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Abstract

Effects of oil charge on illite dates and stopping quartz cement: calibration of basin models

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Abstract

Oil can fill pores in reservoir sandstones at any burial depth by long or short distance migration. There has been a debate since 1920 concerning the effect of oil charge. We have made detailed local measurements of cements and porosity from individual fields and regional compilations from the North Sea. We consider that oil charge can be dated by K–Ar ages of fibrous illite, and oil stops quartz cementation in sands containing less than 20% water. Consequently, abnormally large porosity values can be preserved from 2 km down to more than 4 km of burial. Many oilfields are anomalously porous. K–Ar dates within fibrous illite and quartz cement abundance can now be used to calibrate basin models back though geological time.

Keywords: Porosity preservation; Diagenesis; Sandstones; Hydrocarbon; K–Ar dating

1. Introduction

Oil and gas usually form reservoirs in pores of sandstones and carbonates. Progressive cementation during burial gradually fills in pores and so reduces the volume available for hydrocarbons. Many cements appear to be isochemical, i.e. derived and redistributed within the same sandstone. Information on the timing, age, and growth rates for some of these isochemical cements—specifically quartz and illite—is now good enough to contemplate inverting the logic. Instead of using the geological history to infer the cement timing and volumes, can we potentially use the cements to assist reconstruction of the geological history by calibrating basin models?

2. Quartz cement in pore and reservoir: small size-scale

The most abundant mineral in sandstones is quartz, so it is no surprise that quartz is also the most abundant cement, usually forming as an overgrowth in optical continuity with the underlying grain. Quartz cement is considered to form commonly from local pressure solution of individual grains, quantified by Walderhaug (1994) and modelled by Lander and Walderhaug (1999). They made the simplifying assumption that of the three main steps (dissolution, diffusive transport, and precipitation), precipitation was the determining rate. However, Worden et al. (1998) pointed out theoretically that oil charge into pores would reduce the water connectivity available for diffusion, such that quartz cementation rates would decrease in oil-filled sandstones. Marchand et al. (2000, 2001, 2002) identified well-constrained case

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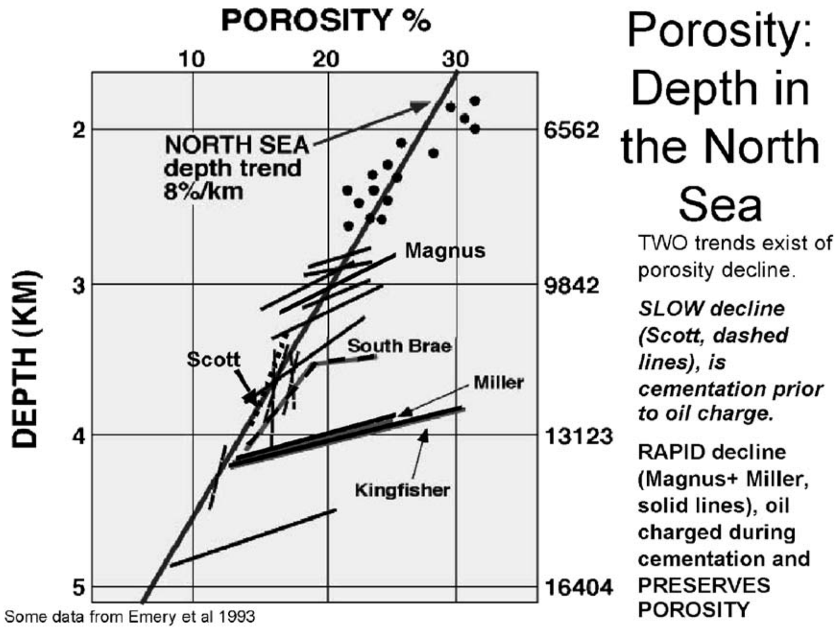
studies where porosity is preserved on the crest of a structurally and sedimentologically simple oilfield. These sands are clean and not coated with enough clays or microquartz to prevent nucleation of quartz cement (Bloch et al., 2002; Aase et al., 1996). It is clear that oil charge halts quartz cementation, where residual water saturation is less than 20%. This is because the residual water no longer provides a connected network to distribute 'diffusing' silica from its source to precipitation site. A similar threshold to estimate connectivity of residual water is commonly used in wireline log analysis—where resistivity of a formation increases very rapidly if residual water declines below 20%—as the electric current is no longer able to flow through conducting saline water but has to pass through resistive minerals instead. England et al. (2003) studied the Scott North Sea oilfield (Fig. 1), which also shows porosity preservation at its crest. Their analyses of cement δ^{18}O show a systematic decrease from crest to flank, compatible with long duration of cement growth overlapping in time with oil charge.

3. Porosity trends in basin: large size-scale

In the fields studied by Marchand et al. (2001, 2002), we plotted the trends of porosity change with depth. A rapid decrease of porosity is seen, some 40%/km loss. This is far in excess of the regional trend of porosity decline derived from wireline information in water-wet sandstones, which is typically 8%/km (Emery et al., 1993). A compilation of porosity information from sandstones of similar depositional quality in the North Sea shows that two trends of porosity decline exist (Fig. 1). More than half of fields show rapid porosity decline and have a maximum porosity, which is much larger than the expected 'normal' porosity for a particular depth. We consider that these are fields where oil charge has started at a shallower burial depth, and so cementation has been halted and porosity preserved to their present burial depth. The remainder of fields have gradients of porosity decline, which are similar to the regional gradient and porosity values, which are close to the expected 'normal' value (Fig. 1). We consider



Porosity: Depth in the North Sea

TWO trends exist of porosity decline.

SLOW decline (Scott, dashed lines), is cementation prior to oil charge.

RAPID decline (Magnus+ Miller, solid lines), oil charged during cementation and PRESERVES POROSITY

Some data from Emery et al 1993

Fig. 1. Graph of porosity in oil reservoir sandstones against depth in the North Sea. Two gradients of decline can be seen within individual oilfields. A slow rate of decrease (dashed) falls on the regional equilibrium line, indicating equilibrium cementation before oil charge. A rapid rate of decrease (solid lines) indicates preserved porosity at the field crest due to oil halting quartz cementation.

that these are fields that were cemented before a recent oil charge.

4. Timing of oil charge: radiometric K–Ar illite dating

Radiometric dating of fibrous illite clay in reservoirs is not a new technique (e.g. Sommer, 1978). However, there has been much discussion on the validity or unreliability due to contamination of the measured age dates. Some authors have considered that fibrous illite is not linked to fluid migration but to a temperature threshold. We have made a regional compilation of published illite ages from the North Sea. This shows a fundamentally simple pattern, with oldest ages closest to the deep graben and youngest ages shallowest and furthest form the graben. This is because the growth of fibrous illite is linked to the maturation of different hydrocarbon kitchens changing with time. A second-order pattern of complexity shows that several illite ages can be present within one structure. These record either the progressive filling of the structure from top to oil–water contact, lasting tens of Ma, or the charging of the structure from different kitchens at different times. The accuracy of such ages is usually better than ± 5 Ma. A detailed case study has been made of the oil charge history around the Magnus and Penguin oilfields at the very northwest of the UK North Sea, overlapping with the Atlantic continental margin. This shows that predictions of the dates of oil charge made from the regional compilation did not fit with K–Ar illite dates measured from the Magnus and Penguin fields if only local hydrocarbon kitchens were considered. However, basin modelling showed that deeper and more distant hydrocarbon kitchen areas could be modelled to match the measured illite ages (Fig. 2). This suggests that hydrocarbon charge into one structure has originated from several hydrocarbon kitchens, starting at deep (present day) and distant locations and becoming progressively shallower (present day) and more local when each kitchen subsided to the required temperature window.

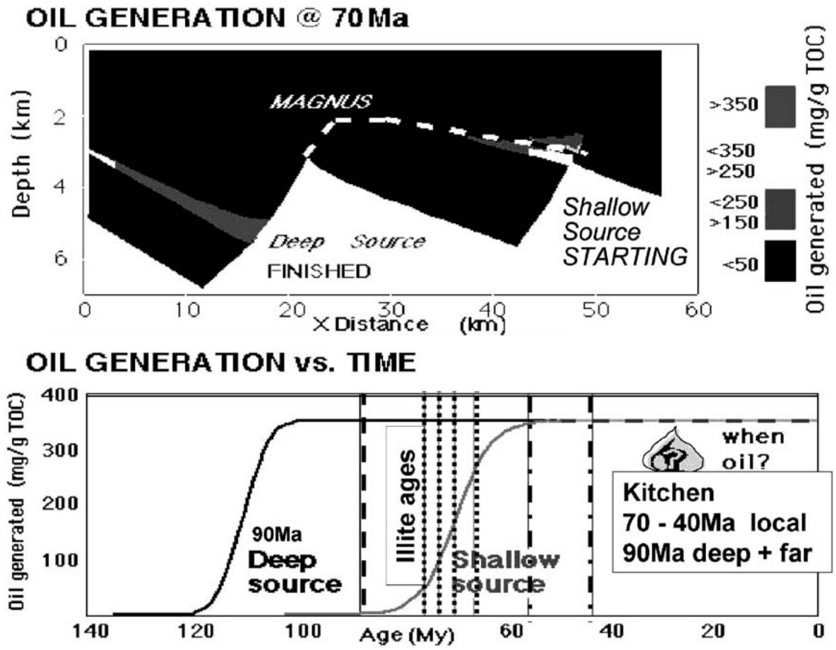


Fig. 2. Basin Modelling of Magnus oilfield shows timing of oil charge predicted from kitchens deep and far away, and oil charge from kitchens local to oilfield. Measured illite K–Ar dates show good correspondence with these predictions, suggesting that K–Ar illite dates can be used to calibrate basin models in less well-known areas.

5. Application to basin modelling

There is an interaction between the progress of cementation, porosity, and oil charge. Predictions of quartz cementation in the aquifer can be run as modules within basin modelling software. If no core is available, basin models are typically calibrated to reproduce present-day conditions such as temperature, pressure, and organic maturity. This often still permits many different scenarios for timing of ancient oil maturation and migration. However, in most basins, reservoir core is available in some part of a nearby petroleum system. Then, the K–Ar illite date of oil charge, quantity of quartz cement, and porosity remaining can be used as ancient calibration points. The modelling of unknown structures must effectively reproduce the timing of oil charge into already-known structural positions in order to halt quartz cementation at a particular value. Utilising ancient calibration points (Fig. 2) greatly reduces the number of scenarios permitted in basin modelling—and leads to predictions with greatly reduced uncertainty.

6. Conclusions

Quartz cementation in oilfields is halted by oil charge. Many oilfields in the North Sea rift basin show unexpectedly high porosities because of this. The timing and duration of oil charge is recorded by K–Ar dates of fibrous illite in the reservoir. Both techniques show that oil sometimes charged at shallow depths and took tens of Ma to fill fields. Basin models need to reproduce these age dates and porosity anomalies, which can be used as ancient calibration points to greatly reduce the number of feasible scenarios, and so improve accurate predictions.

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