

Variations in formation water compositions in a North Sea oil field: Trace waters in oil

J. M. Rosenbaum
M. Coleman

The University of Reading, Postgraduate Research Institute for
Sedimentology, Whiteknights, Reading RG6 6AB, UK

Studies of trace waters in oil have direct bearing on our understanding of the origin and evolution of the brines in sedimentary basins. As part of a project to predict carbonate scale formation in oil fields, over the last year we have monitored the changes in the composition of trace water in oil from a producing well located in the North Sea. Using a technique developed at Reading, we are able to analyse trace waters present in the oil even when a separate aqueous phase does not occur. We have been able to identify two distinct mixing trends in the waters implicating the existence of at least three different components.

History of water production

The well has shown a systematic trend of increasing proportion of water in the total produced fluids (water-cut). During the first four months of production, the oil contained less than 0.5 wt.% water whose chloride content increased from 22,000 to 95,000 ppm. Two weeks later, the water-cut jumped to over 5 wt.% and has slowly increased ever since.

Analytical methods

Water content of duplicate homogenised samples of the produced fluid was determined by Karl Fischer titration. Trace waters were extracted from duplicate oil samples using an extraction technique developed at Reading which allows quantitative determination of water composition. Cation contents of waters were determined using ICP-AES; anion contents were measured using ion chromatography or titration. Chlorine isotope compositions were measured using standard techniques: precipitation as AgCl, conversion to CH₃Cl, and stable isotope ratio mass spectrometry (Eggenkamp, 1994).

Chemical variation of the waters

At the same time the water content of the oil increased, the salinity of the trace water in the oil grew dramatically. The chloride content of these

waters range from 110,000 to 170,000 ppm. Element ratios of the initial waters are distinct from those of the later, high salinity waters. The two sets of waters form distinct binary mixing arrays on element-element diagrams (Fig. 1). Within a trend, the chlorine stable isotope composition of the waters are indistinguishable (Fig. 1). Samples from the two arrays, however, have significantly different chlorine stable isotope composition from each other and from seawater (Fig. 1).

Discussion

We interpret the low water-cut trend to represent the composition of waters in the oil zone of the reservoir, possibly stratified within this zone prior to production. The process of production would produce a local reduction of pressure at the bottom the well in the oil zone and thus eventually draw in aquifer water from below. The high water-cut samples are probably from a highly saline aquifer immediately below the oil-water contact. Given the observed range of chloride content, the *in situ* reservoir temperature, and the diffusion coefficients for chlorine (Eggenkamp and Coleman, 1997), the uniformity of chlorine isotope composition suggests that the waters in each array have only recently been generated by mixing. Diffusion at the reservoir temperature would tend to smooth both the chloride gradient and the chlorine isotope gradients in a time much shorter than that since estimated oil emplacement.

The observed differences in inter-element ratios also show that the waters from the two arrays have not been in diffusive contact with each other for any significant amount of time. We interpret this as evidence that the oil/water interface acts as a barrier to diffusion because the aqueous permeability in the oil zone is very low. Our data strongly suggest the presence of a freshwater lens in the reservoir (A) which is mixing with both water in the oil zone (B) and water in a saline aquifer (C) during exploitation of the field (Fig. 1). Even on the scale of a single part of a sub-basin, the subsurface hydrology of oil-

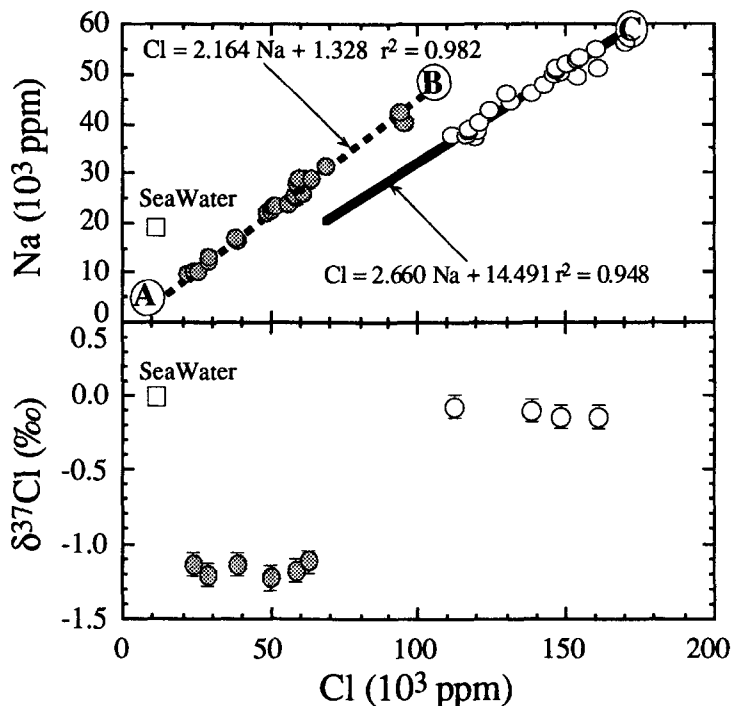


FIG. 1. Chloride content versus sodium content (upper) and chlorine stable isotope composition relative to SMOC (lower) for trace waters in oil from a producing well in the North Sea sampled biweekly over a period of 12 months. Shaded circles are for waters from oil containing less than 0.5 wt.% water; open circles are for oil with >5 wt.% water cut. Approximate compositions of freshwater lens (A), oil zone brine (B), and saline aquifer (C) end members are as shown. Seawater values are shown for comparison. Lines are least squares fit to the two data sets.

bearing regions can be extremely complex, but may be unravelled using a combination of elemental and isotopic tracers.

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References

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