Abstract

Where is the fresh water coming from? Can its source lead to hydrocarbon accumulations?

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In 2016 Hurricane drilled the pilot well 205/21a-7 and produced 6300 barrels of oil and water per day from the basement. The drilling brine was at 56 000 ppm salt concentration, while the water sample from the DST showed 18 500 ppm (RPS, 2017). The question is why the basement water is so fresh?

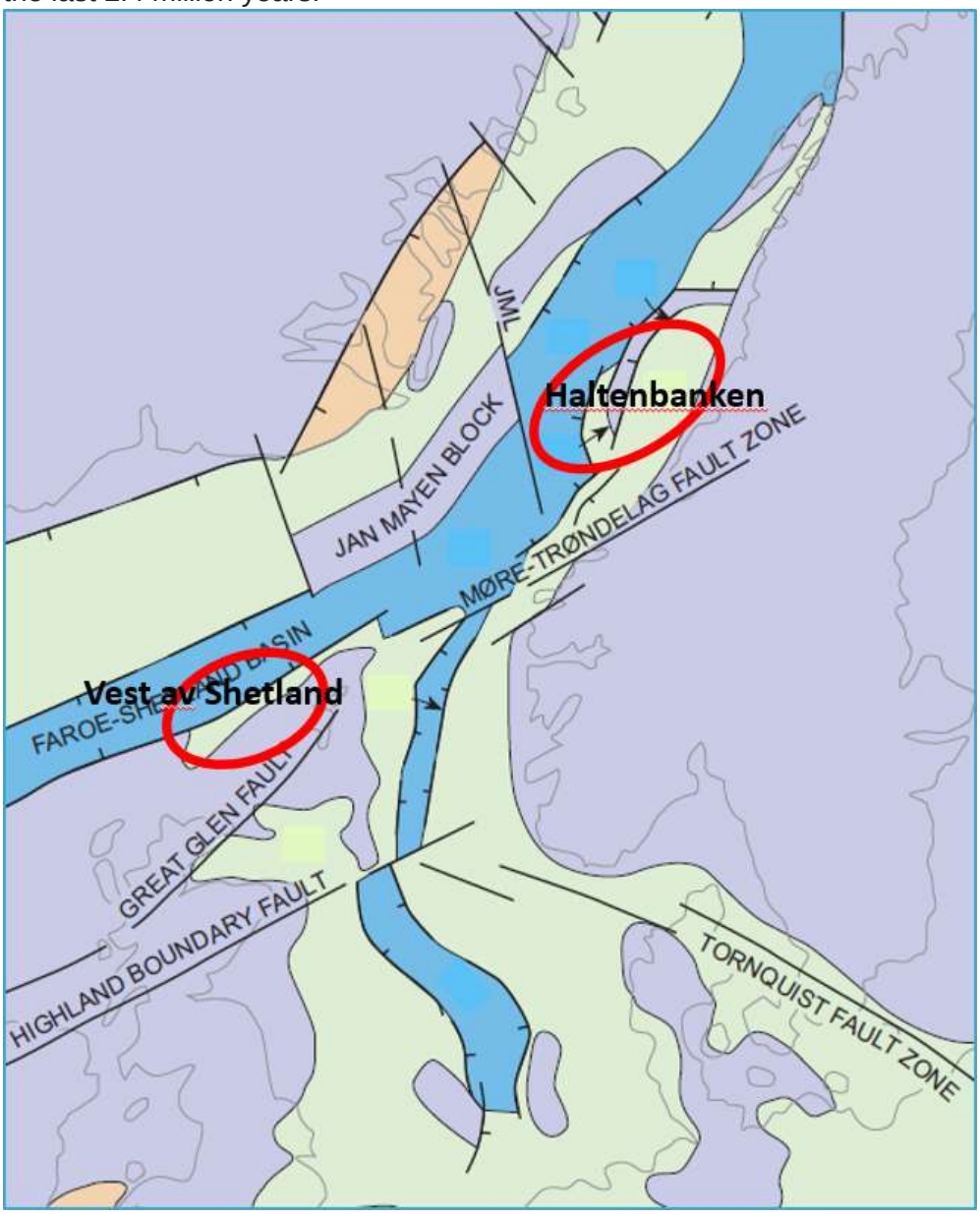
Many studies have discussed the large variation observed in the salinity of the formation waters in the North Sea, Norwegian Sea and in the Barents Sea. In the Barents Sea the formation waters vary from close to fresh in the Pingvin well (7319/12-1) and up to up to 440 000ppm only 300km south east in well 7220/5-2.

Common sea water has about 35 000 ppm salt. It is now believed that the salinity has varied during Phanerozoic. The analysis is based on fluid inclusions within the evaporate. The composition has oscillated between a sea low in $MgSO_4$ (60%) and modern seawater (40%) high in $MgSO_4$. Polyhalite precipitates out of modern seawater while Sylvite and Halite precipitates out of ancient seawater. In periods without any icecaps, the salinity may have been reduced by about 10% compared to today. It is therefore expected that the sea water from Triassic times until now have varied between 30 000 to 35 000 ppm. After deposition the formation water have been exposed to mineral dissolution and precipitation, but more important to large salt deposits such as salt diapirs, salt walls and salt layers. The maximum salt saturation is a function ion composition and temperature. If only NaCl is in the solution the saturation point is about 440 000ppm. NaCl solution is quite unique as the saturation vary very little with changing temperature. In most formation waters there are at least one salt pair with a common ion such as KCl and NaCl. In those cases, the saturation point will be less than 440 000ppm (Warren, 2016). One should therefore expect that the salinity in the formation water would vary from 30,000 ppm as the lower end and up to saturation at 440 000 ppm. The puzzle is how can the salinity get less than about 20 000ppm? Is there a fresh water source?

Hurricane has found a 1156m oil column in the basement, the Roan ridge, west of Shetland. The Roan sand onlaps the basement. A direct conduit between the fluid in the sediments and fluid in the basement fractures. Oil and gas can flow into the basement and the water trapped in the basement out into the sedimentary layers.

There are similar basement ridges and basement horst structures on the Norwegian shelf. The structural map show similarities between the area west of Shetland and Haltenbanken, specifically the Roan Ridge and Revfall fault complex, where the basement forms several horst structures (fig.1). Just west of the Revfall fault complex is the Alve field. The discovery well, 6507 / 3-1 where the Jurassic the formation water salinity is as low as 14 000 ppm. The calculation of the salinity is done by log analysis, not a water sample.

An interesting article in 2005 by McCartney, compiles all information published about the formation water in the Norwegian sector. They point out that low salinity water has been observed in some discoveries such as, Fram, Ormen Lange, Edda, and Veslefrikk. These observations are based on analysis of sampled water. Previous work suggest that the salinity vary from 2 500 to 212 000 ppm (McCartney and Rein, 2005). Their analysis of water shows that where an input of ancient methoric water. Fresh water that cannot have been sourced from overlying glaciers during the last 2.4 million years.

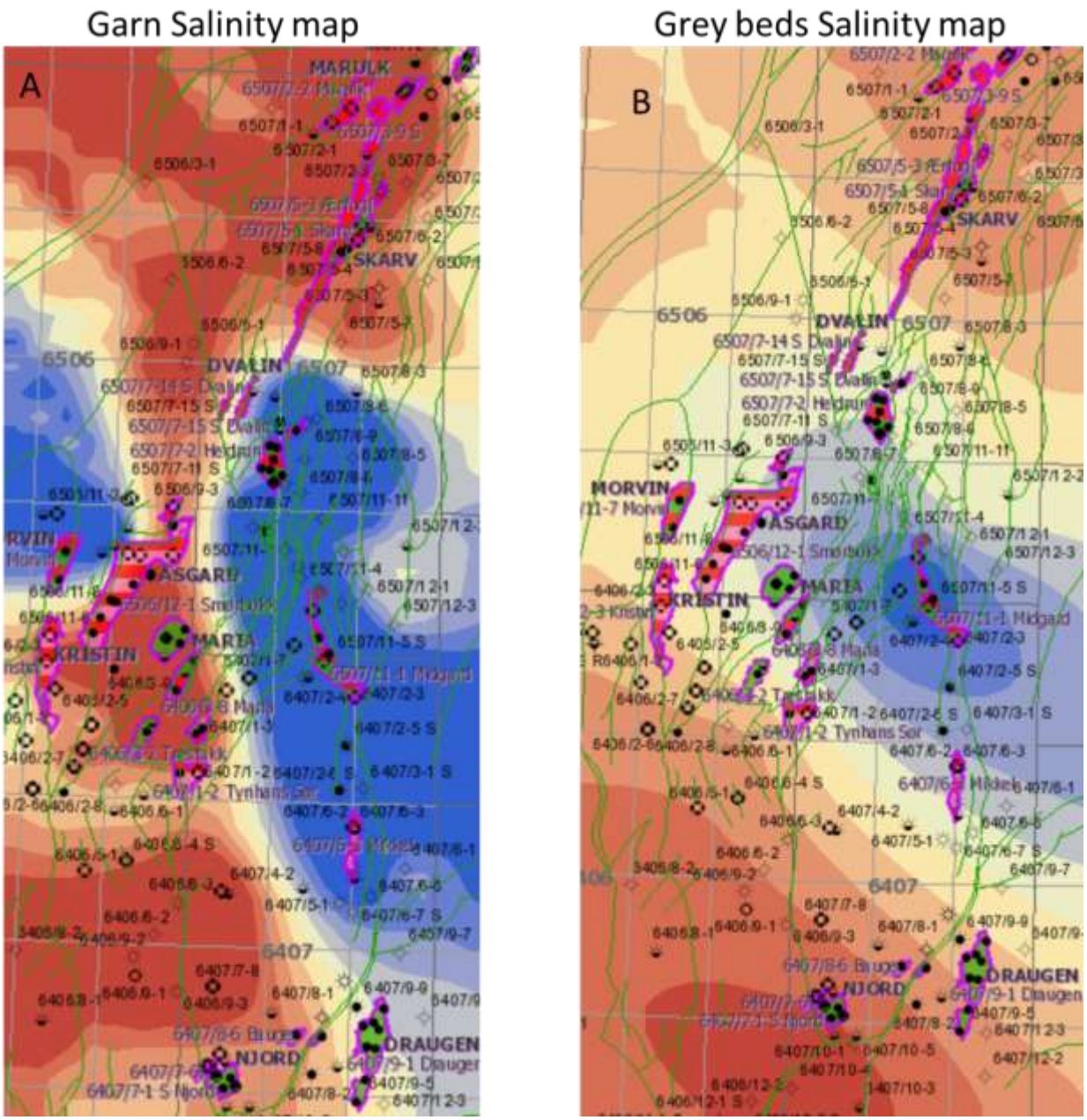


Figur 1. Structural relationship between Roan Ridge west of Shetland and the Revfall fault complex at Haltenbanken.

The challenge with using water sample analysis is that it is very few sample points. Most pressure test samples such as RFT samples are too contaminated by drilling fluid. Only samples form full production tests (DST) gives a close to contaminations free sample.

The alternative method is to calculate the resistivity of the water (Rw) using wireline logs. The petrophysical method. In this study more than 600 exploration wells have been analyzed which have enabled generation of detailed salinity maps (fig 2). Some petrophysical software's calculate the Apparent Rw (Rwapp). Rwapp is the resistivity of the formation water (Rw) that will make the formation 100% water saturated (Sw = 1). The corresponding equivalent concentration of NaCl (salinity) is then calculated. The salinity data was loaded into ArcGIS and contoured using a simple Kriging equation.

In many cases it is difficult to pick the correct Rw for one zone. The salinity map is a good guide but must be based on a dense grid. The Haltenbanken salinity map is based on 204 interpreted wells. It is in particularly where the salinity is very low, it is difficult to find the correct Rw. Based on this study not only the Alve field, but Dvalin (Zidane) and Åsgard field have a quite fresh water zone (fig.2).

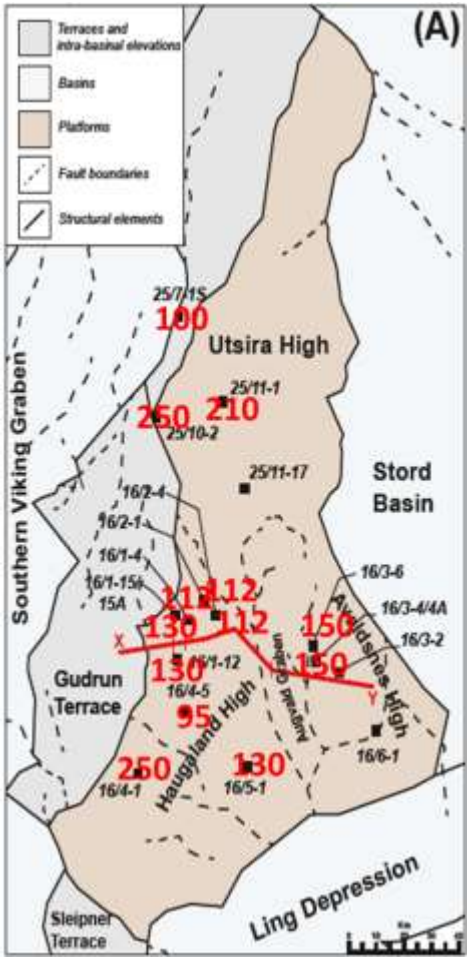


Figur 2. Map A to the left is the Jurassic salinity map and map B is the Triassic salinity map. Blue is high salinity while dark brown is is lower salinity.

On the Norwegian Continental Shelf bedrock of pre-Devonian age are regarded as basement in a petroleum-geological context (www.npd.no). 72 Norwegian exploration wells have penetrated basement (56 wells in the North Sea, 8 in the Norwegian Sea and 8 in the Barents Sea). Most of these were drilled on structural highs with depth to top basement quite evenly distributed between 1200 and 4000m. The thickness drilled have generally been in the order of a few meters. Several

wells have however drilled more than 100m of basement rock: 2/6-3 (142m), 16/1-4 (146m), 16/1-5 (195m), 16/2-5 (488m) 35/3-2 (233m) and 6306/10-1 (207m).

In 2009 Lundin found oil in the basement with 16/1-12 within the Edvard Grieg field. 16/1-15 drilled at the Tellus prospect found good reservoir in altered and fractured crystalline rocks. This was followed by a study of 18 basement cores from the Utsira High (Riber et.al., 2015). At 12 of the well locations it was possible to date the sedimentary layer onlapping the basement. The oldest sediment cover dates to 250 m.y while the youngest at 95 m.y (fig.3). Showing and age span from 250m.y. to 95m.y. This is time equivalent to the onset of the Permo-Triassic rifting. Suggesting that the basement between Norway and the UK was exposed to rifting as well as being airily exposed to meteoric water and weathering. The result being a fractured basement initially filled with mostly meteoric water and mixed with sea water.



Figur 3. In red is the age (m.y.) of the sedimentary layer that onlaps the underlying crystalline basement.

This study shows a correlation between deep to basement and salinity (fig. 2). The salinity is clearly lowered with depth. The fields that have quite fresh water sits either on or laterally close to a basement high. I therefore claim that there is a powerful freshwater source in the North Sea, the Norwegian Sea, the Barents Sea and the West of Shetland and the source is mainly the fluid trapped basement fractures. That is what McCarter referred to as “Ancient Meteoric Water."

The Barents Sea is somehow different as there is probably a freshwater source from the ice cover during the last 2.4 million years as well.

Low saline waters are found in reservoir rocks that are in direct contact with the basement. It is also likely to find hydrocarbons accumulated in the basement highs where gas, oil and water can flow freely between a permeable sedimentary layer that onlaps the basement. There are several opportunities for new discoveries in the basement. Not only along Revfall fault complex, but also east of Agat, Dvalin, Åsgard and several places in the Barents Sea, and in the area of Edvard Grieg and Johan Sverdrup.

It is important to realize that oil and gas have migrated into the basement. No new source concept is postulated! And finally, the basement heights that contain low salinity water and/or hydrocarbons must be the best storage space for CO_2 and a freshwater source for water injection in EOR projects.

References

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