CUDD ENERGY SERVICES

STIMULATION SERVICES

New Technologies & Applications

July 11, 2017

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Topics

- **Utilizing Analytical Information for More Effective Well Completions**
  - **Reservoir Evaluation Utilizing the Mass Spectrometer**
  - **Rock Stress Profile Generation from Drilling Data**

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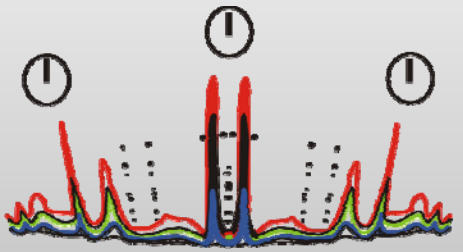
Using Analytical Information for More Effective Well Completions

Joe Lee
Permian Technical Manager

Drill2Frac
A2
Every Well Completed *WELL!*



Crown Geochemistry, Inc.

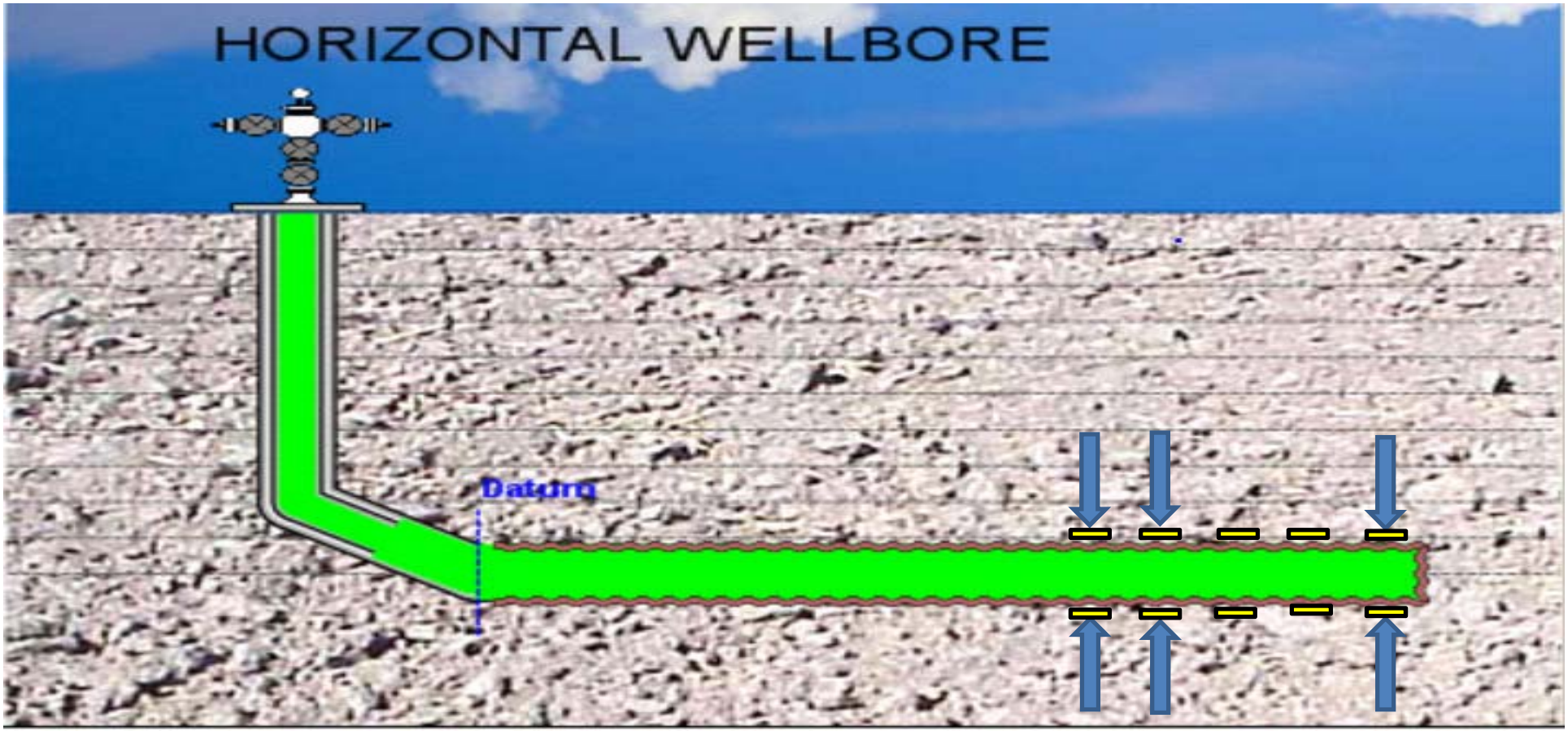
Bruce Warren
President

Industry Issues

- Many Wells are Uneconomical at the Current Oil Price
- Many Technologies are Unaffordable at the Current Commodity Prices
- Many Technologies Involve High Levels of Risk
- Lack of Understanding of What Intervals are Productive

Industry Issues

- Almost All Completion Designs for Horizontal Wells Utilize Evenly Spaced Perforations and Equal Sized Treatments
  - Therefore all Horizontal Wells are Homogeneous!
- Intervals are Being Perforated and Never Effectively Treated



Current Stimulation Analysis Tools

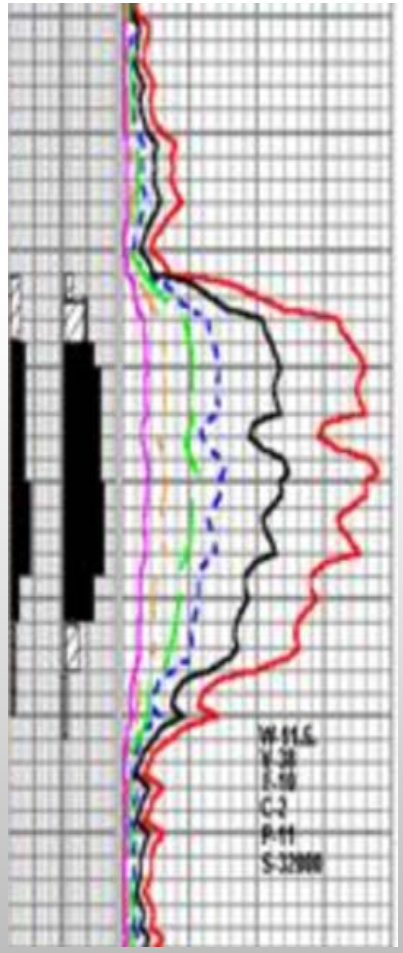
- Well Logging – Gamma Ray, Neutron, Density, Laterolog, PE, Sonic, etc.
  - Gives Relatively Accurate Measurements for Lithology, Porosity, Water Saturations, Rock Stress, etc.
  - Moderate Cost and Relatively Risky
- Cores
  - Excellent Information for Lithology, Mineralogy, Permeability and Porosity
  - Flow Through Tests Can Help Determine Frac Fluid Sensitivities
  - Moderate Cost and Relatively Risky

Current Stimulation Analysis Tools

- Cuttings Analysis – XRF, XRD, SEM
  - Low Risk
  - Low to High Cost
- Mud Logging
  - Used to Analyze Formation Samples
  - Low Risk and Relatively Low Cost
  - Results are Dependent on Personnel on Location
  - Does Not Detect Liquid Hydrocarbons (Stops at C5)
  - Mud Logging Does Not Detect Inorganic Species
    - He, H_2, CO_2, Argon, H_2O, H_2S, etc.

Current Stimulation Analysis Tools

- Mud Logging Strip Log Shows C1 through C5 Uniformly Proportioned Almost Every Time
- Is this an Accurate Measurement?
- Chromatograph
  - A Lab Sample Takes 28 Minutes to Measure C1 plus C2. Two Hours are Required to Measure Through C5. Mud Logging "Forces" the Complete Measurement Cycle in 7 Minutes or Less.



Stimulation Analysis "Wish List"

- Inexpensive
- No Risk
- User Friendly

- Items to be Identified:
  - Sweet Spots
  - Compartments
  - Unproductive or Lower Quality Zones
  - Relative Hydrocarbon Content (Oil, Gas, Water)
  - Rock Stress – How easy or Difficult to initiate a hydraulic fracture

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Using The Quadrupole Mass Spectrometer For Frac Design

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Quadrupole Mass Spectrometer

- The Process - Using a Surface Instrument (Mass Spectrometer) to Measure the Hydrocarbon Content (C1 to C10) that is Released into the Drilling Fluids from the Crushed Rock
- The Mass Spectrometer Identifies Compartments, Productive Pay, Unproductive Pay, “Sweet Spots”, and Stratigraphic Changes
- The Mass Spectrometer is an Inexpensive Tool that Helps in the Design of Engineered Completions
- The Process has been Successfully Applied in Numerous Horizontal and Vertical Applications

Gas Data Analysis
Mass Spectrometer & The Gas Laws

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Pascal's law: (circa 1647 – 1648)

A change in pressure at any point in an enclosed fluid at rest is transmitted undiminished to all points in the fluid.

Avogadro's law: (circa 1811)

.... For a given mass of an ideal gas, the volume and amount (moles) of the gas are directly proportional if the temperature and pressure are constant.

Dalton's law: (circa 1801)

(also called Dalton's law of partial pressures) states that the total pressure exerted by the mixture of non-reactive gases is equal to the sum of the partial pressures of individual gases.

Charles' law: (circa 1787)

... the volume of the gas increases or decreases by the same factor as its temperature

Henry's law: (circa 1803)

... the solubility of a gas in a liquid is directly proportional to the partial pressure of the gas above the liquid.

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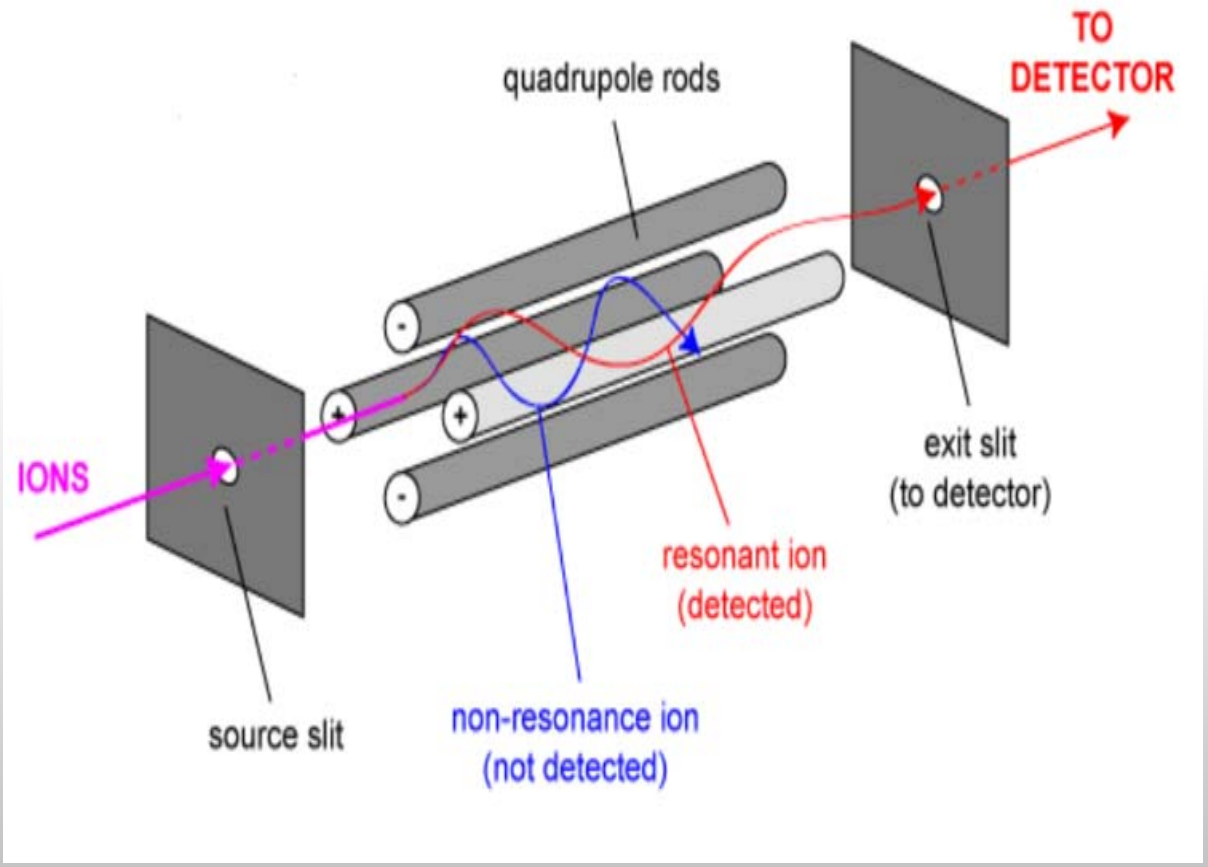
Quadrupole Mass Spectrometer



Only 1 Molecular Weight Can Reach The Detector

The Energy Field Is Rapidly Changed to Detect Different Gas Species

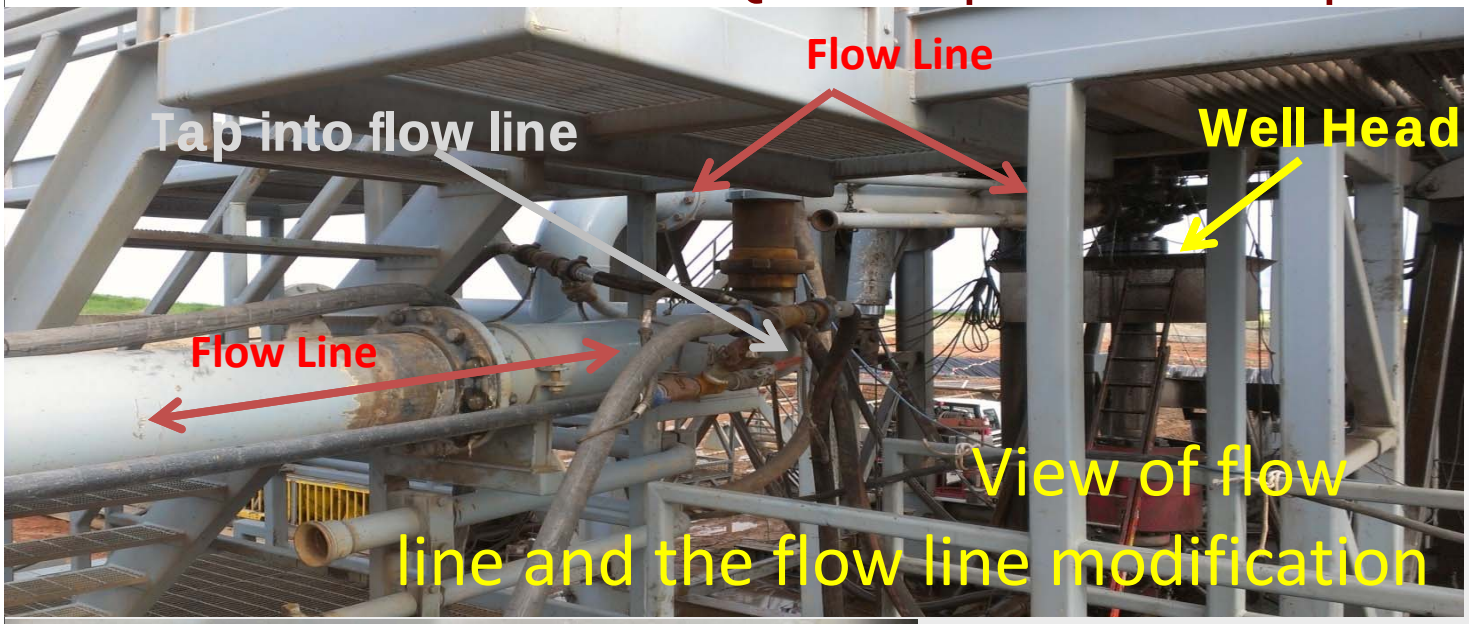
Gas Species of Interest Reach The Detector

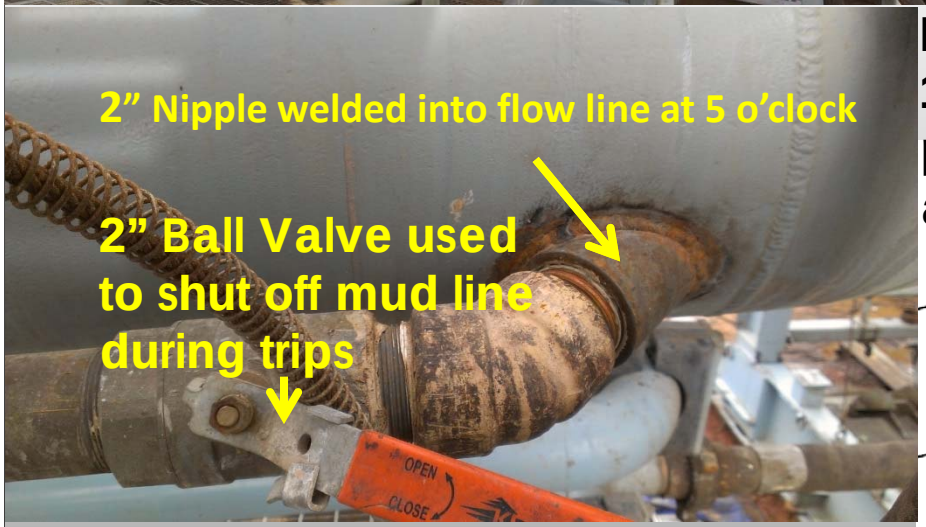
All Other Species "Die" On The Anode

As The Power Increases, The Next Species Is Allowed To Reach The Detector

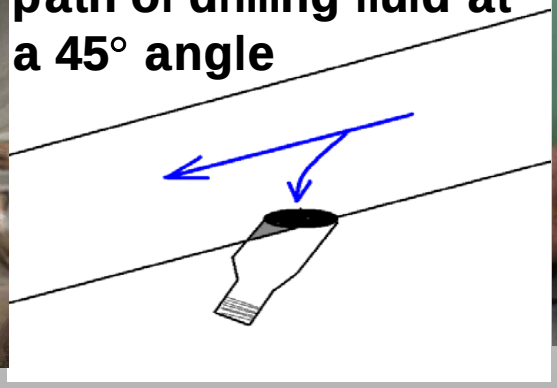
As The Process Repeats, H2 Through C10 is Detected

Quadrupole Mass Spectrometer





Nipple welded with 1.5” inside the flow path of drilling fluid at a 45° angle



The use of a 3” to 2” swedge would be ideal but not necessary

On Location

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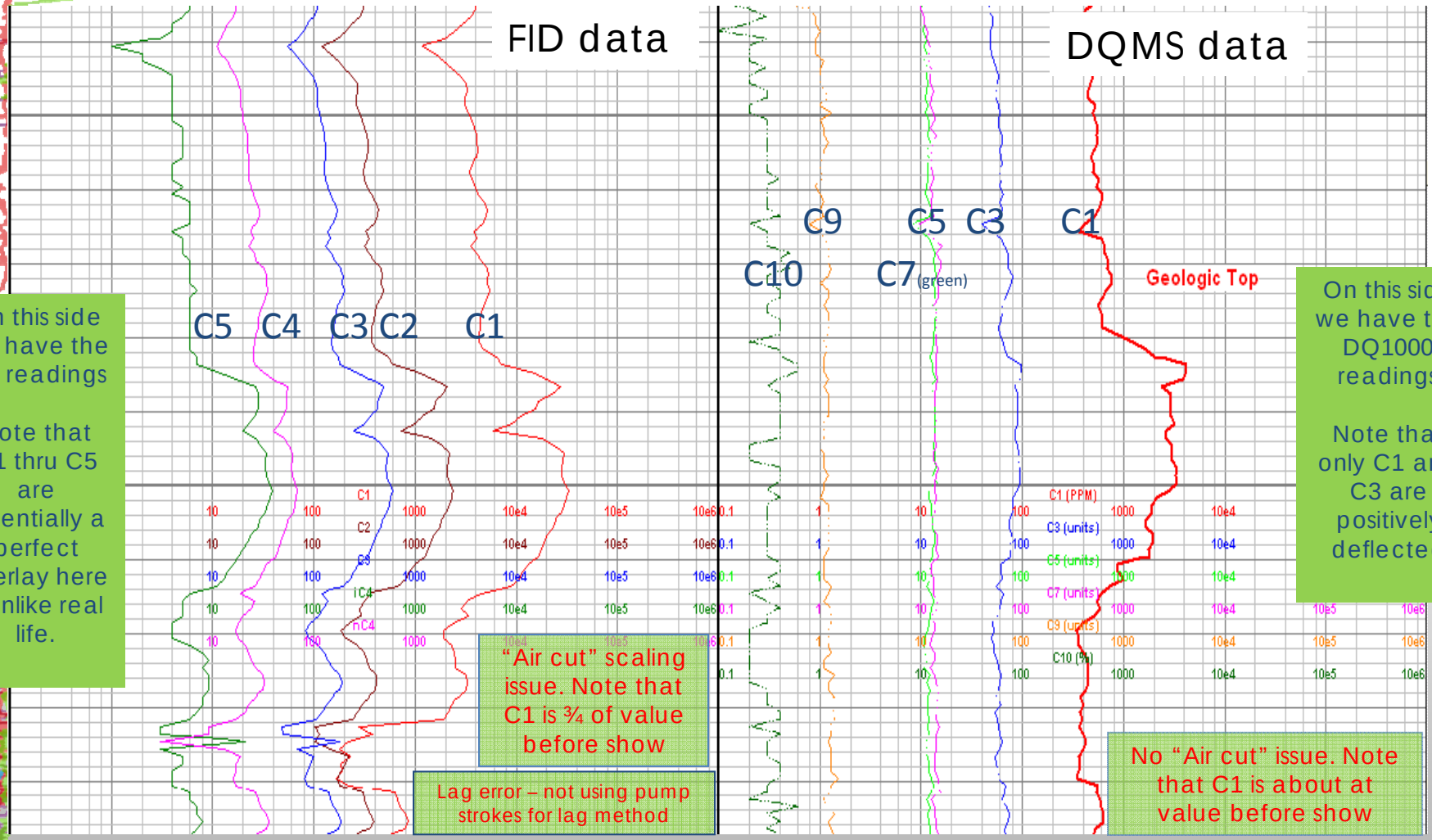
Trailer measures 8’x12’

Chromatograph vs. Mass Spec

North Sea well – 100% Methane (C1) Pay zone



The older gear does not detect the wetter hydrocarbons which are needed to do critical gas analysis.

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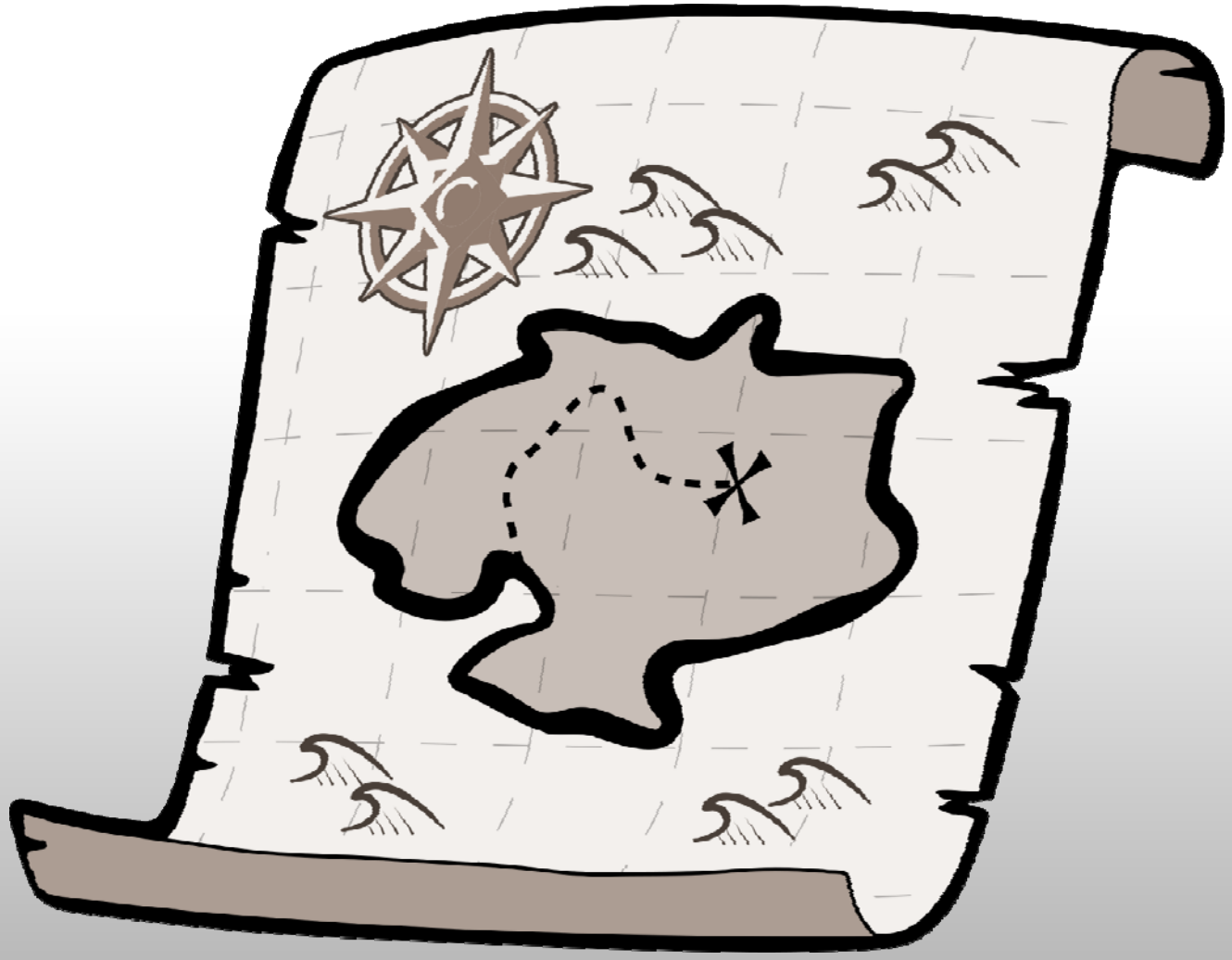

What we really want is a usable map that outlines a path to our rewards while avoiding pitfalls

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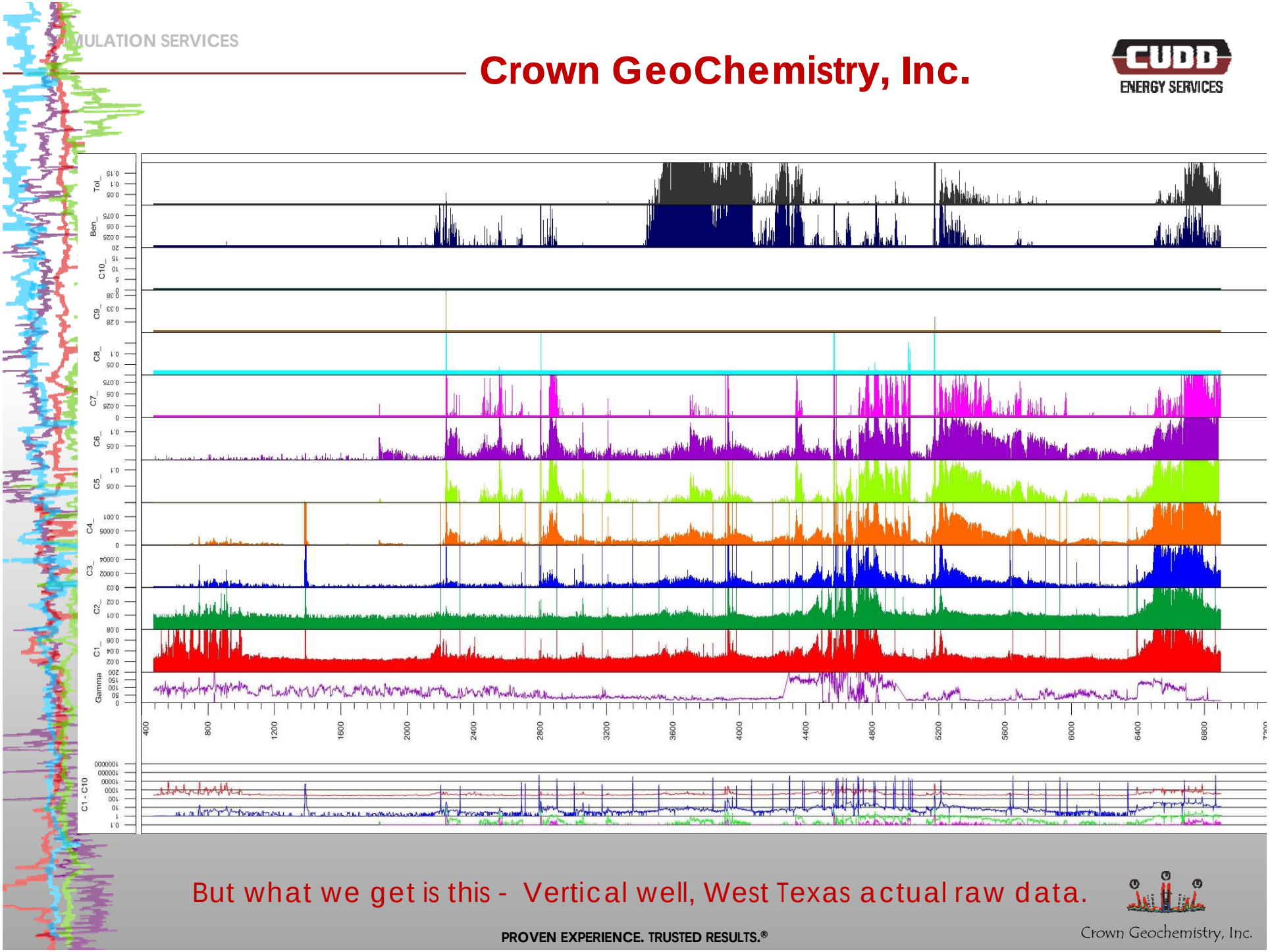

But what we get is this - Vertical well, West Texas actual raw data.

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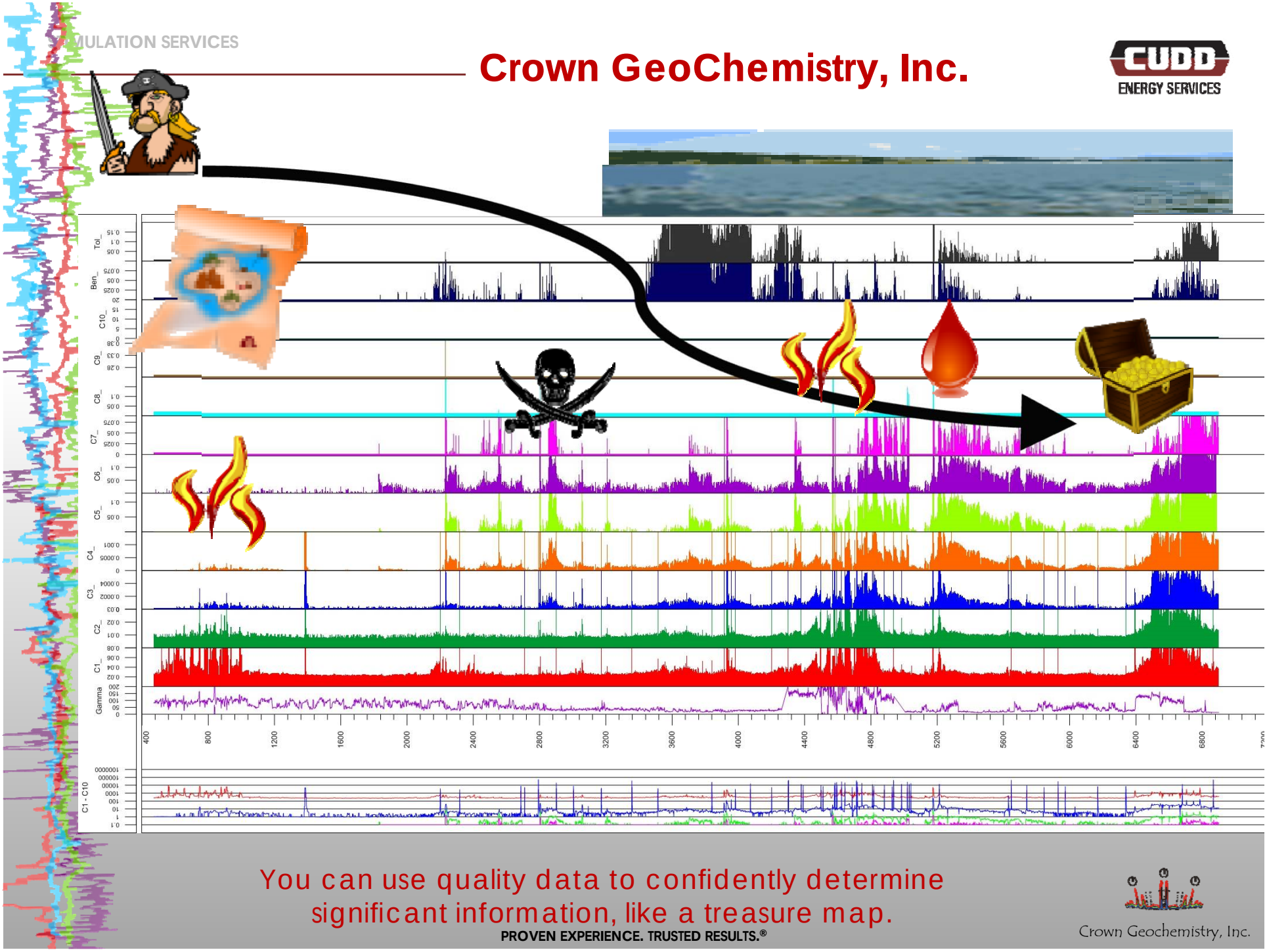

You can use quality data to confidently determine significant information, like a treasure map.

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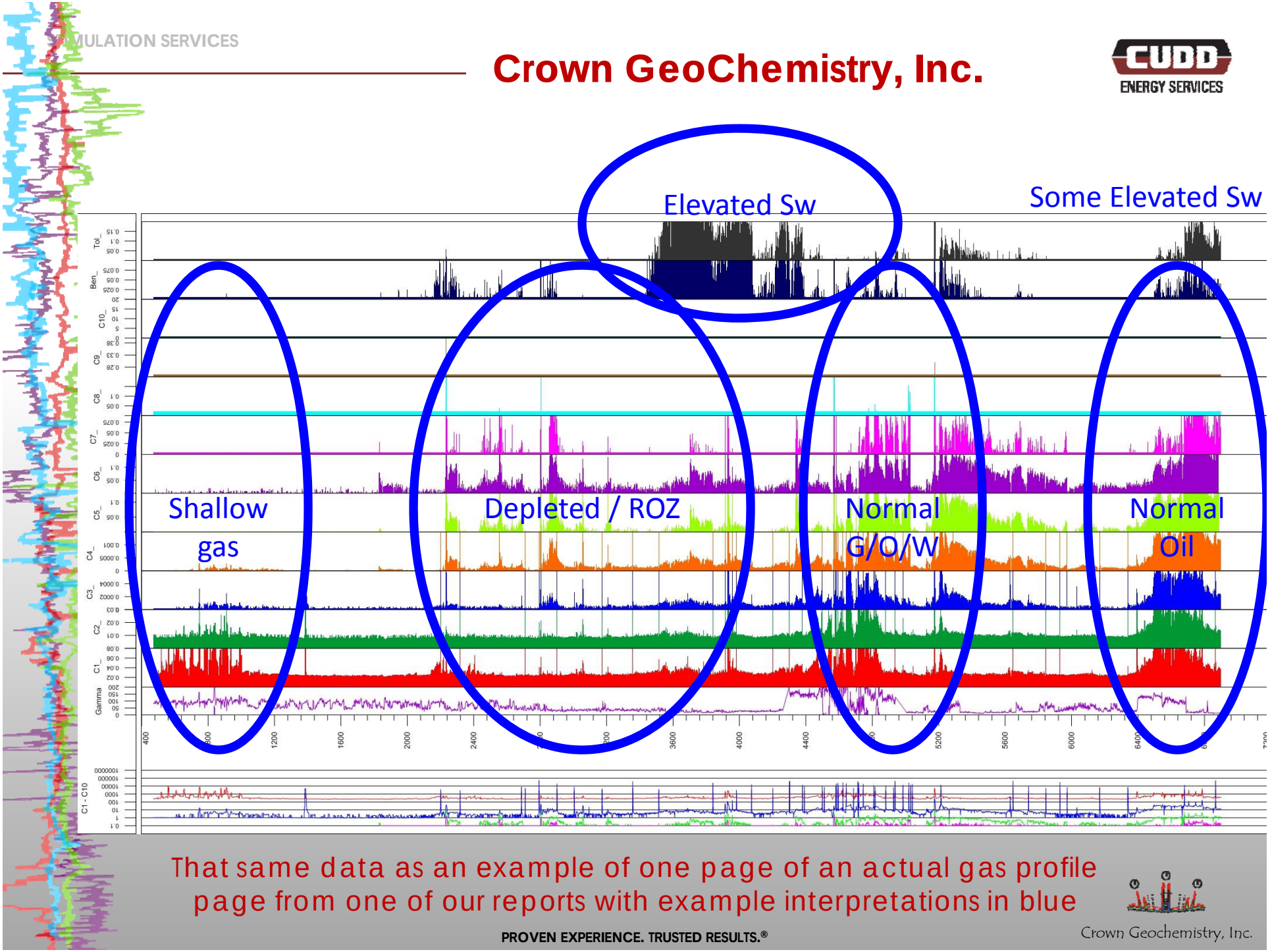

That same data as an example of one page of an actual gas profile page from one of our reports with example interpretations in blue

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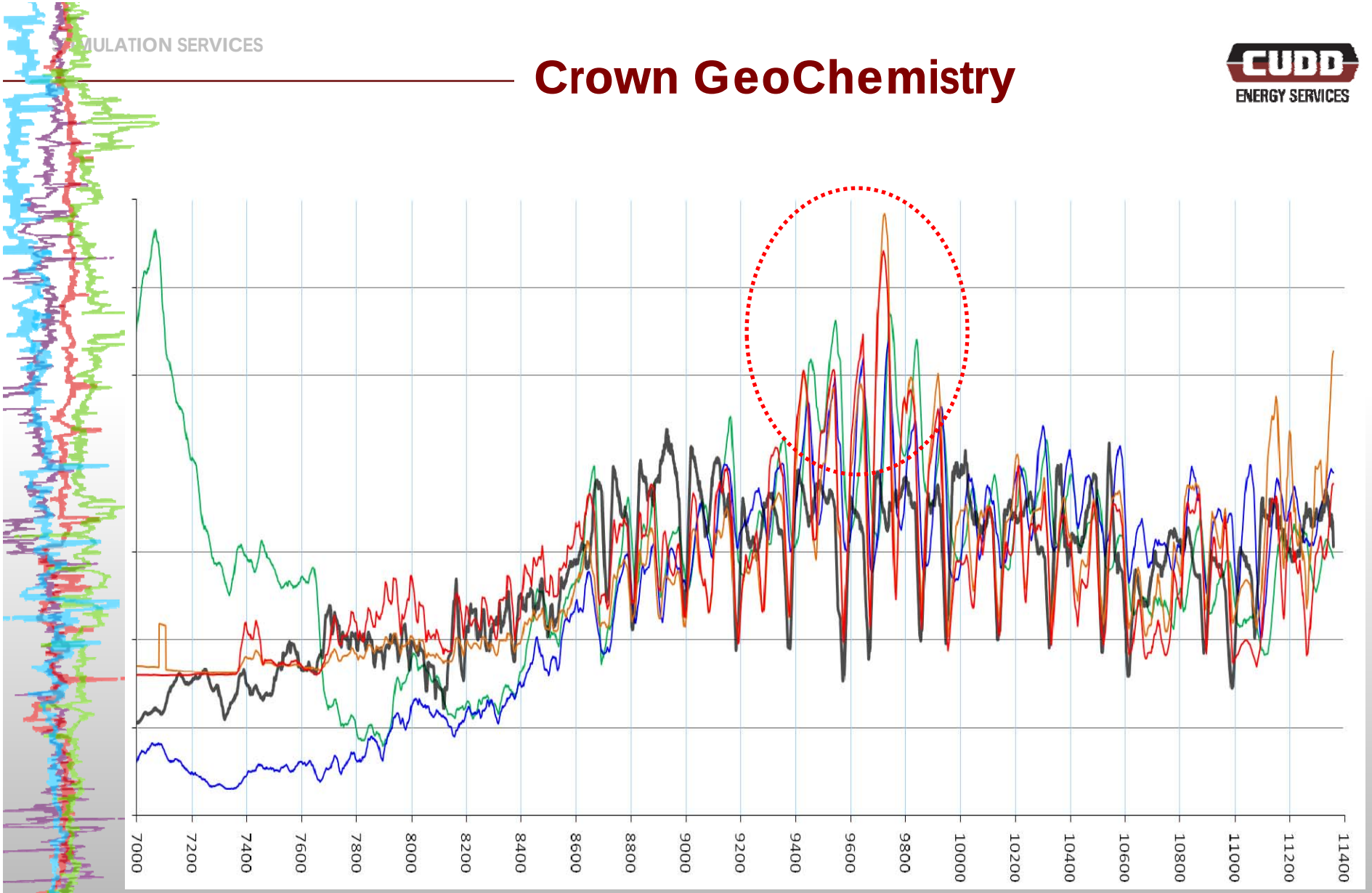


An example of a sweet spot in a lateral well

Drill2Frac

Drill2Frac Concept

- Drill2Frac uses the mechanical specific energy (MSE) measured during drilling to determine differences in formation geo mechanical properties along the lateral
- MSE is a good proxy for UCS and UCS represents rock geomechanical properties
- The resultant geomechanical heterogeneity is represented thru a facies analysis at a stage level of granularity for the *Entire* lateral
- By shifting perf clusters *within a stage* to similar facies, hydraulic fracturing performance could be improved.

D2F Data Requirements

Drill2Frac
Every Well Completed WELL!

Mandatory input data:

- Drilling Data: WOB, ROP, TOR, RPM, DIFP, SPP,Q (LAS/ASCII/XLS/CSV) – Available from Pason or Totco
- Directional data for trajectory plot (LAS/ASCII)
- Drilling report summary (Daily and EOW report)
- Mud motor specifications (Size, Lobes, Stages,...)
- Casing Collar Tally

Optional Calibration data

- Mud Log (Ttl Gas and Lithology)
- LWD Gamma ray
- Other logs (i.e., Sonic, FMI, Tracer, Core etc.)
- Production information

Drill2Frac Deliverables
Trajectory Plot

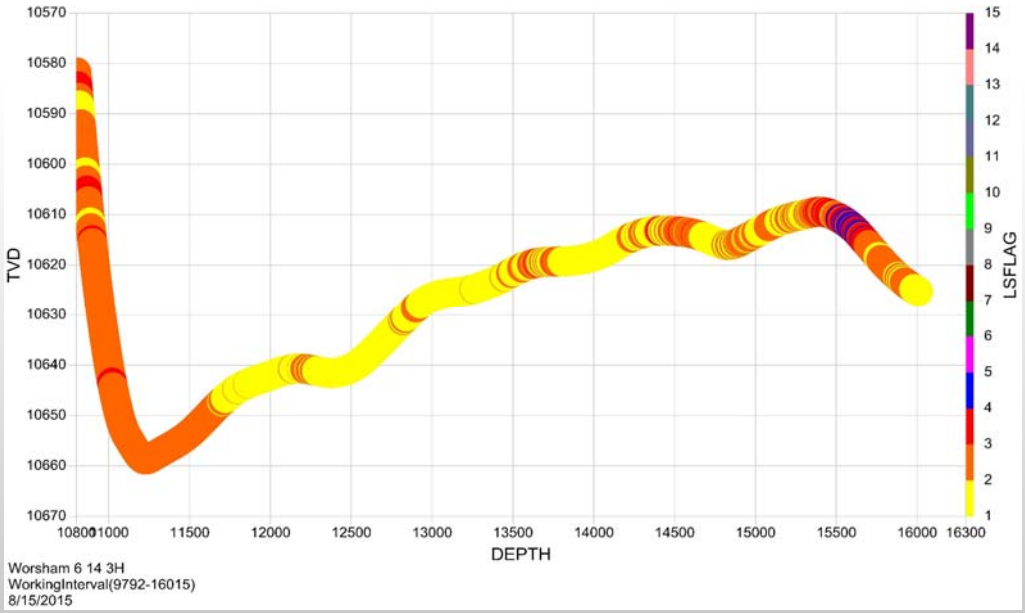
Drill2Frac A2
Every Well Completed WELL!

Hardness Index

COLOUR	HARDNESS	MSE
	HD1	0 - 15K
	HD2	15K - 30K
	HD3	30K - 50K
	HD4	50K - 75K
	HD5	75K - 100K
	HD6	100K - 125K
	HD7	125K - 150K
	HD8	150K - 175K
	HD9	175K - 200K
	HD10	200K - 225K
	HD11	225K - 250K
	HD12	250K - 300K
	HD13	300K - 400K
	HD14	400K - 500K

HARDNESS INCREASES

Trajectory Plot



Drill2Frac /ICES

Every Well Completed *WELL!*

Drill2Frac Deliverables

Differential MSE and Micro Facies Map

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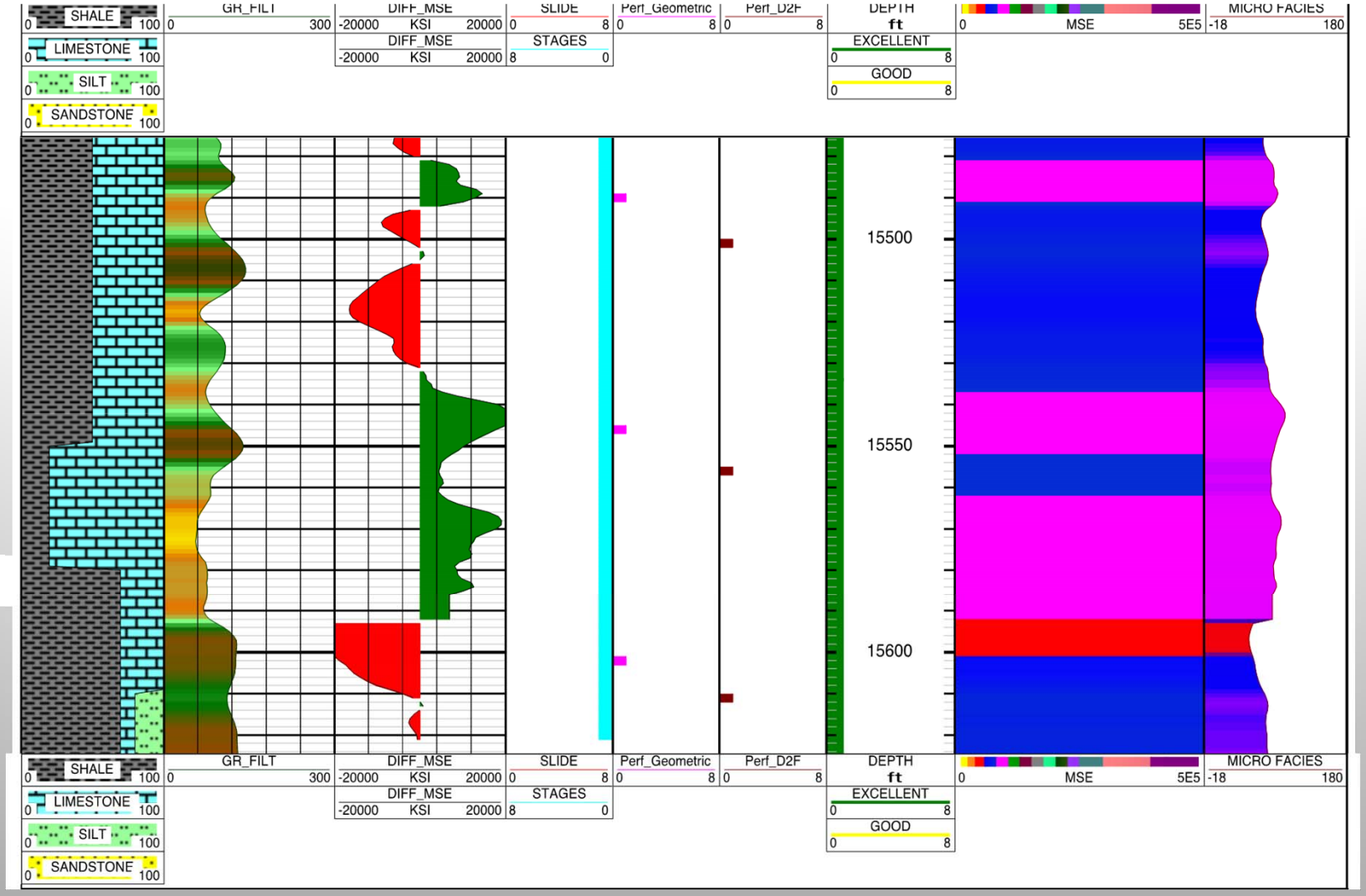

Drill2Frac Deliverables
Completion Design

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Every Well Completed WELL!

Geometric

Stage	Plug Depth	Cluster 1	Cluster 2	Cluster 3	Cluster 4
1		14396	14352	14294	14262
2	14222	14196	14166	14121	14072
3	14043	14017	13983	13920	13874
4	13861	13835	13803	13735	13686
5	13633	13607	13551	13500	13433
6	13408	13382	13351	13316	13283
7	13231	13205	13163	13084	13005
8	12995	12969	12939	12895	12855
9	12820	12794	12716	12646	12565
10	12486	12460	12413	12380	12332
11	12291	12265	12215	12120	12054
12	12028	12002	11966	11916	11886
13	11846	11820	11783	11737	11680

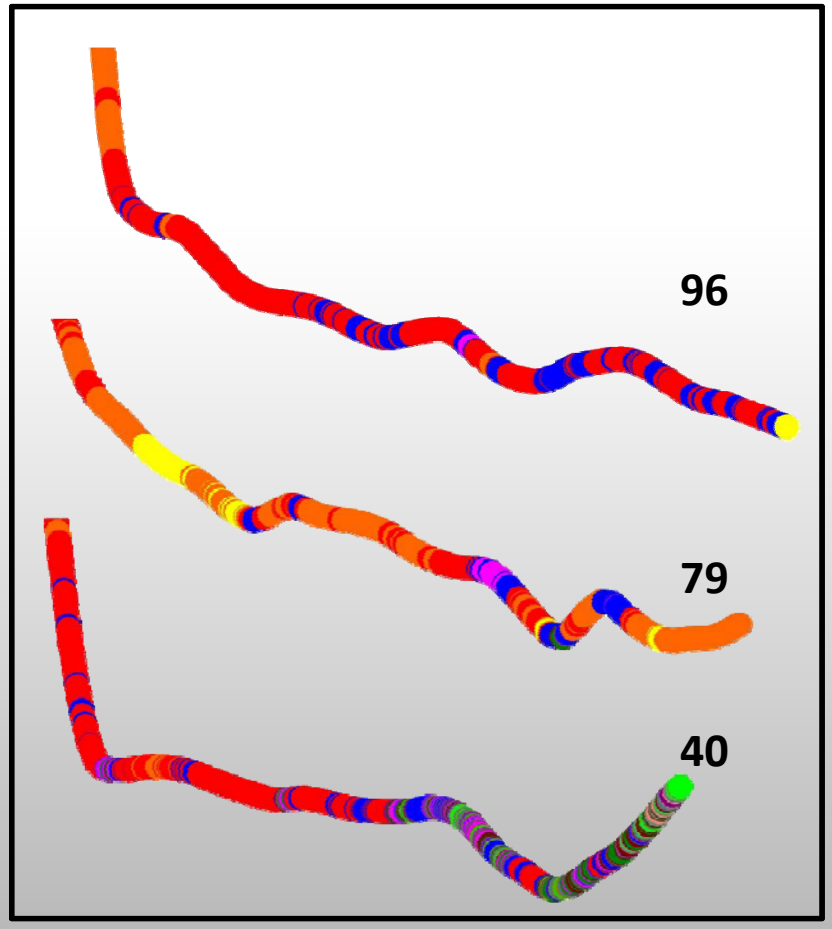
Geomechanical

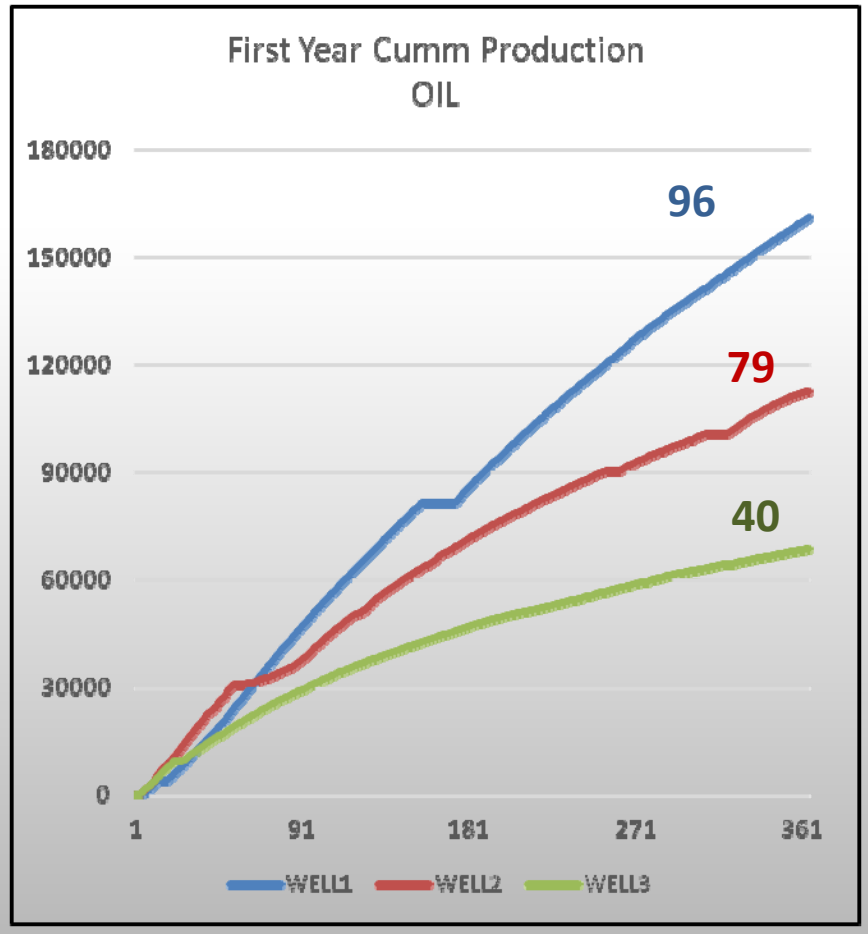
Stage	Plug Depth	Cluster 1	Cluster 2	Cluster 3	Cluster 4
1		14396	14362	14300	14270
2	14222	14196	14166	14125	14072
3	14043	14022	13983	13920	13874
4	13861	13835	13798	13735	13686
5	13633	13607	13551	13490	13428
6	13408	13382	13351	13316	13283
7	13231	xxx	13163	13084	13010
8	12995	12969	12939	12895	12855
9	12820	12780	12680	12646	12555
10	12486	12460	12413	12380	12332
11	12291	12265	12203	12120	12060
12	12028	12002	11966	11912	11895
13	11846	11820	11777	11737	11680

Production Validation: Offset Wells

Permian Basin – Bone Spring

Drill2Frac A2
Every Well Completed WELL!





Stimulation Analysis "Wish List"

- Inexpensive
- No Risk
- User Friendly

- Items to be Identified:
  - Sweet Spots
  - Compartments
  - Unproductive or Lower Quality Zones
  - Relative Hydrocarbon Content (Oil, Gas, High SW)
  - Mineral Content
  - Rock Stress

Process for Utilizing Data For Frac Design

- Crown Geochemistry Analyzes Drilling Mud Data:
  - What Zones are Productive
    - Liquid Hydrocarbon vs Gas vs High SW
  - Compartments
  - Identifies Sweet Spots
  - Mineralogy (XRF)
    - Change in Rock Type
- Drill2Frac Analyzes Drilling Data:
  - Develops MSE plots
    - Perf Cluster adjustment recommendation based on like stress intervals
- Cudd Frac Design Team
  - Cudd Team Reviews data, makes perforation / sleeve placement recommendation, recommends changes / adjustments to pump schedules
    - Cudd Team presents modified completion design to Customer Team for review and final design

Manzano – Cousin Willard 450 #3H

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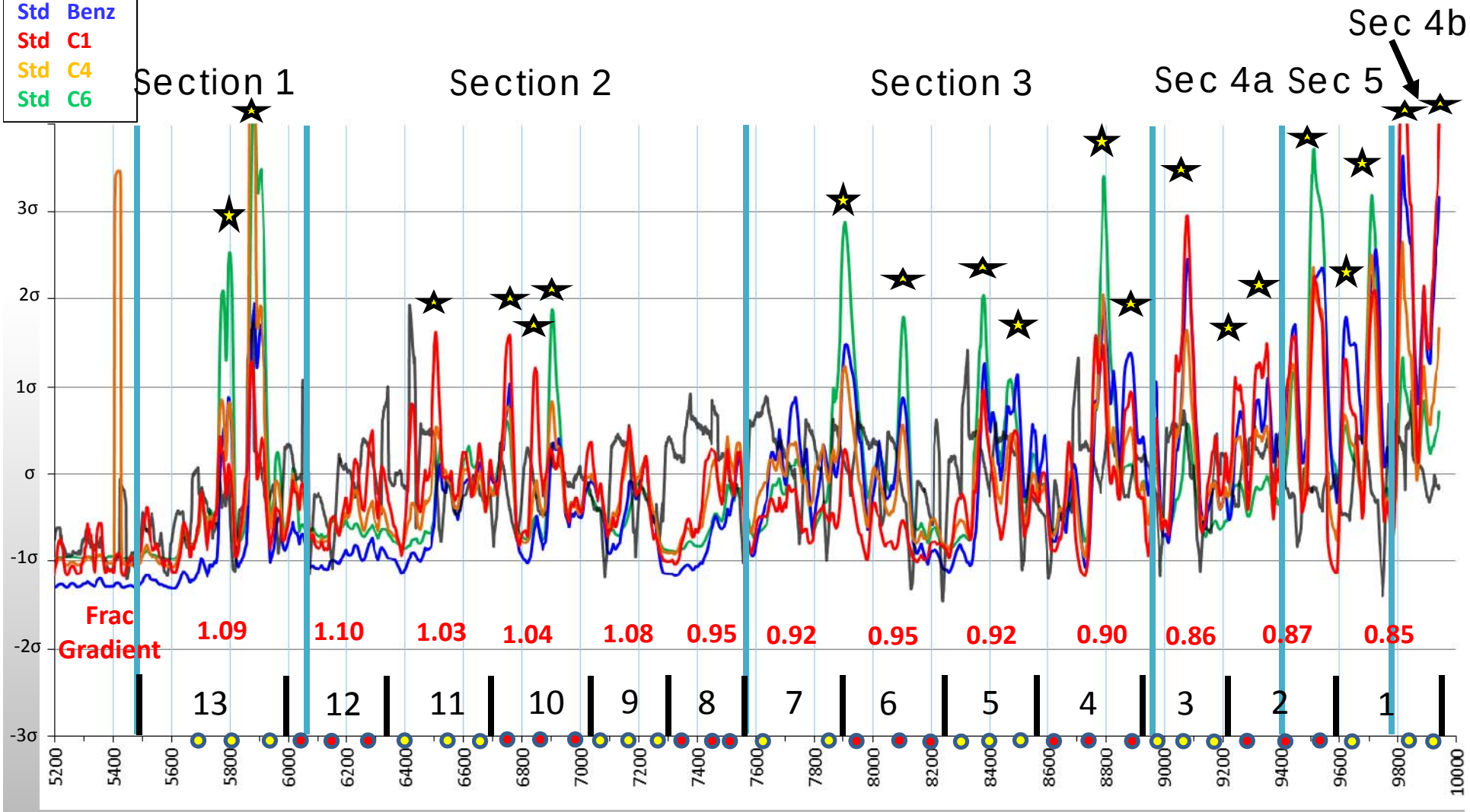

★ Sweet Spot Above 1 Standard Deviation

Manzano – Cousin Willard 450 #3H

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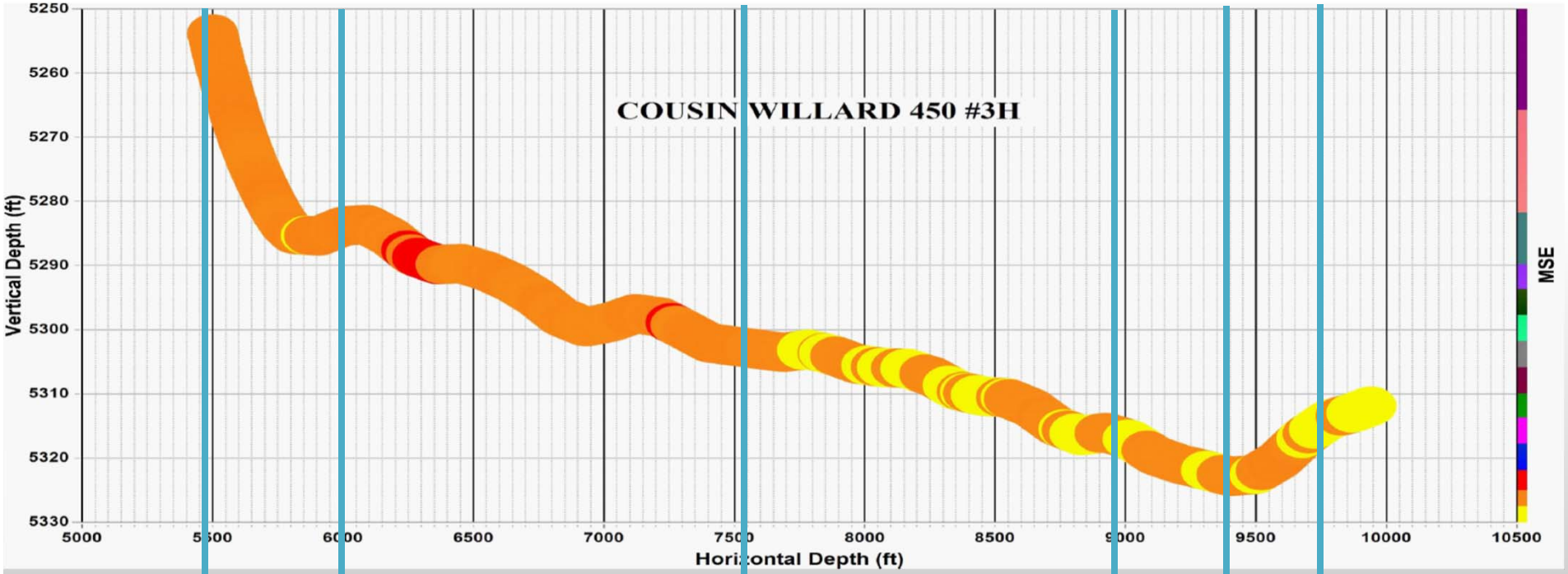
Section 1 Section 2 Section 3 Sec 4a Sec 5 Sec 4b



13 12 11 10 9 8 7 6 5 4 3 2 1

Frac Gradient	1.09	1.10	1.03	1.04	1.08	0.95	0.92	0.95	0.92	0.90	0.86	0.87	0.85

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Questions?