Flow-Back Hydraulic Fracture Treatment Water Composition – Rock-Fluid Interaction in the Montney Shale Controlled by Faults and Maturity Domain*

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Abstract

Extensive sampling of flowback water through time has been performed in the Triassic Montney hybrid shale of the Altares Field, in northeastern British Columbia. The analysis performed on the data of 79 wells has brought to light new facts and understanding on the interaction between injected water and the rocks penetrated. Our analysis indicated that the injected hydraulic fracture treatment water has interacted with some of the sulfides present in the pore network. Thus evidence of barium sulfate precipitation has been repeatedly seen; the rate of precipitation has been assessed and mapped against some of the known structural elements; XRD analysis indicate that the most likely reacting mineral is marcasite. This poorly stable sulfide can easily react in the presence of injected water and is transformed into as sulfate. From the thin section analysis of the zones with sulfate precipitation, the marcasite has been found to be associated with hydrothermal minerals such as saddle dolomite, barite and sphalerite. These occurrences of marcasite together with barium sulfate precipitation has been solely restricted to the coarser silty upper member of Montney in the field. The contoured maps of the semi-quantitative sulfate precipitation clearly indicates gradual increases towards two distinct subvertical faults, both trending North 10 degrees.

A second major finding of our water flowback analysis is the well-behaved change in composition with depth. Each produced water composition being compared to other samples that correspond to the same volume of water recovered. Thus, in the dry gas domain, i.e. below the isotope reversal at 1.5% Ro, the quantity of every molecular element gradually decreases downward in all of the 79 wells studied. This has been interpreted as a downward reduction in water saturation, a complete opposite trend of the one observed above the isotope reversal. The proposed dehydration mechanism relates to some of the water being absorbed by the desiccated clays in the dry gas domain at a vitrinite reflectance value above or equal to 1.5%Ro to create new methane molecules. The present study firmly supports some previous isotope work that indicated hydrogen from the methane in the dry gas domain having two different isotopic signatures, one of which not in line with the isotope from hydrocarbon molecule. It is thus deducted that some of the hydrogen atoms in the newly generated methane molecules originally belonged to water molecules that have been broken down.

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Talk Outline

- Flow-back water collection and analysis
- Well interference and non homogeneous flow-back
- Barium sulfate precipitation
  - Recognition
  - Mapping and interpretation
- Shale dehydration
  - Lines of evidence
  - Mechanism
  - Implications for completion

Flow-back water collection and analysis

- 329 flowback water samples from 98 wells in Altares (British Columbia)

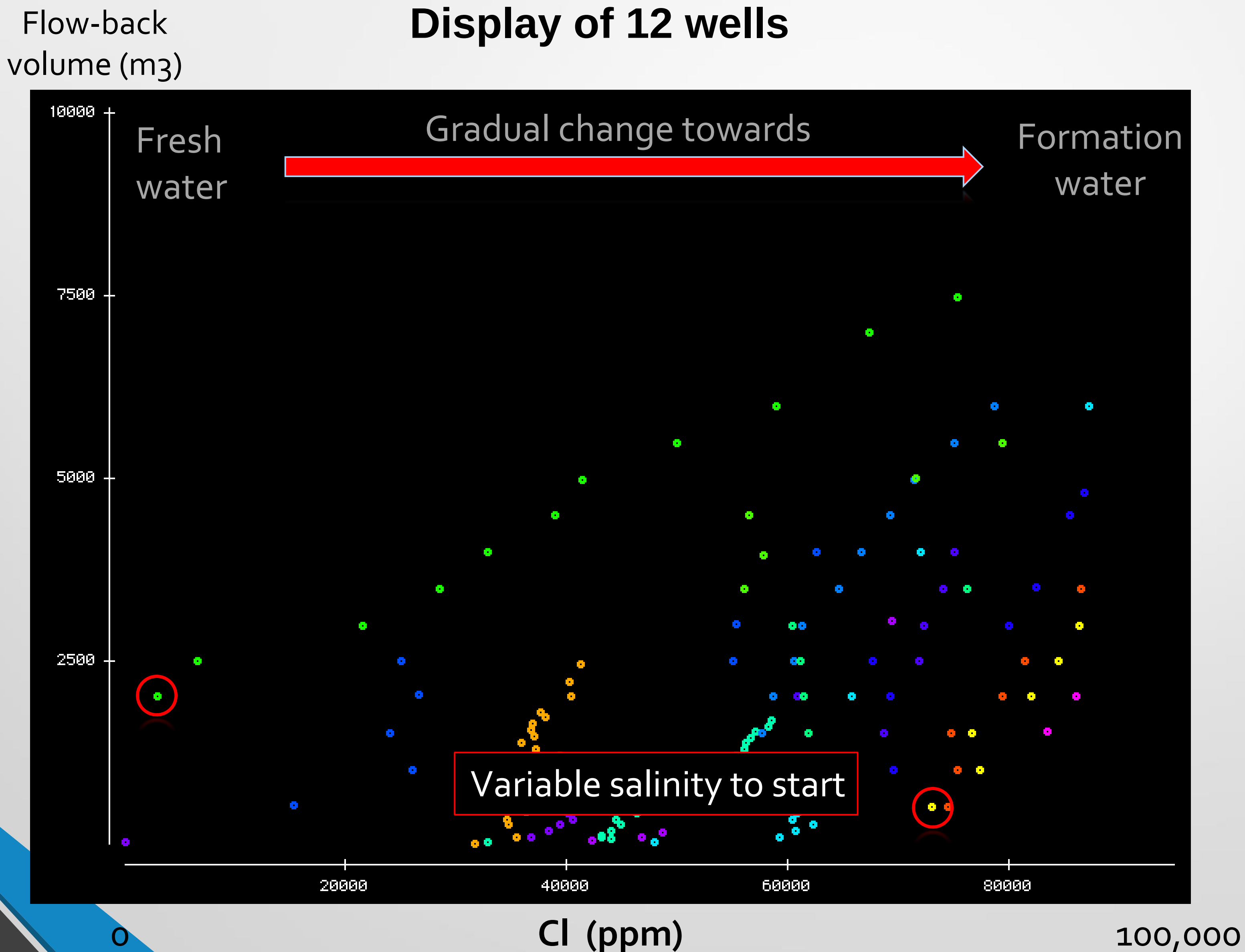
- 31 Hz wells with more than 5 samples through time

- X, Y, Z from the mid point of the horizontal leg

  TVD is used for Z value

Salinity Increase with time

Display of 12 wells

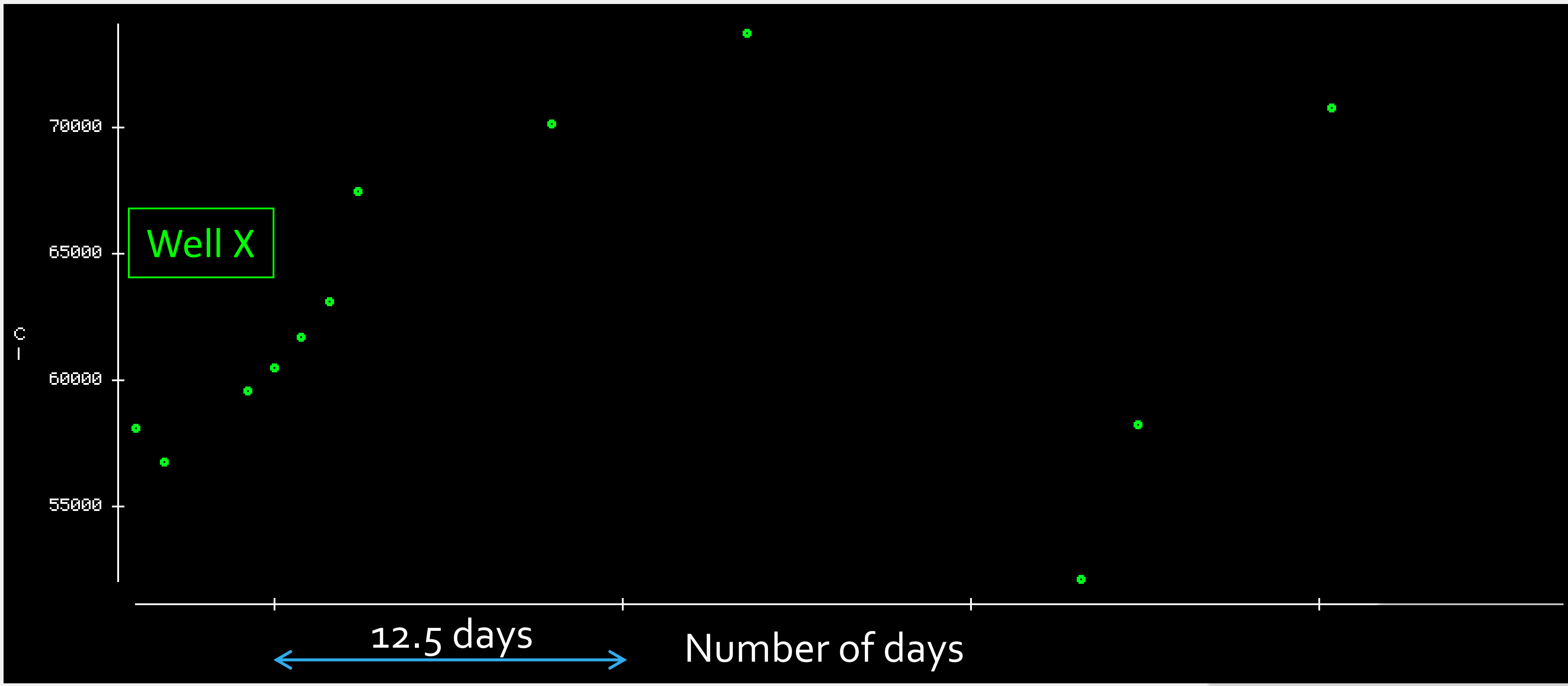


Well interference

as seen by flowback water

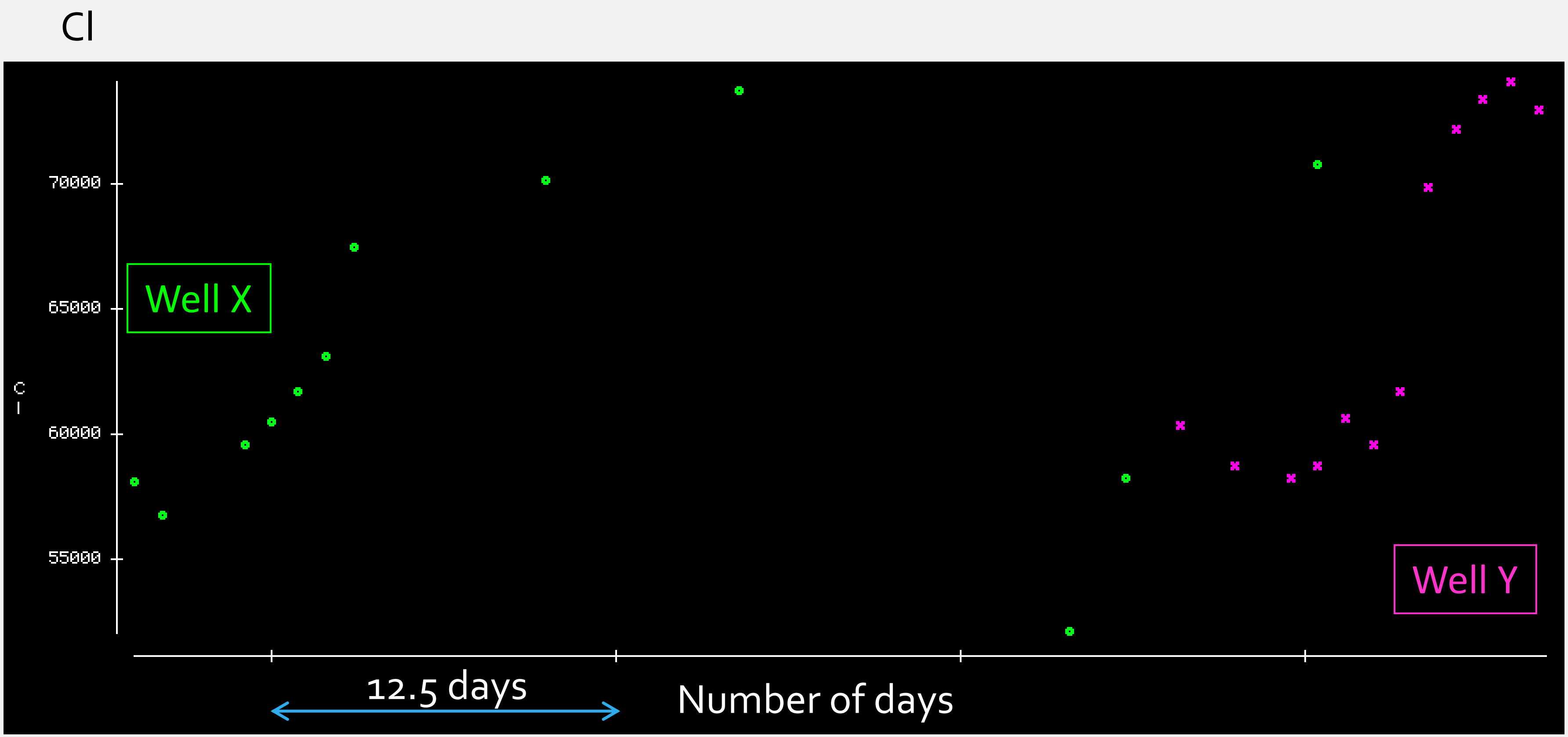
Example of well interferences from the same pad in Altares

Cl



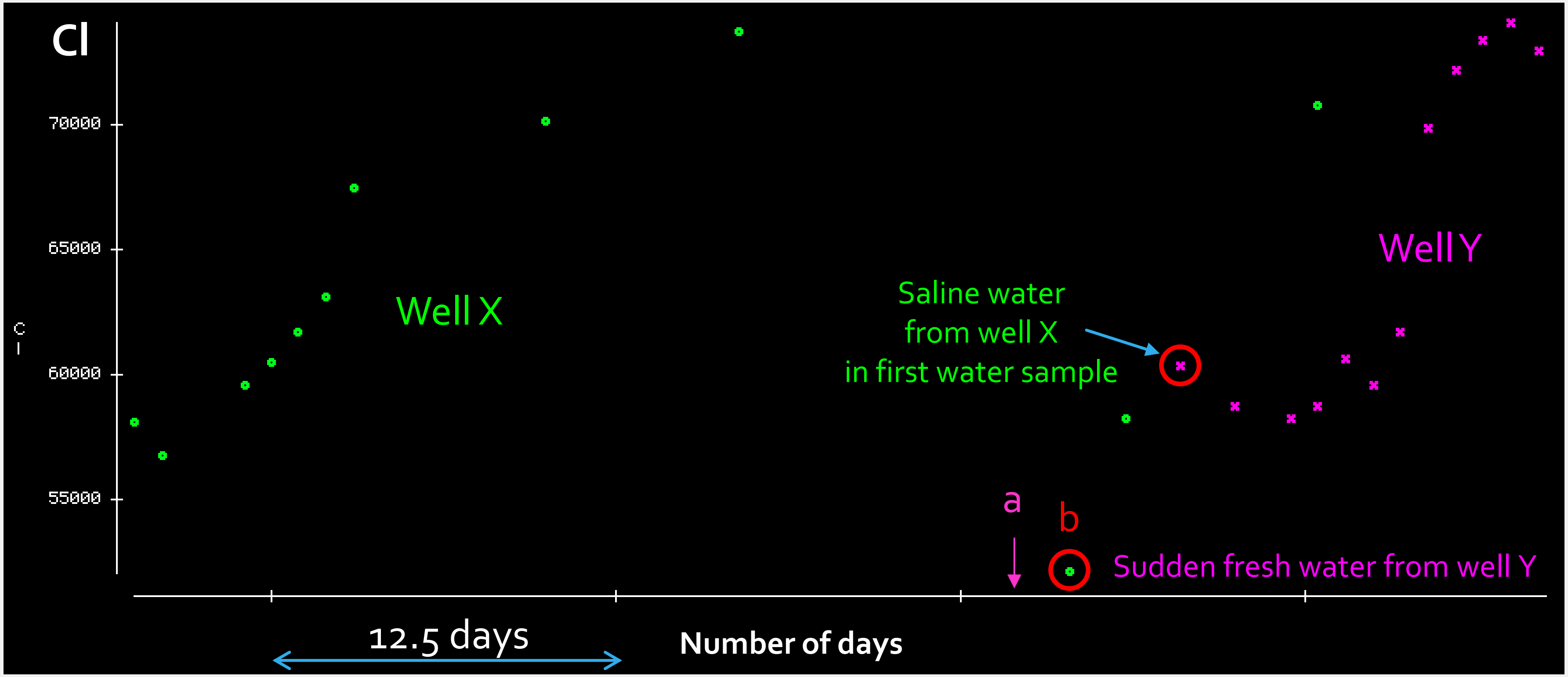
Both wells from Upper Upper Montney

Example of well interferences from the same pad in Altares



Both wells from Upper Upper Montney

Interference from nearby hydraulic fracturing



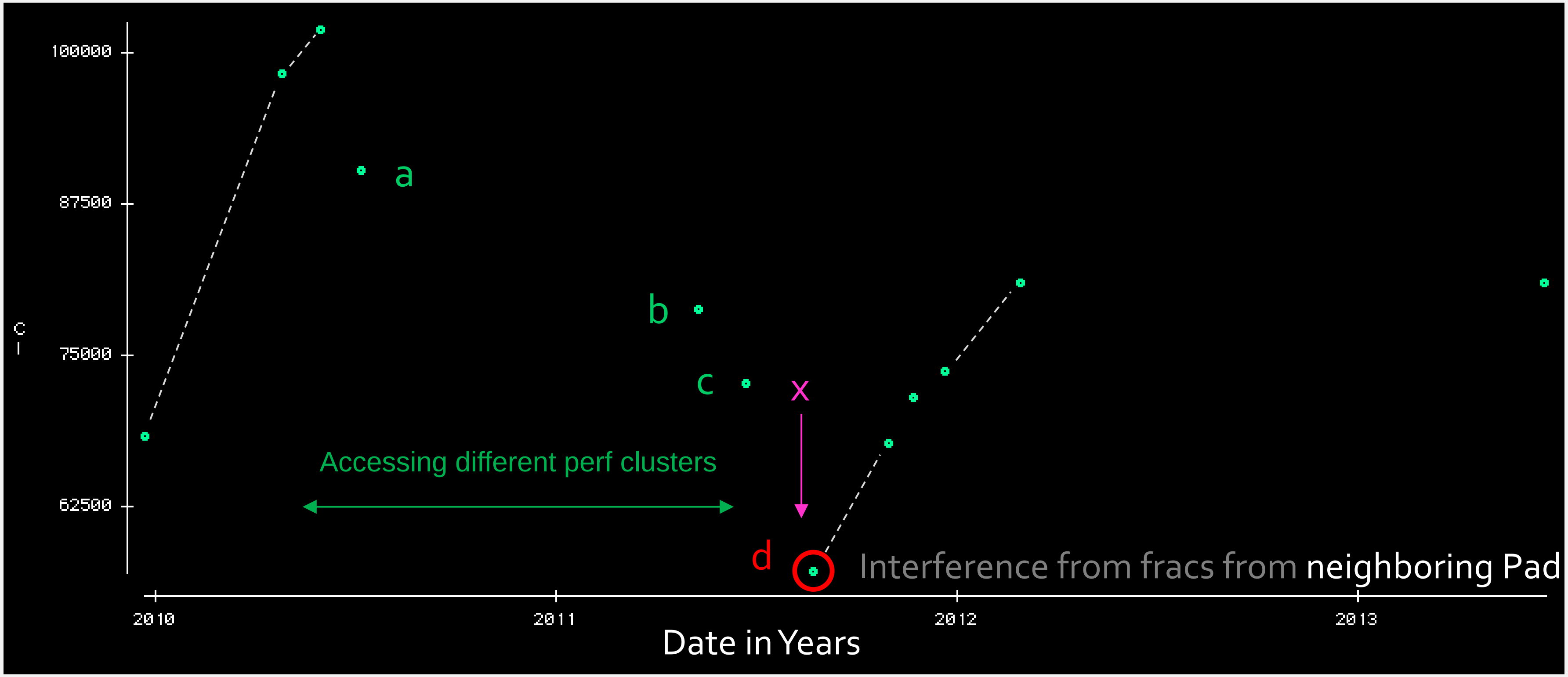
Well Y has interfered with the water flowback from well X: salinity went back to near frac water salinity and started an increase cycle from that point onward.

Well Y last frac March 20th 2012 (point "a"); sample "b" from well X taken March 22nd

The flowback water salinity from well Y shows a high starting value that matches the late samples of well X and decreased before starting a normal increase with time

Two sets of abnormal patterns

Cl



Very low salinity and start of a new salinity increase cycle in an Altares well is interpreted as linked to water breakthrough from Wells from another pad which have respective final completion dates of August 18 and 19th 2011 ("x" on graph)

Sample date for the outlined "d" sample is August 24th 2011

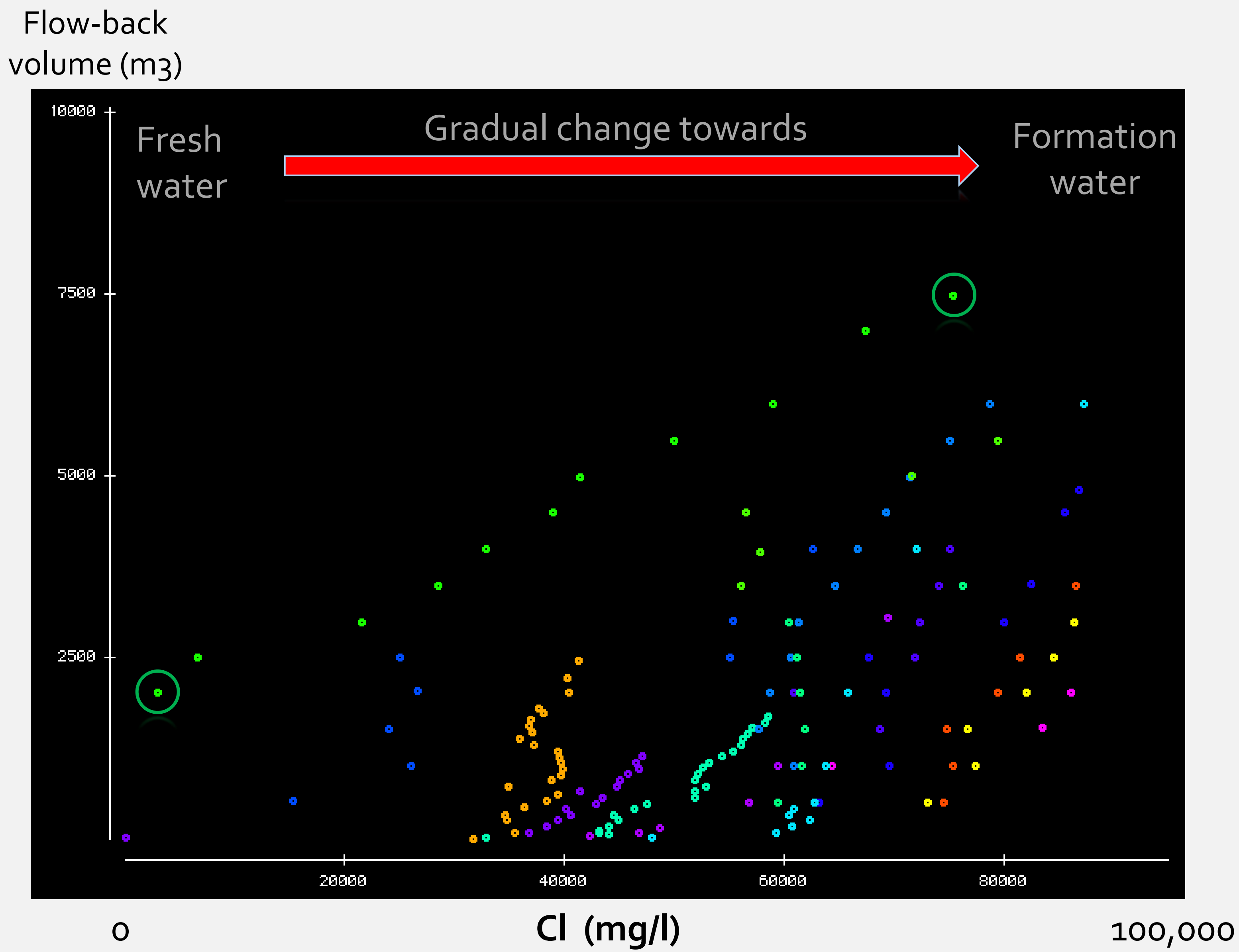
Points a,b and c indicate a possible **step like contribution of various perforations** from heel to toe through time

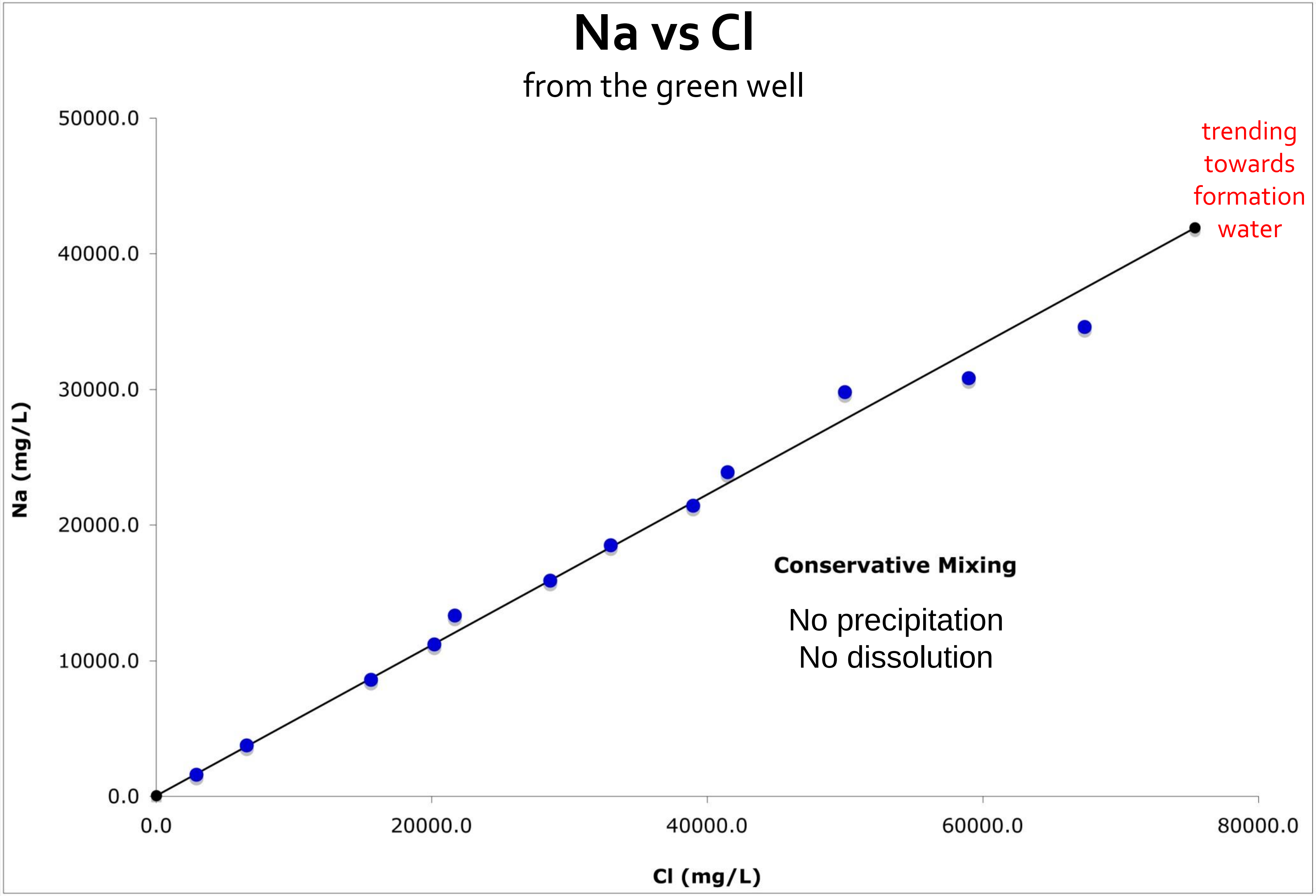
Sulfate Precipitation

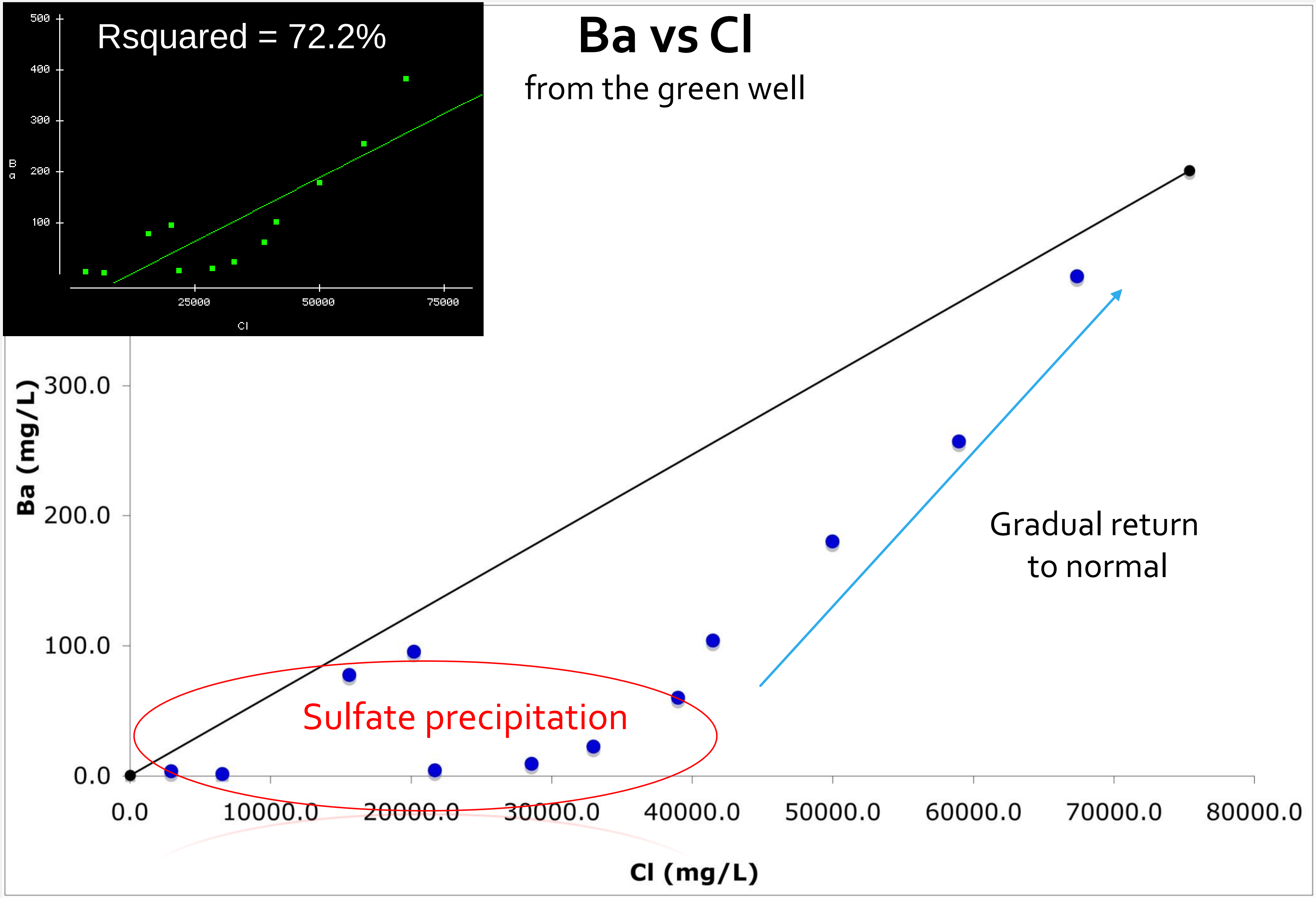
1st step: Look at normal ratios using Na vs Cl

2nd step: Find abnormal patterns (Ba and Sr)

Looking at the Green Well

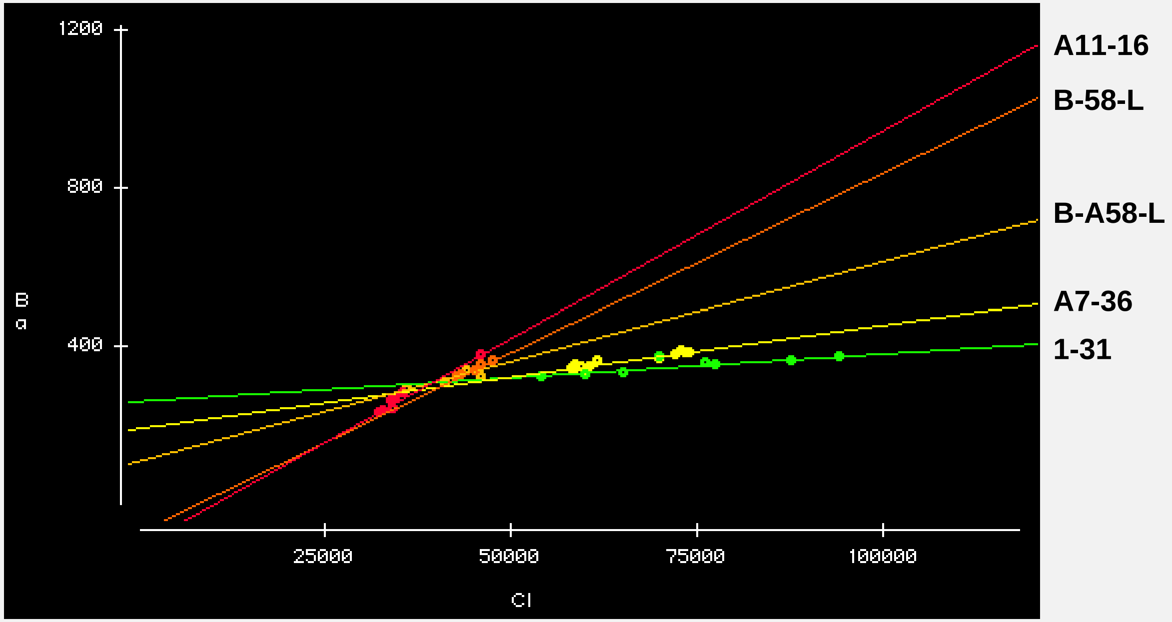



Na vs Cl
from the green well
50000.0
40000.0
30000.0
20000.0
10000.0
0.0
Na (mg/L)
0.0
20000.0
40000.0
60000.0
80000.0
Cl (mg/L)
trending towards formation water
Conservative Mixing
No precipitation
No dissolution



Cl is used as the reference scale

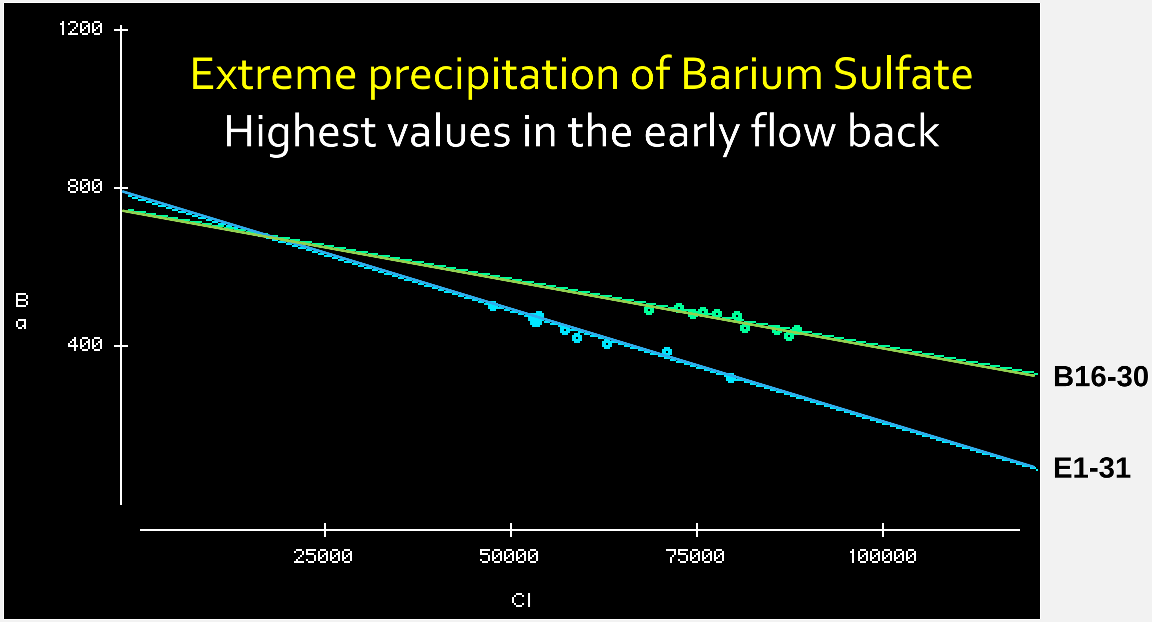
Examples of Barium Sulfate precipitation slopes (part 1)



Slopes calculated per well using all flowback water analyses. The diagram displays a range of observed slopes for wells with **linear Ba-Cl trends** through time (**R squared > 65% used as a cut-off**).

All are from the Upper-Upper Montney: the stratigraphic unit found to have major sulfate precipitation.

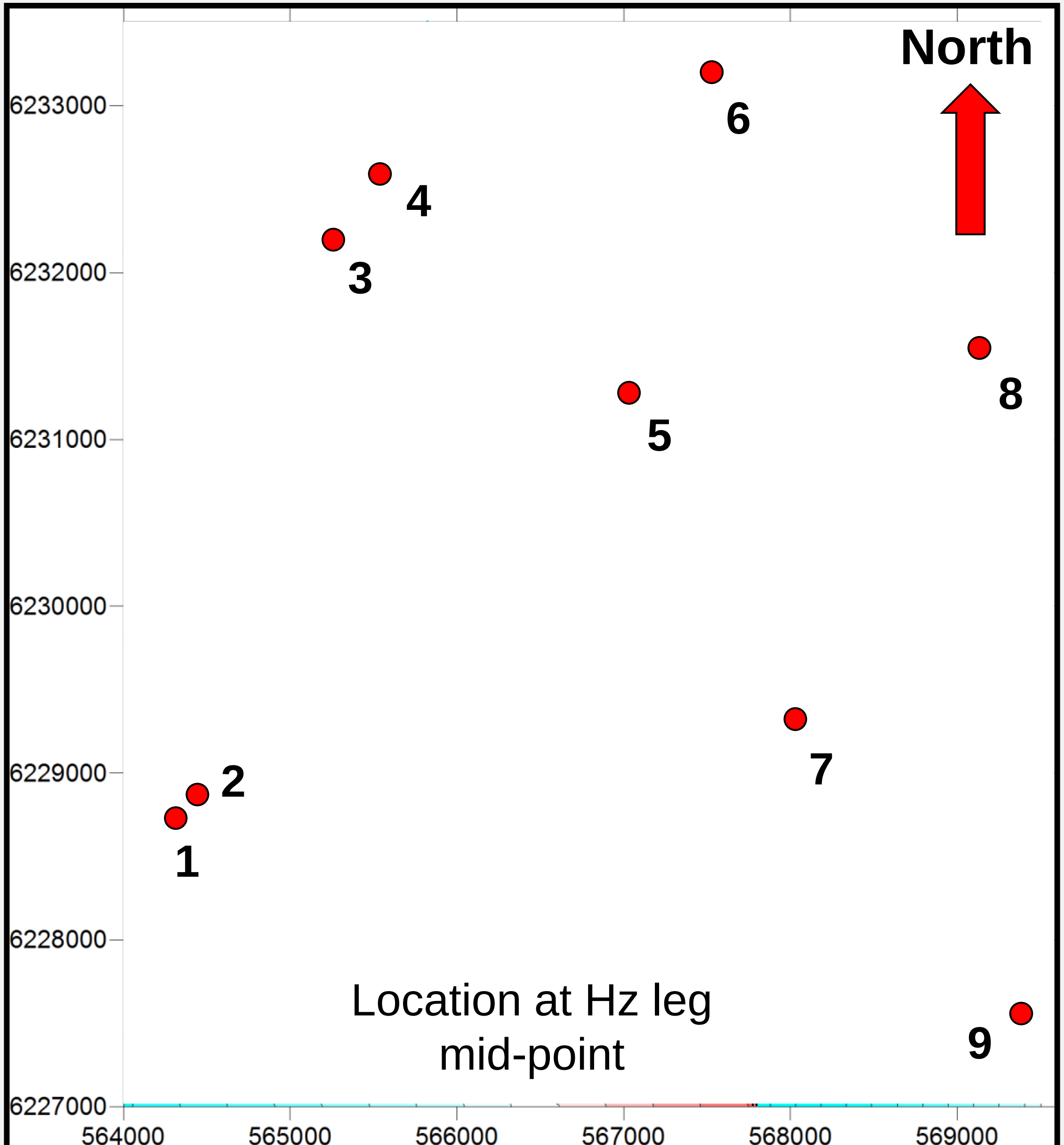
Examples of Barium Sulfate precipitation slopes (part 2)



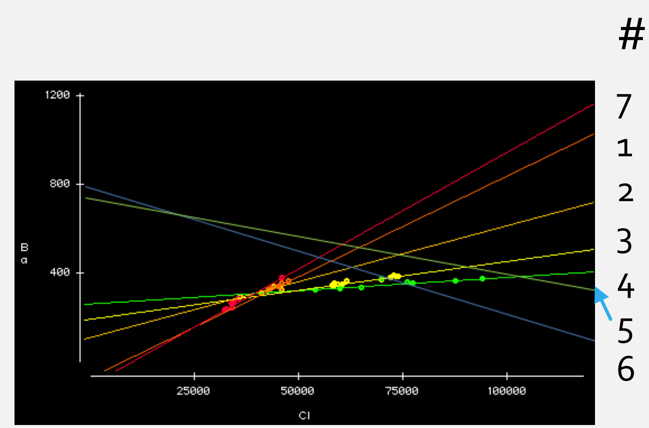
Slopes calculated per well using all flowback water analyses. The diagram displays a range of observed slopes for wells with **linear Ba-Cl trends** through time (**R squared > 65% used as a cut-off**).

All are from the Upper-Upper Montney: the stratigraphic unit found to have major sulfate precipitation.

Sulfate Precipitation in eastern part of Altares Field

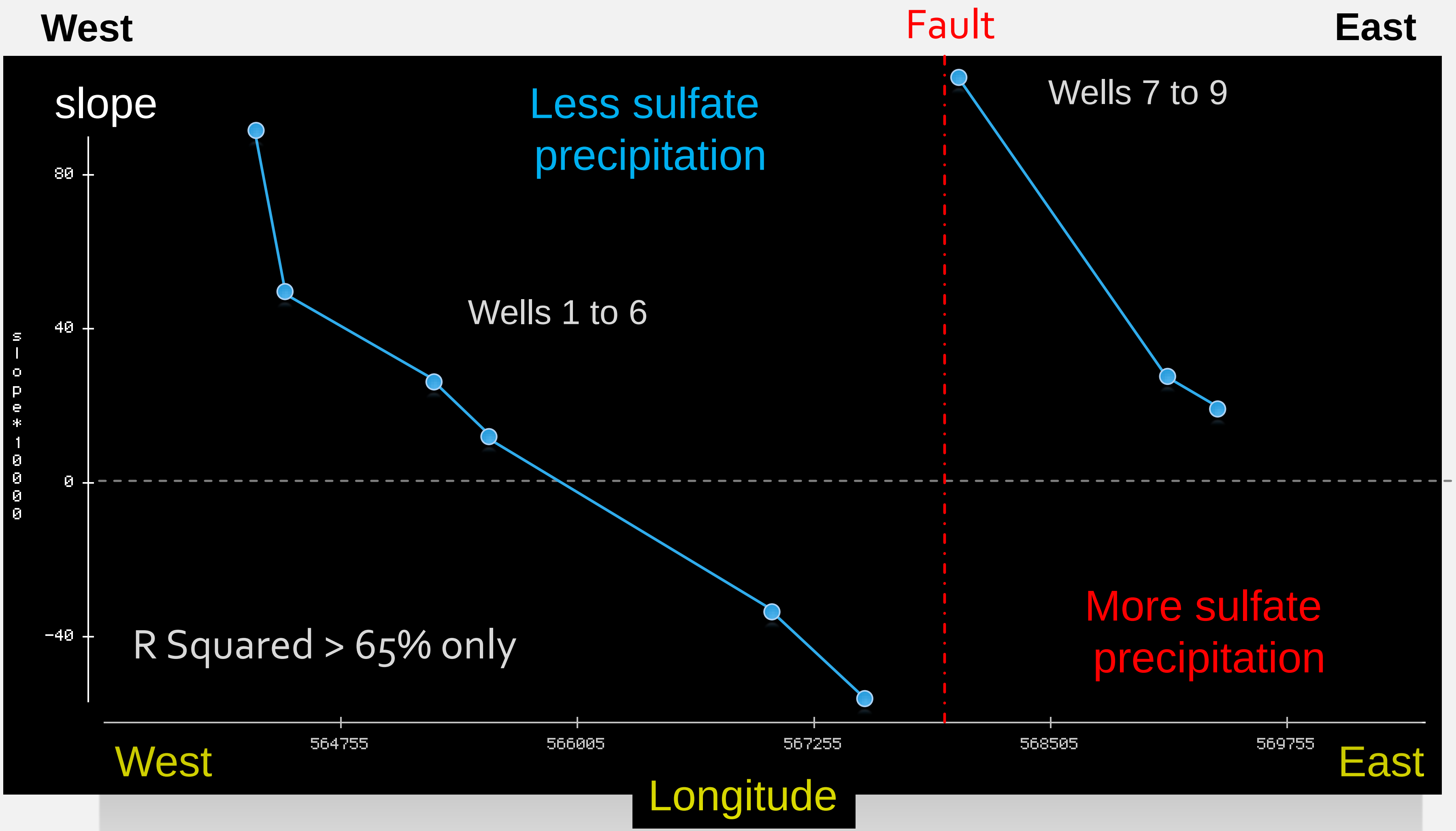


Well #	well name	Ba-Cl slope
1	B-58-L	91
2	B-A58-L	51
3	A-7-36	26
4	1-31	12
5	B16-30	-34
6	E1-32	-57
7	A11-16	105
8	A4-33	28
9	B11-16	20



● Wells with alignment R Squared >65%

W-E Projection of Ba-Cl slope

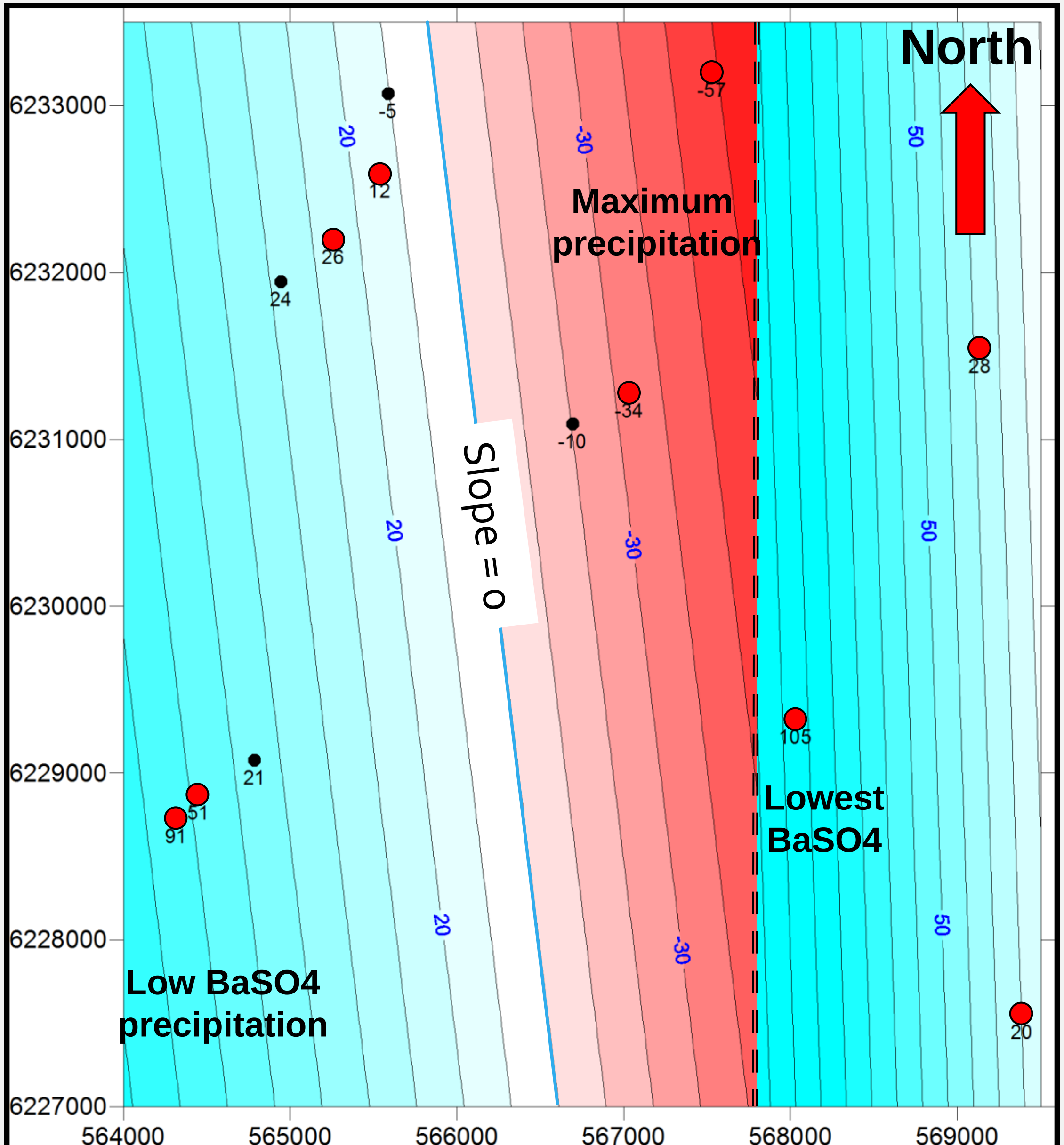


A plot of the Ba-Cl slopes against longitude (X) clearly demonstrates the near West-East distribution of the Ba-Cl trends in the Upper-Upper Montney.

Substantial jump between two trends interpreted as a north trending fault zone

Sulfate Precipitation Contour Map

(number = slope of relationship Ba-Cl from flowback)



A map of the Ba-Cl slopes validates the hypothesis of a sulfate precipitation nearly paralleling some hypothetical North –South Fault

The high precipitation of barium sulfate is interpreted as the result of oxidation of marcasite (as seen in XRD). Marcasite is an iron sulfide typically precipitated from hydrothermal fluids and extremely unstable in presence of water.

Black wells have Rsquared <<65%

● Samples shown earlier

Shale dehydration

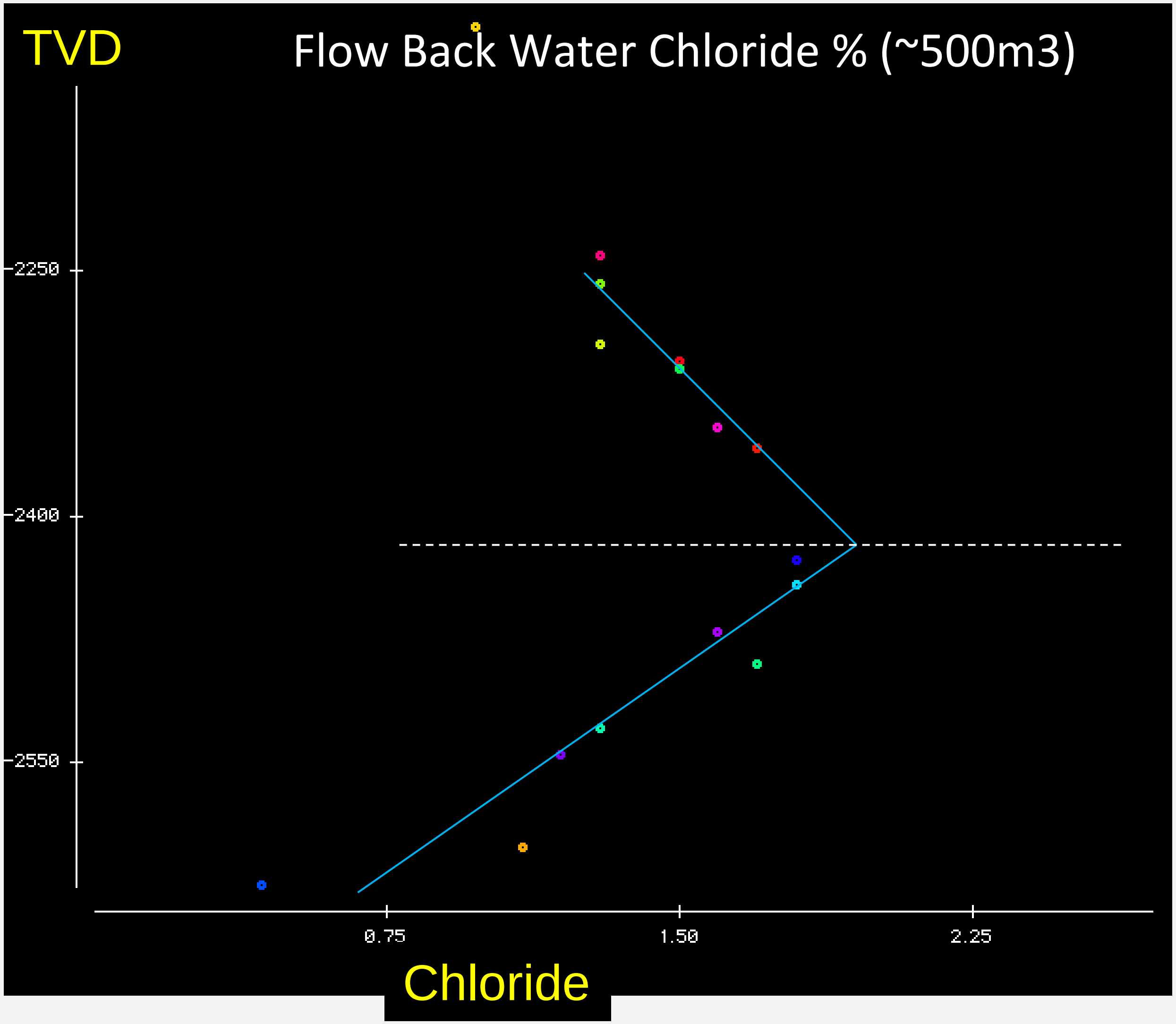
as seen by flow back water

Selection of composition to be displayed is based on volumes of flow back water close to a rounded value (e.g. 500, 1000, 1500, 3000 m^3)

This means that some wells may only appear on only one of the diagrams while others appear on more figures

Dehydration in the Dry Gas Domain

No data filtering



Normal increase of chloride content with depth as expected in a hybrid shale system

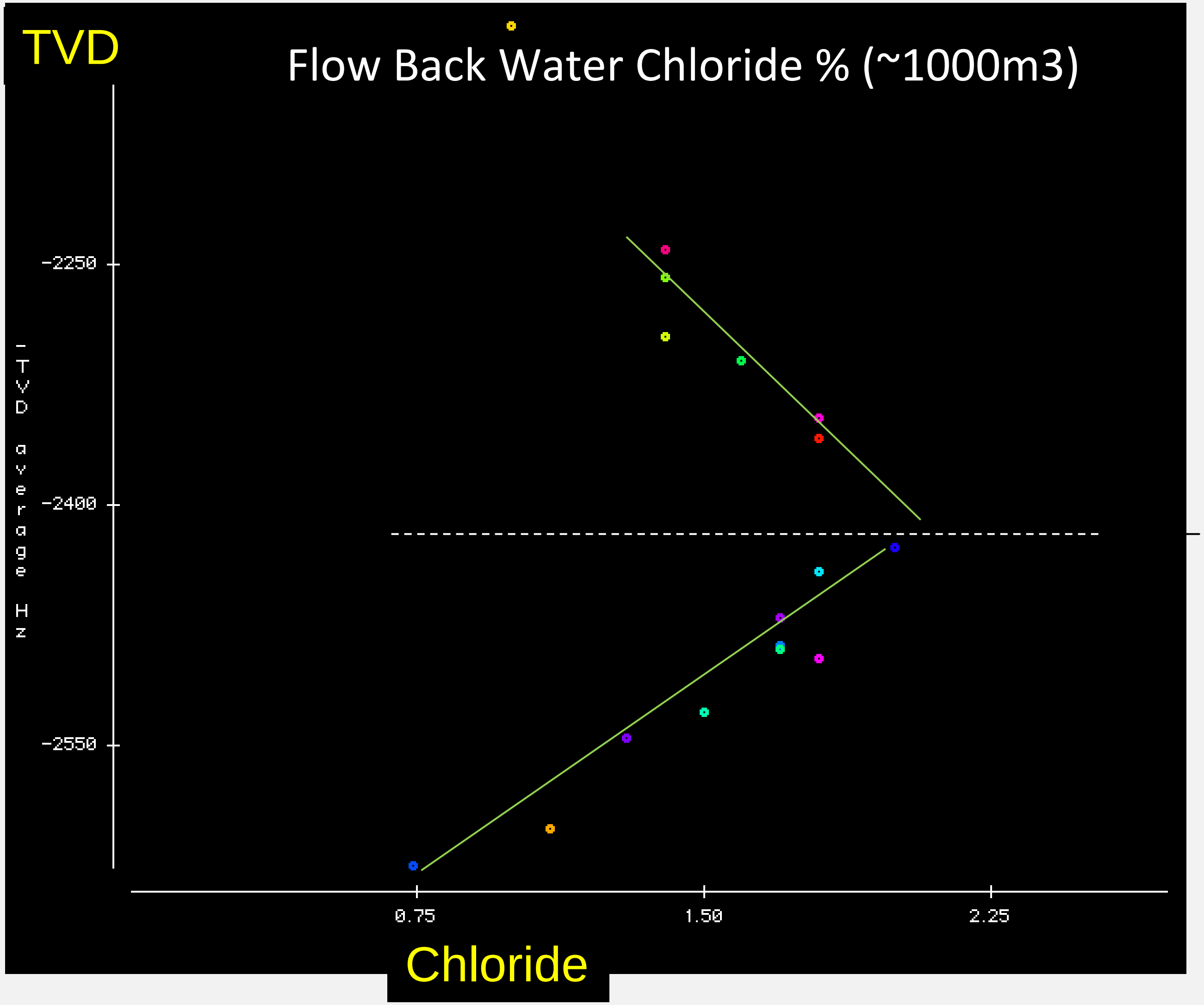
Rock dehydration as a function of burial depth.

Hydrogen from water needed to create methane from ethane or propane

The chloride content is a function of the available connate and movable water and relate to osmosis between the frac water and the in situ waters

Dehydration in the Dry Gas Domain

No data filtering



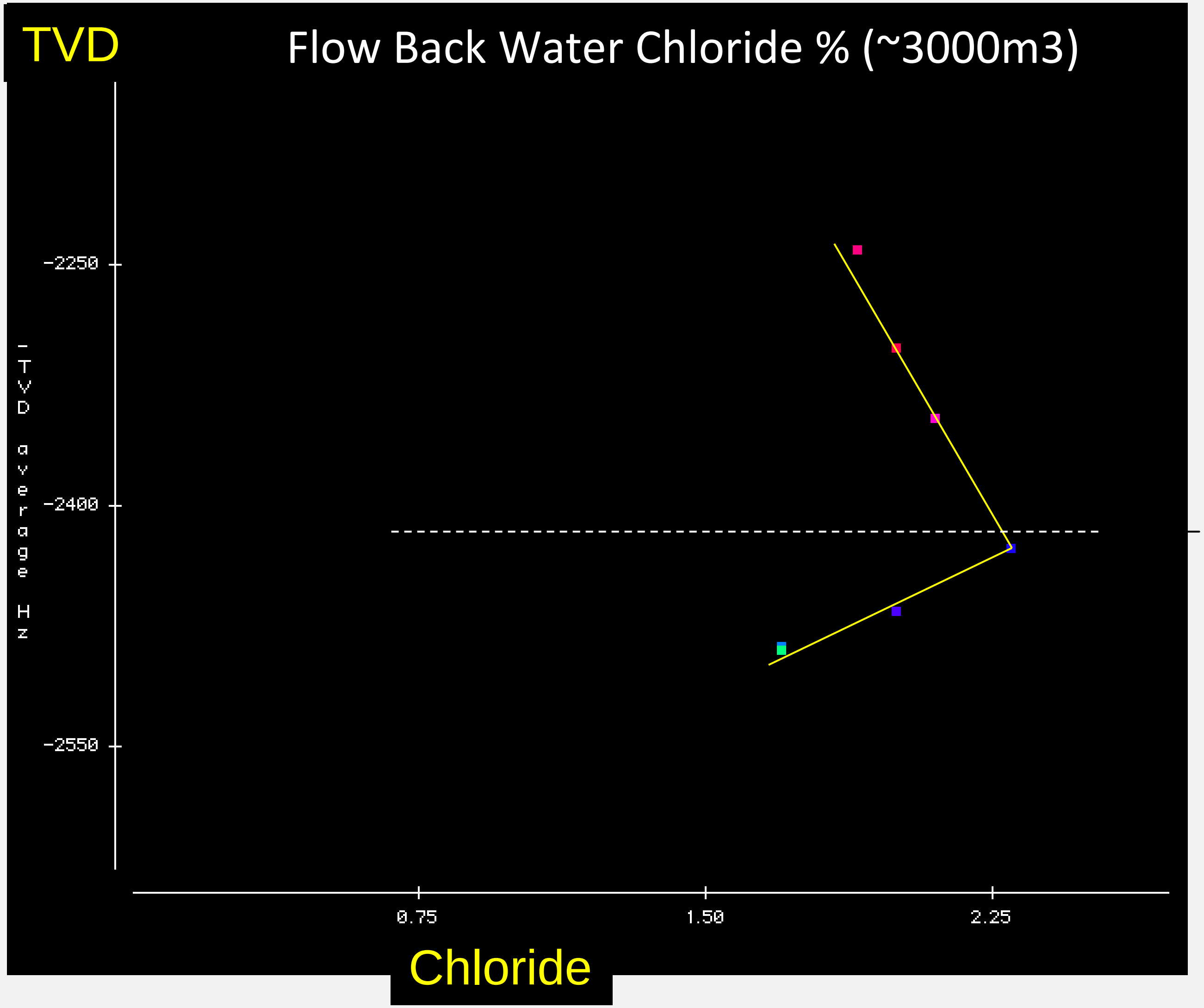
16 wells total

7 wells above Isotope reversal

9 wells below Isotope reversal

Dehydration in the Dry Gas Domain

No data filtering

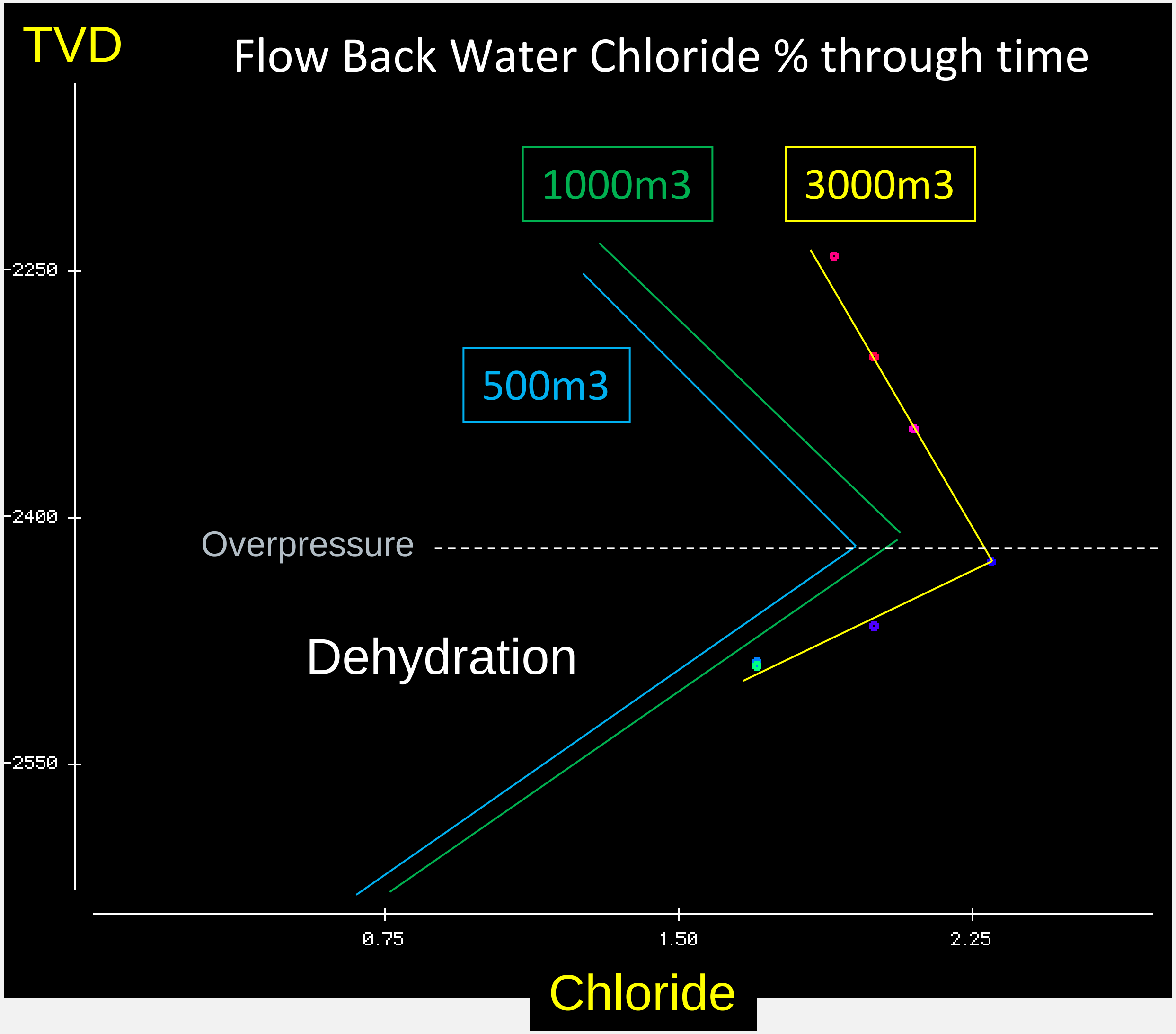


Only 6 wells

3 wells above Isotope reversal

3 wells below Isotope reversal

Dehydration in the Dry Gas Domain



Decrease in chloride content with depth below reversal :

Shale dehydration

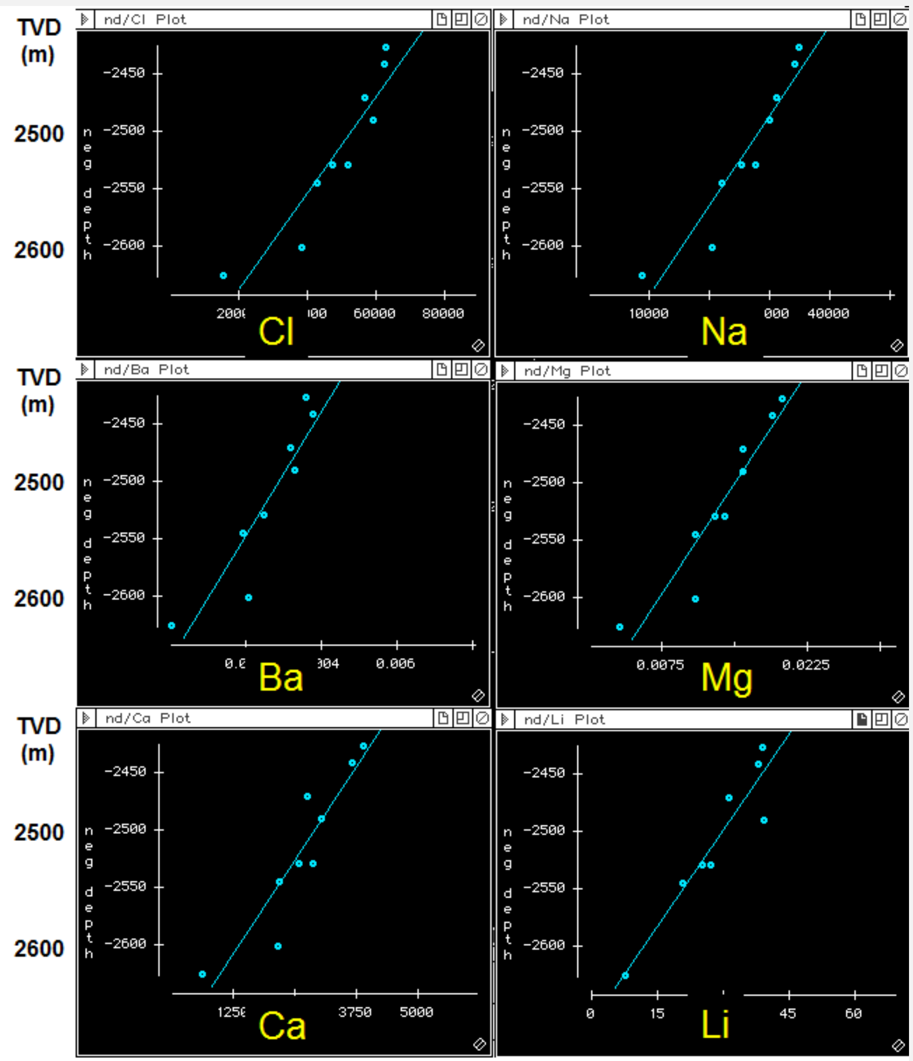
Hydrogen extracted from the interstitial water to generate methane:

$C_2H_6 + 2H \Rightarrow 2CH_4$

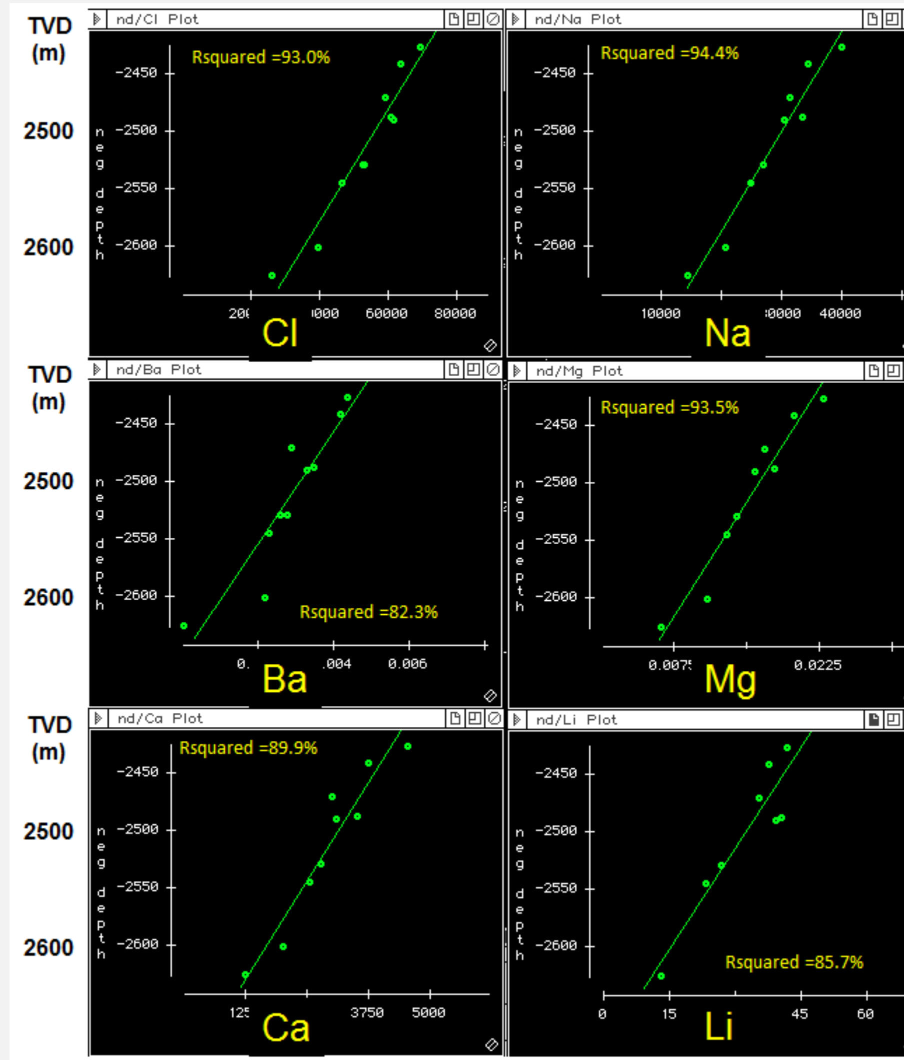
Petrophysics confirmed a decrease of water saturation with depth below 2400 m

The trend below 2400m (below isotope reversal depth)

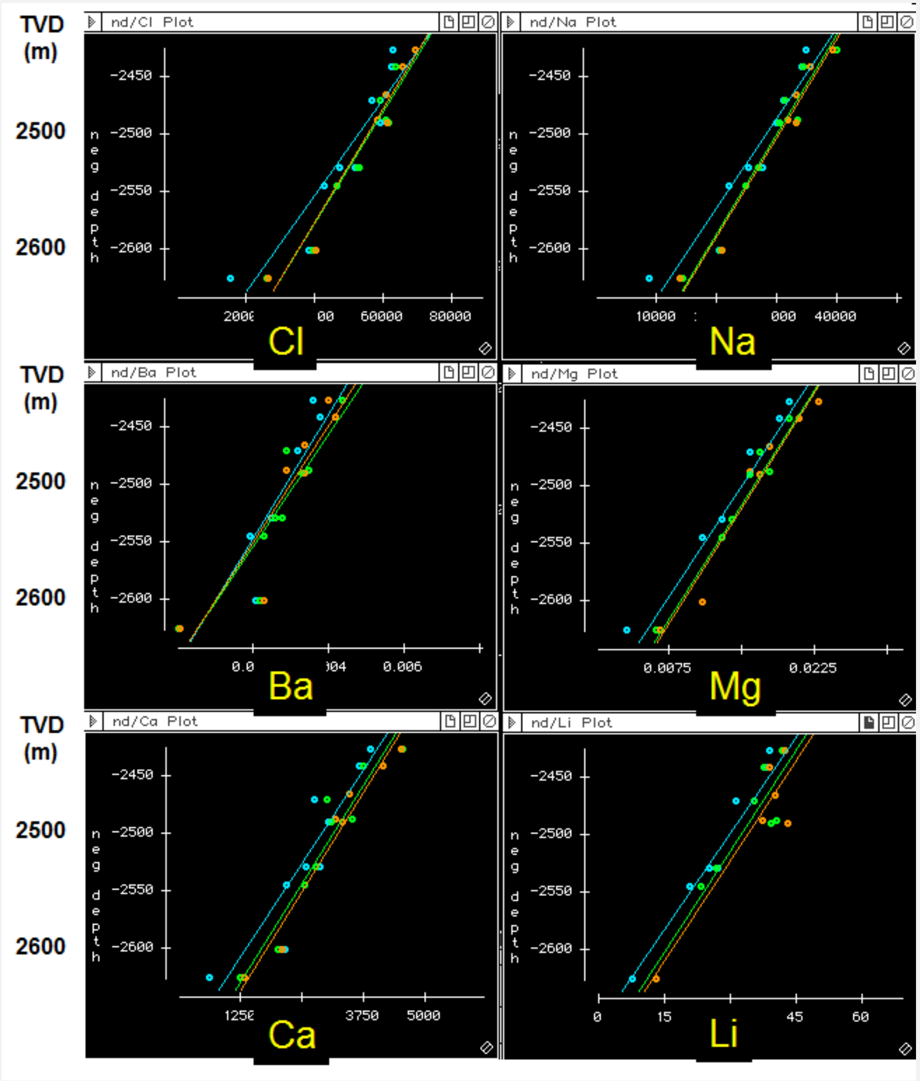
500 m3 flowback water



1000 m3 flowback water



Flowback (500,1000,1500 m3)



Not much change between 100 m3 and 1500 m3

Depth profiles below 2400m TVD

10 Wells arranged by depth

Well 1	U. Lower
well 2	U. Lower
Well 3	U. Upper
Well 4	U. Lower
Well 5	U. Upper
Well 6	U. Upper
Well 7	U. Lower
Well 8	U. Lower
Well 9	U. Lower
Well 10	L. Lower

Trend across stratigraphy

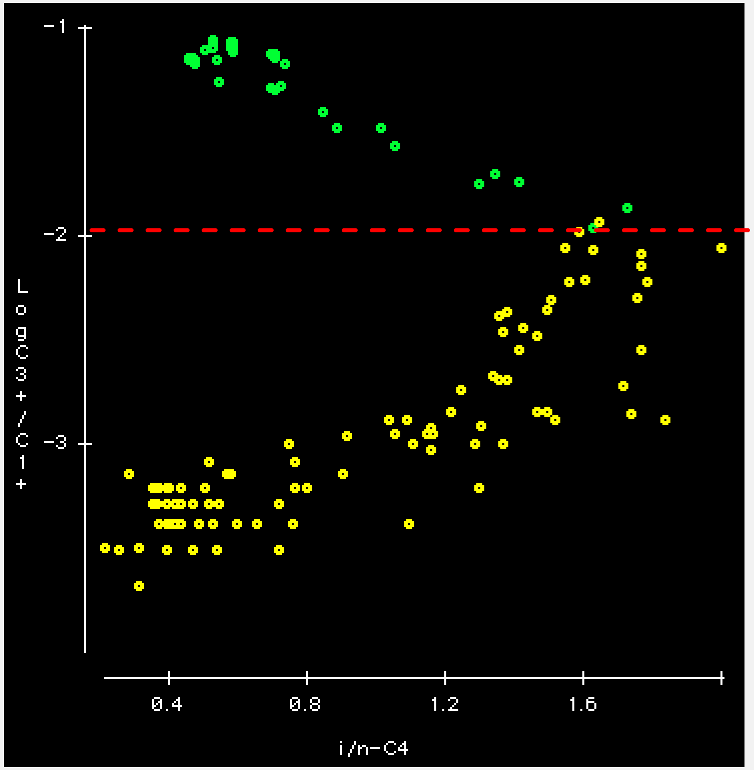
Key takeaways:

- Below 2400m TVD depth, most ions and cations concentrations are decreasing with depth
- The trend does not represent salinity because the same trends are recognized in Ba, Mg, Ca and Li, i.e all cations
- **Water saturation is decreasing with depth below 2400m TVD**
- The sudden reduction in water saturation is linked to shale **dehydration** associated with the **secondary gas cracking process**
- The montney is a **semiconventional reservoir** with calculated water saturations as high as 50% above 2400m TVD.

Analogue: Produced Gas in 172 Barnett Wells

From the whole Fortworth Basin

Log (C3+/C1+)



iC4/nC4

Wet Gas

Dry Gas

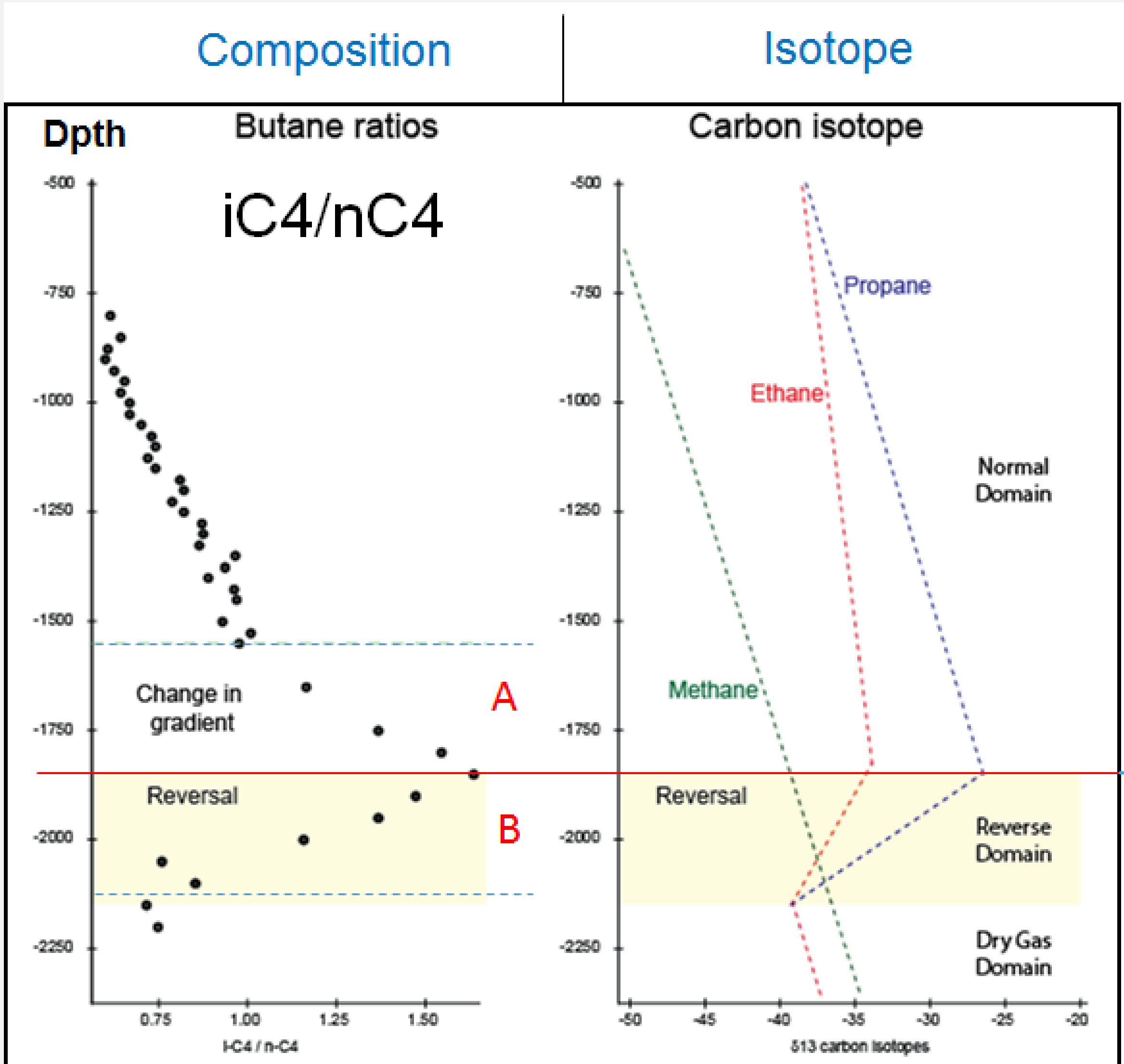
Reaction function of
Temperature
(linear function)

Reaction function of
Temperature
&
Water Availability

Nice negative trend
but lower R squared

Data from Zumberge et al 2013

Chemical reactions linked to burial



Profiles from a 2km thick shale (Quebec) from Chatellier et al. (2013)

Gradual change of large hydrocarbons (including nC_4) into methane

Gradual change of IC_4, C_3 and C_2 Into methane

Conclusions (1)

- Flow-back water analysis has helped
  - Identify well interferences from same pad or from neighboring pads
  - Document late or erratic contribution from various frac stages
  - Recognize and map sulfate precipitation in the Upper Montney of Altares and association with fault
    - Frac water reacting with marcasite and framboidal pyrite
  - Recognize and document shale dehydration

Conclusions (2)

- Implications for field development
  - Sulfate inhibitors have been used in wells targeting the Upper Montney, especially in one area of the field
  - Well spacing can be revisited using the distance of interfering well
  - New knowledge acquired with respect to partial or complete contribution of all of the frac stages need to be integrated in any future development scheme
  - Soaking / marinating can be proposed to greatly improved productivity below 2400m (in that field) as the dehydrated clays will swallow and keep some of the injected water

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