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?
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).
  - Sourcing predictions (organic acids, $\text{NH}_4$, $\text{PO}_4$, $\text{H}_2\text{S}$, 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.
  - $^{87}\text{Sr}^{86}\text{Sr}$ 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.**
Several methods for obtaining water analyses from core - some of the more useful types:

- Dean-Stark crush and leach. API RP40 (1998), Pan (2005), Clinch et al. (2010).
## Comparison of techniques

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

Data points:
- Na, Ca, etc. (mg/L)
- Cl, $^{87}$Sr/$^{86}$Sr (mg/L)
- Depth
Examples of potential use of integrated data sets

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

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

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

Obtain Na/Cl, Ca/Cl, etc from centrifuged core ± water samples from water-leg, transition zone, hydrocarbon-leg.
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 $^{87}\text{Sr}/^{86}\text{Sr}$ 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 vs 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 CaCO₃ expected at perforations - evaporation of FW as it entered the well.
- Benefit – scale management.
- Salt diapir nearby.
- High variation in aquifer formation water salinity (MDT, produced).
- Uncertainties over $S_w$.
- Correlation between $R_w$ and $^{87}\text{Sr} /^{86}\text{Sr}$ 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.
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).
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!