# Formation water samples: Are you missing a trick?

Should core-derived water analyses be part of the standard package of acquired data on new developments?

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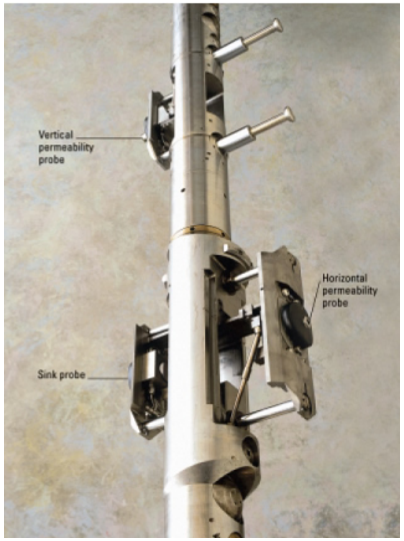
# Outline

- Is one water sample location enough?
- Opportunities provided by core:
  - Centrifuged core.
  - Residual Salt Analysis.
  - Dean-Stark crush and leach.
- Field examples.
- Conclusions.

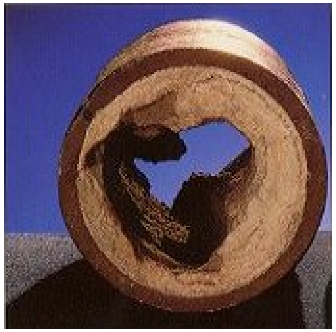
# Water sampling – typical scenario

- Common to collect one water sample from the water-leg during appraisal:
  - DST, production test.
  - Formation testing (MDT, RCI, etc).
- Used during field development planning
  - Calculation of OIIP ($R_w$).
  - 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).
  - Hydrate predictions and inhibitor testing (total salinity).
  - Identifying emulsion risks (total salinity).



# Water sampling – typical scenario

- Also used during production:
  - Baseline data for monitoring (scale, corrosion, hydrate, emulsions, souring).
  - Source of formation water (e.g. identifying casing leaks, identity of water-producing zones, etc).
  - Identification of injection water breakthrough.
  - Quantification of injection water fraction.
- Formation water analyses and associated results used by a wide range of planning and operational functions (water, scale, corrosion management, etc).



# Risks and limitations

- No reliable formation water composition obtained:
  - It may not be possible to collect samples (e.g. tight formation, inaccessible well, tool failure, etc).
  - Sample quality might be very poor (e.g. mud contamination - especially with WBM, no mud tracer).
  - May be necessary to estimate composition (e.g. analogues)
- Formation water compositions may vary across the field:
  - Within and between formations/reservoir units (e.g. Veslefrikk, Brage, Varg).
  - Within and between hydrocarbon-leg and water-leg (e.g. Forties, Alba).

# Implications

- Incorrect formation water compositions may be used, for example:
  - Use of incorrect $R_w$ for the hydrocarbon-leg - incorrect OIIP.
  - Formation water used in scale predictions may not be representative of much of the field but might be used in scale predictions – incorrect scale risk.
- Previously, risks have been accepted but less so with the increasing development of HT/HP and subsea fields:
  - Economics might be marginal – if the OIIP or the number of squeeze treatments required are incorrect, will the economic decisions be incorrect?
  - Retrospective action to solve unforeseen problems may be very expensive - or they may not be possible at all (operational constraints).
- Opportunities to use ‘multiple data’ applications will be missed, e.g.
  - $^{87}Sr/^{86}Sr$ compartmentalisation studies – aids development planning.
  - Produced water allocation studies – aids reservoir management.
- Solution – obtain more data from both water-leg and hydrocarbon-leg.

# Core-derived data - advantages

- Multiple sample locations:
  - Sandstone or carbonates.
  - Water-leg, transition zone, hydrocarbon-leg.
- Low cost:
  - For sub-sampling/analysis only - core already obtained for other purposes.
- Reasonably good quality (usable) data – where preferred protocols followed:
  - OBM (±tracer), low invasion coring techniques, ±plugging and preservation at rig site.

# Core-derived data - disadvantages

- Sample locations:
  - Data limited to core locations (e.g. core might not be cut in the water-leg).
  - Limited measured data in hydrocarbon-leg (but potential for estimated data).
- Sample quality:
  - Can be poor if it is not possible to follow preferred protocols.
  - Mud Aqueous Phase (MAP) contamination – greatest quality risk – can correct for this if contamination is low.
  - De-pressurisation (gas loss) and cooling of core:
    - Alters pH, $HCO_3$ (can correct for this).
    - Might also get evaporation (will not affect ratios but cannot correct concentrations for this).
- Core plug damage.

# Core-derived data

- Several methods for obtaining water analyses from core - some of the more useful types:
  - Centrifuged core. API RP40 (1998), Doorenbos et al. (2001).
  - Residual Salt Analysis. Mearns and McBride (1999), McCartney et al. (2010).
  - Dean-Stark crush and leach. API RP40 (1998), Pan (2005), Clinch et al. (2010).

# Comparison of techniques

| Method | Centrifuged core | Dean-Stark crush/leach | Residual salt analysis |
|---|---|---|---|
| Drilling Mud | WBM or OBM (OBM preferred) | OBM | WBM or OBM (OBM preferred) |
| Mud tracer | Deuterium, tritium | Deuterium, tritium | No |
| Mud sample analyses | Yes, tracer, other analyses | Yes, tracer, other analyses | No |
| Low invasion coring | Yes | Yes | Yes |
| Preserved plug samples | Yes (rig site) | Yes (rig site) | No |
| Water extraction | Ultracentrifugation | Dean-Stark measurement, then crush and leaching with distilled water | Crush and leach with distilled water |
| Analyses | Cations, anions, organic acids, $R_w$, tracer, density, $^{87}Sr/^{86}Sr$ | Cl, $^{87}Sr/^{86}Sr$<br>Other analyses optional (Na, Ca, K, etc) | Cl, $^{87}Sr/^{86}Sr$<br>Other analyses optional (Na, Ca, K, etc) |
| Calculated composition? | No | $^{87}Sr/^{86}Sr$ and ion ratios – No.<br>Ion concentrations – Yes (using measured Dean-Stark water mass) | $^{87}Sr/^{86}Sr$ and ion ratios – No.<br>Ion concentrations – Yes (using log porosity, $S_w$) |
| Mud contamination correction possible? | Yes, if required | Yes, if required | No |

# Centrifuged core

- Advantages:
  - Data for wide range of constituents.
  - Data can be obtained wherever water can be mobilised via ultracentrifugation (where centrifugal forces overcome capillary forces) – water-leg, transition zone, deeper hydrocarbon-leg.
  - Corrections for MAP contamination can be applied to data.
- Disadvantages:
  - Volume of water may be too small for complete analysis or duplicate analysis (e.g. low porosity).
  - High sample dilutions (limits of detection raised).
  - Extraction of small water volumes - greater potential for contamination.

# Dean-Stark crush and leach

- Advantages:
    - Data can be obtained from wide-range of locations – including at locations of low $S_w$ (water-leg, transition zone, hydrocarbon-leg).
    - All relevant measurements undertaken on the same sample – less uncertainty.
    - Corrections for MAP contamination can be applied to Cl data.
    - Potential for ‘bonus’ data.
- Disadvantages:
    - Limited ‘measured’ data of good quality (Cl, $^{87}Sr/^{86}Sr$) – data for other constituents is estimated or if measured, may be of uncertain quality.
    - Cl concentrations unlikely to be valid in evaporite-bearing rocks (e.g. halite).
    - Uncertainties on Cl increase as $S_w$ decreases.
    - If water loss from core occurs, Cl erroneously high (e.g. displacement by mud contamination, gas expansion, evaporation into expanding gas, etc).

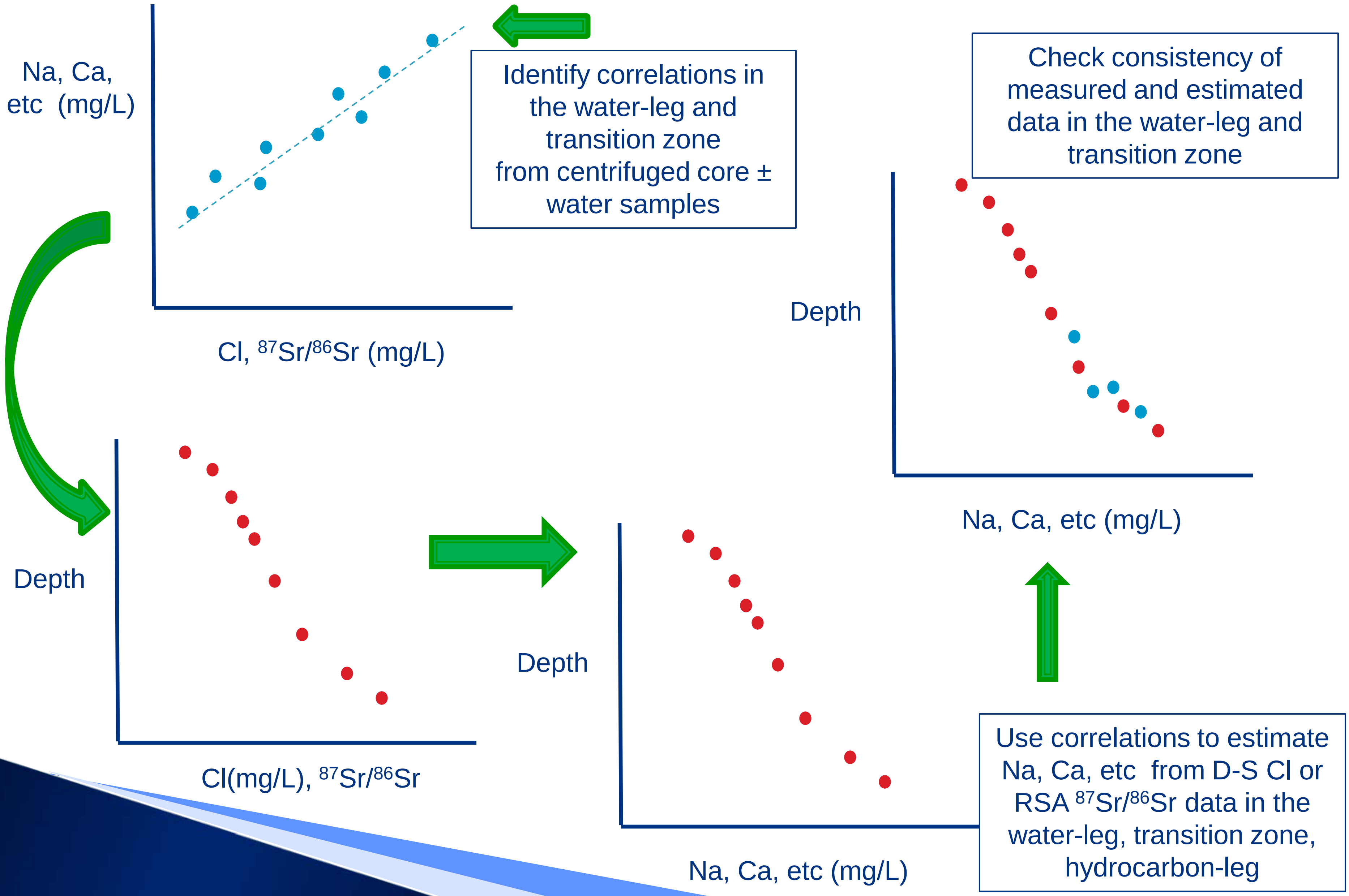
# Residual Salt Analysis (RSA)

- Advantages:
  - Unpreserved core – data can be obtained retrospectively.
  - Data can be obtained from wide-range of locations (water-leg, transition zone, hydrocarbon-leg).
  - Relatively immune to MAP contamination where formation water Sr concentrations are high (e.g. good data can be obtained even with up to 50% contamination).
  - Potential for ‘bonus’ data.
- Disadvantages:
  - Cannot undertake MAP contamination corrections - need to identify high risk samples (e.g. high porosity, high K/Na) and avoid them.
  - Concentrations of other ions need to be calculated using log-derived porosity and $S_w$- adds to uncertainty.
  - Data for concentrations or ratios of other constituents can be of uncertain quality (e.g. reactions during leaching, etc).

# Summary

- Whilst data is not perfect – usable data can be obtained given planning, correct protocols and the right subsurface conditions.
- Centrifuge core samples provide the best quality and range of data (constituents) but may be location limited.
- D-S crush and leach samples and RSA samples provide the widest range of locations, provide good Cl and $^{87}Sr/^{86}Sr$ data, and may provide ‘bonus’ data for other ions.
- RSA samples can be taken from unpreserved core.
- All have something to offer – and there are potential benefits to obtaining all these data and water samples.
- Compared with the collection of a single data set, integration of multiple data sets can result in more data (with quality information) from more locations.

# Examples of potential use of integrated data sets

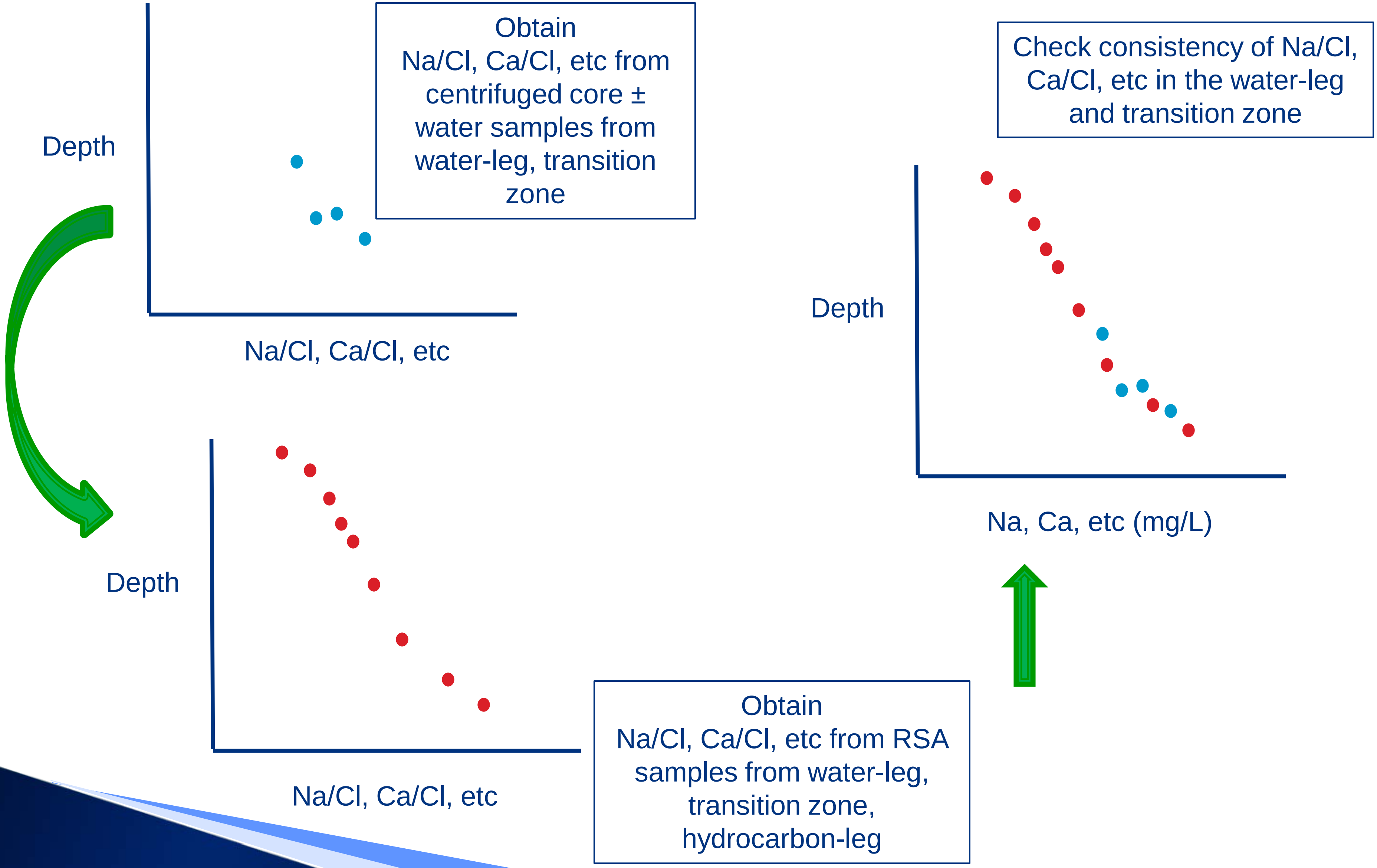


Identify correlations in the water-leg and transition zone from centrifuged core ± water samples

Check consistency of measured and estimated data in the water-leg and transition zone

Use correlations to estimate Na, Ca, etc from D-S Cl or RSA $^{87}$Sr/$^{86}$Sr data in the water-leg, transition zone, hydrocarbon-leg

# Examples of potential use of integrated data sets



Obtain
Na/Cl, Ca/Cl, etc from centrifuged core ± water samples from water-leg, transition zone

Obtain
Na/Cl, Ca/Cl, etc from RSA samples from water-leg, transition zone, hydrocarbon-leg

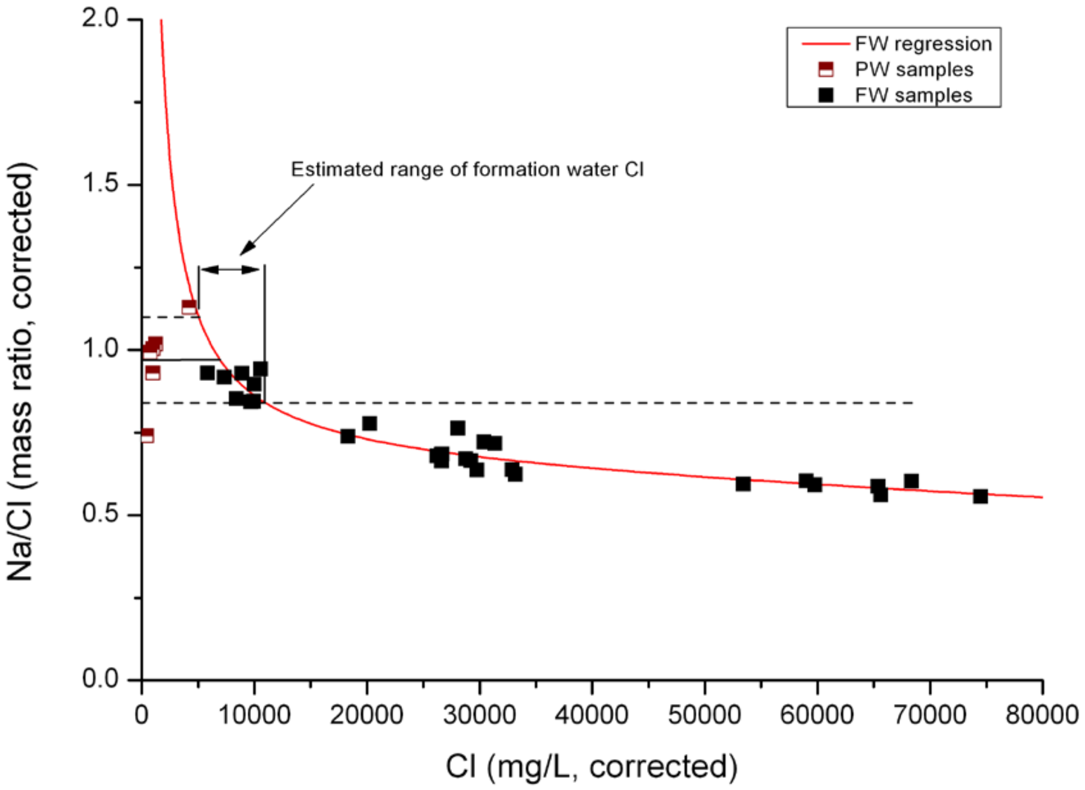
Check consistency of Na/Cl, Ca/Cl, etc in the water-leg and transition zone

# Field examples

- Numerous examples in the literature - typically use core-derived analyses for:
  - Determining $R_w$ in the hydrocarbon-leg for OIIP calculation – centrifuged core, D-S crush and leach.
  - Identifying variations of $^{87}Sr/^{86}Sr$ within the water-leg and hydrocarbon-leg for compartmentalisation studies - RSA.
- Following examples are ‘different’......

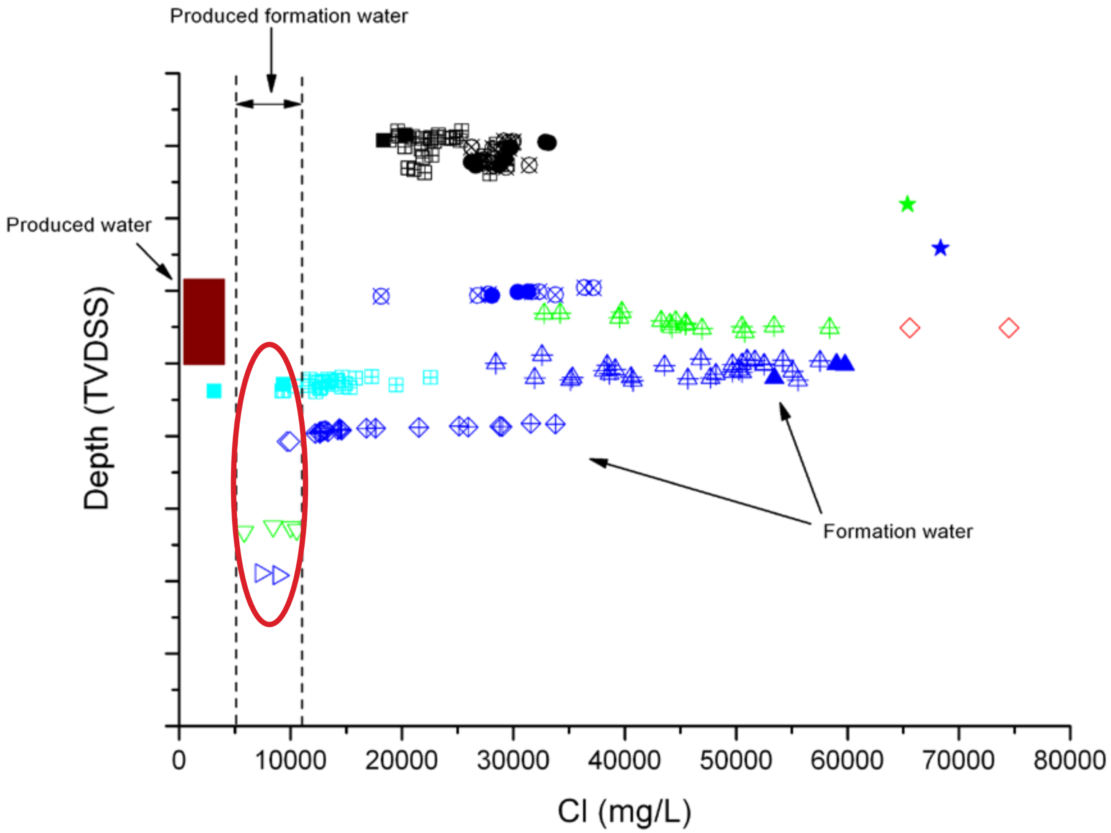
# Field example A (gas) – centrifuged core data

- During PLT $CaCO_3$ scale detected at perforations – but why? Produced water (PW) – low rate, low salinity, no scale risk.
- Centrifuge core – variable formation water (FW) composition in hydrocarbon-leg. Distinctive variation of Na/Cl v Cl.
- Na/Cl and Cl content of PW interpreted as being mixture of hydrocarbon-leg FW (~5-11 g/L Cl) and condensation water.



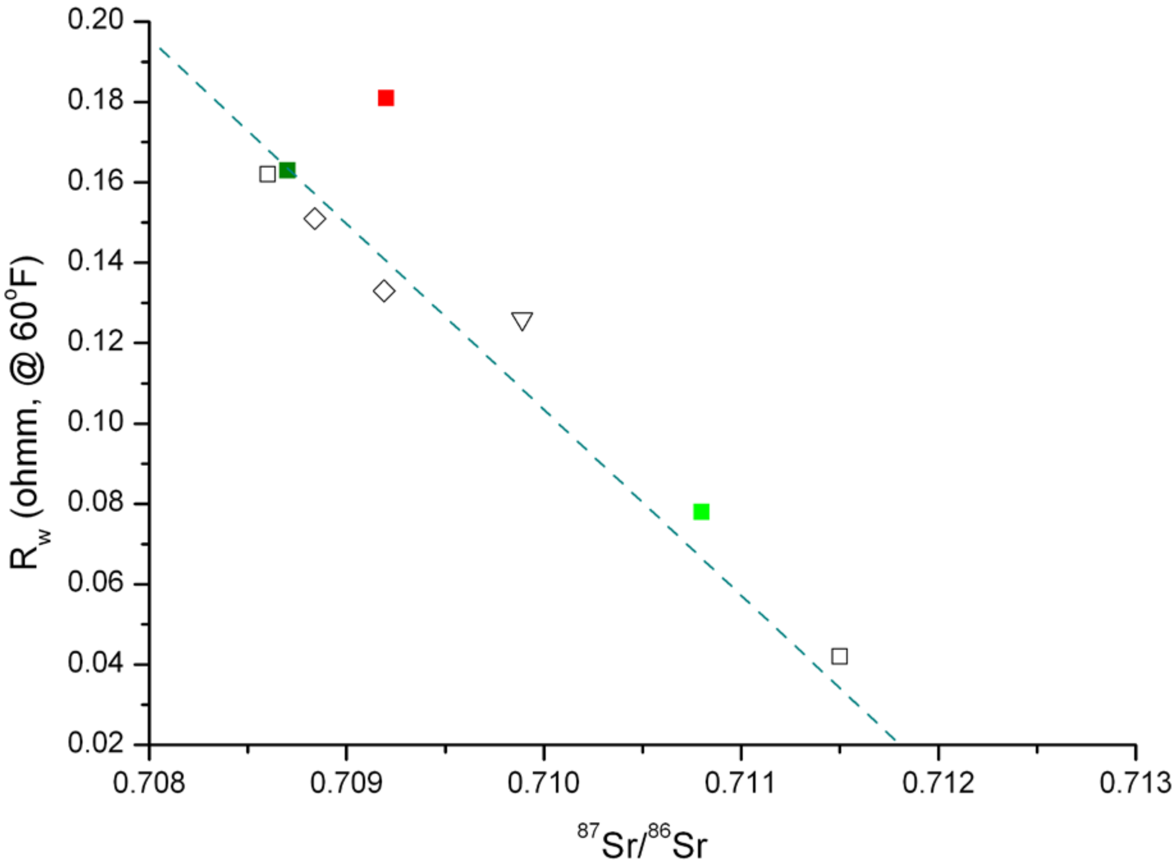
# Field example A (gas) – centrifuged core data

- PVT simulations confirmed condensation in the shallower sections of the well.
- Rate of FW production estimated from FW and PW Cl content and PW rate.
- FW composition estimated from centrifuged core data with similar Cl content.
- Scale predictions - under these conditions $CaCO_3$ expected at perforations - evaporation of FW as it entered the well.
- Benefit – scale management.



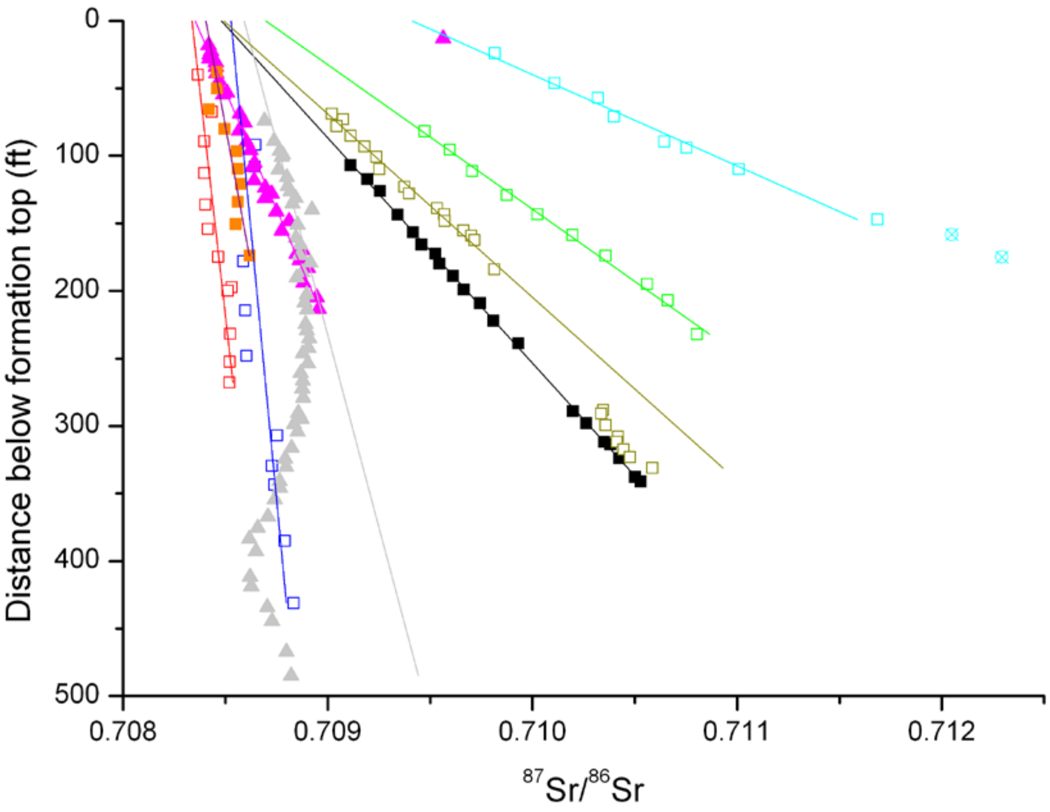
# Field example B (oil) – RSA data

- Salt diapir nearby.
- High variation in aquifer formation water salinity (MDT, produced).
- Uncertainties over $S_w$.
- Correlation between $R_w$ and $^{87}Sr/^{86}Sr$ in water-leg formation water samples.



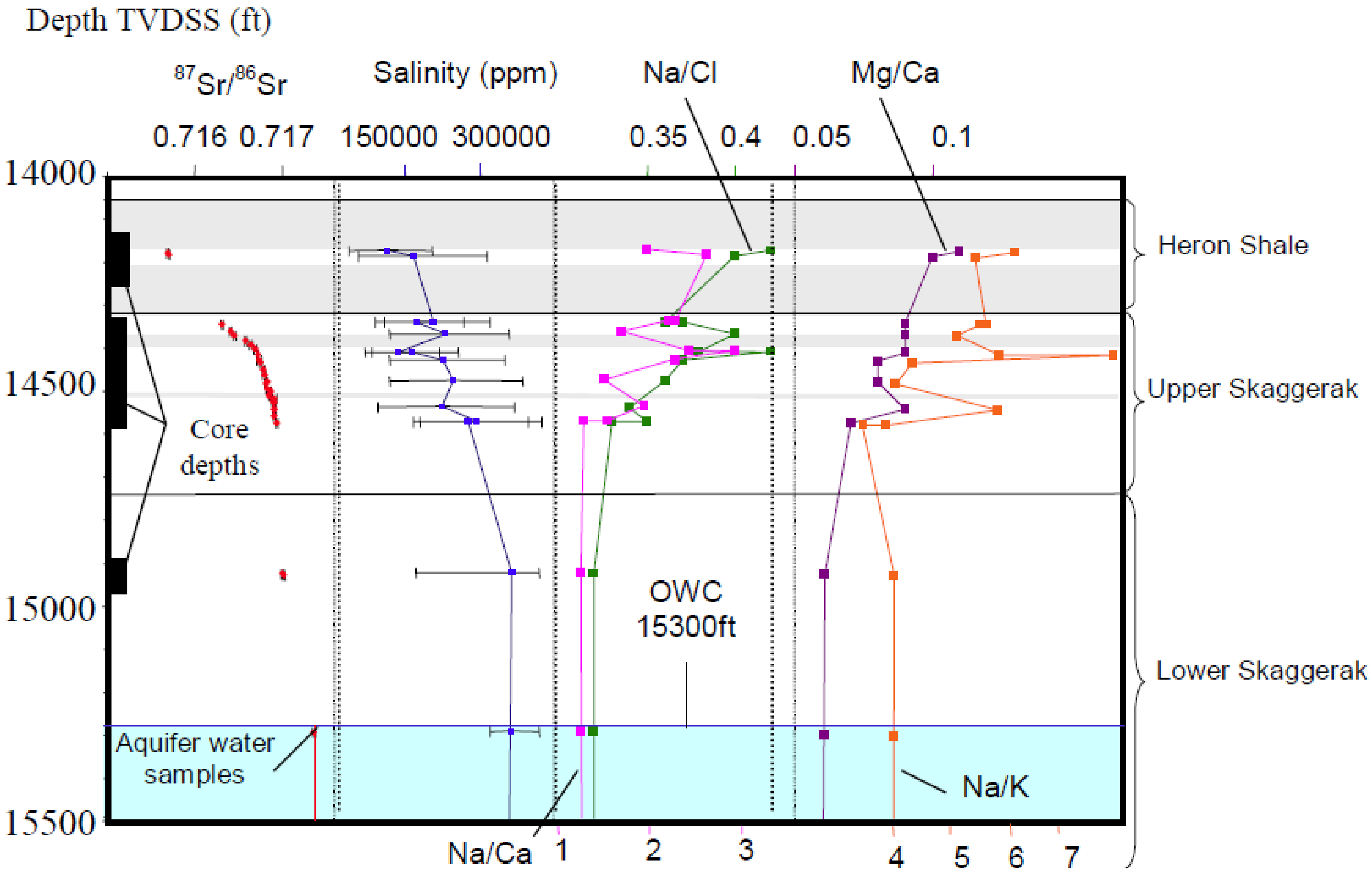
# Field example B (oil) – RSA data

- $^{87}Sr/^{86}Sr$ RSA data available for many wells.
- Oil-leg and water-leg $^{87}Sr/^{86}Sr$ RSA data consistent in different areas of the field and show consistent trends with depth.
- Concluded that aquifer $R_w$-$^{87}Sr/^{86}Sr$ correlation likely to be valid for the oil-leg too.
- Correlation used to estimate $R_w$ in the oil-leg at each location where $^{87}Sr/^{86}Sr$ RSA data available.
- Resulted in a more detailed understanding of $R_w$ variation in the oil-leg and much improved $S_w$ distribution.
- Benefits – field depletion planning.



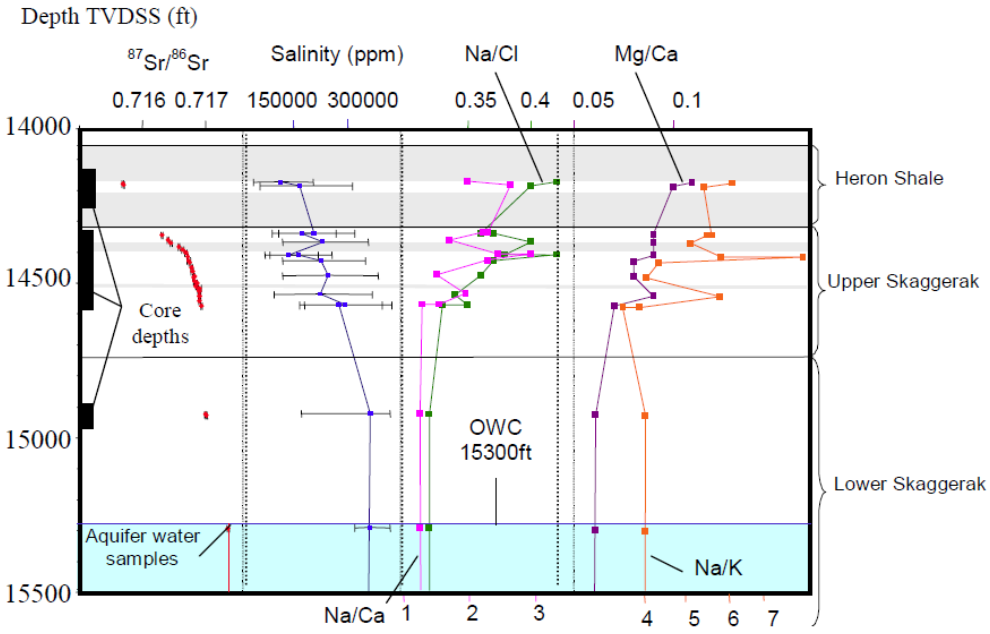
# Field examples – Heron Field – RSA data

- Webb and Kuhn, 2004; RSA (Na, Cl, Na/Cl, Mg/Ca, etc) and water samples show increase in FW salinity with depth in oil-leg and into aquifer (up to 350 g/L TDS).



# Field examples – Heron Field – RSA data

- Risk of halite scale deposition if high salinity aquifer brine produced – so downhole low sulphate seawater ‘wash water’ facility was installed and operated from start of production.
- Produced water contained a mixture of wash water, condensation water and formation water (but from where?).
- Using RSA data and produced water analyses, multivariate analysis showed the formation water was from oil-leg (not aquifer), rate being ~100bbl/d.
- Under these conditions – no halite scale risk.
- Discontinued wash water injection into several wells.
- No subsequent evidence for halite precipitation, increased production, reduced costs, simpler scale management.



# Conclusions

- Collection of ‘traditional’ formation water samples still recommended on new developments.
- But, obtaining core-derived data provides a complimentary and alternative source of water analyses.
- Key benefits:
  - From unique and multiple locations.
  - Reduces uncertainty on decisions (appraisal, development planning and later in production) compared with those based on use of one formation water (aquifer) location alone.
  - Increases the number of applications of formation water analyses.
  - Low cost.

# Conclusions

- There are limitations to the data - it maybe that circumstances in some fields will mean that the data cannot be acquired or used.
- But, they should at least be considered for and/or included in data acquisition programmes for future developments....

....don’t miss a trick!