Are your formation water analyses representative?

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LPS

London Petrophysical Society

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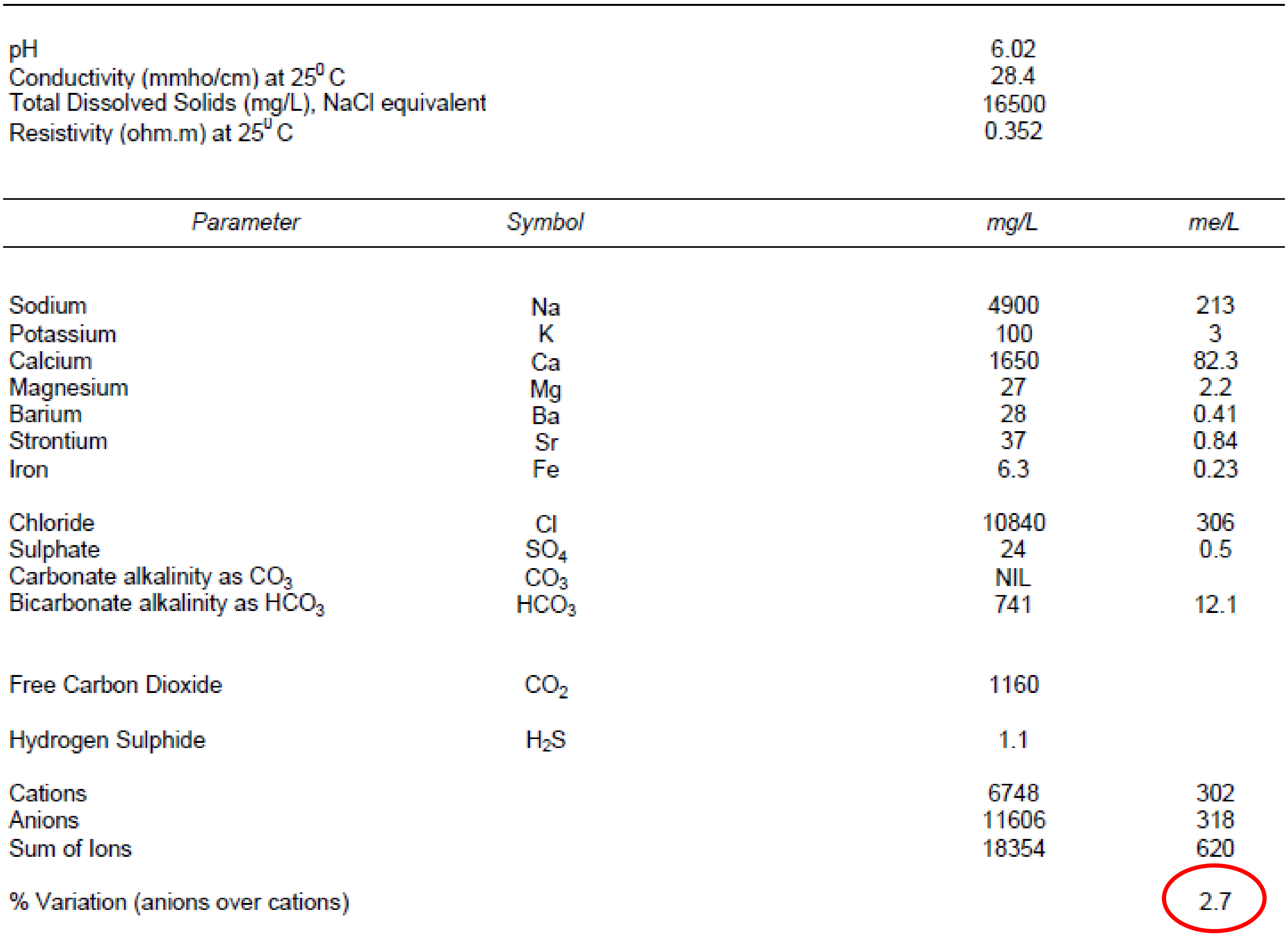
Reported analyses

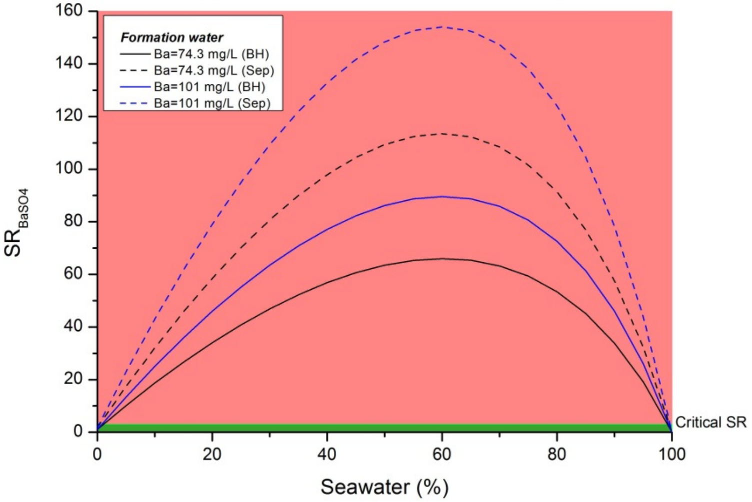


pH	6.02
Conductivity (mmho/cm) at 25^0 C	28.4
Total Dissolved Solids (mg/L), NaCl equivalent	16500
Resistivity (ohm.m) at 25^0 C	0.352

Parameter	*Symbol*	*mg/L*	*me/L*
Sodium	Na	4900	213
Potassium	K	100	3
Calcium	Ca	1650	82.3
Magnesium	Mg	27	2.2
Barium	Ba	28	0.41
Strontium	Sr	37	0.84
Iron	Fe	6.3	0.23
Chloride	Cl	10840	306
Sulphate	SO_4	24	0.5
Carbonate alkalinity as CO_3	CO_3	NIL	
Bicarbonate alkalinity as HCO_3	HCO_3	741	12.1
Free Carbon Dioxide	CO_2	1160	
Hydrogen Sulphide	H_2S	1.1	
Cations		6748	302
Anions		11606	318
Sum of Ions		18354	620
% Variation (anions over cations)			2.7

Who will use these formation water analyses?

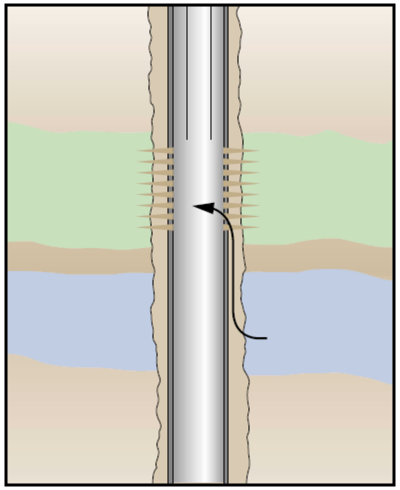
- Analyses may be used directly during field development planning:
  - Calculation of OIIP (R_w).
  - Hydrate predictions and inhibitor testing (total salinity).
  - Identifying emulsion risks (total salinity).
  - Scale predictions and inhibitor testing (major ions, pH)



  - Corrosion predictions, material selection, and inhibitor testing (major ions, pH).
  - Souring predictions (organic acids, NH_4, PO_4, H_2S, SRB).
  - Compartmentalisation studies ($^{87}Sr/^{86}Sr$).
  - Quality control for new formation water analyses (all constituents).

Who will use these formation water analyses?

- Analyses also used during production:
  - Identification and tracking of changes in formation water compositions.
  - Identification of areas of the reservoir with better or worse connectivity.
  - Identification of the source of water production (e.g. casing leak, particular reservoir zones, etc).
  - Produced water allocation.
  - Identification and tracking of injection water breakthrough.
  - Quantification and tracking of injection water fraction.
  - Quality control for new formation water analyses (all constituents).
- Analyses used by a wide range of planning and operational functions.



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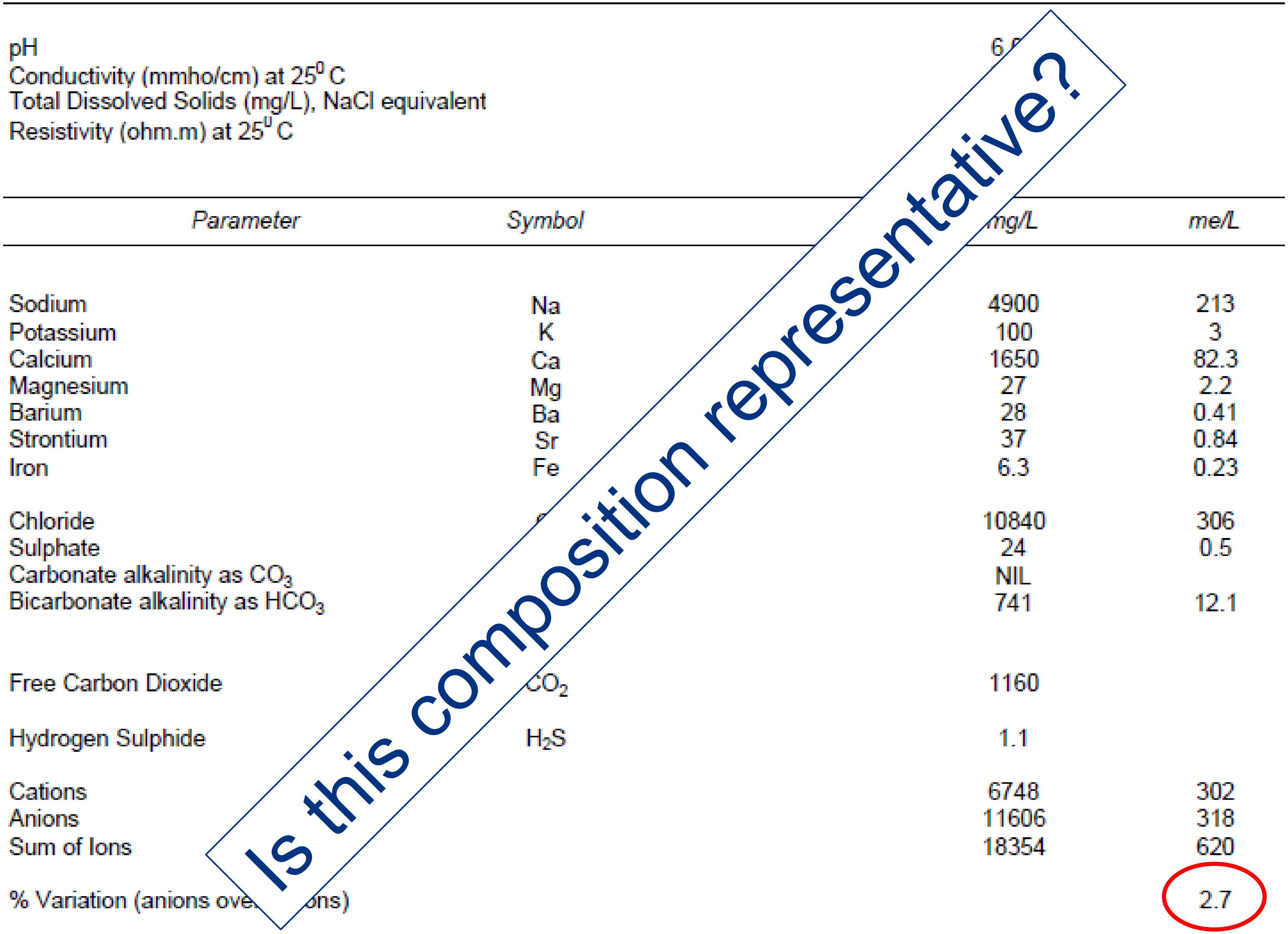

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Is this composition representative?

And if it they are not representative…..?

- Potential implications:
    - Incorrect or sub-optimal decisions.
    - Higher costs.
    - Reduced or lost production.
- For example, potential scale management implications:
    - Failure to predict scale occurrence – requirement for retrofitting scale mitigation capability.
    - Incorrect selection of injection water – more scale to mitigate than for alternative injection waters.
    - Selection of unsuitable or non-optimal scale inhibitors – ineffective or inefficient scale management.

Due diligence

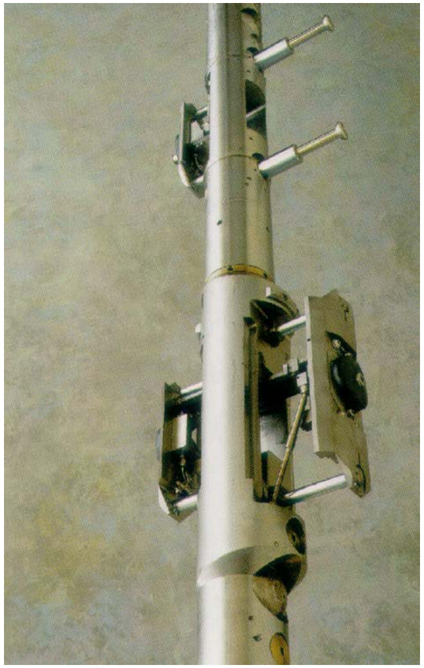
- To avoid these pitfalls, but to also still have a formation water composition to work with, it is important to know:
    - Are the reported analyses representative or not?
    - If not, can representative data be estimated?
    - What are the uncertainties associated with the final ‘recommended’ formation water composition?
- The latter is particularly important and these uncertainties need to be considered when using the composition during field planning and operation.

Outline

- How to determine whether the analyses are representative of the sampling location:
  - Identifying quality risks.
  - Assessing these risks.
- What if they are not representative?
  - Estimating representative formation water compositions.
  - Assessing the quality of estimated compositions.
- Are they representative of all field locations?
- Conclusions

How are formation water samples obtained?

- Field appraisal:
  - Formation testing (e.g. MDT, RCI, etc).
  - DSTs (e.g. wellhead, test separator, wireline sampling).
  - Production tests (wellhead, test separator).
  - Core (centrifugation, residual salt analysis).
- Production:
  - Production wells (wellhead, test separator).



Post-collection sample handling

- This may or may not involve (depending on procedures adopted):
    - Sample re-conditioning.
    - Sample transfer.
    - Sample preservation.
    - Sample transportation.
    - Sample storage.

Analysis of formation water samples

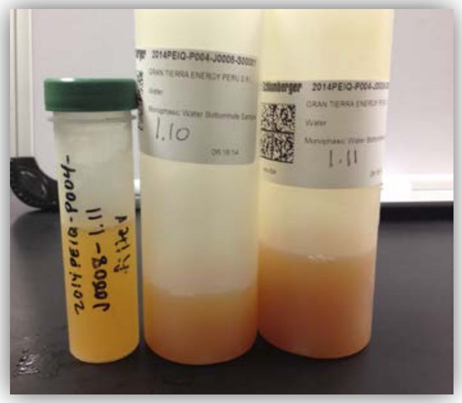
- Location:
  - Downhole probe (e.g. pH, R_w)
  - Field analyses (e.g. at the rig floor, platform).
  - Laboratory analyses.
- Common measurements:
  - 'Physical parameters': Appearance, total dissolved and suspended solids, specific gravity/density, resistivity/conductivity, pH.
  - Cations: Na, K, Mg, Ca, Sr, Ba, Fe.
  - Anions: Cl, SO_4, total alkalinity, HCO_3 alkalinity.
- Less common measurements:
  - Minor ions (B, Li, Mn, Br, PO_4, NO_3, HS, etc), organic acids.
  - Isotopes ($^{87}Sr/^{86}Sr$, stable oxygen and hydrogen isotopes).
  - Flashed gases (GWR, gas composition)
  - High pressure pH.

Identify the quality risks

- Factors that may cause the reported water sample analyses to differ from the *in situ* formation water composition.
- These may arise during the drilling of the sampled zone (e.g. mud contamination) right through to reporting of the analyses (e.g. reporting errors).
- They may include equipment, procedures, events and processes to which the samples are exposed.
- They can be identified by:
  - Knowing <u>what</u> factors can affect formation water compositions and <u>how</u> these factors can affect them.
  - Reviewing available drilling, sampling and analysis documentation to identify which factors might have affected the formation water samples and analyses of interest.

Common quality risks

- Drilling/completion:
  - ➢ Mud contamination, completion fluid contamination.
- Production:
  - ➢ Condensation, evaporation
- Sampling/sample transfer/storage:
  - ➢ Cross-contamination.
  - ➢ Pressure reduction (before and after sampling), gas separation, cooling.
  - ➢ Contact with air.
- Sample preservation:
  - ➢ None used, use of incorrect preservatives.



- Sample analysis:
  - ➢ Random errors, bias errors, use of 'proxy' methods, use of inappropriate methods, misunderstood analyses, reporting errors.

Can quality risks be avoided?

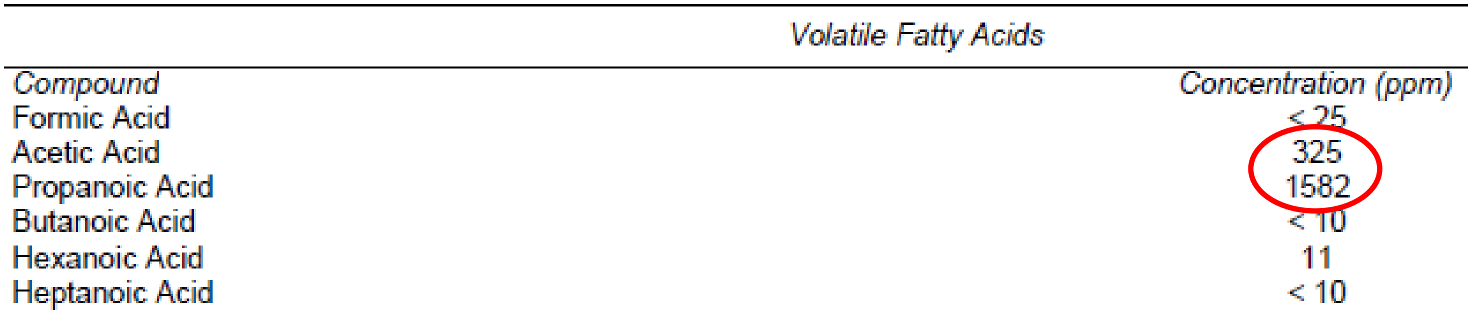
- With careful planning and implementation the number of quality risks can be reduced and their impact minimised. But:
  - Careful planning is not always undertaken.
  - Compromises have to be made.
  - Some factors our outside of our control.
  - Mistakes are made.
- It is common for one or more quality risks to affect the representativeness of formation water analyses.

Assessing the impact of quality risks

- Is there evidence, or is it likely, that the quality risks have significantly affected the compositions of the samples?
- *This tells us whether the water analyses are likely (or not likely) to be representative of in-situ formation water compositions.*
- Where the water analyses are not representative, what methods could be used to estimate them?

Example – the wrong preservative

- Representative propanoic acid analyses required to determine the frequency of fresh MEG shipments to a proposed offshore development with MEG plant.
- Identifying the quality risk:
    - Review of procedures showed sample incorrectly preserved with glutaraldehyde.
    - Quality risk - glutaraldehyde can interfere with propanoic acid analysis.
- Evidence of impact:
    - Compared with typical formation waters, propanoic acid concentration confirmed as high and anomalous (higher than acetic acid).
    - High –ve ion balance.
    - Subsequent laboratory tests confirmed glutaraldehyde caused bias.

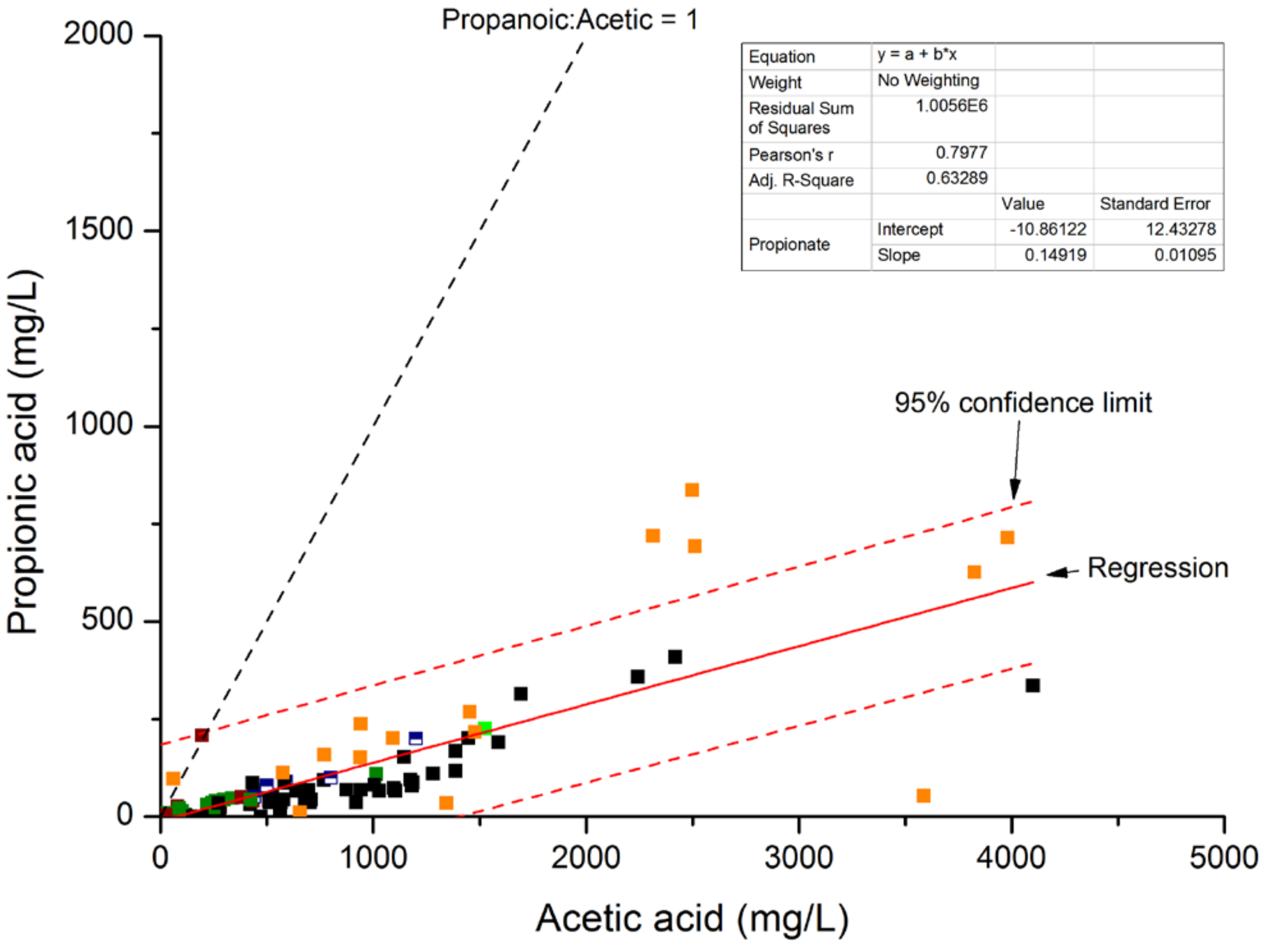


Volatile Fatty Acids

Compound	*Concentration (ppm)*
Formic Acid	< 25
Acetic Acid	325
Propanoic Acid	1582
Butanoic Acid	< 10
Hexanoic Acid	11
Heptanoic Acid	< 10

Example – the wrong preservative

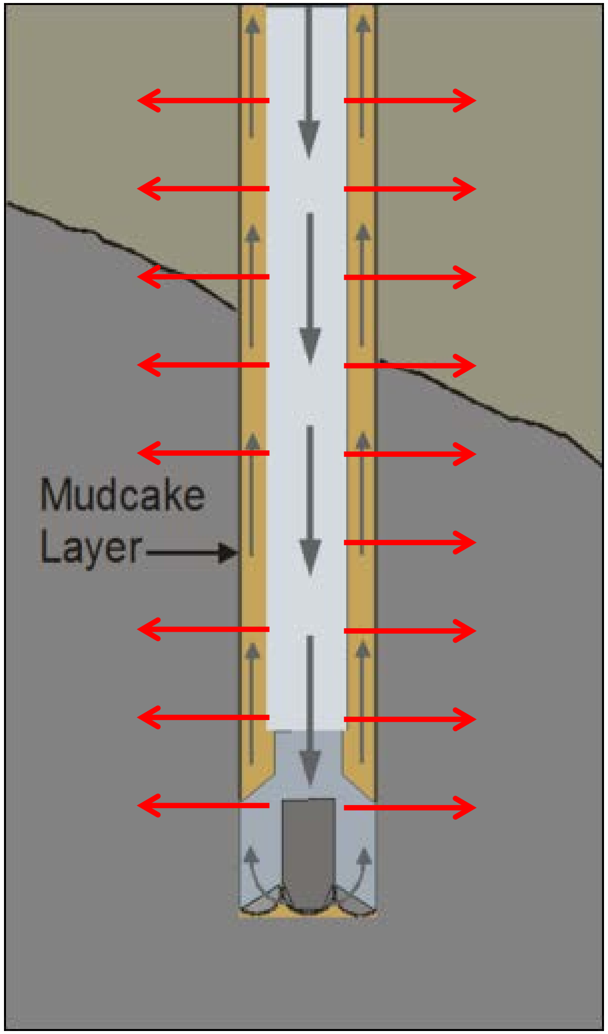
- How was the likely propanoic acid concentration estimated?
- From the acetic acid analysis and typical acetic acid/propanoic acid ratios in formation waters (~10:1).



Equation	y = a + b*x		
Weight	No Weighting		
Residual Sum of Squares	1.0056E6		
Pearson's r	0.7977		
Adj. R-Square	0.63289		
		Value	Standard Error
Propionate	Intercept	-10.86122	12.43278
	Slope	0.14919	0.01095

Example - mud filtrate contamination

- Representative Ba, Ca, SO_4 required for scale management planning.
- Identifying the risk:
  - Well drilled with KCl water-based mud with NaSCN tracer.
  - Formation water samples subsequently obtained via formation testing.
  - Quality risk - mud filtrate contamination of samples.
- Evidence of impact:
  - Presence of SCN in the water samples confirmed mud filtrate contamination.



Example - mud filtrate contamination

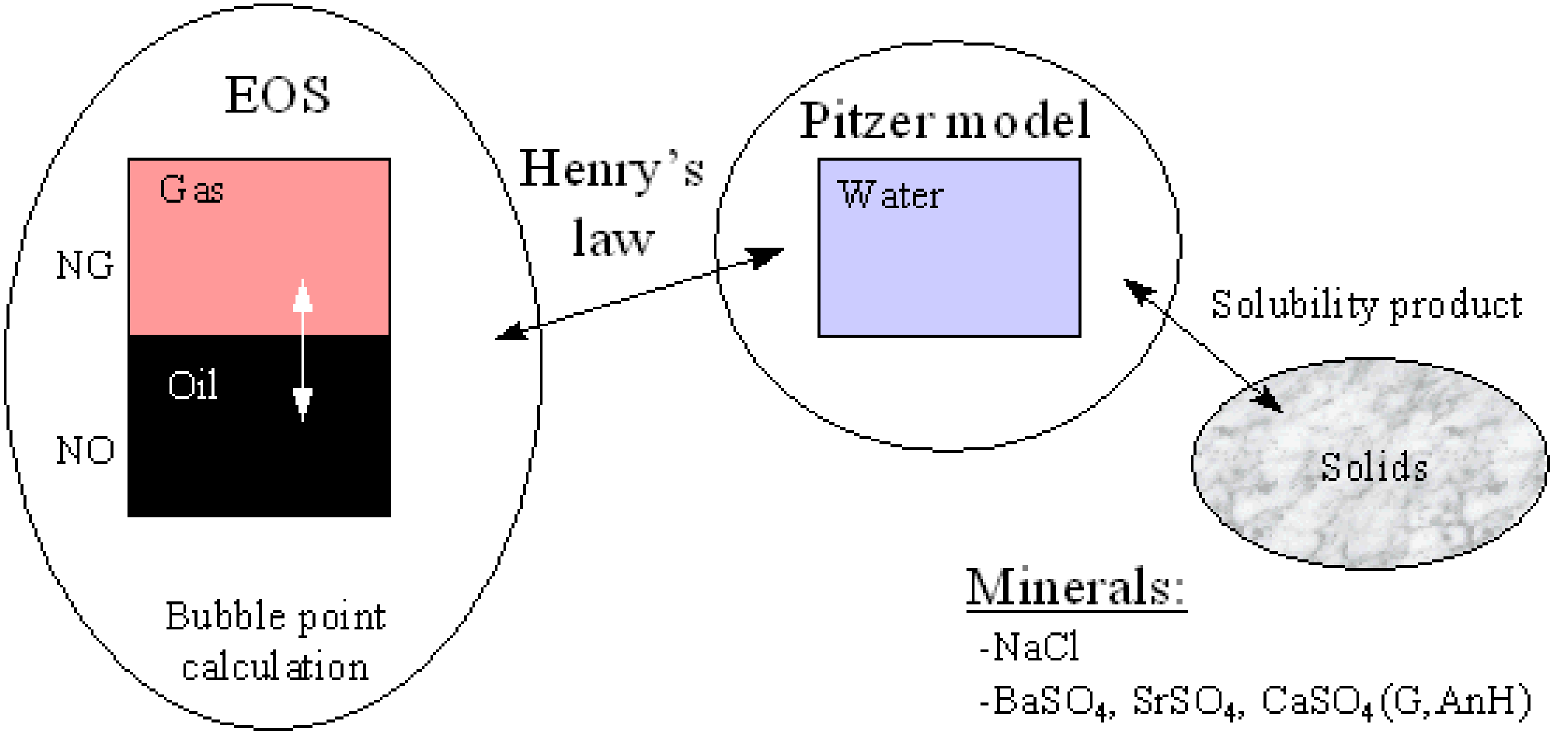
- Reactive transport modelling undertaken to simulate mud filtrate invasion, mixing with formation water, reactions and subsequent pumping out of contaminated formation waters.
- This showed that some ions in the water sample (e.g. Ba, Ca, SO_4) likely to be affected by $BaSO_4$ precipitation and ion exchange in the reservoir.
- By comparing the water sample K analyses with model results, it was possible to demonstrate that ion exchange effects in the sampled zone were negligible (i.e. the zone had very low clay content and low CEC).

Estimation of formation water compositions

- Ca:
  - Very low clay means formation water Ca can be estimated via linear regression of Ca and SCN analyses.
  - If ion exchange effects had been significant, it would have been necessary to use the RT model results to estimated formation water Ca concentrations.
- Ba, SO_4:
  - Due to precipitation of $BaSO_4$, linear regression could not be used to estimate formation water Ba and SO_4 concentrations.
  - But, these could be estimated using scale prediction software to correct for $BaSO_4$ precipitation (e.g. MultiScale™).
  - If ion exchange effects had been significant, it would have been necessary to use both the RT model results and scale prediction software to estimate formation water Ba and SO_4 concentrations.

MultiScale™

- Water-gas-oil equilibrium model.
- Capable of predicting scale risk (saturation ratios, scale mass) at fixed P-T, along a P-T profile, or when waters are mixed.



Minerals:

-NaCl

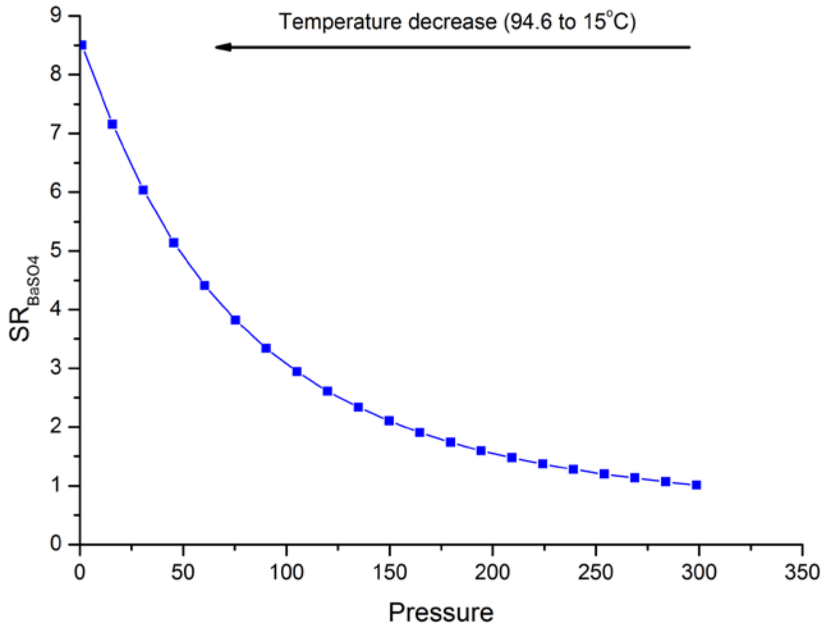
-$BaSO_4$, $SrSO_4$, $CaSO_4$(G,AnH)

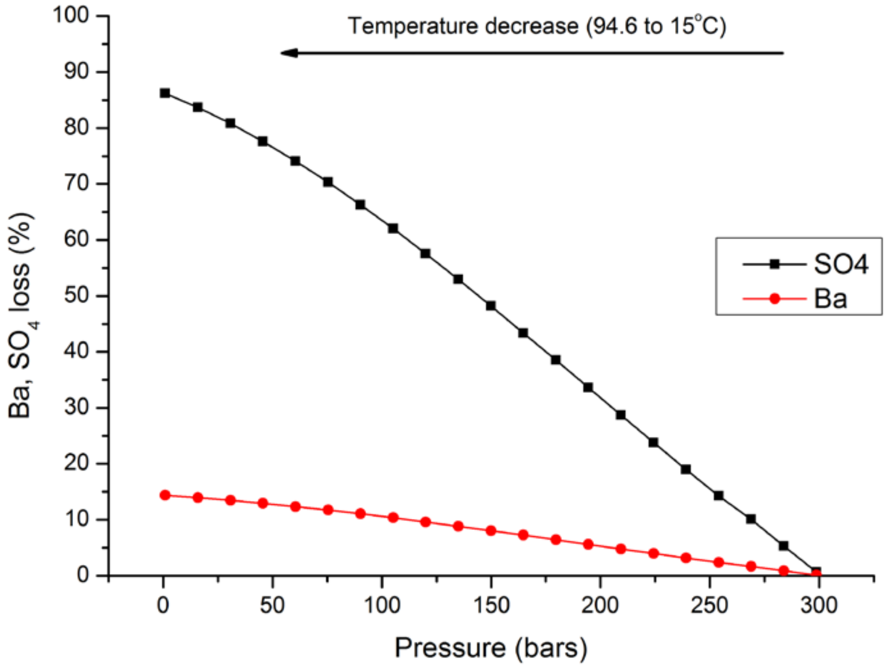
-FeS

-$CaCO_3$, $FeCO_3$

Example - sample cooling/de-pressurisation

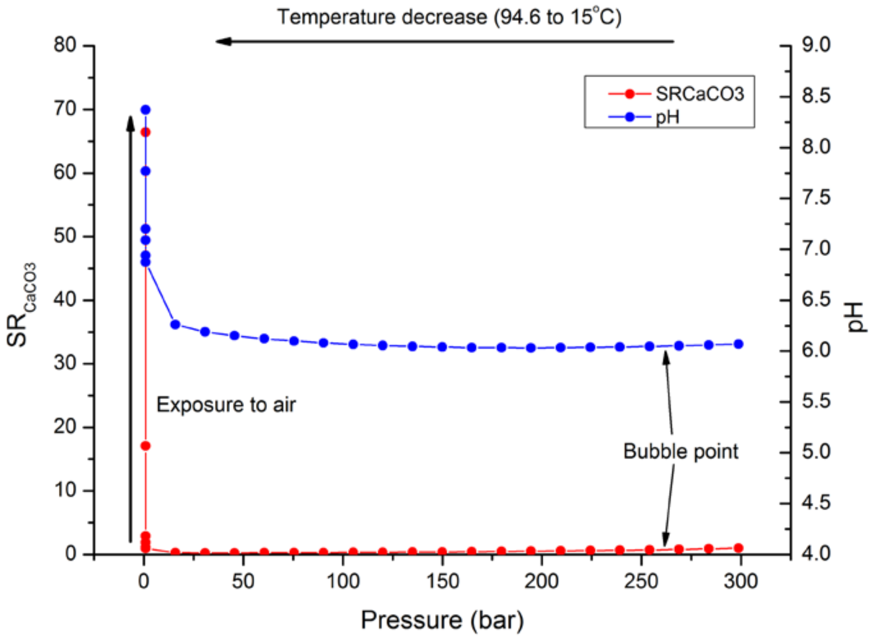
- Formation testing sample, decanted at the well site.
- Quality risk – $BaSO_4$ precipitation before sample analysis.
- MultiScale™ modelling showed that this could modify the formation water composition but not sufficiently to affect scale management planning.

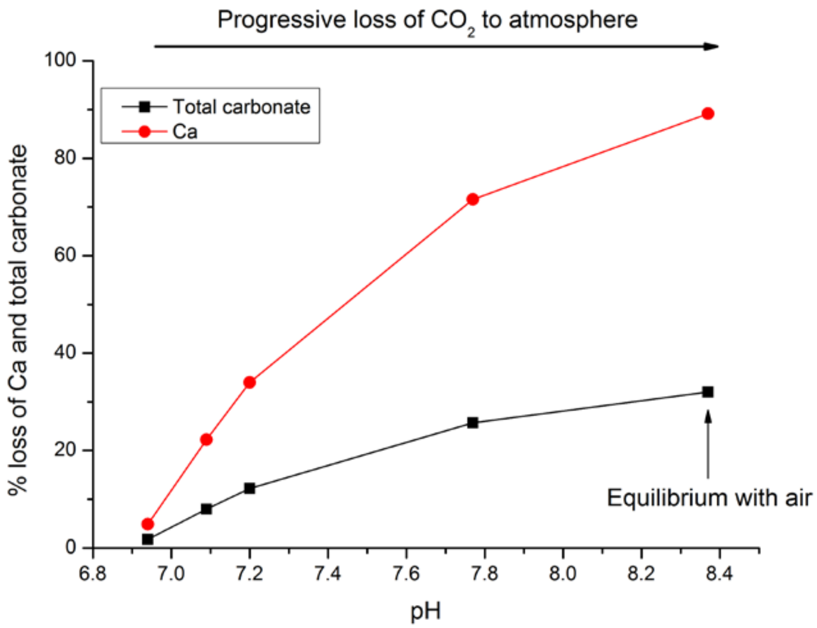




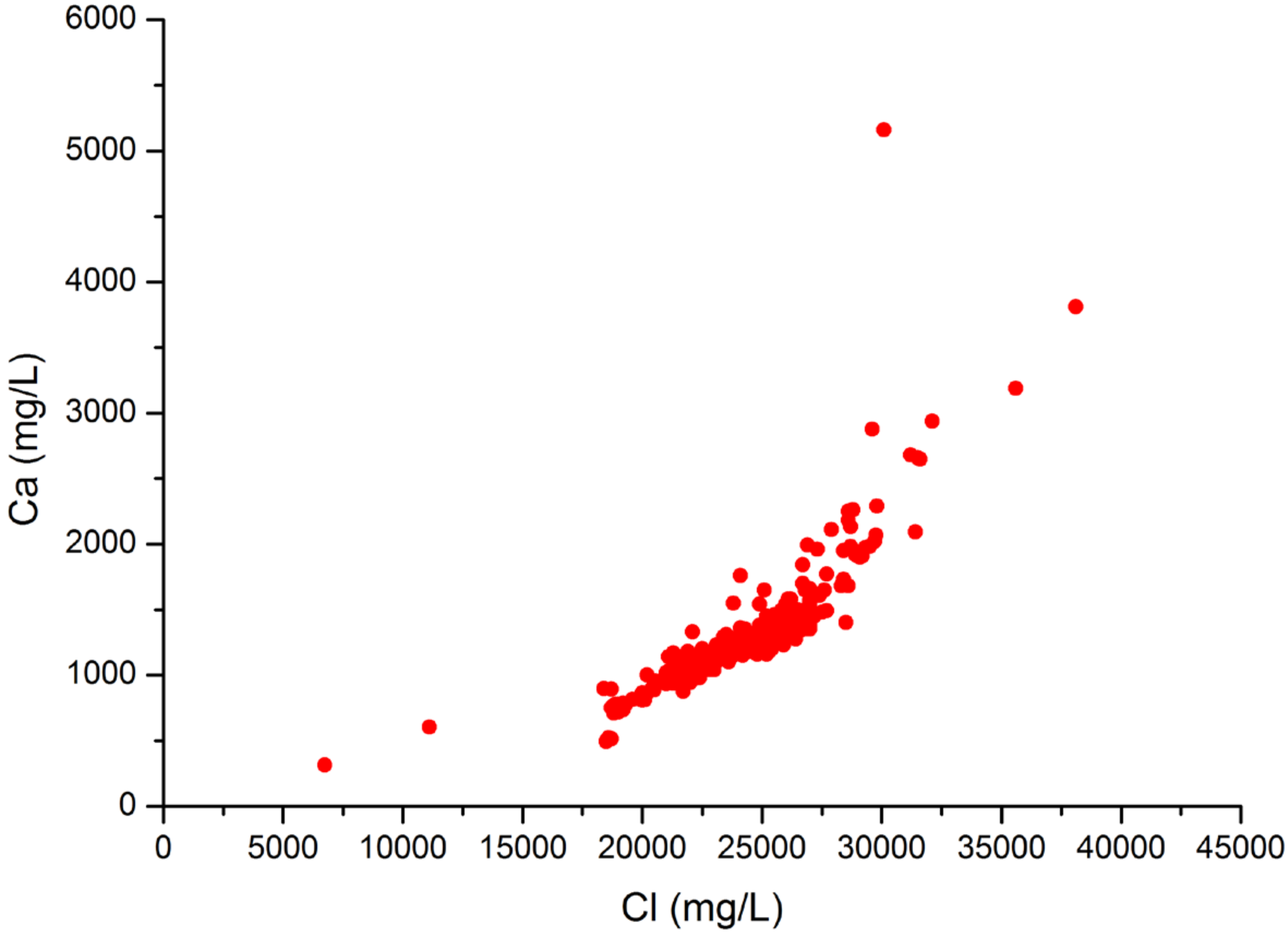
Example - sample cooling/de-pressurisation

- Quality risk – $CaCO_3$ precipitation before sample analysis.
- MultiScale™ modelling showed that this could cause significant change in pH and Ca (89%) and HCO_3 (32%) loss from the sample on decanting.
- Important for scale management planning but difficult to correct.





Example - produced formation water analyses



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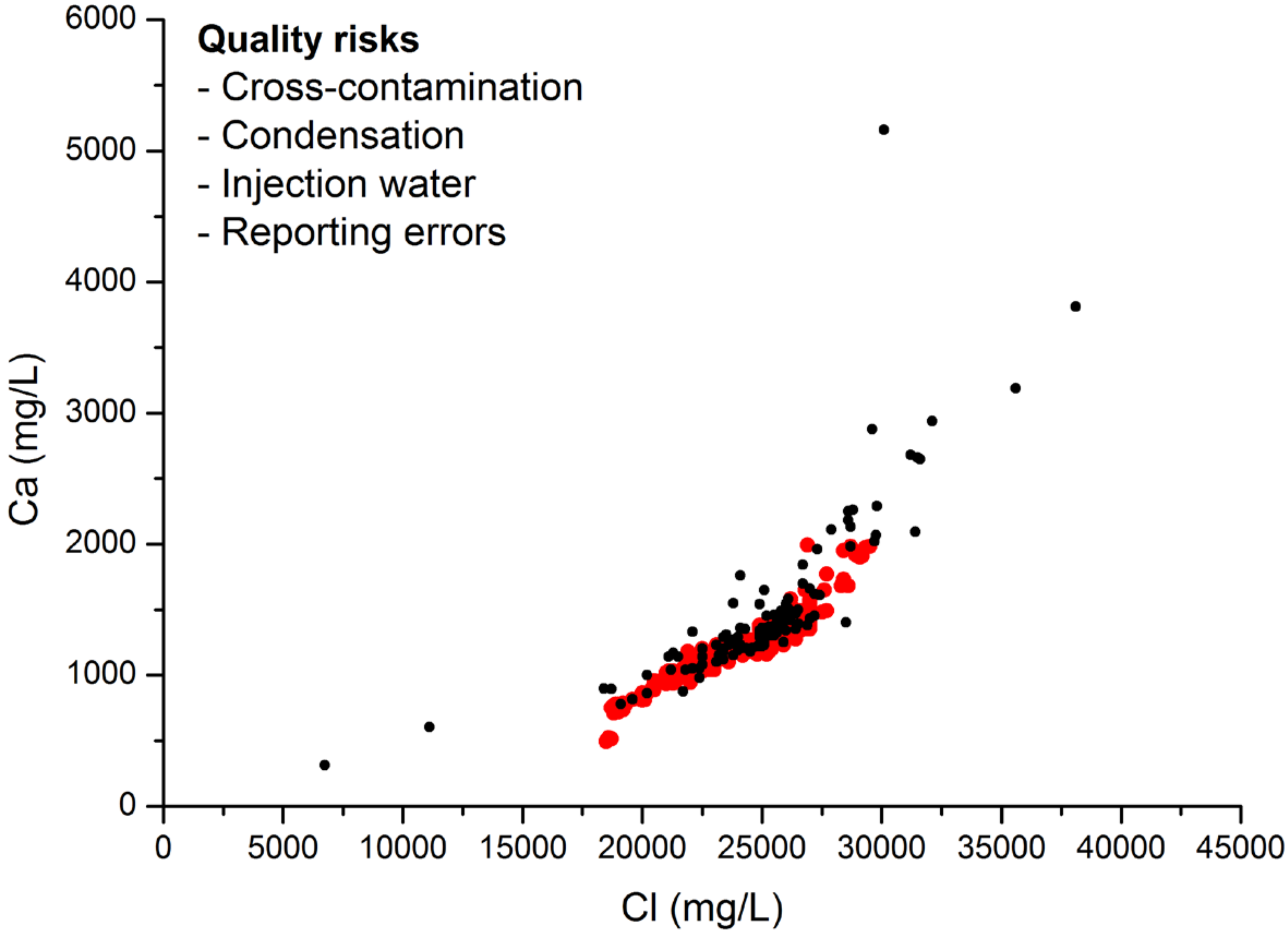
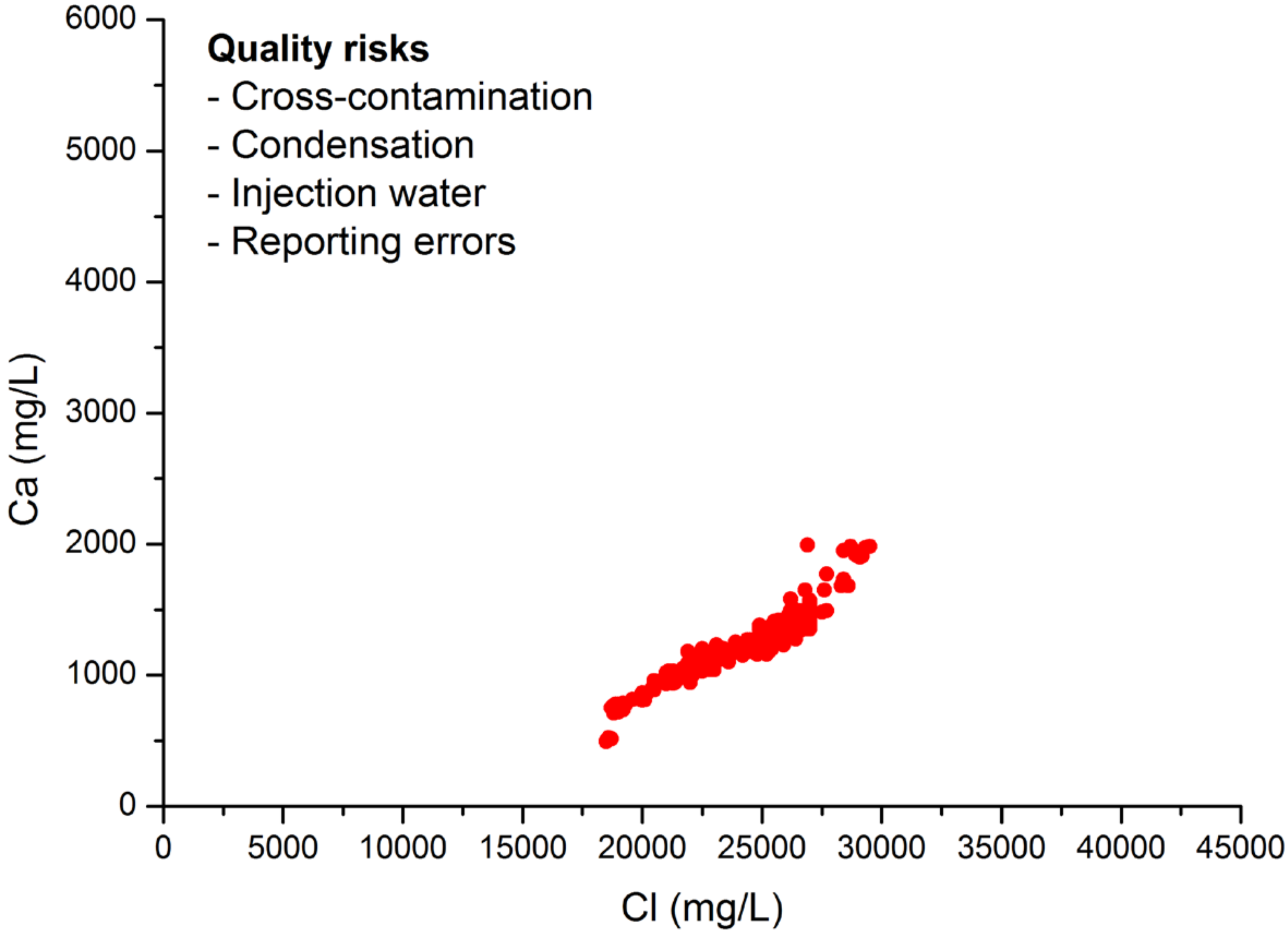


Quality risks

- Cross-contamination
- Condensation
- Injection water
- Reporting errors

Example - produced formation water analyses



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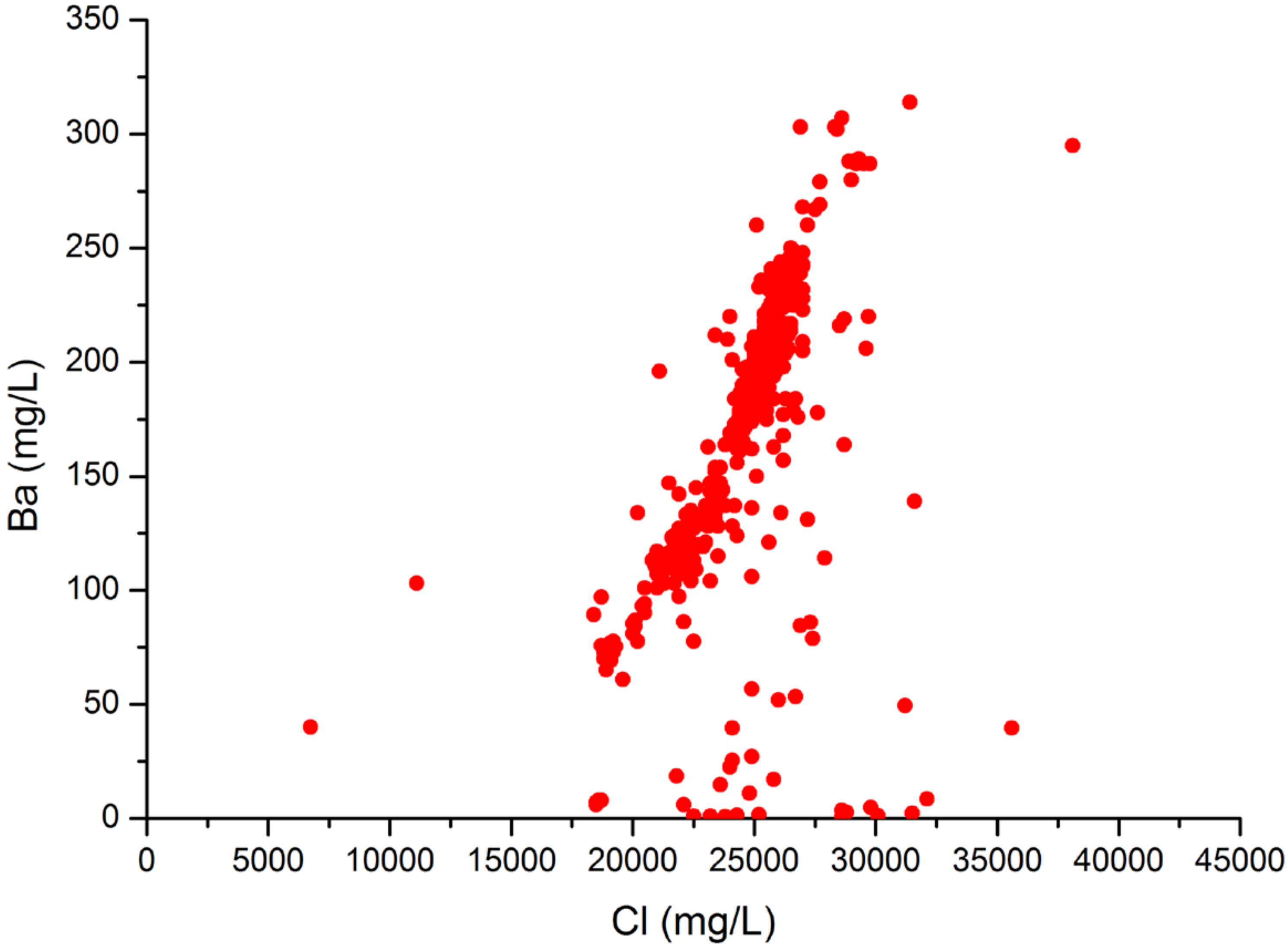

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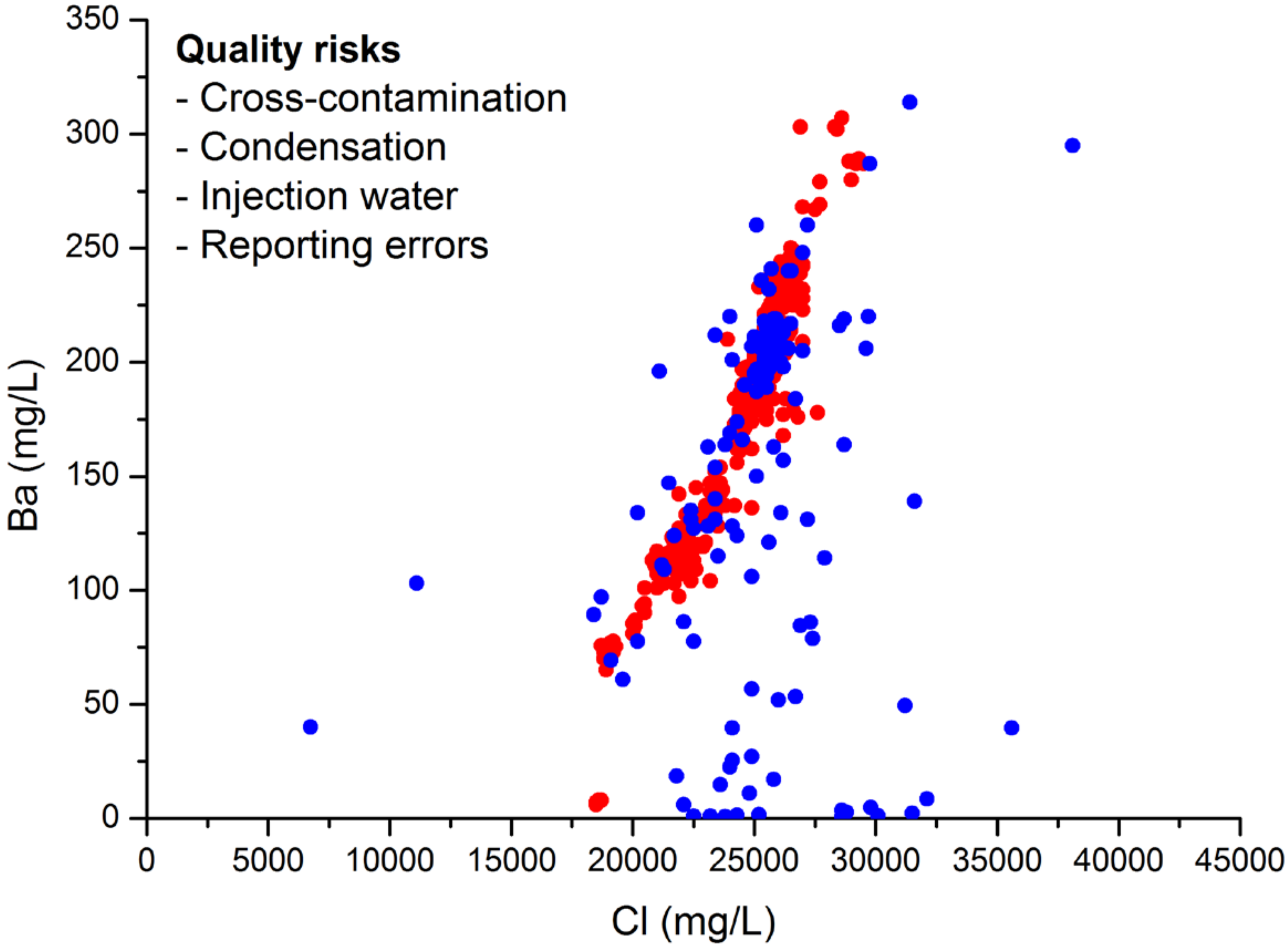

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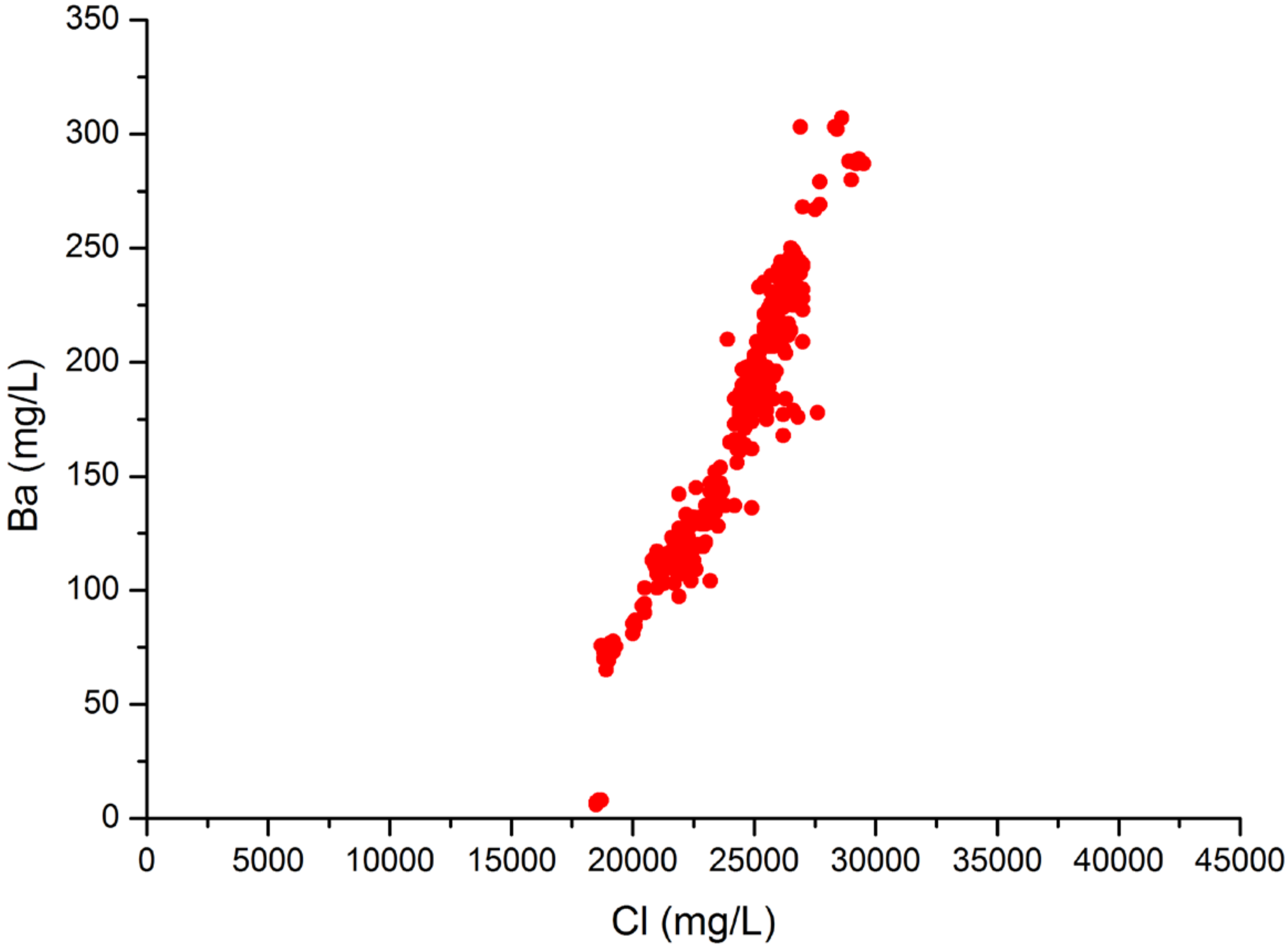
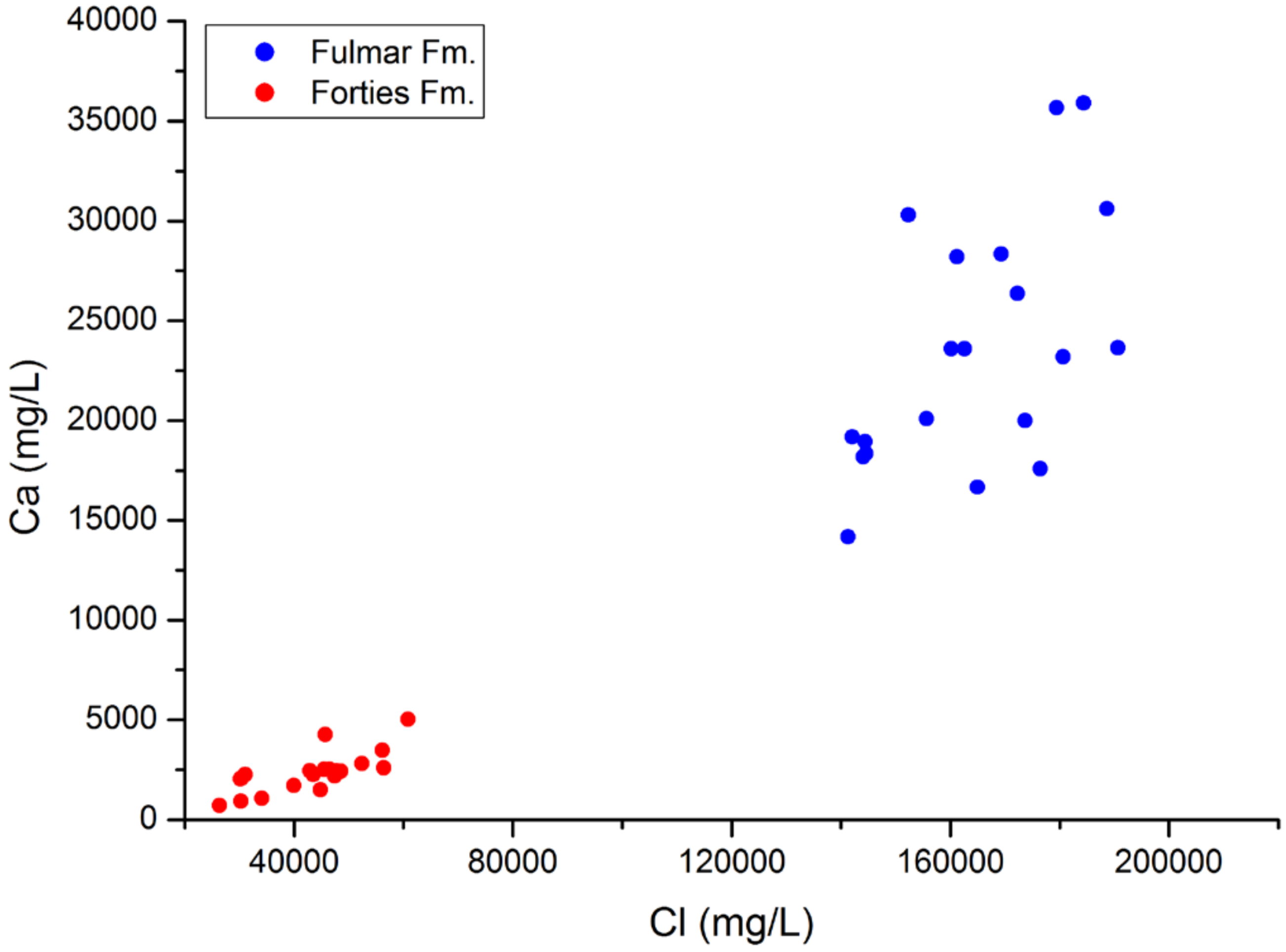


Produced formation water samples

- ‘Cleaned-up’ data subsequently used:
  - To identify areas of good and poor connectivity.
  - As a baseline for more accurately identifying injection water breakthrough.
- Benefitting:
  - Reservoir management (providing constraints on the reservoir model).
  - Scale management.

Use of analogue formation water compositions

- Possible sometimes – degree of constraint can vary…..



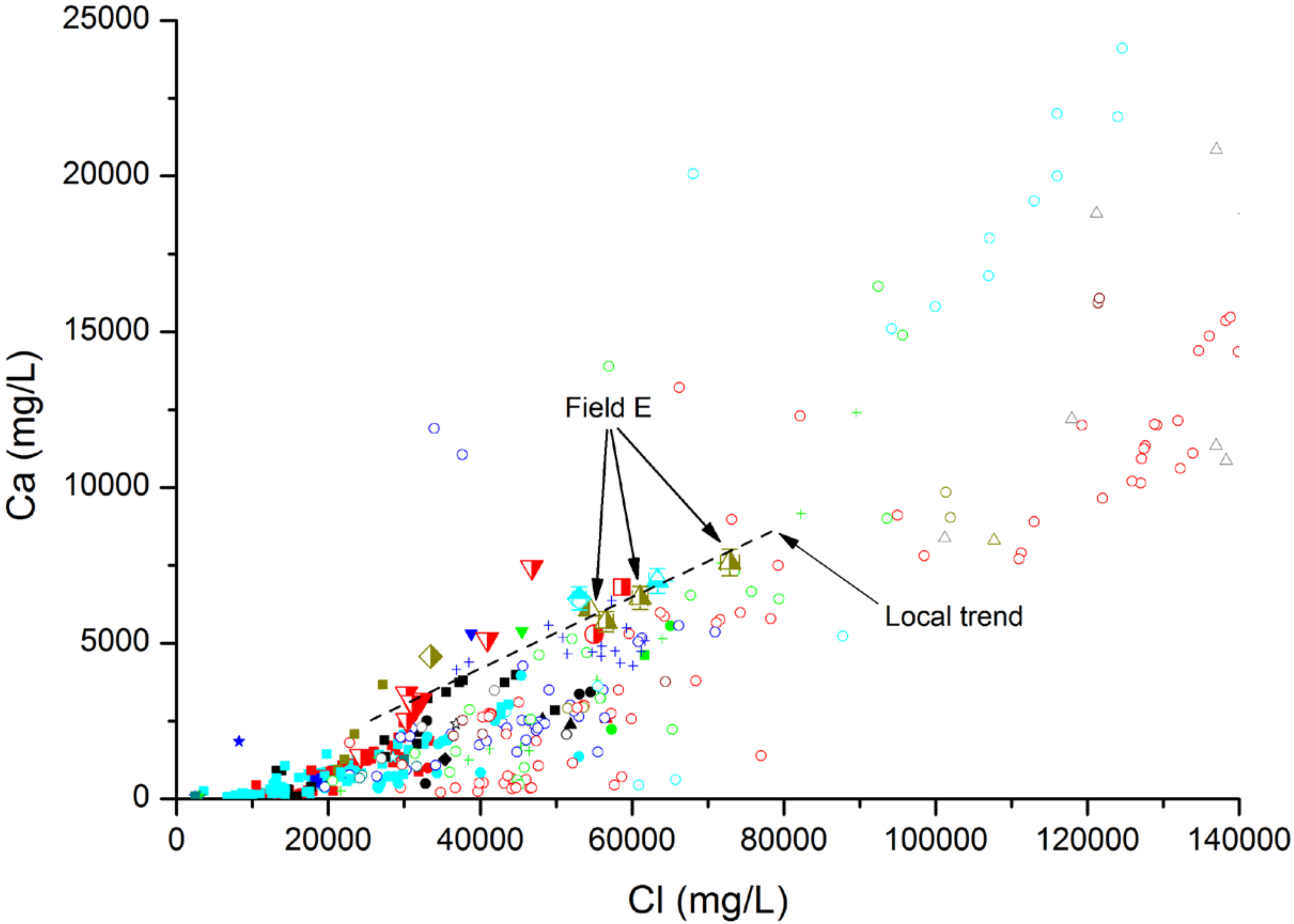
Building confidence in estimated compositions

- Checking ion balances – can support validity of estimated major ion concentrations.
- Comparison with measured pressure gradients – ditto.
- Comparison with analogue formation water data – can support validity of estimates of all ion concentrations.

Comparison with formation pressures

- Where pressure data have been obtained, a pressure gradient can be calculated.
- A theoretical pressure gradient can also be calculated from the estimated formation water salinity (e.g. obtained from mud-contaminated samples).
- Where the latter overlays the former, this indicates that the estimated salinity is reasonable.
- But, this is not always a sensitive technique – need good pressure data.

Comparison with analogue formation waters



Representative at all field locations?

- Differences in composition can occur between wells, between reservoir zones, between the water-leg and the hydrocarbon-leg, and within the hydrocarbon-leg.
- Prediction at other locations is challenging:
  - Is the aquifer well connected, active, or compartmentalised?
  - Are the reservoir zones connected?
  - When were hydrocarbons emplaced?
  - Was the aquifer connected or compartmentalised during this period and was the aquifer active?
- But, we can comment on the risk that differences may be present. For example:
  - Well connected, active aquifer, recent and fast hydrocarbon emplacement – lower risk between wells and between water-leg and hydrocarbon-leg.
  - Compartmentalised aquifer – higher risk between wells in aquifer.

Conclusions/advice

- Try to obtain good quality formation water samples and analyses (this is not always possible).
- After analyses have been obtained, determine whether they are representative by:
  - Identifying the quality risks.
  - Assessing the potential impact of these risks on the analyses.
- Where the impact is likely to be significant, try to estimate representative compositions and try to confirm that the estimates are reasonable.
- To minimise the risks when using the 'final' compositions, make users aware of any uncertainties associated with the compositions.
- Do not assume that one composition will be valid for all locations across the field – assess the risk.
- Do not assume that the formation water composition from an adjacent field will be the same as that in your field – assess the risk.