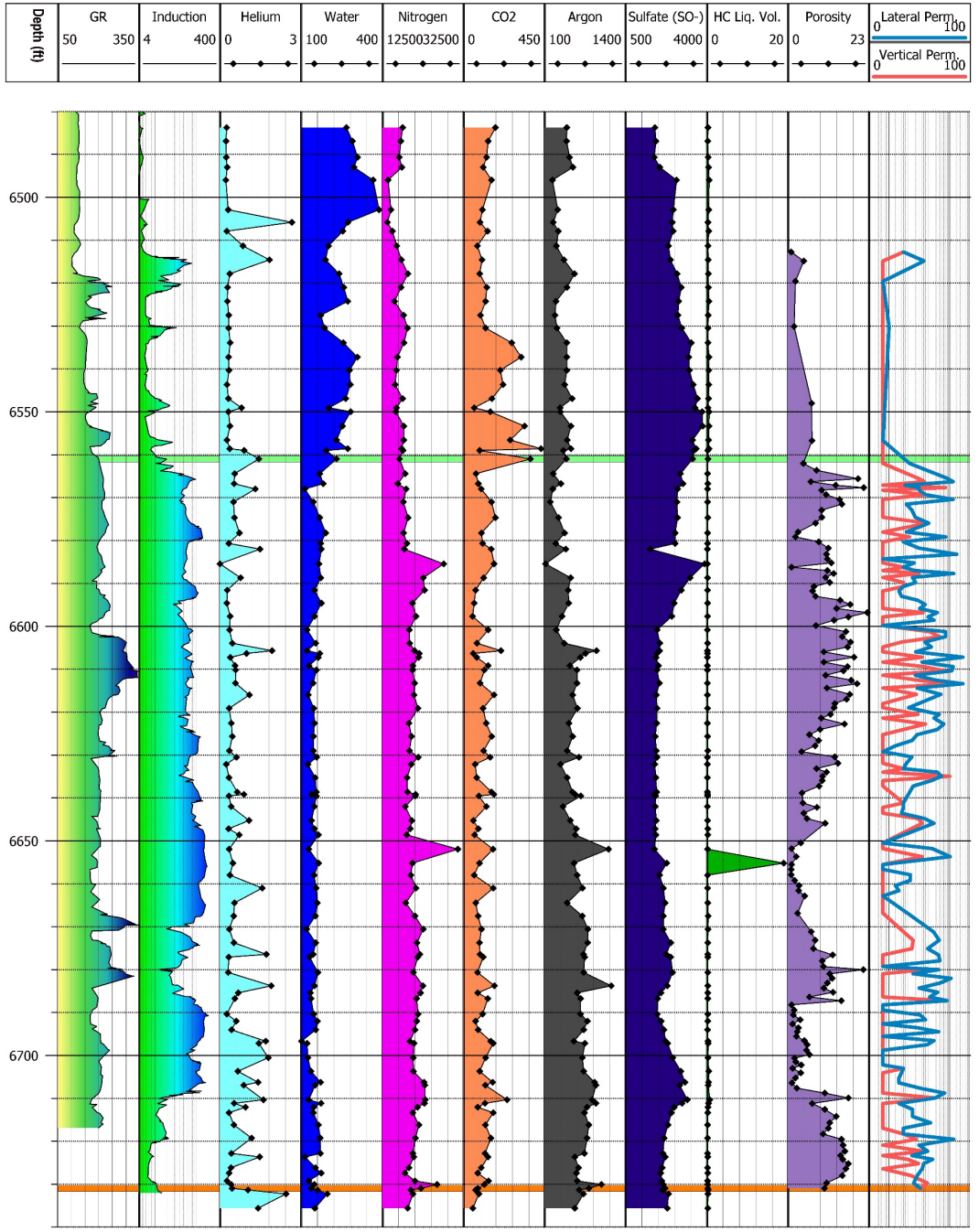
- Recently AHS has recently significantly improved its helium sensitivity
- The ~ 5 ppm of helium in air (under operational conditions ~0.2 nanomoles) can readily be detected well above baseline levels
- This enables the ready measurements of sub-nanomole quantities of helium in small volume rock samples – RVS is suitable for analyzing helium in addition to other compounds in legacy rock samples

RVS Analysis of B.A. Saskatchewan Landing Core

- 102 core chips were collected and submitted for RVS analysis
- In addition to the helium - nitrogen and carbon dioxide data were examined as they were present in the DSTs and the production
- Other RVS data including water, argon, sulfate, and some hydrocarbon data were also examined
- In addition to RVS data, legacy wireline and core analyses data were utilized in the interpretation of the core data



Ground Truthing

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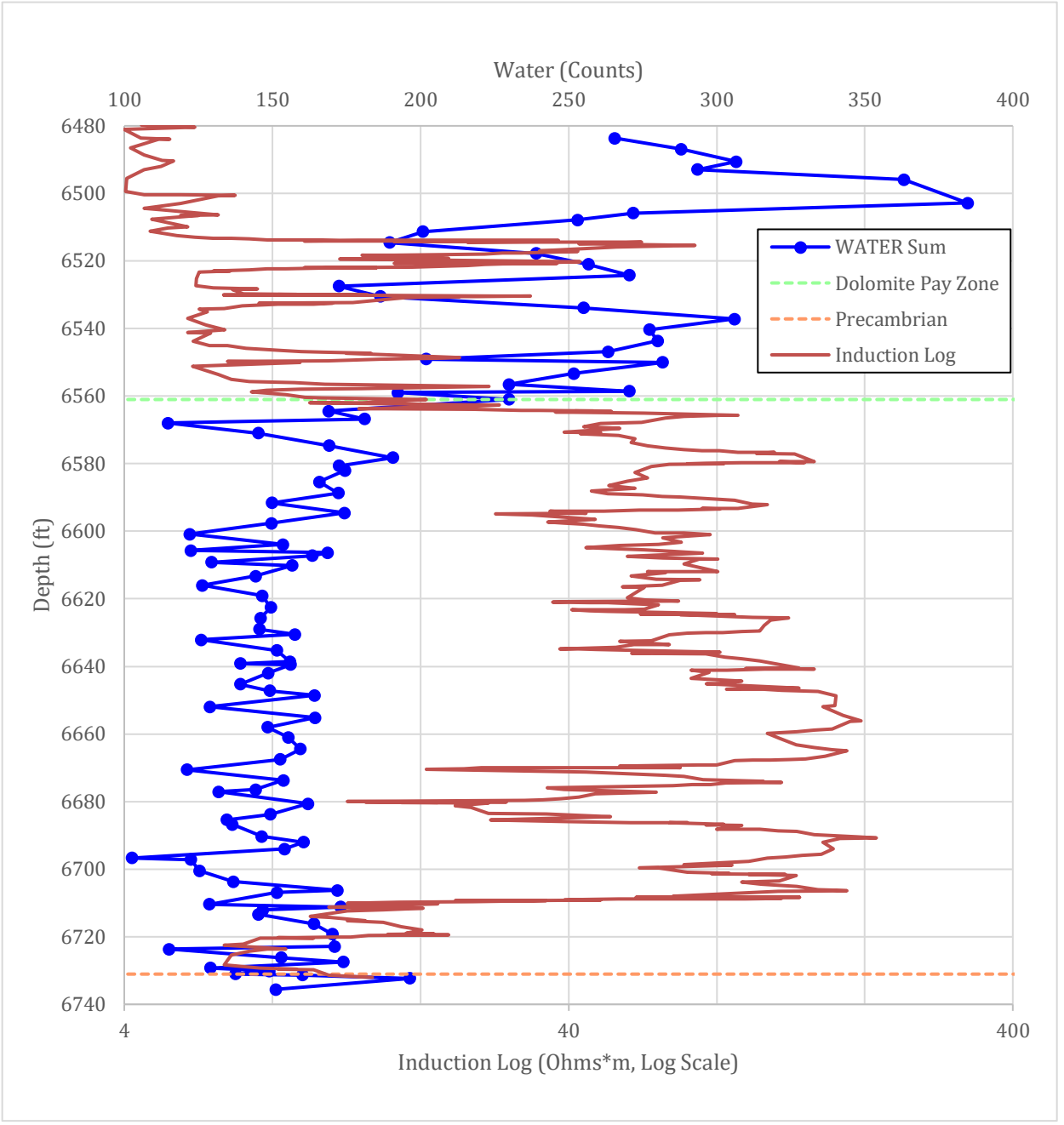
- With 60 year old core it is important to establish that the volatiles data relate to subsurface at the time of drilling
- RVS water data has been previously shown to have quantitative relationships to subsurface water content



Ground Truthing

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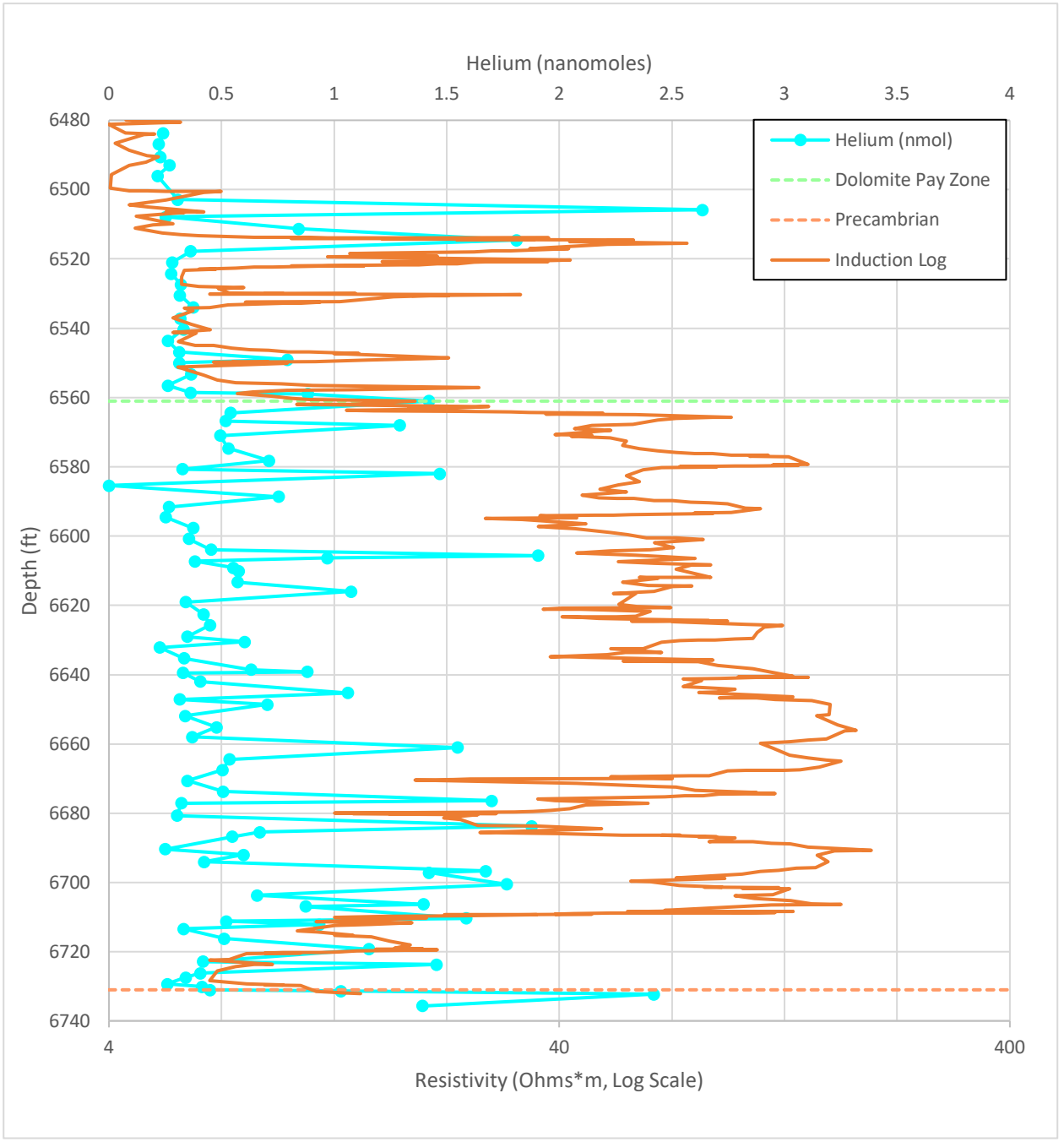
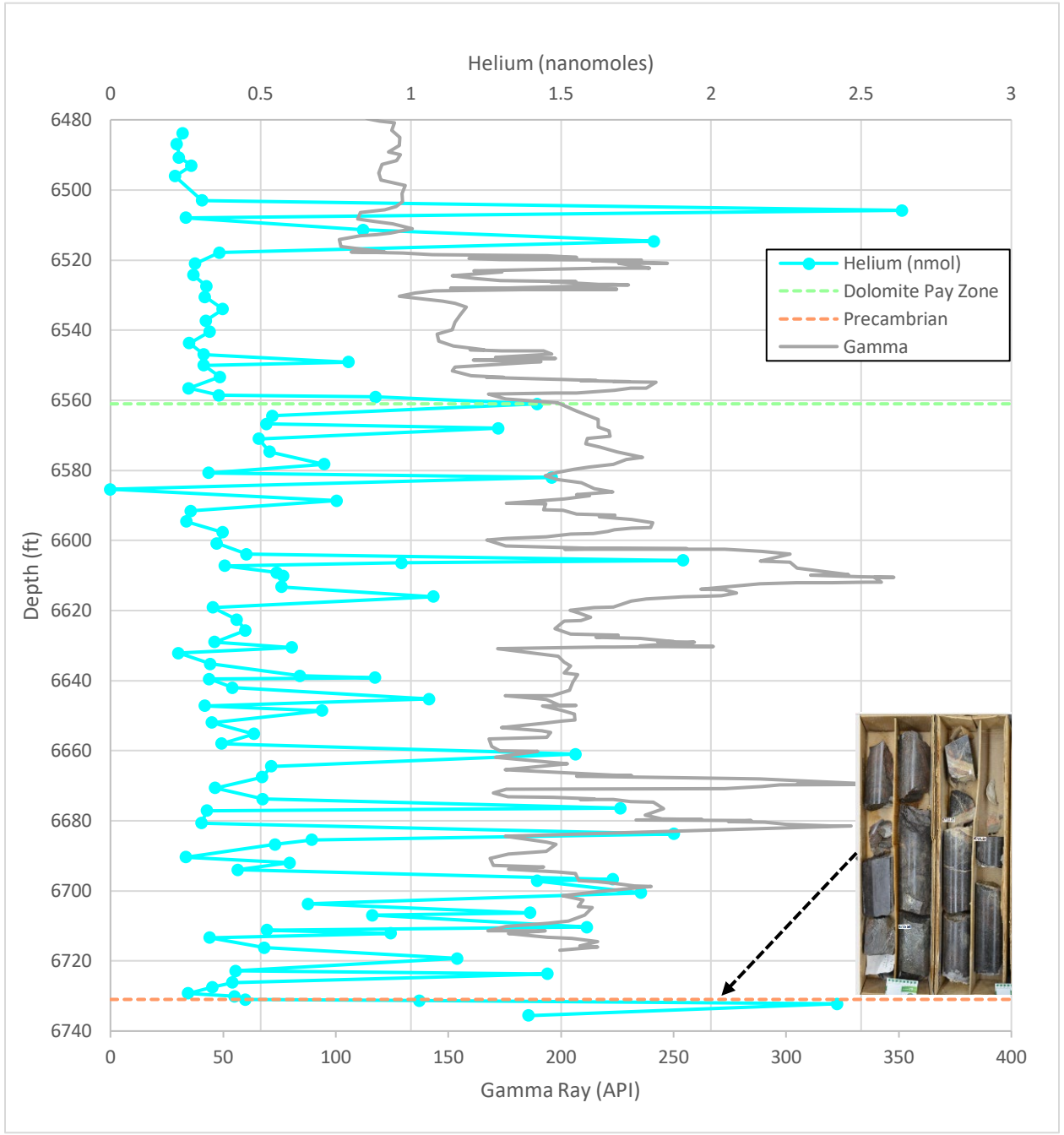
- With 60 year old core it is important to establish that the volatiles data relate to subsurface at the time of drilling
- Helium responses also shows correlations with the induction log of the time
- Other RVS data such as nitrogen shows similar relationships



Helium Sourcing

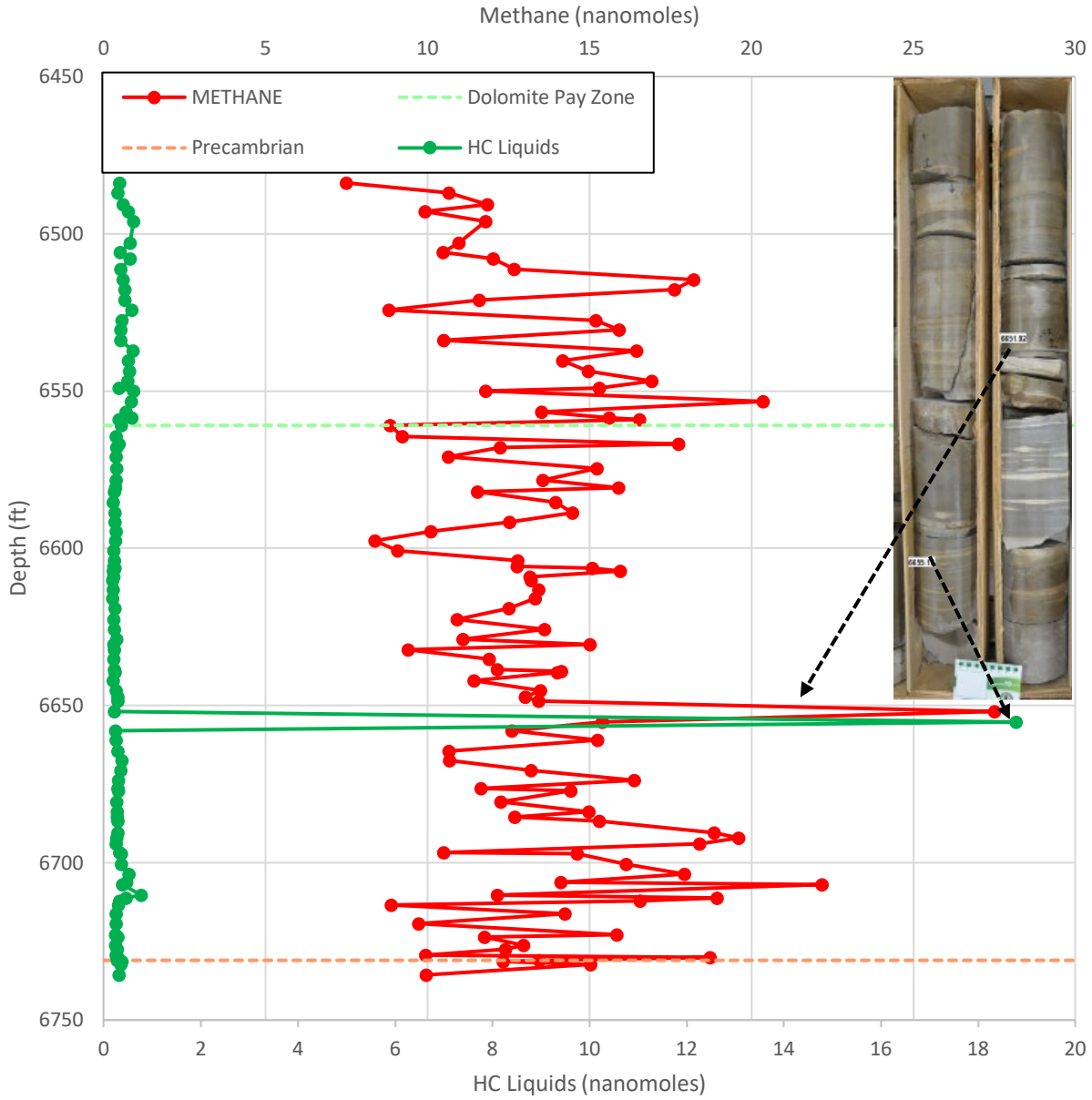
- There appears to be no strong correlation between the helium measured and the historical gamma ray log data
- The helium being measured is not self sourced from alpha particle emission but is related to the subsurface helium system
- On average the helium in the Precambrian granite is higher than observed elsewhere in the core



Understanding RVS Data Distributions

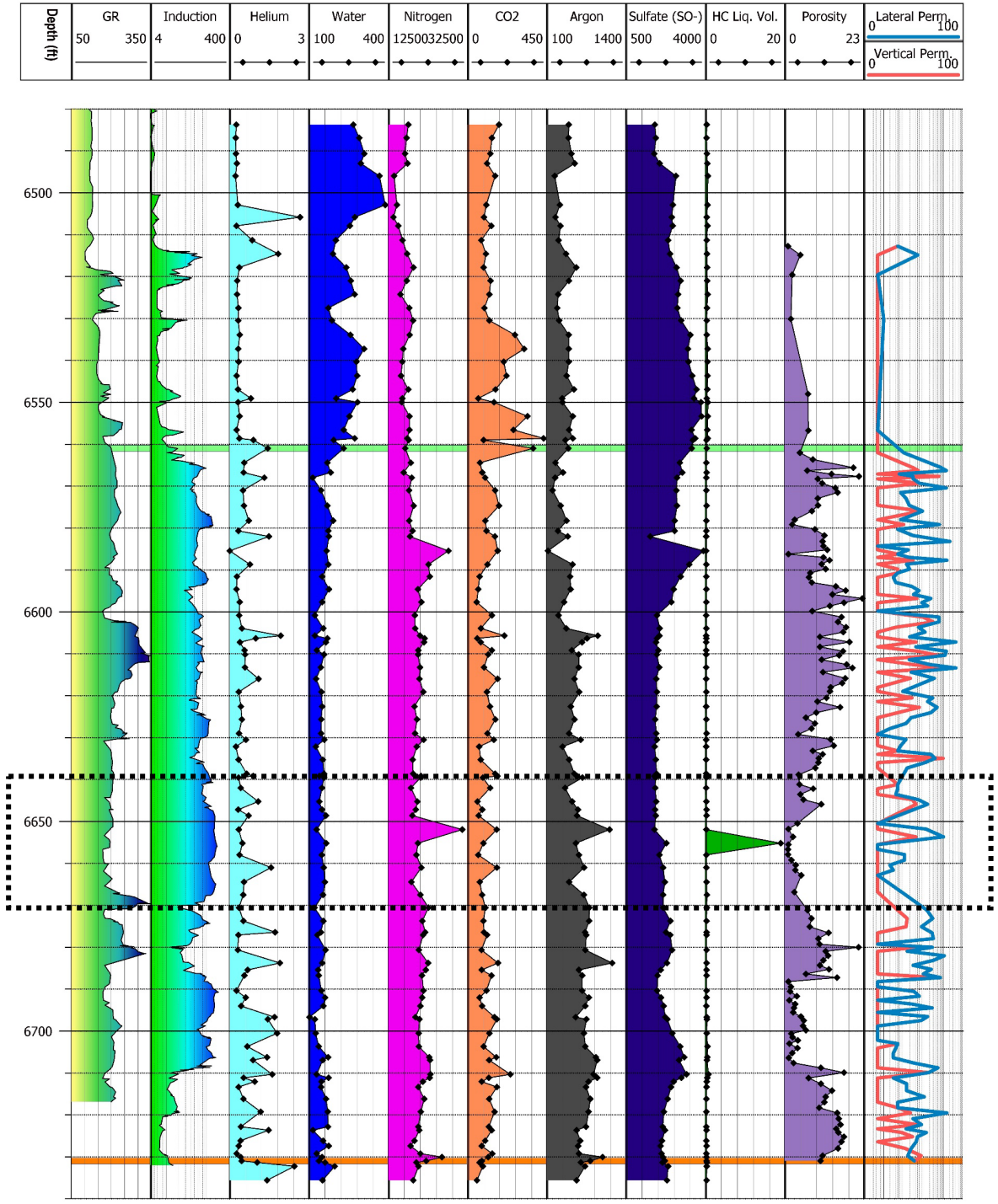
- While there is no recorded hydrocarbon data in the production or the DSTs there does appear to be a trace of one hydrocarbon liquid filled fracture in a section of the core with a discrete high lateral permeability
- Immediately above this depth no significant quantities of liquid hydrocarbons are observed but this higher concertation of methane in the core is
- Compounds are accessing or being restricted from spaces based in part on their size distribution

Volatile	Helium	Argon	Nitrogen	Menthane
Kinetic Diameter (pm)	260	340	364	380



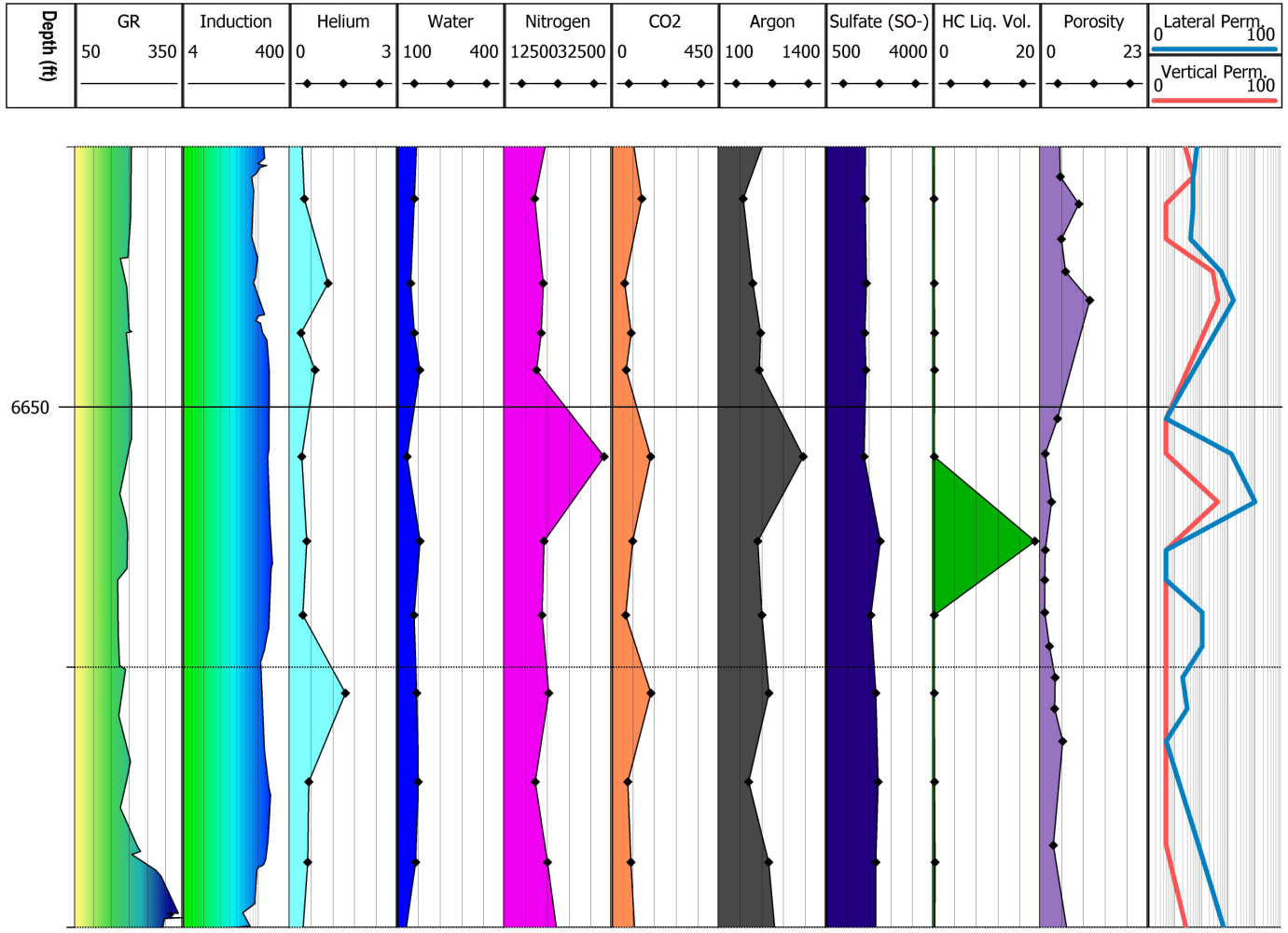
Understanding RVS Data Distributions

- Other smaller compounds show high concentrations at this position similar to methane
- Highest nitrogen, 2nd highest argon, and discretely decreased water content



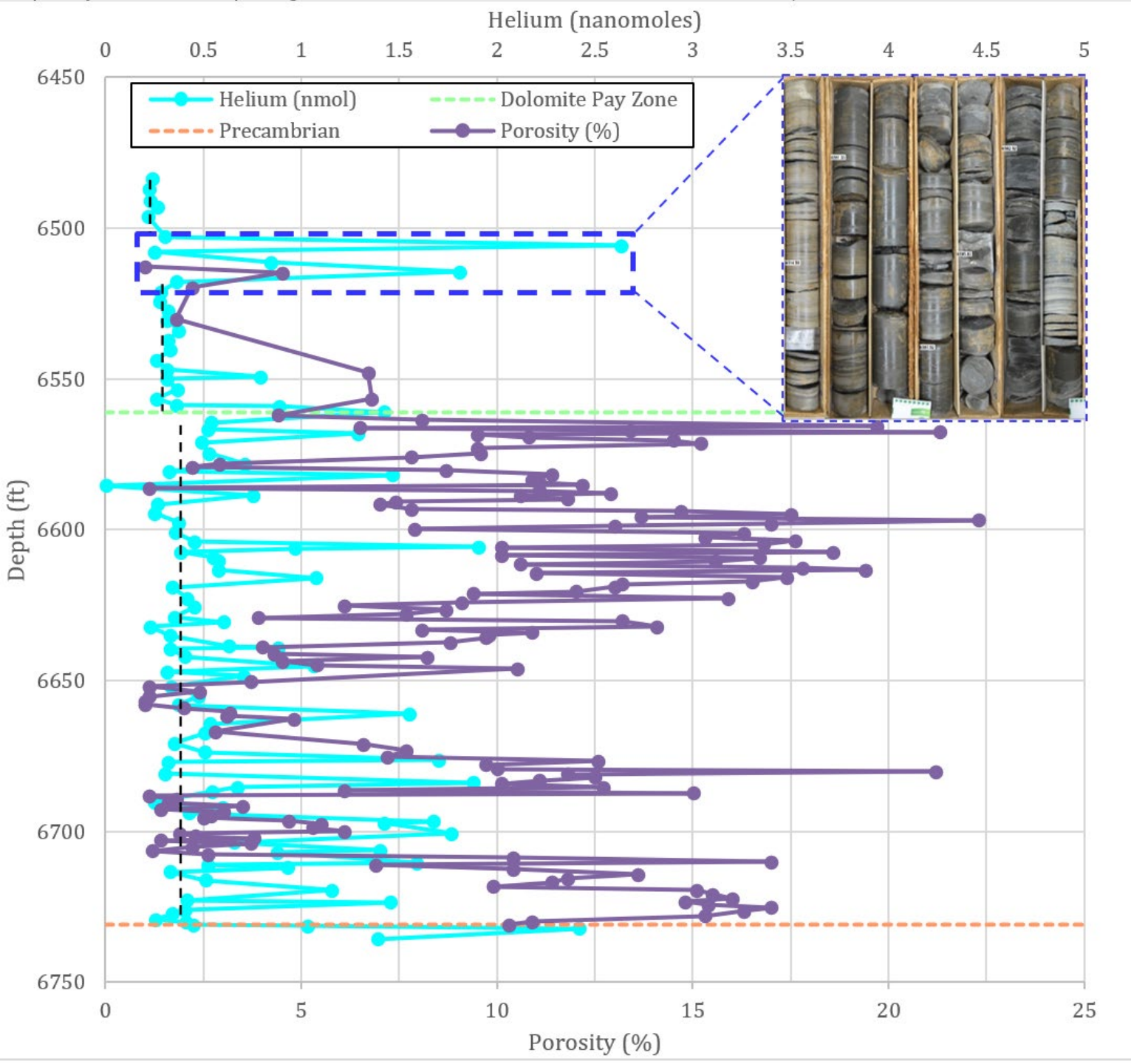
Understanding RVS Data Distributions

- Distribution can be observed as being linked to properties like porosity and vertical permeability
- Common occurrence in the RVS data; build up of different species can relate to where those compounds encountered tight rock



RVS Helium Distributions

- In RVS data from legacy samples He accumulates either in sealing features or immediately below them; its small size and buoyancy allow it to force itself into or against these tight rocks where it is trapped
- This behavior is observed at multiple depths such as 6556.7, 6661, and 6710.37 which show correlations with low porosity measurements
- Other such high helium responses can be correlated with low vertical permeability
- There appear to be three baselines within the data that show transitions at such depths, though 6518-6559 is likely linked to water content
- High responses from 6505-6515, which correlate to a shale package, may be the most significant sealing feature encountered given the lowest baseline is observed above this depth



RVS Helium Distributions

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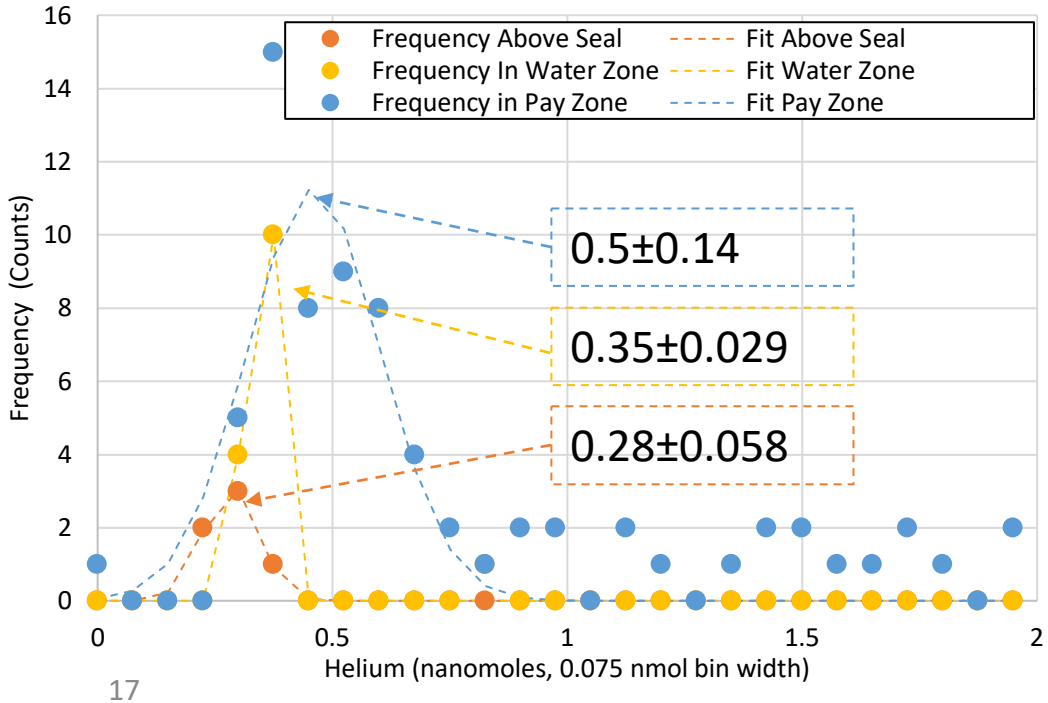
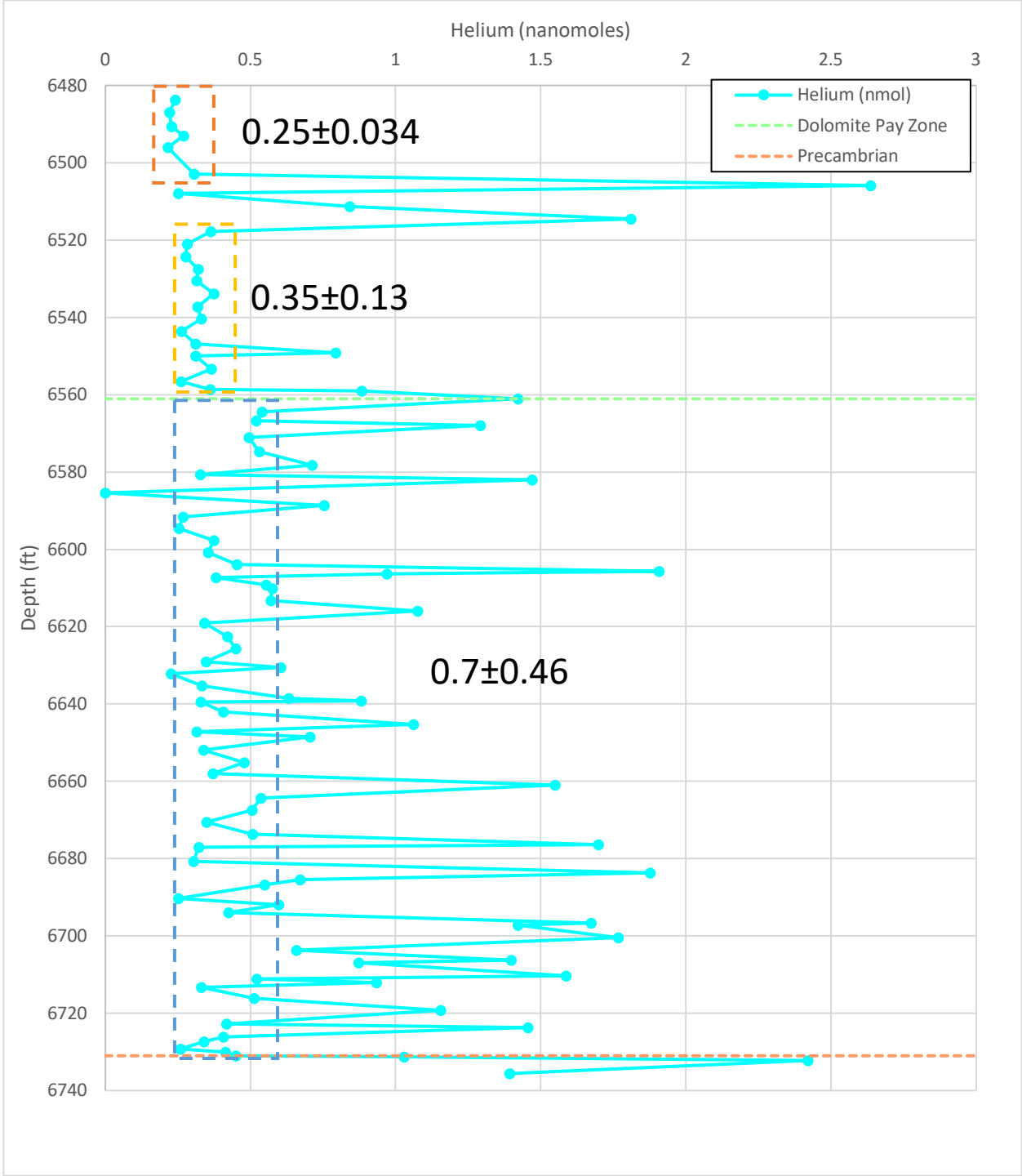
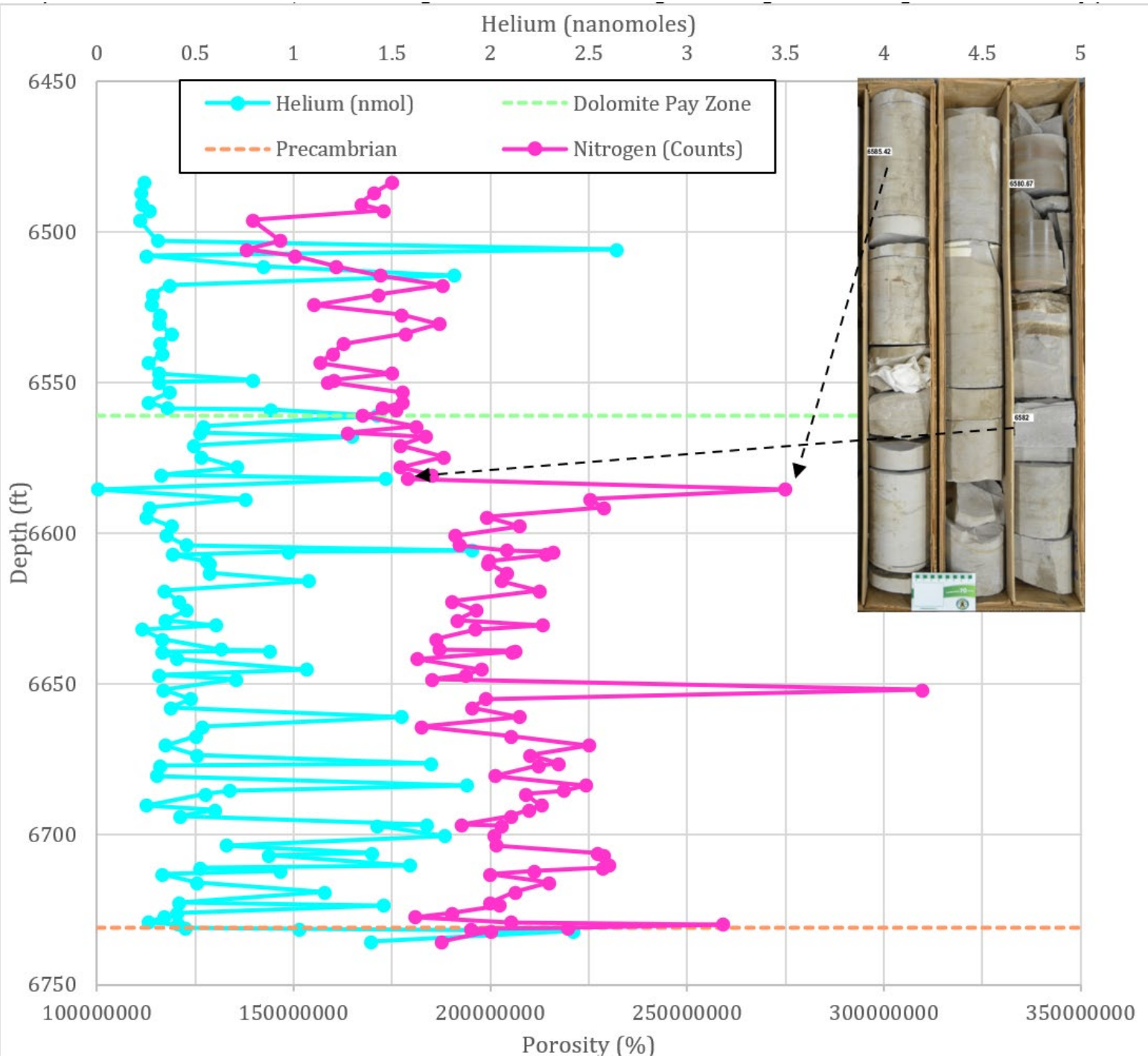
- Identified apparent baseline shifts are statistically significant
- T-test shows significant difference at the 97.5% confidence level between the identified zones





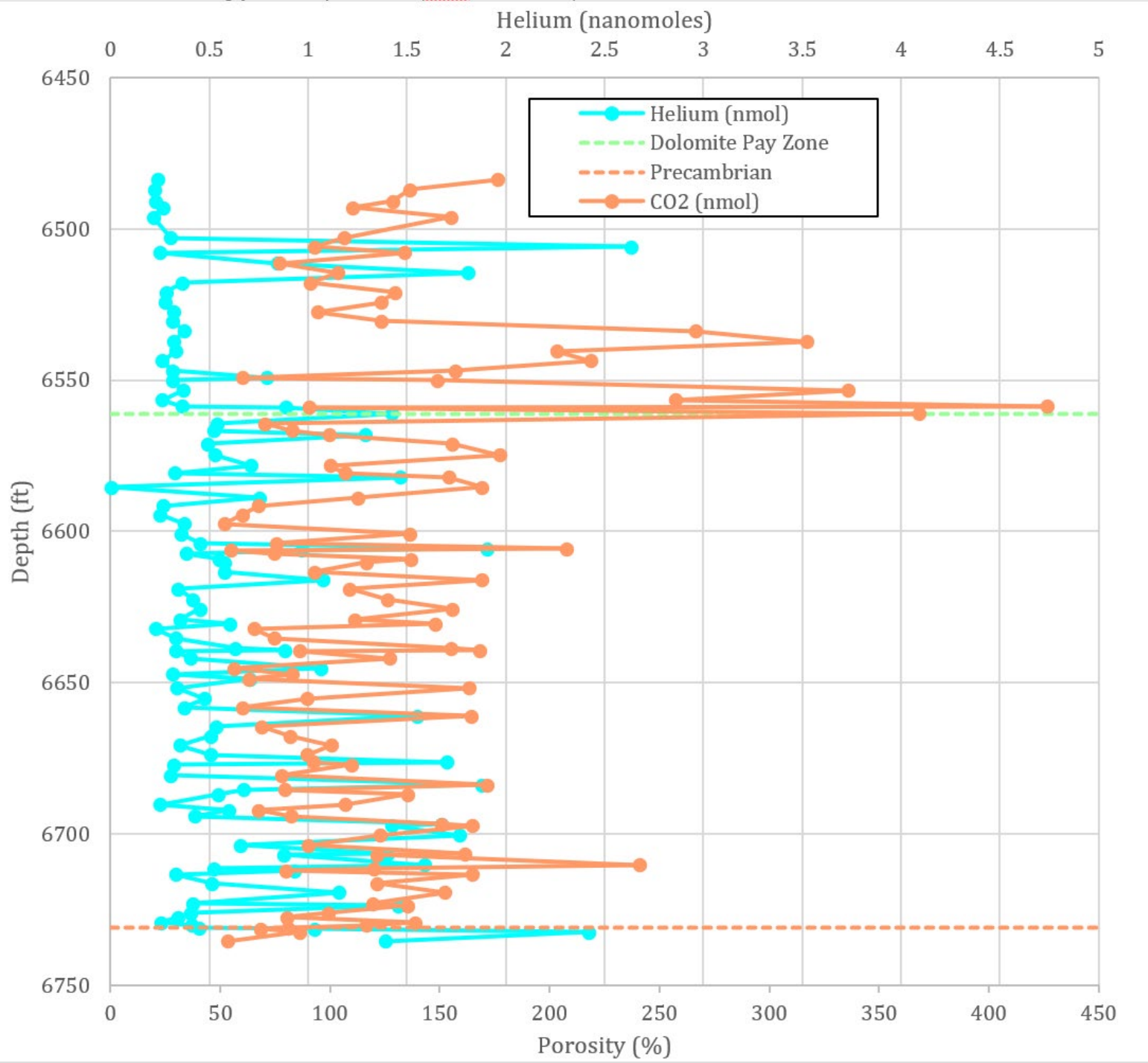
RVS Helium vs Nitrogen

- Distribution can be observed as being linked to properties like porosity and vertical permeability
- Nitrogen shows a significant build up and then baseline shift at 6585.4 ft
- Suggests significant baffle/seal to nitrogen but not helium, consistent with very low porosity zone and no measurable vertical permeability



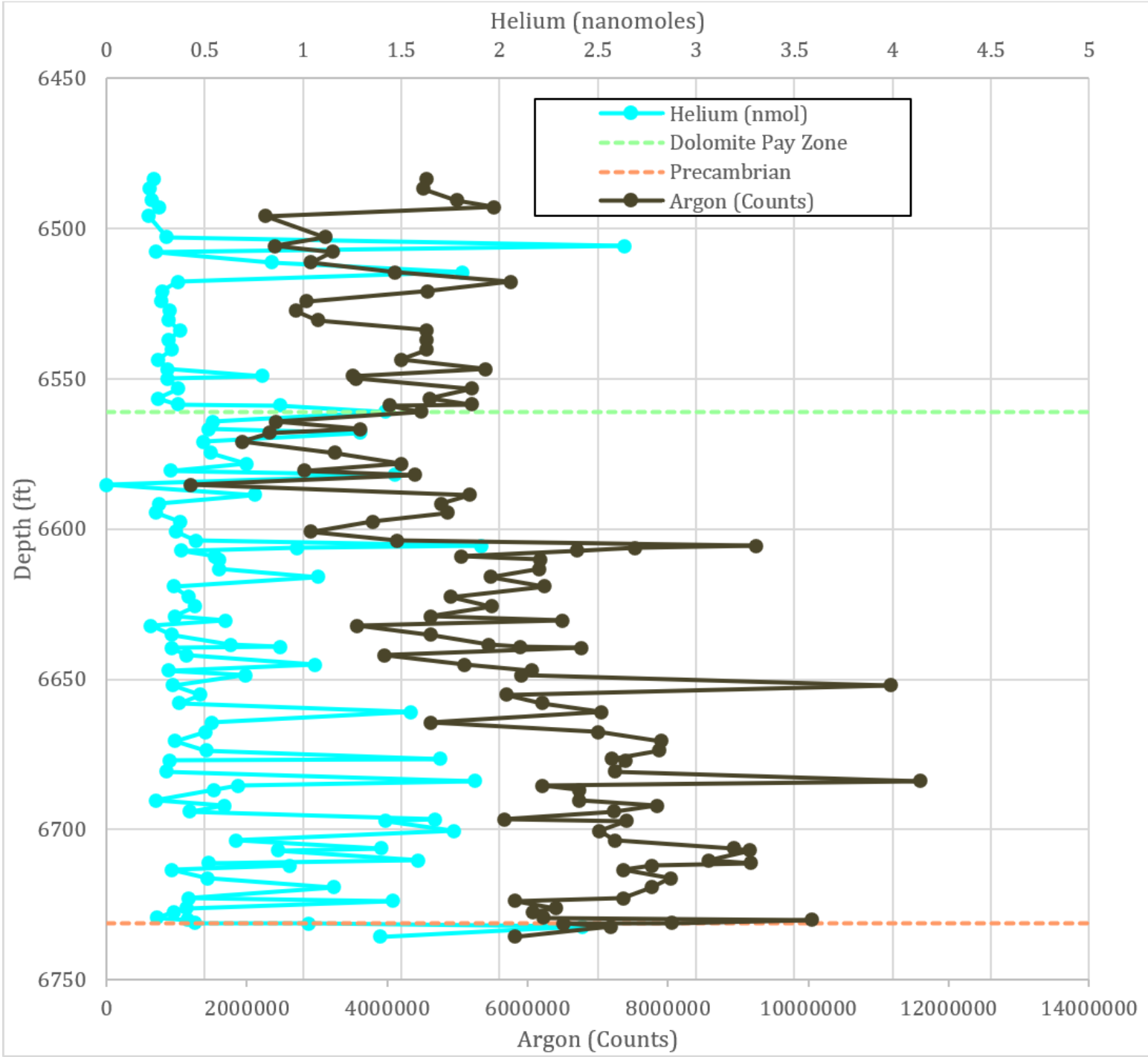
RVS Helium vs Carbon Dioxide

- No obvious distribution between CO2 and helium
- Enhanced CO2 appears to be in present in the water zone below a low water show, an enhanced nitrogen show, and an enhanced induction log response



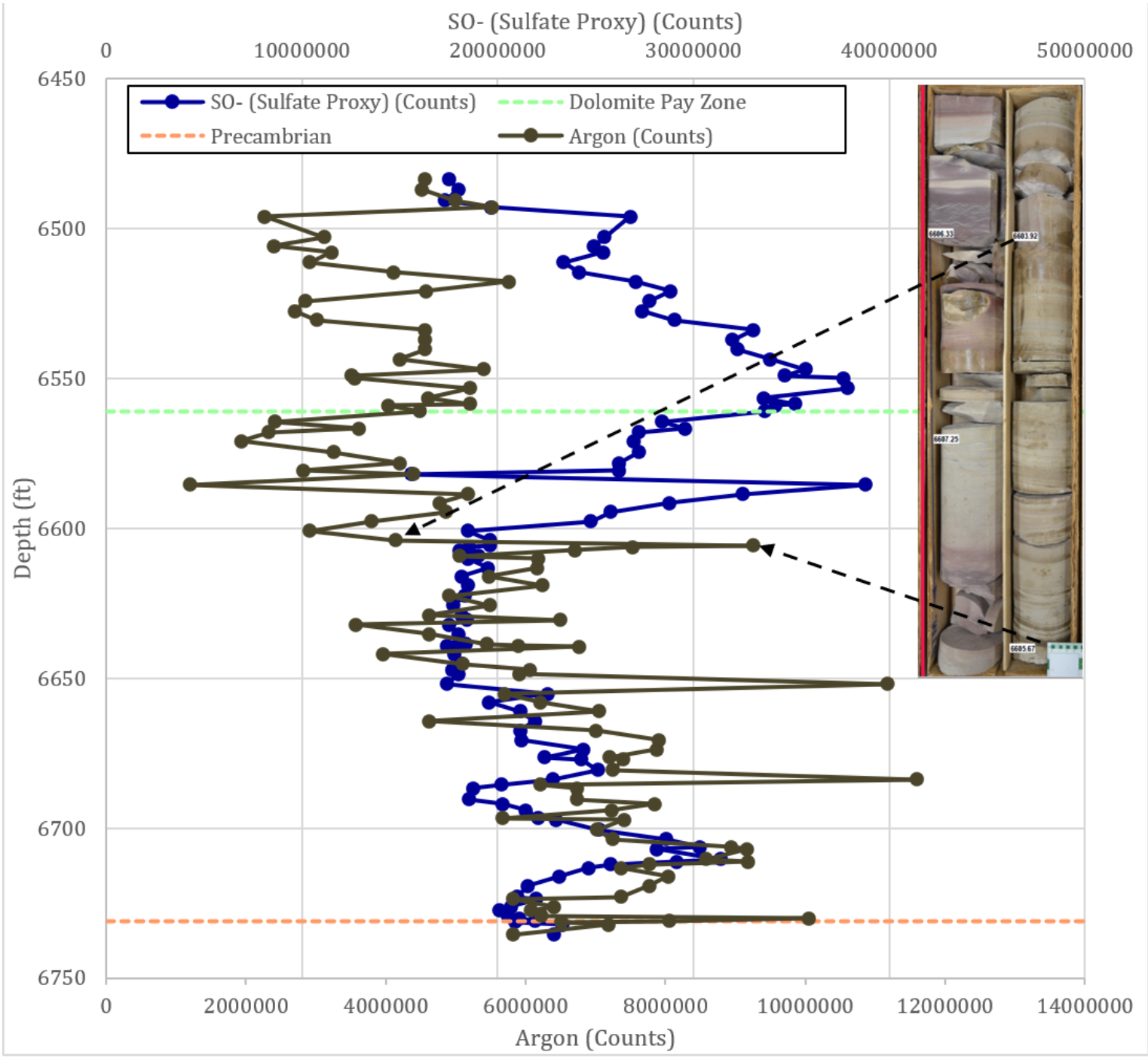
RVS Helium vs Argon

- Argon is similar in several properties to molecular nitrogen in size and inertness
- Yet it contains a different distribution than not only helium but nitrogen too



RVS Argon Sourcing

- Argon can be self sourced from the decay of potassium 40
- While there are no strong correlations with the GR log and RVS does not measure potassium it does measure compounds that relate to the deposition environment
- SO- molecular fragment serves as a proxy for sulfate in RVS data and provides information on depositional settings relating to salinity
- Apparent relationship between sulfate and argon suggest argon is self sourced from potassium 40



Conclusions

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- The RVS analysis of the B.A. Saskatchewan Landing core (101/03-10-017-14W3/00; 62H013) demonstrated that helium could still be measured and evaluated in a way that can contribute meaningful information to the analysis of the subsurface helium system utilizing several decades old samples
- The distribution of helium and other volatiles enabled the identification of key features including:
  - The potential top of helium migration “seal” at 6505.8 ft,
  - The enhanced helium content in the Precambrian basement granite which may provide further insights into local helium sourcing,
  - Molecular fractionation of nitrogen away from helium
- These interpretations are reinforced by the available legacy core analyses

Looking Forward

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- The value of the analytical procedure applied to these rocks lies directly with what we are seeing at the nanopore scale with the gas relationships to each other and with the rock. Given the molecular size of helium and the associated gases, these results are one step closer in developing a fundamental understanding of the true controls on the helium system in the province. Viewing these results in relation to other producing and potential exploration areas may help in maximizing helium recovery and reducing risk.
- These results frame the next phase of investigation that will use petrographic analysis and to better understand helium migration and trapping in Saskatchewan.

Acknowledgements

AHS would like to thank the great folks at the Saskatchewan Geological Survey, especially Jessica Flynn, Taggart Priddell, and Melinda Yurkowski for the opportunity to work on this exciting project with them and contribute to the evaluation and understanding of the subsurface helium system in Saskatchewan

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Questions?